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# Quality Assurance Plan for the Water and Atmospheric Resources Monitoring (WARM) Program

**Version 1.0**

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Illinois State Water Survey
Institute of Natural Resource Sustainability
University of Illinois at Urbana-Champaign

Champaign, Illinois

# QUALITY ASSURANCE PLAN FOR THE WATER AND ATMOSPHERIC RESOURCES MONITORING (WARM) PROGRAM

**Version 1.0, effective May 1, 2010**

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**QUALITY ASSURANCE PLAN FOR THE WATER AND ATMOSPHERIC RESOURCES MONITORING (WARM) PROGRAM**

## Approval Form

The Quality Assurance Plan has been reviewed and approved by the following authorized Illinois State Water Survey signatories:

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# Abstract

The Water and Atmospheric Resources Monitoring (WARM) Program of the Illinois State Water Survey (ISWS) was organized in 1983 as the Illinois Benchmark Network, consolidating several existing and newly formed statewide water and atmospheric resource monitoring efforts. The original structure contained data collections that measured climate variables, soil moisture, shallow groundwater levels, and suspended sediment in streams. In the early 1990s, the initial effort was reorganized, expanded, and renamed the WARM Program.

The purpose of the WARM Program is to collect, compile, and analyze quality long-term data on Illinois' water and atmospheric resources and to provide these data to users and decision-makers across Illinois and the U.S. on a timely basis. In order to provide maximum utility for users, data quality is given a high priority. This WARM Quality Assurance Plan (QAP) provides descriptions and collection procedures of each monitoring network in the program, details the quality assurance and quality control practices implemented for each, and documents archiving and formatting practices employed throughout the program to enhance the reliability of the collected data.

## Contributors

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## Acknowledgements

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# Acronyms and Abbreviations

BSMP – Benchmark Sediment Monitoring Program
CSI – Campbell Scientific, Inc.
DRTF – Drought Response Task Force
GOES – Geostationary Observational Environmental Satellite
IBN – Illinois Benchmark Network
ICN – Illinois Climate Network
IDNR – Illinois Department of Natural Resources
ISMN – Illinois Soil Moisture Network
ISWS – Illinois State Water Survey
NGVD – National Geodetic Vertical Datum
NOAA – National Oceanic and Atmospheric Administration
NWIS – USGS National Water Information System
NWS – National Weather Service
OWR – IDNR Office of Water Resources
QA – Quality Assurance
QAP – Quality Assurance Plan
QC – Quality Control
SGWN – Shallow Groundwater Well Network
SWPTF – (Illinois) State Water Plan Task Force
SOP – Standard Operating Procedure
U of I – University of Illinois at Urbana-Champaign
USACE – U.S. Army Corps of Engineers
USEPA – U.S. Environmental Protection Agency
USGS – U.S. Geological Survey
WARM – Water and Atmospheric Resources Monitoring
WSRC – Water Survey Research Center

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# QUALITY ASSURANCE PLAN FOR THE WATER AND ATMOSPHERIC RESOURCES MONITORING (WARM) PROGRAM

## Section 1.0. Purpose of Plan

### 1.1. Background

The Water and Atmospheric Resources Monitoring (WARM) Program was originally organized in 1983 as the Illinois Benchmark Network (IBN). The purpose of the network was to consolidate existing statewide water and atmospheric resource monitoring efforts into a single program with centralized management and data-reporting functions. The IBN contained monitoring programs that measured climate variables, soil moisture, shallow groundwater, suspended sediment in streams, reservoir monitoring, and extraction of data from other agencies monitoring selected streamflows in Illinois. In the early 1990s, the IBN was reorganized, expanded, and renamed the WARM Program.

The purpose of the WARM Program is to collect and compile data on Illinois' water and atmospheric resources and to make those data available to users on a timely basis. In order for these data to provide maximum utility for users, it is important that the quality of the data be documented and any limitations on their use identified. This Quality Assurance Plan (QAP) provides descriptions of each monitoring network in the WARM Program and details the quality assurance (QA) and quality control (QC) practices that have been implemented to enhance data reliability.

WARM is housed within the Illinois State Water Survey (ISWS), located in Champaign, Illinois. ISWS is a division of the Institute of Natural Resource Sustainability (INRS) at the University of Illinois at Urbana-Champaign (U of I). Prior to July 2008, the ISWS was a state agency within the Illinois Department of Natural Resources (IDNR).

### 1.2. Source Documents


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Hendrie, L. K. 1981. *Illinois Solar Weather Program.* Illinois State Water Survey Contract Report 276, Champaign, Illinois.

Hollinger, S. E. and S. A. Isard. 1994. A soil moisture climatology of Illinois. *Journal of Climate* **7**(5):822–833.

Hollinger, S. E., B. C. Reinke, and R. A. Peppler. 1994. *Illinois Climate Network: Site Descriptions, Instrumentation, and Data Management.* Illinois State Water Survey Circular 178, Champaign, Illinois.

*Illinois Compiled Statutes: 1998*. State Bar Association Edition, 1999. West Group, Springfield, Illinois.

Isard, S. A., M. R. Welford, and S. E. Hollinger. 1995. A simple soil moisture index to forecast crop yields. *Physical Geography* **16**(6):524–538.

Keefer, L. L. and D. B. Shackleford. 2001. *Determination of Total Suspended Sediment Concentration (SSC) by Filtration, ISWS Sediment Laboratory Standard Operating Procedure.* No. 1, version 1.5, Illinois State Water Survey, Champaign, Illinois.

LeFaivre, M. H. 2007. Illinois State Water Survey Quality Management Plan, Champaign, Illinois.

Peppler, R. 1995. *The Illinois Water and Atmospheric Resources Monitoring (WARM) Network.* 1994 Annual Report, Illinois State Water Survey Miscellaneous Publication 165, Champaign, Illinois.

U.S. Environmental Protection Agency. 1999. *EPA Requirements for Quality Management Plans.* USEPA Report QA/R-2USEPA, Quality Assurance Division, Washington, D.C.

Wendland, W. M. 1981. *Illinois Windpower Program*. Illinois State Water Survey Contract Report 266, Champaign, Illinois.

## 1.3. Scope of Covered Activities

This plan covers all data collection, reporting, QA, QC, and archival practices for the following WARM networks: the Illinois Climate Network, the Illinois Soil Moisture Network, the Shallow Groundwater Well Network, Illinois Reservoir Monitoring, and the Illinois Benchmark Sediment Monitoring Program. Illinois River stage and streamflow monitoring are collected and disseminated by the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (USACE). These data are provisional and are not archived at ISWS because data are subsequently superseded and are available from the USGS.

## 1.4. Revisions to the Plan

This QAP will be reviewed annually by the primary contributors or successive staff in positions working most directly with the described operations. Revisions to the QAP will be coordinated by the WARM Program Manager, approved by the full WARM Committee, reviewed by the ISWS QA/QC Committee, approved by the ISWS Director, and posted on the ISWS Web site.

# Section 2.0. WARM Management and Organization

## 2.1. ISWS Mission Statement, Mandate Statutes, and Quality Policy

### *2.1.1. Mission Statement*

The ISWS is the primary agency in Illinois for research and information on surface water, groundwater, and the atmosphere. Its mission is to characterize and evaluate the quality, quantity, and use of these resources. The mission is achieved through basic and applied research by collecting, analyzing, archiving, and disseminating objective scientific and engineering data and information, and through service and extension programs. This information provides a sound technical basis for the citizens and policymakers of Illinois and the nation to make wise social, economic, and environmental decisions.

### *2.1.2. Mandate Statutes*

The legislation that enumerates the powers and duties of the State Scientific Surveys within the Institute of Natural Resource Sustainability, University of Illinois, charges the Water Survey Division "to act as the central data repository and research coordinator for the State in matters related to water and atmospheric resources." (20 ILCS, 801/1-25, part 16 - Illinois Compiled Statutes). Executing this charge means that the Water Survey will review and evaluate water and atmospheric monitoring efforts, make recommendations for monitoring necessary and appropriate data that fully characterize the water and atmospheric resources of the state, and establish data collection networks to provide such comprehensive monitoring. Further execution will ensure that data are adequately archived and made available to the general public, for scientific investigations and research, for outreach and education, and to serve the needs of the state and nation, now and in the future.

### *2.1.3. Quality Policy*

The ISWS has implemented a quality management system that uses a graded approach to quality assurance. The levels of managerial controls and resource allocation for quality assurance purposes are based on the intended use of the data generated and the degree of confidence needed in the data. The ISWS is committed to ensuring that quality management principles and practices are utilized for activities involving production of environmental data and the appropriate use of historical data.

## 2.2. WARM Mission Statement and Committee Charter

### *2.2.1. Mission Statement*

The mission of the WARM Program is to collect, compile, and analyze quality long-term data on a wide variety of water and atmospheric resources of Illinois and to provide these timely data to users and decision-makers across Illinois and the U.S.

#### *2.2.2. Committee Charter*

The WARM Committee serves as the governing authority for WARM. Its function is to oversee data collection for specific long-term monitoring activities of the ISWS and to provide oversight of and recommendations for data collections to ensure continuous and appropriate monitoring of Illinois' water and atmospheric resources. This oversight extends to changes in data-collection equipment and locations and is needed to support new and existing programs and mandates, especially when such modification requires additional funding.

The Committee shall consist of the following staff: WARM Program Manager (chair), scientific center directors or appointed representatives, National Atmospheric Deposition Program director or an appointed representative, the primary staff member in charge of each WARM data collection network, the ISWS Quality Assurance and Site Safety Coordinator, and additional appointed staff as necessary to ensure that expertise in all aspects of water and atmospheric resources are represented adequately.

### 2.3. WARM Organizational Structure

The WARM Program Manager serves as chair of the WARM Committee and has overall administrative and scientific responsibilities for program activities. The Program Manager reports directly to the ISWS Director and has responsibilities for the day-to-day operations of the WARM networks and preparing monthly data reports for distribution to the scientific community and the public. The ISWS Quality Assurance and Site Safety Coordinator works closely with the WARM Program Manager and network coordinators to implement the Quality Assurance Plan components. Network coordinators and support staff that devote a portion of their time to the WARM Program report to the WARM Committee chair through their respective center heads. An ISWS organizational chart that shows these relationships is provided in Figure 1 of the ISWS Quality Management Plan, which is available to ISWS staff at http://www.isws.illinois.edu/iswsdocs/so/qaqc/ISWS_QMP_V1.8_2007.pdf.

## Section 3.0. WARM Program Elements

### 3.1. WARM Products

The WARM Program provides regularly scheduled data summaries from each network. These data summaries are made available to internal staff, water supply managers, agriculturalists, the scientific community, and the public electronically through the ISWS WARM Web site (http://www.isws.illinois.edu/warm/).

The *Illinois Water and Climate Summary* (*IWCS*) is a monthly technical report that summarizes data from all WARM networks concerning data collected and analyzed from the previous month. Originally published in paper form and distributed by U.S. mail, the report became available on the WARM Web site in 2001. *Soil Moisture Summary* reports are published monthly. Detailed data summaries from each site in the Illinois Climate Network are available on the Web pages via daily maps of selected atmospheric and agricultural variables of interest, as well as downloadable, comma separated value (CSV) files (ASCII format). Updated statewide information on shallow groundwater levels, provisional monthly streamflow, and benchmark sediment monitoring also are available on a regular (daily or monthly) basis.

In conjunction with the U of I Department of Crop Sciences' Integrated Pest Management Program, WARM provides daily maps of selective pest and crop growing degree-day accumulations on the WARM Web site. These value-added maps can be used by agricultural producers and businesses to estimate the appearance and development of crop predator insects during current crop stages so that mitigative measures impacting crop yields can be assessed and properly addressed if necessary.

In addition, the WARM Program maintains an Internet-based inventory of other water and atmospheric resource databases that contain information on long-term data collection activities within Illinois. These databases include networks operated not only by the ISWS, but also by other state and federal agencies that are conducting or have conducted data collections in Illinois, currently or in the past. The inventory does not contain these collected data, but provides a resource of information relating to the specifics of collected data, the number of monitoring sites in Illinois, the period of data collection, as well as contact information for acquiring the data. This inventory is updated annually.

Finally, in addition to Internet access, the WARM Program responds to numerous individual data requests each year for program data and site-specific water and climate information. These requests are generated by a wide variety of users from the news media, the scientific community, agricultural producers, attorneys, and the public. Much of the hands-on responses for data requests are accessed via the continuous development of user-friendly Web pages for data dissemination. ISWS meteorologists, climatologists, and hydrologists also participate in the Illinois Governor's Drought Response Task Force (DRTF), which is activated when the state's water resources are strained during drought situations. The data collected via the WARM Program provide essential benefits to the state during such time.

## 3.2. WARM Network Descriptions

### *3.2.1. Overview*

In the late 1970s, scientific staff conducted an assessment of ISWS data collection programs and projected the needs for future water and atmospheric data and information applicable to the ISWS mandate to monitor and analyze Illinois' resources. It was concluded that the ISWS's data collections of basic water and atmospheric information in Illinois were lacking in a number of areas to the level necessary to respond adequately to a growing number of state and national questions on topics such as sources of alternate energy, agricultural development, water management, stream quality, and climate change. As a result, beginning in 1981, a number of projects were launched to enhance existing programs and initiate new basic data monitoring to increase our knowledge on basic and extreme conditions in these interrelated resource areas.

In 1983, the activities of these projects were combined into a common data collection program and named the Illinois Benchmark Network (IBN). The program linked the Illinois Climate Network, the Illinois Soil Moisture Network, the Illinois Shallow Groundwater Well Network, and the Illinois Benchmark In-stream Suspended Sediment Monitoring Network into a single data management structure, collecting data from a multitude of locations around the state. At the same time, the program expanded to include compilations of selected data collected by the USGS on Illinois streamflows and regular polling of selected lake and reservoir operators for reservoir levels across the state.

Throughout the histories of each of these monitoring efforts, data analyses, dissemination, and archiving were handled exclusively within the individual programs themselves, and for good reason: the funding sources and users of the data collected were quite varied and somewhat specific to the individual networks and their respective units within the ISWS. Thus, the networks maintained a high level of independence from each other. Nevertheless, there was a considerable desire by IBN staff and justification within the designed internal mandates of the programs to monitor data within each network across as much of Illinois as was possible and practical.

Due to the long north-south extent of Illinois, structuring of the networks to provide adequate resolution of collected variables and to achieve a high degree of regional representation loomed as a costly internal expense in staff time and travel within the ISWS units. Furthermore, in those early years, many networks used data-recording platforms requiring extensive manual attention and frequent site visits. It was realized that travel from Champaign by several program-specific technicians to the same or nearby sites for data collection and sensor repair was an inefficient use of resources. With the added limitations of unknown future funding and the number of staff that could be dedicated to these efforts, a high level of collaboration was sought to coordinate and maintain data collections from each network.

ISWS was fortunate in those years to maintain four regional offices from which staff could be drawn. Consequently, the state was divided geographically into separate regions of responsibility for data collection. Since, as with most field data monitoring, the electronic and mechanical expertise required of the technicians within each IBN program were similar, all IBN technical staff were trained on each sensor platform within the IBN. Beginning in 1983, ISWS staff from each base of operation was assigned to conduct regular data collection and instrument repair at all IBN program sites within their region. Subsequently, data were forwarded to the Champaign office for processing by the assigned personnel within the individual networks. The regional structure substantially reduced the amount of staff travel time and expenses within each program by sharing tasks within the entire IBN program, spreading knowledge of each network to several staff, and reducing staff exhaustion because of long travel times.

In subsequent years one of the regional ISWS offices closed and as technology advanced, many observation sites were converted from manually intensive operations to fully automated data collection systems. In addition, remote downloading of data was initiated at a large number of locations. These changes impacted operations such that site visits became less frequent. Travel to sites within some networks was reduced to an "as needed" or "scheduled maintenance" basis. Nevertheless, due to the method of some data collections, the need for manual data collection remained at many sites and although greatly reduced, a small amount of field data collection and cooperation between the networks continues today. Regardless of the reduced inter-network field needs, a combined effort of data dissemination has retained a high level of cooperation.

Further changes in the WARM Program will be covered within the individual network discussions below. This section of the QAP provides detailed descriptions on each WARM data collection network, including data collection activities, quality assurance procedures, information on all instrumentation deployed within each network, data dissemination, and archival processes. Some meta-data for these programs are documented in the following sections. Additional, extensive information can be found online at Web sites of the various networks. These are identified within each sub-section below.

### *3.2.2. Illinois Climate Network*

**3.2.2.1. History.** The Illinois Climate Network (ICN) began with two primary components: 1) the Illinois Solar Weather Program (ISWP), developed in 1981 to investigate alternate energy potentials in Illinois using solar power (Hendrie 1981, 1983), and 2) the Illinois Windpower Program (IWP), also designed in 1981, a separate project collecting data necessary to derive quantitative, small-scale assessments of the potential for wind power generation in Illinois (Wendland 1981). The objectives of these combined programs were to document the spatial distribution of solar and wind energy across Illinois, to assess the seasonal and annual magnitudes of these potential energy resources, and to investigate the impacts of climatic variability on the energy potential of these resources. Rocket and Scott (2006) conducted an extensive study of the ICN solar data in the area of solar power generation. At the time of this publication, wind power turbines were well-established in many areas of northern Illinois. However, the low heights of sensors within the IWP were insufficient to provide the best data to make an appropriate wind power assessment for Illinois. Regardless, these wind data have been well employed by other users.

The ISWP selected observation sites for solar sensors, and soon thereafter, it was decided that instrumentation for both the ISWP and IWP would be placed at the same locations. Six sites were installed in 1981 and eight additional sites were established in 1982. Three more locations were added in 1986. Initially, since many of the recording sensors were equipped with mechanical clock drives, frequent site visits were necessary. Work included changing paper charts on a weekly or bi-weekly basis, winding and/or servicing clocks, inking or replacing tracing pens, as well as quality assurance of instrumentation when needed. Additionally, as with the initiation of any new monitoring system, the placement of many sensors at multiple sites, each with their own unknown levels of durability, longevity, and data outages from exposure to normal and extreme weather conditions, provided numerous opportunities for sensor errors and malfunctions to occur.

Power outages severely impacted data collection, requiring frequent attention, repair, and occasional sensor replacement. This was especially true during lightning and freezing rain storms. Often, severe weather events occurred at several locations nearly simultaneously, taking down many sites at the same time. As a result, data archives in the early years of operations were incomplete and contained many periods of missing data, which were discovered only during scheduled site visits. These down periods frequently were extended while waiting for delivery of repair parts, laboratory and/or manufacturer maintenance and re-calibration, and/or the time needed for purchasing and delivering new sensors.

Eventually, data collections improved with installation of early data-logger models, allowing electronic data storage to replace paper charts. Dates of these changes were not specified. Although improvements to ICN data collections were structured to a high degree of organization and worked well, frequent blocks of missing data continued to occur. In reality, because the frequency of data outages continued, early ICN data records were not archived. This lent support for development of a quasi- to fully-automated electronic data collection process with which data could be downloaded remotely on a regular basis.

This automated process was first accomplished in 1988 at a new ICN monitoring location with installation of a high quality data logger capable of storing large amounts of data, connected to a telephone modem for automatic data downloading to an ISWS computer each day. Progressively, each site in the network was converted to the automated process. Fourteen sites underwent the conversion in 1989, three more stations were transformed in 1990, and a new site was installed in 1991. The conversion of an individual site to automatic status represents the start of the archived, electronic climate data record for that station within the ICN database. Information collected prior to the conversion generally remains only in paper chart archives and early logger storage banks.

**3.2.2.2. Monitoring Variables and Objectives.** The primary monitoring objective is to collect continuous high quality data on atmospheric and soil variables in Illinois to develop a climatological information database. Program goals are to enhance our knowledge of the atmospheric and upper soil surface phases of the hydrologic cycle within the state and to provide timely information in support of investigations, research, and service to all interested data users.

Initial monitoring at ICN sites included the following variables: air temperature, relative humidity, precipitation, wind speed, wind direction, solar radiation, and soil temperatures at 10 centimeters (cm, 4 inches) and 20 cm (8 inches) of depth. Dew point temperature and potential evapotranspiration data were computed from these observations and added to the hourly records. Barometric pressure sensors became a permanent part of the sensor array at each site in 1992 due to collaborative support the ICN provided to a national research project, STORMFEST, studying the synoptic and mesoscale structures of mid-latitudinal, mid-winter cyclones over the central

U.S. A 12-level soil temperature profiler was added at each site in 1996. In 1998, five sites were equipped with soil heat flux plate sensors.

Observations of shallow groundwater levels (local water table heights) began at most ICN sites in 1996, and others were added as late as 2006, although instrumentation was not added at most sites until 2004. Prior to that, manual readings were collected using a metal tape. Instrumentation to determine the soil temperature at the 10-cm level was installed at eight sites in 2000; the remaining sites followed with this measurement in 2006. During the summers of 1997–1999, ICN staff participated in an external research study across the central Midwest by installing leaf wetness sensors at five ICN sites. The sensors were subsequently removed. A further discussion of each of these variables will be covered in later sections.

**3.2.2.3. Number and Locations of Monitoring Sites.** The 19-station ICN network is shown in Figure 3.1. Station locations, surface elevations, and starting dates of automated operations are given in Table 3.1. The map is inclusive of all network sites after the conversion to automated downloading began in 1989. Most sites continue to be located where they were sited at the start of the automated record. Two sites, at Peoria and Springfield, were moved approximately 1000 m in 2002 and 2004, respectively. The site at Wildlife Prairie Park was decommissioned, and its equipment was moved to Big Bend Fish and Wildlife Conservation Area in 2004.

**3.2.2.4. Siting Criteria.** Criteria used for siting of ICN stations were those documented by the ISWP solar power study in 1981 (Appendix I). The primary scientific site selection criterion was based on ensuring good exposure for the solar sensor. Per additional requirements, sites were to be located as much as possible on property possessing a relatively secure environment, which for practical purposes required either state or public property. This covered several needs: ease of servicing, site security, property ownership longevity, and sympathetic site hosts. As stated earlier, for convenience of operations, it was decided to establish the ISWP and the IWP wind climate study at the same locations. In retrospect, the original selection process chose locations where more restrictive wind exposure requirements were well satisfied at some sites, but considerably less so at other stations.

In addition to the solar radiation and wind sensors, program managers of the two studies chose to include instrumentation for monitoring air temperature, relative humidity, precipitation, soil temperature, and soil moisture (Hendrie 1981; Wendland 1981). Collectively, these two programs formed the genesis of the ICN.

The ICN structure in place during the change to automated data downloading was reviewed and expanded by Hollinger et al. (1994), who provided the first documented record on ICN site selection criteria for sites already in place for many years. They reported that (1) efforts were made to locate the ICN stations in areas without obstructions to air flow within a radius of one kilometer around the station's tower, (2) locations were to be flat with uniform vegetation in all directions, and (3) sites should display a constant roughness height characteristic throughout the year. In practice, they pointed out that such locations had been very difficult to find, and if pinpointed, were too remote and costly to equip with power and telecommunications.


Figure 3.1. Illinois Climate Network

**Table 3.1. Locations and Starting Dates of Automated Data Collections at ICN Sites**

| *ISWS No.* | *3-Letter ID* | *Name* | *Latitude (deg N)* | *Longitude (deg W)* | *Altitude (m)* | *Start date of automated record* |
|---|---|---|---|---|---|---|
| 1 | BVL | Bondville | 40.05 | 88.37 | 213 | 20 Aug 1990 |
| 2 | DXS | Dixon Springs | 37.45 | 88.67 | 165 | 9 Feb 1990 |
| 3 | BRW | Brownstown | 38.95 | 88.95 | 177 | 25 Aug 1989 |
| 4 | ORR | Perry | 39.80 | 90.83 | 206 | 1 Jul 1989 |
| 5 | DEK | DeKalb | 41.85 | 88.85 | 265 | 1 Jan 1989 |
| 6 | MON | Monmouth | 40.92 | 90.73 | 229 | 21 Jul 1989 |
| 7 | SFM | Kilbourne | 40.17 | 90.08 | 152 | 1 Jan 1989 |
| 8 | ICC | Peoria | 40.70 | 89.52 | 207 | 1 Jan 1989 |
| 9 | LLC | Springfield | 39.68 | 89.62 | 177 | 1 Jan 1989 |
| 10 | FRM | Belleville | 38.52 | 89.88 | 133 | 16 Nov 1989 |
| 11 | SIU | Carbondale | 37.70 | 89.23 | 137 | 14 Dec 1989 |
| 12 | OLN | Olney | 38.73 | 88.10 | 134 | 24 Oct 1989 |
| 13 | FRE | Freeport | 42.28 | 89.67 | 265 | 1 Jul 1989 |
| 14 | RND | Rend Lake | 38.13 | 88.92 | 130 | 18 Apr 1990 |
| 15 | STE | Stelle | 40.95 | 88.17 | 213 | 1 Jan 1989 |
| 18 | *WFP | Wildlife Prairie Park | 40.73 | 89.75 | 186 | 1 Jan 1989 |
| 20 | STC | St. Charles | 41.90 | 88.37 | 226 | 1 Jan 1988 |
| 22 | *BBC | Big Bend | 41.63 | 90.04 | 182 | 11 Jun 2004 |
| 34 | FAI | Fairfield | 38.38 | 88.38 | 136 | 14 Sep 1991 |
| 81 | CMI | Champaign | 40.08 | 88.23 | 219 | 16 Feb 1989 |

* Sensors at Wildlife Prairie Park were moved to Big Bend Fish and Wildlife Conservation Area in June 2004.

In the final assessment, most ICN site locations represented a compromise between an ideal exposure, the availability of power and telecommunications, and ease of servicing sites. Stations are located at U of I Agricultural Experiment Farms, Southern Illinois University Agronomy Experiment Farms, several community colleges in the state, other university property, within a private "community" city, and within a state wildlife conservation area. All locations adequately satisfy the requirements of accessibility, site longevity, and security. However, because obstructions exist closer to some stations than desired, disruptions to wind flow were identified. These are described in terms of azimuthal roughness lengths (Hendrie 1983; Hollinger et al. 1994) generated at each site. Further details of site attributes and metadata, station characteristics such as ambient land use, descriptions of the surrounding landscape, and aerial and azimuthal ground-level photography were added to more fully document the surface conditions at every location (Hollinger et al. 1994).

In 2003, new site criteria for future ICN sites were drawn up by the WARM Program Manager and approved by the WARM Committee (Appendix II A). An evaluation of current ICN sites in 2006 found that several existing sites would not pass some criteria as a new site location. These evaluation criteria are provided in Appendix II B, which are adapted from those of the Climate Reference Network (after LeRoy 1998). In addition, due to potential changes in the landscape in recent years around sites, azimuthal roughness length calculations were re-computed in 2005 from individual site wind data from years 2000 to 2004. An update of the roughness length data, aerial and site photographs in azimuthal directions, a schematic of individual site sensor locations, and other meta-data material are found at in the files of the WARM Program Manager and Technician. Metadata are to be reviewed at least once every five years.

**3.2.2.5. Instrumentation and Equipment.** Attributes of all instruments, including their specifications and accuracies, are described in this section, updated from Hollinger et al. (1994). Dates of sensor installations, changes, and basic tracking of instrumentation at all ICN sites are recorded and archived by the WARM technician. A sample of that record is shown in Appendix III.

A schematic layout of a typical ICN station is shown in Figure 3.2. More precise locations of sensors at each site are found on file with the WARM Program Manager, the WARM technician, and on the WARM Web pages. Most sites operate using commercial power, but seven remote stations operate via solar power. In the event of a power failure or an extended period of cloudy days (and low sun angle) during late fall and early winter at solar-powered sites, each site has sufficient back-up battery power, which will sustain most instruments for several days of operations.

The sensors and equipment associated with a fully-instrumented ICN site in 2009 are as follows:

<u>Direct measurements on</u>
- air temperature
- relative humidity
- wind speed and direction
- barometric pressure
- solar radiation
- precipitation
- soil temperature
- soil moisture
- groundwater level

<u>Supporting equipment</u>
- instrument tower with masts
- weather shelters
- data logger
- telephone modem or cell phone
- battery for backup power
- multiplexers
- lightning protection
- solar collectors (if needed)
- shallow wells

Accuracy standards (Table 3.2) prescribed by the World Meteorological Organization (WMO 1983) assisted staff in a determination of the instruments to be installed at the ICN stations. In some cases, funding considerations resulted in selection of original instruments that did not meet the most stringent accuracy standards. In accordance with funding, higher quality instrumentation was continuously evaluated and installed when available in order to achieve the highest data quality across the network.

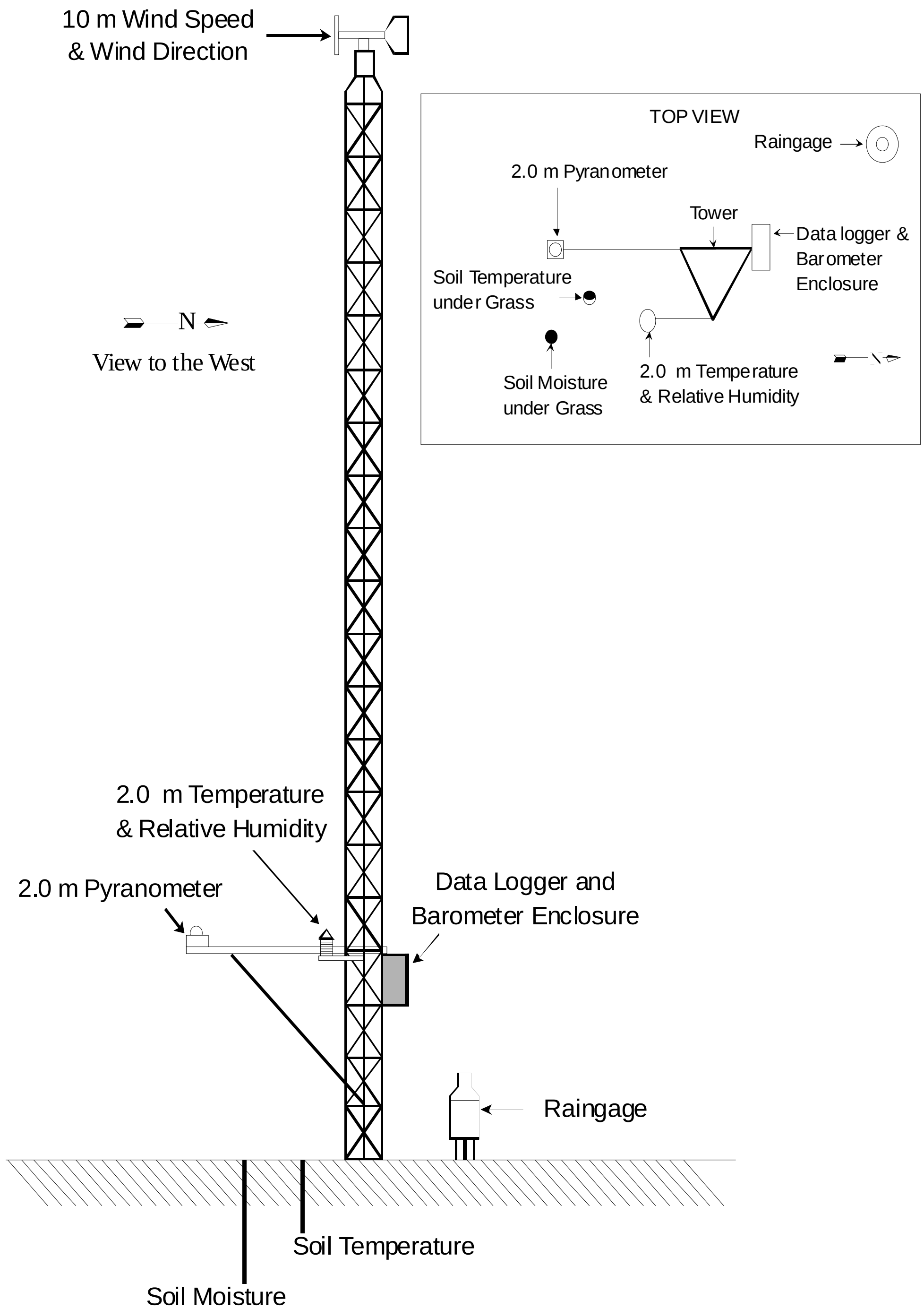


Figure 3.2. Typical ICN weather station structural layout (after Hollinger et al. 1994)

**Table 3.2. WMO Accuracy Standards Used at ICN Sites (After Hollinger et al. 1994)**

| *Weather variable* | *Accuracy standard* Climatology | *Agricultural meteorology* | *Automatic weather station synoptic meteorology* |
|---|---|---|---|
| Dry bulb temperature | ± 0.1°C | ± 0.1°C | ± 1°C |
| Relative humidity | ± 3% | ± 1% | -------------------- |
| Wind speed | ± 0.5 $ms^{-1}$ | ± 10% above 1 $ms^{-1}$ | ± 2 $ms^{-1}$ below 20 $ms^{-1}$<br>± 10% above 20 $ms^{-1}$ |
| Wind direction | ± 10° | ± 10° | ± 20° |
| Precipitation | 0.1 mm up to 10 mm,<br>± 2% for greater amounts | 0.1 mm up to 10 mm,<br>± 2% for greater amounts | 0.5 mm up to 5 mm,<br>± 10% for greater amounts |
| Solar radiation | ± 1 MJ $m^{-2}$ $d^{-1}$ | -------------------- | -------------------- |
| Barometric pressure | ± 0.3 hPa | -------------------- | -------------------- |

*3.2.2.5.1. Data Logger, Communications, and Lightning Protection.* Beginning with the automated electronic data downloads in 1988, sensors at each ICN site have been interrogated by a site data logger located within a weather shelter on the instrument tower. Prior to 2007, data programming and archives were accomplished with Campbell Scientific, Inc. (CSI) 21XL data loggers, and most recently using PC208W (ver. 3.01) Data Logger Support Software, also created by CSI. Earlier software versions of PC208 were used in prior years. In 2006, increases in the number of observations being collected over the years, even with expanded memory, placed a temporal urgency on repairs due to communication failure at the sites. The amount of storage of downloaded variables in these original data loggers was roughly nine days, after which data would begin to be overwritten. The usefulness of the nearly 20-year-old data loggers, which also had ceased to be repairable by the manufacturer, had expired.

During the last half of 2007, data loggers at all sites were modernized and progressively changed to CSI model CR1000. Download software was converted to LoggerNet (ver. 3.3, now ver. 3.4.1 in 2009), also a CSI product. The *Instruction Manual for LoggerNet* is located in the offices of the WARM Program Manager and WARM technician. Maximum storage on the new data logger models is sufficient to hold more than one year of continuous data.

Programming on the data logger controlling operations is generated from a common program standard, but one which is somewhat unique at individual locations, depending on the instrument array installed at each site. Program changes are performed using a laptop computer, brought to the site by the WARM technician.

An ISWS domain computer (**warm**) is dedicated to interface remotely with each station on a prescribed schedule, primarily during a 60-minute period reserved for daily downloading, specifically during the hour just after midnight CST. (Clock time on the communications computer and at all ICN sites remain on CST year round.) Since the start of automated downloading, communications occurred via a telephone link. The original telephone modems at each site are CSI model DC112. Their download speed is 1200 baud, and take up to 3 minutes to download one daily and 24 hourly records from each site during each call. This speed is exceedingly slow by today’s standards, but still sufficient for the once-a-day midnight downloading process used at most sites with no current impending need of faster communications. In early years, due to their remote locations or because of other local situations, four sites used analog cell phones made by Motorola. By 2007, digital modems or direct land-line service had replaced all of these cell phones, mostly due to the termination of analog cellular service in these areas.

In June 2007, one of these analog cell phones was replaced with an Airlink Raven model C3211, a digital wireless modem. This technology downloads data via the Internet. Total download time is a matter of a few seconds and charges are based on total monthly data volume, instead of connection time and number of calls. In 2008, two additional Raven modems were installed, replacing one shared telephone line and one digital cell phone. In early 2009, only one digital cellular telephone remained in service. During fall of 2009, a fourth Raven Internet cellular telephone was installed, replacing a land line that had been converted to service incompatible for data transmission.

Originally, communications at about one-half of the sites occurred via line-sharing with the site host. At these locations, a remote relay was installed on the telephone line to route service to the site data logger, allowing access to the station’s modem at midnight, a time when on-site personnel typically were absent and the need for voice phone service was quite minimal. The benefit to ISWS was no site telephone charges at these locations. By 2009, the number of shared telephone sites had been reduced to five, primarily by direct line telephone service.

Prior to 1997, site visits were frequent, especially during the thunderstorm season due to damage from direct or nearby lightning strikes. Beginning in 1997, an extensive grounding system was installed at each site and shielded cable was used to connect all instruments to the data logger. In addition, each data logger and its associated instruments were protected from electrical surges and lightning strikes by installing a CSI model 1619 surge protector. The new CR1000 data loggers have additional manufacturer surge protection built in. Since the start of the enhanced lightning protection, lightning damage has been far more infrequent. Occurrences were reduced by over 95 percent with similar reductions in damaged sensors and equipment. Nevertheless, lightning continues to be a concern at each location. Kilbourne and Big Bend, whose soils are mostly sand based, are considered particularly at risk.

*3.2.2.5.2. Air Temperature and Relative Humidity.* The history of air temperature and relative humidity sensors at ICN sites has been quite varied. Early in the record, these data were monitored using Vaisala temperature and humidity probes, models HMP112Y and HMP35, or a CSI probe, model CS500, made by Vaisala. The variety was due, in part, to the power supply at the sites, power consumption of the sensors, sensor performance, and the sizes of back-up batteries at each station. The HMP112Y model was used at the commercially powered sites because of its higher power consumption. In general, these sensors were not polled when commercial power failed and battery power was the only power source at the site. The power draw of the temperature and relative humidity sensors exceeded the amount of power available to run the entire sensor array sufficiently for the length of time commercial power might be down. The HMP35 model sensors were used at some of the solar-powered sites due to its low power consumption and high reliability. Model CS500 probes were also used at solar-powered sites and consumed the least amount of power; but they also were the least accurate of the temperature/relative humidity models within the WARM sensor inventory. By 2004, the Vaisala model HMP112Y sensors had been retired. Vaisala no longer manufactured the relative humidity sensor located inside this model. Thus, when relative humidity calibration was no longer possible, the unit was retired and removed from ICN site inventory.

Temperature and relative humidity probes are mounted inside a radiation shield attached to a leg of each weather tower at a height of approximately 2 meters (m) above ground. Each model above requires a 9- to 15-volt DC power supply and draws a current of 20 milliamperes (mA), 4 mA, or 2 mA, respectively. The operating temperature for the HMP112Y and HMP35 sensors is from -5° to +55°C. A 216 micrometer (µm) sintered bronze filter (replaced with Tyvek on newer models) protects a platinum thermistor, the temperature sensor, and a capacitive type humidity sensor from dust particles. The temperature measurement range is -40° to +80°C with an output uncertainty of ±0.3° at 20°C. The measurement range for relative humidity is 0 to 100 percent. In the 0 to 80 percent range, output uncertainty is ±2 percent at +20°C. The output uncertainty in the 80 to 100 percent range is ±3 percent at 20°C.

Manufacturer temperature accuracy for the Vaisala temperature and humidity probes fail the standard for climatology and agricultural meteorology purposes (Table 3.2), but they are suitable for automated weather stations used for synoptic meteorology. The humidity accuracy is suitable for climatology. Empirically, the humidity sensor was found to be relatively reliable; some of the sensors have been in the field at times for more than two years without significant drift or failure.

Beginning in 2006, a newer model CSI sensor, HMP45, was purchased progressively when necessary and installed as older models failed calibration. These new sensors are comparable to the HMP35 and require only slight modifications to the data logger programming.

*3.2.2.5.3. Wind Speed and Direction.* The site anemometer is mounted on each tower at a height of roughly 9 m (30 feet).The original wind velocity sensor installed at each ICN site to monitor wind speed and direction used an R. M. Young model 8003 Propvane anemometer. This instrument has a functional wind speed range of 0 to 50 meters per second ($ms^{-1}$), with a threshold speed of 0.2 to 0.4 $ms^{-1}$. The propeller weighs 31 grams (g) and has a distance constant of 3.3 m. The distance constant is the wind passage required for a 63 percent recovery from a step change in wind speed. With wind speeds greater than 1.3 $ms^{-1}$, the propeller makes one revolution per 30 cm of wind passage. Below wind speeds of 1.3 $ms^{-1}$, slippage increases (i.e., a greater wind passage is needed per revolution) down to the wind threshold.

Wind direction is measured from 3 to 360 degrees. The 10K-ohm precision potentiometer that measures wind direction had an open section in the potentiometer element from 0 to 3 degrees. The open section of the potentiometer element was oriented approximately between 0 and 3 degrees related to true north. Rotation of the vane clockwise from north to east, south, and west caused the azimuth signal to increase in value until the vane reaches 360 degrees, where the signal falls to zero. Values within the open section range from 1 to 6. The vane and propeller combination have a damping ratio of 0.34. With the exception of the damping ratio, these anemometer characteristics meet all requirements for air quality and atmospheric dispersion studies (Finkelstein et al. 1983). The damping ratio is slightly less than the suggested ratio of 0.4 or greater.

Beginning in 1998, ICN staff slowly began replacing existing anemometers with a much improved R. M. Young model 5103 wind monitor. This device is fitted with the same propeller as used on the model 8003. The advantage in accuracy of the model 5103 over the older model 8003 is that it outputs a series of pulses, which are in proportion to the wind speed rather than a varying DC voltage as used with model 8003. These pulses are continuously counted by the data logger, whereas the data logger would only poll the DC voltage of the model 8003 every 10 seconds. Intuitively, the model 8003 wind sensor frequently may have missed many extremes of maximum wind gusts because these are short-term transient features that often may have occurred during the 10-second gap in polling.

The model 5103 anemometer has a functional wind speed range of 0 to 60 $ms^{-1}$ with a threshold speed of 0.9 $ms^{-1}$. The propeller has a diameter of 18 cm and a distance constant of 2.7 m. The direction sensor is a balanced vane with a 38 cm turning radius. This 10K-ohm precision potentiometer has a 360-degree mechanical range and a 355-degree electrical range (5 degrees open). The vane and propeller combination has a damping ratio of 0.25. R. M. Young model 5103 anemometers were installed at all sites by the beginning of summer 1998 and were completed in summer 2001.

*3.2.2.5.4. Barometric Pressure.* A CSI SBP270 barometric pressure sensor with a Setra Model 270 variable capacitance barometer is used to measure atmospheric pressure at each station. The sensor has an accuracy of ±0.2 millibar (mb) over a pressure range of 800 to 1,000 mb. The operating temperature of the sensor is -18° to 79°C. The Setra barometer cannot be repaired economically. In 2008, several solid state barometers made by Vaisala, model PTB101B, were purchased to replace the Setra models as needed. A few have been installed and have yet to encounter problems.

*3.2.2.5.5. Solar Radiation.* Solar radiation is monitored using an Eppley model 8-48 black and white pyranometer mounted on a 2.7 m arm extending south from each tower at a height of approximately 2 m. The pyranometer is calibrated at the factory to a National Institute for Standards and Technology traceable blackbody with a wave band from 295 to 2,800 nanometers (nm). The pyranometer sensitivity is 9 to 10 microvolt per watt per meter squared (μv $w^{-1}$ $m^{-2}$), with an impedance of 340 to 350 ohms and a temperature dependence of ±1.5 percent over a temperature range of -20° to 40° C. It has a linear response within 1 percent from 0 to 1,400 μv $w^{-1}$ $m^{-2}$ and a response time of 4 seconds. Cosine response is better than ±5 percent from normalization at zenith angles of 70 to 80 degrees and better than ±2 percent for zenith angles of 0 to 70 degrees. If all the errors are additive in the same direction, the worst-case error would be ±7.5 percent for zenith angles of 70 to 80 degrees and ±4.5 percent for zenith angles of 0 to 70 degrees. Assuming the sun is between a zenith angle of 0 to 70 degrees during 67 percent of a day, the accuracy for a day would be approximately ±5.5 percent or ± 1.4 megajoules per square meter per day (MJ $m^{-2}$ $day^{-1}$).

*3.2.2.5.6. Precipitation.* Originally, site installations included a Belfort 5915 weighing bucket rain gauge fitted with a potentiometer, which acts as an interface to the data logger. These remain operational. Gauges are located outside the rain shadow area of the weather tower. Each gauge has a 203.2 millimeter (mm) (8-inch) aperture opening and a depth allowing maximum precipitation totals of 304.8 mm (12 inches). Although this capacity is expressed in inches, it is measured in terms of weight. A precipitation accumulation of 25.4 mm (1 inch) at 17°C (62.6°F) is equivalent to 822.7 g (1.814 pounds) of water. The accuracy of this type of rain gauge over the range 0 to 152.4 mm (0 to 6 inches) is 0.26 mm (0.03 inch, ±0.5 to 1 percent), and over the range 152.4 to 304.8 mm (6 to 12 inches) is 1.52 mm (0.06 inch ± 1 percent). An evaporation shield (funnel) is installed during the warm seasons to retard evaporation from the collected precipitation. It is removed during winter and a one-quart charge of environmentally safe antifreeze is added to each rain gauge bucket to allow for better catch of snow, to help melt frozen precipitation, and to protect the bucket from damage due to the expansion of freezing rain water.

All Belfort rain gauges in the network were modified for use with the Campbell data logger. Originally a stand-alone recording rain gauge, the mechanisms associated with the chart recorder and the pen arms were removed to reduce friction. On many gauges, a 1000-ohm linear potentiometer manufactured by Honeywell Corporation indicates the position of the Belfort weighing mechanism. Some gauges retain a Belfort rotary potentiometer. Gauges are interrogated once each hour by the data logger through the potentiometer, and its position indicates the level of liquid in the bucket. Precipitation is determined subsequent to downloading by subtracting the weight of water collected at the end of each hour or day from the weight at the beginning of the hour or day. Negative hourly observations are assumed to be evaporation and are ignored. Other negative and many small positive values are due to "noise" in the instrument caused by wind eddies, pressure and temperature fluctuations, electrical noise, and mechanical backlash of the instrument. These are common problems with the Belfort gauges, many being manufactured in the 1950s.

In summer 2008, Belfort gauges were replaced by Ott Pluvio2 precipitation gauges as the primary precipitation gauge. The Belfort gauges remain in place for a comparative study. The Ott Pluvio2 rain gauge represents a contemporary method in rainfall measuring technology. The gauge is mounted on a 4-inch galvanized pipe embedded 3 feet into the ground. This puts the orifice of the gauge approximately 1 meter above ground, which is standard. The gauge is attached to the station grounding system with a #6 bare copper wire. A two-pair shielded cable connects the gauge to the data logger through the station lightning protection system, which delivers the 12-volt operating voltage and carries the serial data at a 1200 baud rate (SDI 12) to the data logger. This is a communications protocol for connecting intelligent sensors to the CR1000 data loggers. Like the Belfort gauges, the Pluvio2 is a weighing bucket gauge, but instead of a mechanical scale, it uses a precision load cell with a resolution of 0.01 mm (0.0003 inch) for weight measurements and possesses a rainfall depth capacity of about 74 cm (29 inches).

The data logger polls a gauge at one-minute intervals. The gauges' firmware filters out sudden and unrealistic inputs such as wind gusts or debris. Insects and bird droppings may be light enough to register as legitimate. The bucket content is computed every six seconds, but initial event data are retained for five minutes before being accepted. At times when rainfall is very light, data may be retained for a full hour before they are accepted. If the rainfall amount does not reach the minimum threshold, there is no output.

*3.2.2.5.7. Soil Temperature.* Soil temperature is measured using Campbell Scientific model 107B temperature probes and is taken at depths of 10 cm (4 inches) and 20 cm (8 inches) under sod. Each probe consists of a Fenwal Electronics UUT51J1 thermistor in a water-resistant casing. Overall probe accuracy is determined by a combination of the interchangeability specification, the precision of the bridge resistors, and the linearization error. A worst-case error occurs if all the errors are in one direction. In this case, the error is ±0.4°C for temperatures ranging from -33° to +48°C. The overall accuracy is typically better than ±0.2°C, with the major error component being the ±0.2°C thermistor specification. During 2000, temperature sensors were installed at 10 cm (4 inches) under bare soil at eight ICN sites. In 2004, bare-soil temperature sensors were installed at the remainder of the ICN sites.

*3.2.2.5.8. Soil Moisture.* Automated, Stevens-Vitel Hydra soil moisture capacitance probes are attached to the ICN data logger and report data hourly within the regular downloading data stream at depths of 5, 10, 20, 50, 100, and 150 cm. Historic soil moisture data, which did not report via the ICN data stream, were collected manually using Troxler neutron probes. Full and detailed information on these sensors, a part of the ISMN, is located in Section 3.2.3.

*3.2.2.5.9. Water Table.* Most ICN sites possess a shallow groundwater sensor manufactured by Druck, Inc., model PDCR 1830-8335. (The exception is at Champaign with no well attached to the ICN). These instruments are pressure transducers that measure the depth of water over the transducer. Their functionality is that they are used by the data logger to compute the distance from the top of the well casing to the top of the water level in the well. These sensors are polled hourly and the data are downloaded within the site's regular data stream process. More information on these and other water table observations are found in the sections on the Illinois Shallow Groundwater Network, Section 3.2.4.

**3.2.2.6. Calibration Procedures and Calibration Verification**. All instruments within the ICN are calibrated before being installed in the field. Once installed, the instruments are verified periodically for proper operation. This verification is accomplished through daily data validation checks and field visits.

*3.2.2.6.1. Data Loggers and Communications.* All calibration operations were performed by the manufacturer of the CSI 21XL loggers, who had no recommendation on frequency of such events. Calibrations occurred due to other needs for returning the loggers to CSI, such as lightning strikes or memory upgrades.

The CSI CR1000 loggers perform self-calibration of the analog voltage measurements to compensate for errors due to temperature. This process is described in detail in the *Operator's Manual* for the logger found in the offices of the WARM Program Manager and WARM technician.

No field or lab calibration is performed on data loggers. Telephone modems have no calibration procedure and are repaired when needed.

*3.2.2.6.2. Temperature and Humidity Probes.* Each model of temperature and relative humidity sensors are discussed independently in the following sub-sections.

**3.2.2.6.2.1. Vaisala Model HMP112Y.** A calibration form is used to provide a hard-copy record of dates of service, dates of previous calibrations, repairs made, and notes relevant to the calibration. Copies of the calibration forms are kept for reference in the WARM laboratory. Most of these instruments were manufactured and purchased during the late 1980s or early 1990s. The time interval resulted in some variation in the circuitry of the sensors.

Temperature calibrations are usually performed concomitant with a relative humidity (RH) calibration. If temperature and RH sensors both have failed, the voltage regulator circuit is checked. Vaisala RH sensors can exceed observation limits when they accumulate salt deposits. When this is noted, sensors are washed with de-ionized (DI) water and air dried before proceeding with the calibration. An accumulation of fine particles is typically found inside the sintered bronze filter, which covers the temperature and RH sensors. This is removed and the filter is washed in DI water.

Temperature and RH calibration procedures performed in the WARM laboratory are summarized in the following sections, but are covered in greater detail in the C*alibration Procedures Manual* found in the WARM laboratory. The manual also details the most common repairs and sources for spare parts for these sensors.

3.2.2.6.2.1.1. Temperature Adjustment. The instrument to be calibrated is connected to the laboratory data logger, which uses the Campbell P2 program. A 100-ohm resistor is attached in place of the temperature sensor to simulate a temperature of 0° C. The data logger display is observed and potentiometer R37 is adjusted until a reading of 0 millivolts (mv) is obtained, corresponding to 0° C. Next, a 133.33-ohm resistor network is attached and potentiometer R39 is adjusted to a reading of 864 mv or 86.4° C. Each of the above adjustments may affect the other, so the procedure may have to be repeated until no change in output is noted.

3.2.2.6.2.1.2. Relative Humidity Linearization Adjustments. Vaisala does not require that the HMP 112 instruments be linearized routinely, but because the humidity sensor is often replaced or exchanged between instruments or because the instruments spend long periods of time in the field, experience suggests that the following procedure may add a certain undocumented level of accuracy to the calibration.

The RH sensor is rinsed with DI water to remove any accumulated salts. If sensors are slow to respond to humidity changes during calibration, some may need to be soaked in DI water for long periods of time to leach out contaminants. When sensor response continues to be inadequate after soaking, sensor replacement is required. Jumper X5S is removed from the terminal strip in the center of the circuit board. The RH sensor is replaced with the 45.8 picofarad (pf) calibration capacitor, and potentiometer R12 on the circuit board is adjusted to a value of 0 mv, as displayed on the data logger. The 45.8 pf capacitor is replaced with the 56 pf calibration capacitor, and potentiometer R17 is adjusted to 1000 mv. The procedure is repeated several times until no further adjustments are necessary. Jumper X5S is reconnected and potentiometer R28 is adjusted to a value of 940 mv as observed on the data logger display.

3.2.2.6.2.1.3. Relative Humidity Calibrations. The instrument is placed inside the Vaisala model HMK11 calibrator, where it is exposed to an atmosphere in equilibrium with a saturated lithium chloride solution (simulating a RH of approximately 12 percent) for about one hour. After that time, potentiometer R12 is adjusted to the appropriate value given in a calibration table found on the calibrator. Next, the instrument is transferred to the chamber containing the saturated potassium sulphate solution (RH of approximately 97 percent), and after about one hour, potentiometer R17 is adjusted to the appropriate value, again from the calibration table. The above procedure is repeated, alternating between solutions until no further adjustments are necessary.

At this point the instrument can be considered calibrated and both temperature and relative humidity sensors can be assigned a multiplier of 0.1 for their respective programs in the data logger. However, an additional step, detailed below, has been added to attain greater accuracy for the relative humidity reading.

1. The instrument is transferred from the Vaisala calibrator to a humidity chamber, still being connected to the laboratory calibration data logger. The chamber is a sealed plexiglass box equipped with circulating fans and wet bulb and dry bulb thermometers. Trays of saturated salt solutions are placed in the chamber, the fans are started, and the atmosphere is permitted to stabilize for about one hour. At that time, wet bulb and dry bulb temperature readings are made, a barometric pressure measurement is taken, and the relative humidity inside the chamber is computed using a psychrometric computer. This information and the instrument output as read from the data logger are recorded on the calibration sheet.

2. The above procedure is repeated using a range of salts. Water and wet towels are placed inside the chamber to simulate the upper extreme of the humidity range. At each stage, the calculated relative humidity and the instrument output from the data logger are recorded on the calibration sheet.

3. After a sufficient number of values have been recorded, usually four, a linear regression is performed on the data to generate a multiplier and offset for the Campbell P2 program. Multipliers are usually near 0.098 and offsets range from -5 to +5.

3.2.2.6.2.1.4. Storage Procedures of HMP112Y Instruments. A small bag of desiccant is placed against the circuit board and the cover is reinstalled. Silicone grease is used on the O-ring to assure a moisture-proof seal, and the cleaned sintered bronze filter is reinstalled over the temperature and RH sensors. Multipliers and offsets computed from the calibration procedures are recorded on a paper tag and attached to the end of the instrument cable where they will be available during a subsequent installation of this sensor. The multiplier and offset also are recorded on the field copy of the station program, kept inside an enclosure at the site.

**3.2.2.6.2.2. Vaisala Model HMP35.** Replaceable components include the RH sensor and the small circuit board inside the body. No components on the circuit board can be replaced. No linearization is required for this instrument. Calibration of the HMP35 model follows the procedure for the HMP112Y model above.

**3.2.2.6.2.3. Vaisala Model CS500.** There is very little circuitry inside this instrument and thus, very little to fail. Failures noted have been RH over-ranging. No adjustments are possible on this sensor. After washing or replacing the RH sensor, the instrument is calibrated in the humidity chamber as detailed above in the three-step procedure for the HMP112Y model (Section 3.2.2.6.1).

*3.2.2.6.3. Anemometers.* Anemometer calibration involves wind direction and wind speed functions. The most common causes of calibration error with model 8003 are bearing, potentiometer, or generator failure. Bearing and potentiometer replacement are the only maintenance items in model 5103.

**3.2.2.6.3.1. Bearings.** Empirically, bearing longevity with R. M. Young 8003 prop vane anemometers was about one year. In contrast, bearings in the model 5103 anemometers are lubricated with a light grease, or alternatively, a 50/50 mixture of Mobile 1 synthetic grease and Mobile 1 synthetic 5W20 motor oil. Numerous sensors that have been in service for several years have bearings that are still serviceable.

For the 8003 sensor, two identical bearings are located in the hub, which supports the propeller shaft. The outer bearing is more exposed than the inner one, and it is usually the one that fails. The inner bearing can be reused after disassembly, cleaning, and lubrication. Particles are removed from the area in the hub between the two bearings where they tend to collect. Silicone grease lubrication is placed on the threads of the hub and also on the "O" ring. The all stainless steel shafts require a lock nut to hold the propeller firmly in place. Over time, the nylon nuts supplied by the manufacturer eventually become loose. Experimentation has determined that a 6-32 stainless steel locknut can be substituted safely.

**3.2.2.6.3.2. Generator.** Output errors reporting low or no wind speed (model 8003) are often the fault of the generator located in the rear of the body behind the propeller hub. The generator is secured with a small set screw under the body. No repairs are possible to this unit; therefore, when the generator fails, it must be replaced. During routine servicing, the coupling on the end of the shaft requires inspection due to wear. Lubrication is needed for the small bearing at the shaft end of the generator.

**3.2.2.6.3.3. Housing.** Two ball bearings support the vertical shaft on the model 8003 sensor. These bearings rarely need replacement. The wires which slide on the commutator at the bottom of this shaft can sometimes wear and break. A small capacitor was added across the wind speed voltage divider to stabilize the voltage.

**3.2.2.6.3.4. Wind Direction Potentiometer.** The potentiometer, the position of which determines wind direction, occasionally fails. However, most have been in service for many years. Bad spots on the device can be detected during calibration (item 3 of section 3.2.2.6.1.6), and if found, require replacement of the potentiometer.

**3.2.2.6.3.5. Wind Speed Calibration.** A calibration form is used to provide a hard-copy record of each maintenance event. This record documents dates of service, time in service, repairs made, and any other notes relevant to the calibration. Copies of the calibration record are kept for reference by the WARM technician.

The output of the R. M. Young model 8003 varies from instrument to instrument. For the best accuracy, the following calibration procedure is used:

1. To electrically simulate field conditions, a 10-m cable is attached between the anemometer being calibrated and the laboratory data logger, which is identical to the units in the field. The Campbell P2 program is used to read the output from the anemometer.

2. The propeller shaft is connected to the R. M. Young model 18801 selectable-speed-calibrating unit. Using a shaft speed of 1800 rpm, an output speed of 19.7 mi $hr^{-1}$ would be expected. A multiplier is computed from the output voltage read by the data logger to convert the output voltage to miles per hour. The multiplier is entered into the P2 program and verification is made that the output is approximately 19.7 mi $hr^{-1}$. Most multipliers are near 0.017.

The standard wind speed multiplier, provided with the R. M. Young model 5103, produces a very accurate and reproducible output. No wind speed calibration is required for this instrument. The condition of the bearings is checked with the R. M. Young model 18310 propeller torque disk. This instrument provides a simple pass/fail test for wind speed threshold.

**3.2.2.6.3.6. Wind Direction Calibration.** For accurate azimuth readings, both anemometer models are calibrated in the lab using the technique described in the following paragraphs. These directions are specifically written for model 5103. Slight variations exist in the calibration technique applicable to model 8003 and are addressed in the calibration manual located in the WARM laboratory.

1. The wind vane instrument is cradled in the R. M. Young model 18112 vane angle bench stand to produce accurate azimuthal readings. With the 10-m field simulation cable attached between the anemometer and the laboratory data logger, the Campbell P5 program is used to verify that the maximum voltage reading occurs at exactly 360 degrees. A setscrew on the potentiometer shaft can be loosened when adjustments are necessary. The maximum voltage reading obtained at 360 degrees is recorded on the calibration form.

2. The instrument is slowly rotated clockwise through the potentiometer open section (0 to 3 degrees) and the azimuth and voltage readings at the ends of this region are recorded. Voltages are also recorded at 90, 180, and 270 degrees of azimuth. The five recorded voltage and corresponding azimuth values are used to generate a linear regression, which yields a multiplier and offset for the P5 program. Typical multipliers are in the range of 355 to 359, with offsets between 1 and 6.

3. While the instrument is in this position, the sensor is rotated through the complete range of azimuths to observe any unusual departures from a smooth scrolling of output values. If problems are noted, replacement of the potentiometer is required.

4. All multipliers and offsets are recorded on a paper tag and attached to the instrument. These data are entered into the site data logger program when the newly calibrated anemometer is returned to service.

*3.2.2.6.4. Barometric Pressure.* An accurate portable barometer stored in the WARM laboratory is used as a standard to check the accuracy of the barometers at all ICN sites. During the years when the WARM laboratory was located at U of I Willard Airport, this barometer was periodically checked for accuracy using a traceable mercury barometer in the Aviation Shop located at the airport, a device used by University staff to calibrate aircraft altimeters. The Aviation Shop no longer has the mercury barometer and no other standard is currently available. It should be noted that this barometer rarely required correction, and care has been taken to protect it from improper handling which could compromise its accuracy.

*3.2.2.6.5. Solar Radiation.* No field or laboratory calibration of the solar radiation sensors is available. Sensors are substituted with spares in storage when data values appear largely different from those at neighboring sites. During 2005–2006, a manufacturer-calibrated sensor was progressively moved from site to site to check on each site's quality assurance. This check is the only quality assurance method recommended by the manufacturer.

*3.2.2.6.6. Precipitation.* For the Belfort rain gauges, the data logger display on each unit is used to read responses from the Campbell P5 program. This output shows the position of the rain gauge-mounted potentiometer as various weights are placed in the catch bucket, representing accumulated precipitation. The type of potentiometer connected to the rain gauge in not important to the calibration procedure. Values displayed by the data logger are in volts.

A table of information is collected for various "depths" of simulated precipitation providing correction factors specific to each gauge that are placed in each field data logger program. To initialize the calibration, a temporary multiplier of 1 and an offset of 0 are used. With the catch bucket in place on the bucket platform, the data logger value is recorded in the first position on the calibration record sheet, representing 0 inches of accumulation. A 1-inch equivalent rain gauge weight is next placed in the bucket and the displayed value is recorded on the record sheet. This step is repeated until all values from 0 through 12 inches of simulated precipitation are recorded as additional weights are placed into the catch bucket. Using these 13 values, a linear regression computation is performed to produce a new multiplier and offset for the P5 program. Typically, new multipliers are in the range of 21 to 22 for the linear potentiometer and 14 to 15 for the Belfort rotary potentiometer. Offsets range from 0 to -6. After computing the multiplier and offset, both numbers are entered into the Campbell P5 program. The program is compiled, and an accuracy check of the calibration is performed by removing the gauge weights, one or two at a time, and observing the data logger display. These values usually range about ±0.05 inches. The above procedure is best performed on a day with little wind to avoid buffeting of the gauge, which would impact calibration accuracy.

The Ott Pluvio2 rain gauge has built-in accuracy-checking software called a "guided accuracy test." This test can be performed in the field and it is recommended that it be done on a day with relatively calm conditions to avoid the influence of wind on the test. The field laptop computer is connected to the gauge through its USB port, and the PCMCIA card in the laptop is used to provide a USB 2 connection. Start the “Ott Pluvio2 Operating Software” and click on “connect.” Click on “tools” and select “guided accuracy test.” The test requires a tare weight in excess of 2500 grams. One of the 7 amp hour station batteries works well for this weight. The exact weight of the battery is unimportant. A second test weight of around 200 grams is also required and its exact weight will have to be known and the value entered during the test procedure. The gauge software then computes the weight of the test weight, compares it to the entered value, and yields a pass/fail statement. The manufacturer recommends that the guided accuracy test be performed at least once per year. On-screen instructions for the test are provided and the procedure takes no longer than 10 minutes. The screen should be maximized when the test is first started since some of the windows that come up during the procedure are small and difficult to interpret.

*3.2.2.6.7. Soil Temperature.* No adjustments to the Campbell Model 107 soil temperature probes are possible, but a laboratory accuracy check can be performed in the WARM laboratory. A vacuum flask is filled with water. The probe, attached to a Campbell data logger, and the traceable mercury thermometer are submerged. The readings from the two instruments are compared. Subsequently, small corrections can be made by entering an offset into the program.

These temperature sensors are often removed from service when they develop a large offset. It is unknown whether a large correcting offset, used in the program, will make the instrument accurate again over its useful range. The instruments usually develop these offsets in summer, suggesting that lightning may play a role in shortening their useful lives.

**3.2.2.7. Data Representative Quality Objectives.** It is the objective of the ICN to maintain the highest level of quality in the operations of its instrumentation and to conduct a timely and efficient assessment of the collected data. A QC program is described in Section 3.2.2.10. The representative quality of the data is limited by the large and different spatial and temporal variabilities inherent within the multitude of variables being measured.

By their nature, weather data are representative of the region in which they are recorded only to the extent allowed by each variable’s temporal and spatial scale at each site. The spacing of the ICN sites was selected to best represent the maximum number of variables being observed in accordance with the number of available sites, funding, and site selection criteria. Some data are well-representative of their area, while others are less so. This can be due to instrumentation somewhat, but is most likely related to high spatial variability by individual meteorological variables. Most data monitored by the ICN are considered an appropriate representation for the immediate locale in which they are recorded, but the distance from the site for which these data remain valid varies considerably among the variables. In the end, transferability of data to locations away from where they are recorded is at the risk of the user.

In general, temperature, relative humidity, solar radiation, and barometric pressure have less spatial variability than soil temperature, wind speed/direction, precipitation, and soil moisture, due mostly to the nature of the particular variable, but partially by the manner in which the observations are taken. Temperature and relative humidity values could possess significant variability due to local effects, topography, surface cover, and anthropogenic features, but these factors themselves also can be highly variable and hard to document. Regardless, by definition, large-scale air masses have significant homogeneity in temperature and relative humidity, making regional variability small. Barometric pressure data (when converted to sea-level pressure) are unaffected by surface features. Also, assuming similar seasonal cloud cover that no surface-based shadows strike the instrument, solar radiation observations should be similar over a long distance east and west. This may not be the case at St. Charles, our closest site to Lake Michigan (Changnon et al. 1979a), or at Belleville, just downwind of the city of St. Louis, due to lake and urban impacts on cloud cover, respectively (Changnon et al. 1979b). Conversely, north-south latitudinal variability in insolation will occur with distance from an individual site. With all of these noted influences, siting criteria are designed to identify environments where such local effects are likely to be substantial and thus eliminate those locations from site consideration.

Wind data are highly influenced by the location of obstacles around each site. Even given the flatness of some of the Illinois terrain, the approximate 9-m height of ICN wind observations are far from sufficient to eliminate influential effects from ambient objects. An extensive analysis of the approximate roughness lengths surrounding each ICN station has been conducted and is provided by Hollinger et al. (1994). This was repeated in 2005 with results posted within the WARM Web pages. Furthermore, similar to precipitation cells, wind speed and direction also can possess exceedingly small-scale features, especially during extreme weather events. These are irresolvable within the ICN.

Soil temperature could possess large variability within a region for several reasons. Surface cover and soil types can vary significantly a short distance away from each site and greatly influence these data. Although the siting criteria for ICN soil temperature sensors require sensors to be located under sod, control over the nature of the cover rests with the property managers where sites are located. Some sites have heavy sod; others are located in areas in full public view with well-manicured lawns. Occasionally sites are mistakenly sprayed with herbicide for ease of weed control around the ICN tower, creating bare ground patches. Attempts are made to standardize surface covers at all sites, but lawn watering and mowing schedules around each site are controlled by ICN hosts. More research is needed on the comparison of soil temperature data to neighboring agricultural ground, as well as the effects of a variety of annual covers and tilling/low till/no till farming practices to associate observations with impacts on soil temperature representation.

Perhaps the variables least representative to areas adjacent to data collection sites are soil moisture and water table depth. Research by Scott et al. (2009) indicates that soil moisture (and likely water table depth) varies considerably over a single research field of observations. Variability is small within 30 cm of the surface (about ±3 percentage points), but it increases at depths below 1 m (as high as ±10 percentage points in summer). Other influences greatly impact seasonal soil moisture variability as well: localized topography that creates ponding, soil types, bulk density, permeability, porosity, as well as seasonal variability in the water table height. The depth and breadth of water trapping lenses as well as local tiling are important factors. Observations of most of these factors are not typical prior to soil moisture site installations, but they can greatly impact representativeness of collected data and may need to be addressed by certain data users.

Adequate assessment of current ICN station spacing as it applies to regional representativeness of measured variables has not been performed. Hubbard (1994) explained 90 percent of the variance in daily measurements of maximum air temperature collected in a weather mesonetwork in the High Plains with a station spacing of about 61 km (38 miles). He documented that 30.5-km (19-miles) spacing would be needed to achieve the same criterion level for minimum air temperature, relative humidity, solar radiation, and evapotranspiration. His work suggests that a site spacing of about 20.9 km (13 miles) would be necessary for soil temperature, 9.6 km (6 miles) for wind speed, and site separations of less than 4.8 km (3 miles) would be required to attain the 90 percent variance level for convective precipitation observations. On this latter point, extensive past research by ISWS staff (e.g., Huff 1970) agrees, indicating that a station spacing of 3.2–4.8 km (2–3 miles) would be adequate to resolve convective rainfall, typical of precipitation during spring and summer months, while spacing of 9.6 km (6 miles) would be needed to measure the more widespread stratiform precipitation systems typical of Illinois weather events in cooler seasons.

Although no spatial resolution testing of the measured variables of the ICN data stream has been undertaken to verify Hubbard's (1994) work in Illinois, an assessment of average station spacing has been performed. By averaging the distances to the three closest stations at each ICN site (ignoring the Champaign site due to its extreme closeness to Bondville), an average station spacing across the ICN was computed at 87 km (54 miles). This is far larger than Hubbard's (1994) broadest representativeness maximum air temperature of 61 km (38 miles). However, there are five site couplets within the ICN that have station spacing between 40 and 57 km (25 and 35.5 miles). In addition, the locations Bondville and Champaign lie about 12 km (7 miles) apart. Data from these six pairs can be tested to assess the potential for an adequate database for a site separation standard of most variables monitored by the ICN within an economically and operationally feasible plan.

In summary, all meteorological variables are considered to accurately represent conditions for the site at which they are collected. Transferability of data to other locations involves some level of uncertainty, depending on the distance from the observation site, the spatial variability of the particular variable of interest, and the general weather conditions of the day and of the most recent past. The risk acceptance is determined by, and is the responsibility of, the data user. Nevertheless, all recorded data gathered from the instrumentation, operating by ICN standards, are considered as providing factual information on weather and soil conditions occurring at a particular place and time. These data will not give precise information on what occurred at a location away from an individual ICN site, but they do represent a sample of what occurred locally and regionally during a particular time period or event.

**3.2.2.8. Sampling Schedule and Procedures.** Each ICN station data logger is programmed with a set of site-specific instructions to retrieve data from the station's sensor array. Most sensors are polled at 10-second intervals and accumulated over a one-hour time interval. This includes wind speed and direction, solar radiation, air temperature, relative humidity, 4- and 8-inch soil temperatures, barometric pressure, precipitation (Belfort), groundwater depth, and soil heat flux. The 12-level soil temperature profiler and the Pluvio II precipitation gauge are polled once a minute and the continuous soil moisture probes every 10 minutes.

At the end of each hour, the data logger program calculates averages for all variables and stores the information in a set of hourly records. The hourly wind direction computation is a vector average and precipitation is listed as an hourly gauge total. For the continuous soil moisture and groundwater depth sensors, instantaneous (hourly) values are stored for each hour. Standard deviation values for the hour are computed for wind speed, wind direction, solar radiation, air temperature, relative humidity, precipitation, barometric pressure, soil temperature readings at 4 and 8 inches, and bare soil temperature at 4 inches.

Computations of dew point temperature (requiring readings of air temperature and relative humidity) and potential evapotranspiration (PET, requiring air temperature, relative humidity, solar radiation, wind speed, and barometric pressure) are made from the hourly data and are added to the hourly data string. Formulae for the PET computation are given in Hollinger et al. (1994).

Since the beginning of barometric pressure records, maximum and minimum readings of pressure and times of occurrence within the prior hour have been recorded at each site. Beginning in 1999, data logger programming was altered in a progressive manner across the network to record hourly extremes of air temperature and relative humidity and their times of occurrence, and maximum wind speed, the time of occurrence, and the wind direction at that occurrence time. Total daily precipitation by the Belfort gauges is reported as the current amount of liquid in the gauge bucket. Daily data output from the Pluvio 2 gauges lists an accumulated sum of hourly totals. For both gauges in winter, the totals are obtained with an antifreeze mixture added to the collection bucket.

Finally, operational information such as data logger programmable read-only memory signature (prom sig) and cell phone battery voltage (where applicable) are included in the hourly grouping. Additional daily output includes the maximum and minimum values and times of occurrence of the data logger battery voltage, and internal data logger panel temperatures over the prior day are included. All tabular data listed in this section are considered *raw data* files and have some individual site specificity. Appendix IV shows a sample listing of hourly and daily data tables downloaded daily from ICN sites.

As of fall 2009, data access via Internet had been established at four stations (Olney, Orr, Fairfield, and Dixon Springs). Thus, data downloading on an hourly basis was initiated at these four sites, plus two land lines with local service (Champaign and Bondville). The local sites initiate downloading sequentially, beginning at 10 seconds after the hour. The Internet phones are turned on only for the first 10 minutes of each hour. Time is given for them to fully activate. Downloading at the Internet site begins at 90 seconds after the top of each hour.

At the end of each day, an accumulated set of 24 hourly records, called the *hourly table,* covering the 24-hour period of the previous day, is readied for downloading to the ISWS communication computer at the13 sites not downloaded hourly. At the same time, a single record of daily summary information, called the *daily table*, is similarly structured for downloading. This latter table lists daily extremes and times of occurrence of selected sensor values measured over the previous 24 hours, including maximum wind speed (and the wind direction at the time), air temperature, relative humidity, the 4- and 8-inch soil temperatures, the 0-, 5-, 10-, and 20-cm level soil temperature profiler data, and after installation at each site, the 4-inch bare soil temperature.

The scheduled time for daily data downloading is just after 0000 Central Standard Time (CST). (For long-term consistency, CST is maintained by the ICN communications computer and with the field data loggers throughout the year.) To avoid various intermittent communication glitches, communication to each station is tried up to five times until successful. If downloading does not occur after five attempts, downloading will not be attempted again until the next scheduled event.

Data loggers at the five shared telephone sites (Belleville, Carbondale, DeKalb, Freeport, and Rend Lake) are set via a switching device at the sites to be accessible once a day only during the midnight hour. Due to that one-hour availability, these sites are the first in line to be downloaded after the two local telephone service sites, beginning at one minute past midnight. The one remaining cell phone site (Peoria) has a one-hour period of accessibility three times during the day, at 0000, 0800, and 1430 CST. Its 0000 call is scheduled after the first attempt on each of the shared lines. The remaining nine direct-line sites are available at any time during the day, via the automatic call or with a manual phone call initiated via Loggernet software on the ICN communications computer. By design, the 0000 automatic call to these sites is scheduled no sooner than 10 minutes after midnight. The Internet phones are accessed the same as with all other hours, 90 seconds after the start of the hour. Communications with the Internet phones do not interfere with calls to the other phones and can occur simultaneously; however, communication log messages are intermixed.

By agreement with individual site hosts with shared lines, limits on site accessibility are in place to avoid times they require use of their telephones. Data from two sites (Freeport and Belleville) with shared telephone lines can be accessed during normal working hours if office personnel at the site are present to manually switch the phone line to the data logger via a toggle switch on a remote relay. Relays at the other shared sites are located away from the host’s access, and baring a field visit, are available only during the midnight time interval.

At many sites, limits to communication access are designed to avoid excessive power consumption (draws by the modems) on site batteries, particularly at solar-powered sites during late fall and early winter when the sun angle is low, seasonal cloud cover is high, and especially on days with exceedingly cold temperatures. Sites with limited access have built-in delays of 10 seconds to one minute to ensure sufficient time for modems to turn on and be ready for use. Potential occurrence is noted only by monitoring reported battery voltages from the data logger.

An accurate time standard is maintained on the ICN communications computer from the Network Time Protocol via the U of I computer system. During communications with field sites, clocks on the Campbell 21X data loggers are checked during daily downloads and adjusted to the communications computer clock whenever they differ by more than 10 seconds. Field time is corrected with the Campbell 1000 data loggers whenever clocks deviate in excess of one second.

Data loggers at all field sites possess error-checking capabilities and maintain a memory of the last successful data downloaded to the communications computer in order that no duplicate information is downloaded during successive connections. Communication messages, detailing all operations, successful or not, are stored to assist in troubleshooting the system when communication failures occur.

**3.2.2.9. Written Standard Operating Procedures.** Operating procedures covering all laboratory and field activities reside in the offices of the WARM technician and/or the WARM Program Manager. Instructions are provided for field checks of sensor quality and more precise details to be followed during field and laboratory calibration checks. Included with this documentation is a quality assurance tracking list, which documents the full history of the sensor and instrument inventory owned by ICN, including property tag numbers (when required), the current status of operational quality, and locations of sensors, both in the field and working spares on hand. The WARM technician keeps documentation files, including sensor specifications from the manufacturer and contact information needed for returning instruments for repair or when purchasing new sensors.

**3.2.2.10. Quality Control Practices.** Quality control procedures are designed to identify and edit where possible erroneous information that is presented in the collected data in order to avoid adding these data to the permanent archived ICN data files. Raw data downloaded from field data loggers to the communications computer are stored as ASCII files with the variable structure as displayed in Appendix IV. The number of observed variables and concomitant data as displayed has changed over the years as more data have been added to (or occasionally subtracted from) the data sets. These raw ASCII files are written to permanent archive storage within the office of the WARM Program Manager on ISWS computers, **warm** and **warmer**, as well as archived CD storage.

Data are evaluated through a series of numerical procedures, which check for missing records and the correct number of data elements within a record, as the data are arranged into the proper format leading to the QC analysis. The original QC program consisted of a series of instructions written in C, FORTRAN, and dBASE IV programming languages, which provided for an automated computer evaluation of the collected data at each site. An on-going process began in 2008 to convert all programming to .NET programming. This should be completed late in 2010.

Initial checks are intra-site, and compare data at adjacent times to highlight potential errors in both the hourly and daily data. Programming checks for data inconsistencies such as a change in a weather variable at an individual site in excess of a specified range over one hour and exceeding seasonally set hourly and daily ranges of values for individual variables across the entire state. Items that fail these checks are flagged by the QC programming process to be checked manually later by ICN staff. During these checks, data are approved as accurate, manual edits are made, or programmed edits using nearest neighboring data edits are preformed. Official, quality-controlled data reside on the Datastorm SQL.

A complete list of editing processes, archive files, and storage locations for ICN data are provided in Appendix V. Some of the data checks are listed below.

Questionable hourly data for each variable are flagged when any of the following data checks occur:
– limits checks - hourly data outside prescribed seasonal limits
– comparison checks - reported values that are not possible or are unreasonable, such as:
  - solar radiation at night
  - negative wind speeds

- wind direction that is negative values or values in excess of 360 degrees
    - 4-inch soil temperature greater than 8-inch soil temperature by more than 10°C
- – duplicate record checks - data records within the same download sequence with dates and times that are identical
- – checks for missing hours - hours within the same download sequence with no record
- – time consistency checks - changes between adjacent hours that exceed specific thresholds (5°C in temperature, 20% relative humidity, 2 millibars in pressure) or data that remain exactly the same to the thousandth of a unit for three or more hours

Questionable daily data for each variable are flagged when any of the following data checks occur:

- – limits checks - daily data outside prescribed seasonal limits
- – comparison checks - reported values that are not possible (e.g., minimum daily values that are higher than maximum daily values)
- – duplicate record checks - data records within the same download sequence with dates that are identical
- – checks for missing days - days within the same download sequence with no record
- – time consistency checks - data between neighboring days that remain exactly the same to the thousandth of a unit for two or more days

All flagged data are checked visually by the ICN program manager to verify the reasonableness of the reported data. Flags are cleared if reported data are considered acceptable. All edited data and any remaining unreasonable and missing data retain flags in the permanent record to indicate data that were either estimated (E) from adjacent hours or from neighboring sites, or were unable to be edited and will stay marked as missing data (M) in the official file. Hard-copy records of flagged data, as well as edits made to the hourly and daily data tables and dates of QC procedures, are kept on file by ICN staff.

Momentary power outages to sensors cause many data records to record values near zero. In early years of the ICN, this occurred most frequently with air temperature and relative humidity sensors since they were not supported by battery backup at commercially powered sites due to their high power consumption. At certain seasonal times, these values fail to be indicated by the programmed automated limits checks. For example, cold season minimum temperatures and extreme cold season maximum temperatures and all minimum relative humidity have “normal” values that will fall into the range of near zero. Thus, some of these values can be superfluous readings that are undetectable numerically from actual data. Values on days with these flagged daily data are compared with valid hourly maximum/minimum data found in the raw hourly data tables. When appropriate, quality values are substituted within the appropriate daily maximum/minimum slot. Since, in most cases, the hourly data values are not suspect, daily error flags are removed.

After all flagged data have been considered, all data are written to permanent records. Within the daily data files, averaged daily data are added to the data stream. Daily averages are computed from the hourly values for wind speed and direction, air temperature, relative humidity, dew point temperature, solar radiation, 4- and 8-inch soil temperatures, potential evapotranspiration, and sea-level pressure.

Inter-site evaluations are made manually by plotting averaged data over long periods of time to pinpoint sensors that may have drifted in their readouts. Edits are made (and sensors are replaced) when an unreasonable trend in data is observed at one site that is not reported at neighboring sites, indicating a potential instrument problem rather than a true climatic trend. However, failing sensors due to drift in sensor performance are not caught adequately by these numerical processes. An on-going process is to maintain raw ASCII files downloaded from data loggers, process data through error checking routines written in .NET programming, and then write data directly to an ISWS Structured Query Language (SQL), Datastorm. Within these programs are algorithms that are significantly more powerful in data QC checking and editing. Automated edits will be based as before on sudden defined changes in intra-site temporal consistency and limit checks now defined by data values within the seasonal “range” (undefined totally at this writing) of acceptable values based on historical data at each site. Programming also will include inconsistencies suggested by data comparisons between nearest neighbor checks. Precise procedures will appear in a future edition of this document.

**3.2.2.11. Data Users.** Various displays of ICN data appear on WARM’s Web pages, specifically located at: http://www.isws.illinois.edu/warm/datatype.asp, as well as elsewhere in those pages with value-added products. ICN data also are incorporated into the *IWCS*. These disseminated data are used for planning and monitoring purposes by state and federal governmental groups and the agricultural community within Illinois. Numerous monthly data tables and reports are used by individuals and private businesses involved in research to assist in their regular operations requiring current data climate information. Other data users include government officials, the legal community, various research organizations, and the public. Requests for data assisting litigation occur at times. Written reports are provided to users upon request.

**3.2.2.12. Data Reduction and Archival Protocols.** As described earlier, data are downloaded once a day to an ISWS computer from most sites and hourly at six stations. These raw data files are stored as part of the permanent record. A portion of the raw data is reduced automatically and a manual QC of flagged data takes place (described previously). After these data have been cleared or permanently marked with QC flags, the newly edited hourly and daily data are appended to the permanent archives in electronic form. The primary set of these records includes running hourly files of the current year’s data and running period-of-record files of daily archive data. Daily data are stored in separate files by site, and hourly data are stored in yearly files by site. These data are stored in the Datastorm SQL. In addition, a weekly backup is run on the computers receiving and processing raw data. Field data loggers also have storage capabilities of over one year.

**3.2.2.13. Data Quality Assessment Procedures.** Quality assessment of ICN data is performed and maintained during daily QC operations. Erroneous data that suggest a sensor problem, as well as all sensors showing missing data, are reported to the network technician by way of a work order to analyze the reported problem and re-calibrate, repair, or replace the malfunctioning sensor or equipment. The work order form used for ICN repairs is shown in Appendix VI. The QC supervisor will document the symptoms of the potential erroneous instrument and the technician will record and date the activities involved in returning the station to full working order. Actions taken may involve documentation on the site's sensor logs.

**3.2.2.14. Personnel Qualifications and Training.** ICN staff work in three functional areas. The first of these is the primary management of the program, overseeing all operations and determining applicability of collected information to numerous data users. The second involves the technical and mechanical operation and maintenance of network. The last area includes computer programming for development of processes to assure data quality, designed dissemination products, and data archives.

Currently, the WARM Program Manager headlines the ICN organization, oversees all operations, and is responsible for the total functionality of the program; however, this is not necessarily a permanent function of the WARM Program Manager. If the WARM Program was to expand, the following qualifications would fall to the ICN supervisor.

The individual in charge of the ICN evaluates the automated QC process, conducts manual data editing, ensures that data are disseminated to users in a timely manner, and provides guidance that maintains the highest possible data quality from data collection to archives. For these purposes, the person should possess a master's degree in the atmospheric sciences or have substantial experience working with and understanding the variability of atmospheric data, as well as working with instrumentation in a field setting. It is highly important for the individual to understand the weather and climate of Illinois and the typical variability of meteorological data across the state. Required abilities are to work with large data sets, perform or oversee standard statistical and graphical analyses for quality assessment of data, outline development of dissemination products, ensure accuracy and clarity of Web products, develop new value-added products when necessary, respond to users, clearly communicate with and supervise subordinates, and respond to decisions of the WARM Committee and ISWS Director. Computer experience, Internet fluency, and excellent verbal and written communication skills are essential.

Technical and mechanical processes in the field and the coincident sensor quality assurance component in the laboratory require a skilled program technician. This effort involves setting up and maintaining each site's physical infrastructure, skills in evaluating and preserving the quality of all instruments in the sensor arrays during field and/or laboratory operations, and ensuring all suggested and/or required codes and operational guidelines are adhered to, including ISWS standards of staff safety. These professional tasks require staff with expertise in both mechanical processes and electronics. Education with an academic degree working in one or both of these areas of study or completion of adequate trade school experience is preferred. Significant post-academic, hands-on experience, including operation of appropriate tools used in electronics and those required for fabrication and maintenance of the field facilities is required. The technician must be able to assess the power and communication needs of the ICN instrument array at each site, as well as be familiar with standard techniques and those provided by instrument manufacturers for sensor calibration. Of prime importance is the ability to develop the appropriate skills to trouble-shoot problem areas with sensors and facilities, both in the field and in the laboratory, and/or to align with adequate manufacturer contacts to fulfill these needs quickly.

The last functional area within ICN involves personnel who write computer programs to evaluate the quality of the collected data, structure dissemination products for the benefit of users, and construct and maintain adequate data archives. It is the prime responsibility of the individual performing these tasks to ensure that all computer programming is maintained from downloading of data through all QC and analyses processes provided by the program manager to the appropriate data archives. Required skills of the individual include appropriate computer programming used by the project at the time, including Web development expertise. Good communications skills, Internet fluency, and the ability to work as a team member under the supervision of the ICN program manager are essential.

### *3.2.3. Soil Moisture Network*

**3.2.3.1. History.** A soil moisture monitoring network (ISMN) in Illinois began in 1981 as part of the IBN with the installation of access tubes for neutron probe measurements at or near six ICN sites and two independent locations. Observations were added at seven ICN sites in 1982, two more in 1986, and at one in 1991. In 1998, one of the original (independent) sites was decommissioned and removed. There have been two other locations with short periods of neutron probe observations. Three ICN sites never had these observations collected nearby.

Beginning in 1998, conversion to continuous automated soil moisture sensors was initiated. Six sites were converted in that year, two sites were converted in 1999, and five more were converted in 2000. The remaining four sites were converted in 2001. During the conversion process, one additional ICN station was equipped with soil moisture monitoring for the first time (in 1998), one in 2004 (coincident with the decommissioning of the remaining independent site), and another in 2007, bringing the soil moisture monitoring sites to all 19 ICN sites. Initial analyses indicated sufficient comparison between the two data collection platforms to terminate neutron probe observations at all but eight sites in 2004. The remaining neutron probe observations were maintained until late in 2008.

Due to the decommissioning of the neutron probe observations, most specific descriptions, procedures, and protocols concerning the neutron probe data have been moved to Appendix VII to keep information in the following sections current, while ensuring an understanding of the historic soil moisture data collection procedures.

**3.2.3.2. Monitoring Variables and Monitoring Objectives.** Neutron probe sensors produce only soil moisture data. The automated continuous sensors also include soil temperature observations at the same level.

Soil moisture is an important factor in the growth of crops. It also can assist in tracking impacts within other water resources of the state during developing and prolonged periods of precipitation extremes. As a part of the hydrologic cycle, soil moisture data can provide critical and timely information on where dry conditions may be developing across the state due to rainfall deficits. Assessment of current soil moisture conditions can be very useful for estimating impacts of a developing dry environment.

Soil moisture assessment is important not only during drought, but also during recovery when equally important data can be obtained. Computations can be made on the necessary levels of precipitation required to recharge soils with moisture, levels which in general must first rise in soil moisture observations before moisture would be available to reverse deficit trends in the state’s other water resource variables. Basically, the monitoring objective of soil moisture data collections is to obtain the necessary base of long-term information from which comparison assessments can be made between these data and other water resources in the state during periods of extremes in precipitation.

**3.2.3.3. Number and Locations of Monitoring Sites.** The full, historic ISMN is shown in Figure 3.3. The current network is a 19-station soil moisture array, coincident with the ICN sites and fully incorporated within that system as standard ICN sensors. The sites in italics never had neutron probe readings. Two original sites with neutron probe observations (underlined) were decommissioned after a long period of operation. Geographic locations, elevations, dates of neutron probe monitoring, and starting dates of continuous soil moisture probe operations are given in Table 3.3. Data from two additional sites are included in the table and in the ISMN archives, but these were short-term data collections associated with other research programs and were not part of the ISMN. Soil characteristics for each site are provided in Table 3.4 (after Hollinger and Isard, 1994).

**3.2.3.4. Siting Criteria.** Current siting criteria are minimal. All current sites are co-located with ICN equipment in order to download soil moisture data automatically within the full ICN data stream. Locally, the most important siting factor is to avoid placing monitoring probes in areas prone to flooding and/or standing water. However, no documented siting criteria exist from the days of earliest neutron probe observations. Scott et al. (2009) found that surface readings taken from 11 sites across a 5.9 hectare sodded field site at Bondville were similar in soil moisture content near the surface, but differed greatly below 1 meter of depth, suggesting that considerable analyses of topography and soil profile conditions should be undertaken to develop appropriate siting protocols before installing new soil moisture sites to the ISMN. Plans for these are under consideration within the auspices of the International Soil Moisture Working Group (Pierzynski et al. 2005), a program sponsored by the United Nations Educational, Scientific and Cultural Organization.

**3.2.3.5. Instrumentation (Description and Performance Attributes).** The continuous soil moisture sensors installed to replace the neutron probes are manufactured by Stevens-Vitel, model Hydra-20 soil moisture probes. These sensors produce a four-channel output of voltages used to obtain measurements of soil moisture and temperature.

Measurements yield information within a cylinder approximately 2.5 cm in diameter and 6 cm in length, a volume of approximately 12 cubic centimeters ($cm^3$). These probes determine soil moisture by making high frequency complex dielectric constant measurements. The measurements resolve the capacitive and conductive parts of a soil's electrical response. The capacitive part is most indicative of soil moisture. In addition, soil temperature is determined from a calibrated thermistor incorporated into the probe head.


Figure 3.3. Illinois Soil Moisture Network. Period-of-record observations include data from sites with both neutron probe and capacitance sensors (dots), neutron probe sensors only (asterisks), or capacitance sensors only (triangles)

**Table 3.3. Locations and Data Collection Periods of Soil Moisture Network Observations**

| *Site no.* | *ID* | *Site Name* | *County* | *Latitude (deg)* | *Longitude (deg)* | *Altitude (m)* | *Dates of neutron probe record* | *Start of continuous record* |
|---|---|---|---|---|---|---|---|---|
| 1 | BVL | Bondville | Champaign | 40.05 | 88.22 | 213 | 2/2/1981 - 12/1/2004- | 7/16/1998 |
| 2 | DXS | Dixon Springs (Bare cover) | Pope | 37.45 | 88.67 | 165 | 4/19/1981 - 12/1/2004 | 10/4/2000 |
| 3 | BRW | Brownstown | Fayette | 38.95 | 88.95 | 177 | 4/30/1981 - 12/1/2008 | 7/7/1999 |
| 4 | ORR | Perry | Pike | 39.80 | 90.83 | 206 | 5/6/1981 - 11/29/2004 | 8/10/1998 |
| 5 | DEK | DeKalb | DeKalb | 41.85 | 88.85 | 265 | 5/21/1981 - 11/30/2004 | 12/16/1999 |
| 6 | MON | Monmouth | Warren | 40.92 | 90.73 | 229 | 6/19/1981 - 11/29/2004 | 8/24/1998 |
| 7 | SFM | Kilbourne | Knox | 40.17 | 90.08 | 152 | ---------- | 12/14/2007 |
| 8 | ICC | Peoria | Tazewell | 40.70 | 89.52 | 207 | 10/25/1982 - 12/1/2008 | 9/5/2001 |
| 9 | LLC | Springfield | Sangamon | 39.68 | 89.62 | 177 | 7/22/1982 - 12/1/2008 | 10/18/2001 |
| 10 | FRM | Belleville | St. Claire | 38.52 | 89.88 | 133 | 5/13/1982 - 11/29/2004 | 9/12/2000 |
| 11 | SIU | Carbondale | Jackson | 37.70 | 89.23 | 137 | 11/24/1982 - 12/1/2008 | 9/21/2000 |
| 12 | OLN | Olney | Richland | 38.73 | 88.10 | 134 | 7/23/1982 - 11/30/2004 | 9/23/1998 |
| 13 | FRE | Freeport | Stephenson | 42.28 | 89.67 | 265 | 4/15/1982 - 12/1/2008 | 10/20/1998 |
| 14 | RND | Rend Lake | Jefferson | 38.13 | 88.92 | 130 | 8/5/1982 - 12/1/2008 | 11/15/2000 |
| 15 | STE | Stelle | Ford | 40.95 | 88.17 | 213 | 3/31/1986 - 11/30/2004 | 3/9/2001 |
| 16 | MTF | Topeka | Mason | 40.30 | 89.90 | 152 | 6/1/1981 - 12/1/2008 | ---------- |
| 17 | OAK | Oak Run | Knox | 40.97 | 90.15 | 265 | 6/1/1981 - 6/15/1998 | ---------- |
| 20 | STC | St. Charles | Kane | 41.90 | 88.37 | 226 | ---------- | 8/19/1998 |
| 22 | BBC | Big Bend | Whiteside | 41.63 | 90.04 | 182 | ---------- | 7/8/2004 |
| 32 | MSV | Martinsville | Clark | 39.37 | 87.88 | 193 | 8/31/1988 - 12/31/1992 | ---------- |
| 33 | GEF | Jeffersonville | Wayne | 38.43 | 88.45 | 142 | 10/26/2988 - 2/20/1991 | ---------- |
| 34 | FAI | Fairfield | Wayne | 38.38 | 88.38 | 136 | 9/26/1991 - 12/1/2008 | 8/23/2000 |
| 81 | CMI | Champaign | Champaign | 40.08 | 88.23 | 219 | 6/27/1986 - 12/1/2004 | 10/23/2001 |
| 82 | DXS | †Dixon Springs (Grass cover) | Pope | 37.45 | 88.67 | 165 | 4/29/1981 - 12/1/2004 | 10/4/2000 |

† co-located with site #2

### Table 3.4. Soil Characteristics at the Soil Moisture Network Sites (After Hollinger and Isard 1994)

| *Name* | *Soil Series* | *Family* | *Texture* | *2-meter depths* Total porosity (mm) | *2-meter depths* Field capacity (mm) | *2-meter depths* Wilting point (mm) |
|---|---|---|---|---|---|---|
| Bondville | Flanagan-<br>Elburn | fine, montmorillonitic, mesic Aquic Argiudolls<br>fine, silty, mixed, mesic Aquic Argiudolls | silt loam<br>silt loam | 945 | 867 | 503 |
| Dixon Springs | Grantsburg | fine, silty, mixed, mesic Typic Fragiudalfs | silt loam | 932 | 846 | 540 |
| Brownstown | Cisne | fine, montmorillonitic, Mollic Albaqualfs | silt loam | 894 | 832 | 492 |
| Perry | Clarksdale | fine, montmorillonitic, mesic Udollic Ochraqualfs | silt loam | 943 | 879 | 496 |
| DeKalb | Flanagan-<br>Drummer | fine, montmorillonitic, mesic Aquic Argiudolls<br>fine, silty, mixed, mesic Typic Haplaquolls | silt loam, silt clay loam | 799 | 765 | 441 |
| Monmouth | Muscatine | fine, silty, mixed, mesic Aquic Hapludolls | silt loam | 1008 | 784 | 484 |
| Peoria | Clinton | fine, montmorillonitic, mesic Typic Hapludalfs | silt loam | 875 | 913 | 523 |
| Springfield | Ipava | fine, montmorillonitic, mesic Aquic Argiudolls | silt loam | 946 | 858 | 634 |
| Belleville | Weir | fine, montmorillonitic, mesic Typic Ochraqualfs | silt loam | 927 | 968 | 551 |
| Carbondale | Parke | fine, silty, mixed, mesic Ultic Hapludalfs | silt loam | 1002 | 883 | 497 |
| Olney | Bluford | fine, montmorillonitic, mesic Aeric Ochraqualfs | silt loam | 794 | 798 | 575 |
| Freeport | Dubuque | fine, silty, mixed, mesic Typic Hapludalfs | silt loam | 963 | 927 | 463 |
| Rend Lake | Cisne | fine, montmorillonitic, mesic Mollic Albaqualfs | silt loam | 831 | 802 | 640 |
| Stelle | Monee | fine, illitic, mesic Mollic Ochraqualfs | silt loam | 833 | 805 | 429 |
| Topeka | Plainfield | mixed, mesic Typic Udipsamments | loamy sand | 892 | 400 | 148 |
| Oak Run | Rozetta | fine, silty, mixed, mesic Typic Hapludalfs | silt loam | 905 | 838 | 519 |
| Martinsville | Cisne | | | 811 | 797 | 684 |
| Jeffersonville | Cisne | | | 808 | 774 | 487 |
| St. Charles | Proctor | fine, silty, mixed, mesic Typic Argiudolls | silt loam | 896 | 716 | 427 |
| Fairfield | Cisne | fine, montmorillonitic, mesic Mollic Albaqualfs | silt loam | 807 | 763 | 567 |
| Champaign | Drummer | fine, silty, mixed, mesic Typic Haplaquolls | silt clay loam | 930 | 727 | 452 |

Pure water, soil particles, and air have a very low electrical conductivity. However, natural or man-made salts present in soil (fertilizers, for example) dissolve into the soil water. These dissolved salts increase the conductivity of the water and soil. The dielectric constant of moist soil has a small, but significant, dependence on soil temperature while soil conductivity varies strongly with temperature. The soil temperature measurement made by the probe is used to remove most of the temperature effects on soil moisture.

The output of the soil moisture data is in volts, which is converted by proprietary software supplied by the manufacturer to water fraction by volume (wfv), essentially identical to values of water equivalence by volume used in ISMN's output reports from the neutron probes. With a crude knowledge of soil type, according to the manufacturer, the accuracy in terms of wfv is ±0.015 to 0.020.

**3.2.3.6. Calibration Procedures and Calibration Verification.** The Stevens-Vitel probes have no calibration procedures. When probes show periods of unreasonable wfv data (high atypical variability without coincident rainfall, apparent noise in temporal trends, values of zero in clay or loam soils, etc.), they are removed from service.

**3.2.3.7. Data Quality Objectives.** Data quality is desired to be as accurate as possible. Typically, measured data are representative for some distance adjacent to the sensor. However, perhaps more so than with most observed variables, data may be far more valid at the precise soil moisture location than even short distances away from the site. Local effects, such as siting stations near rivers or streams, or within drainage areas defined by the immediate topography, were avoided during site selection and should be less of a concern to data quality. However, the variability of near surface soil moisture, recharged primarily by precipitation, begins with the unevenness of that precipitation, and then proceeds with much higher changeability due to the aforementioned variability in soil properties at each site.

The relationship of current soil moisture levels to recent precipitation totals is an important one, especially when levels are near saturation. However, this determination can be quite complex at times. When saturation is reached, no more water can be absorbed by the soil, and most additional precipitation will run off. Output from continuous sensors indicates a rapid increase/decrease couplet in soil moisture data during and just subsequent to heavy rainfall events, impacted further by initial soil moisture content and other near-surface and subsurface soil variables, most of which are unobserved at ISMN sites. Water in the soil between field capacity and saturation is weakly held in soil pores, percolates through the soil profile, and is referred to as drainage. Water lost though drainage can result in rapid changes in soil moisture readings as indicated from hourly data by the continuous sensors, but often due to this rapid movement, is totally unobserved in the neutron probe observations.

The porosity of the soil and its field capacity are largely a function of the soil type. This can change over distances far shorter than that between the current ISMN observational site array. Table 3.4 provides information in these areas for each of the observation sites.

In winter, frozen conditions render soils impervious to absorption and percolation of liquid precipitation. This can cause measurements at northern sites to remain constant for several weeks, regardless of precipitation amounts, while observations in unfrozen soils in southern Illinois continue to vary, altering the temporal consistencies of change with precipitation on soil moisture maps. Data output from the continuous capacitance probes are irretrievably impacted with frozen soils due to different dielectric responses with all-liquid versus all-solid $H_20$. Empirically, neutron probe data appear largely unaffected by frozen soils.

Furthermore, windy conditions blow snow into drifts over sites or away from sites, enhancing or reducing snow cover overlying sensor locations. Long periods of sub-freezing temperatures allow time for sublimation to reduce the amount of snow available for later melting and percolation. Likewise, rapid melting of snow before complete thawing of surface soil layers above deeper sensors can result in runoff or partial percolation at a time with no coincident precipitation occurrence. All of these conditions render a one-to-one relationship between precipitation and soil moisture conditions in winter virtually unattainable and potentially quite variable across the network due to Illinois' long north-south extent often lying in a transition zone between severe and mild wintertime weather conditions.

Lastly, all soil moisture observations in the ISMN are taken under a sod cover. As stated in the ICN section above, control over the nature of the cover rests with the host managers where sites are located. Sod thickness can impact temperature and moisture fluxes, as well as transpiration and evaporation. When comparing data across the entire network, different sod types and thicknesses likely yield different soil moisture use by sod roots. Care must be taken when associating these data to adjacent areas where soil moisture observations are not made, especially those under a different surface cover (Scott et al. 2009).

**3.2.3.8. Sampling Schedule and Procedures.** The Stevens-Vitel continuous soil moisture sensors at each site are connected to the ICN data logger, polled for their information once an hour, and downloaded automatically within the regular ICN raw data stream in accordance with the schedule at each site. Sensors are placed at six depth levels: 5, 10, 20, 50, 100, and 150 cm. Output includes four data values, recorded in volts, for each of the six levels every hour. Conversion to useable soil moisture data occurs during data processing.

**3.2.3.9. Written Standard Operating Procedures.** A manual describing output and proprietary data reduction for the Stevens-Vitel probes resides with the WARM Program Manager.

**3.2.3.10. Quality Control Practices.** Quality control of the continuous sensors relies on observed changes in the output data. Most are easily detected via objective limit checks or perusing temporal plots of values. More subtle changes are difficult to identify and may take long-term analyses, especially if the difference between measured and expected data is small. No field verification of observed data is possible.

**3.2.3.11. Data Users.** Users of these data are in three main areas: research, agribusiness/farming operations, and government interests. Researchers, especially those developing agricultural models to study crop development and soils, are becoming increasingly interested in long-term data on soil moisture. Data are important for initialization factors of analyses such as those investigating hydrologic budgets and in assessing ground truth of moisture in comparison with other moisture-sensing platforms such as space-based systems.

Soil moisture conditions affect farming operations and agribusiness enterprises in Illinois, both of which are major industries in the state. The level of soil moisture influences farming operations from tilling to planting to harvest and during the application of chemicals. Agribusinesses use these data to develop new hybrids and in real-time operations they perform for the farmer.

State government agencies find the information on soil moisture useful to track moisture changes, especially during periods of precipitation extremes. These periods frequently are times when other water resources in the state begin showing stress. Tracking soil moisture regionally or across all of Illinois can provide an early indication of the spatial extent of developing conditions that may later lead to environments that require actions in which government intervention becomes necessary. This is especially true with developing drought conditions. A dearth in rainfall is often quickly followed by a drop in soil moisture. Other water resources of the state (e.g., streamflow and groundwater levels) follow at a slower pace. Likewise, recovery of essential water sources within the state first requires recovery in soil moisture. Given the severity of an individual drought, these data provide an early indication of the speed at which this may occur.

Soil moisture information is provided to users online through publication of the *Soil Moisture Summary* within the WARM Web pages. This is a monthly technical report produced by ISMN staff on current soil moisture conditions in Illinois and posted on the Web. It emphasizes changes in soil moisture during each month from each site and level individually, and a mapping of current end-of-month values compared to seasonal norms. Expansion to Web-based daily soil moisture dissemination is planned for 2010.

**3.2.3.12. Data Reduction and Archival Protocols.** The Steven-Vitel continuous data are stored in the raw state within the ICN data string, and are merged into a version of the neutron probe analysis package on *Quattro Pro 12*. Final archiving is on the Datastorm SQL. Regular trend analyses and dissemination formats of continuous soil moisture data are under development.

**3.2.3.13. Data Quality Assessment Procedures.** Data quality assessments are performed during regular QC activities. They include analytical comparisons observed between sites or at the same sites with prior observation periods to identify potential data quality inconsistencies.

**3.2.3.14. Personnel Qualifications and Training.** Most of the personnel requirements and expertise needed to operate and maintain the ISMN are the same as the requirements in place for personnel within the ICN (Section 3.2.2.14). In addition to an emphasis on meteorological knowledge, expertise in soil characteristics would be a strong advantage.

### *3.2.4. Shallow Groundwater Well Network*

**3.2.4.1. History.** The shallow groundwater well network (SGWN) was established in the early 1960s as part of the ISWS charter to study and characterize the water resources of the state. These wells provide information on changes in statewide shallow groundwater (water table) levels. They are located in rural areas remote from domestic or municipal pumping so that only natural fluctuations in shallow groundwater levels are measured. The network originally monitored and maintained 21 water table wells throughout the state, with at least one well located within each Illinois Crop Reporting District (CRD). Currently, 17 sites are being monitored regularly and are termed the "WARM" wells.

A second set of wells within WARM exists at most ICN sites and is referred to as the "ICN" wells. Drilling at the climate stations began during late 1996 and early 1997, and was completed in 2006. Shallow 4-inch diameter wells were constructed at each location. Hand measurements of depth-to-water were collected initially, but eventually each ICN well was outfitted with a pressure sensor that sends data to the ICN station's data logger. More information is available at: http://www.isws.illinois.edu/warm/sgwdata/about.aspx.

**3.2.4.2. Monitoring Objective.** The near-surface shallow water table is influenced by local topography, coincident with the land surface in low-lying areas, and forming a subdued replica of the surface at upland locations. That is, to a large extent, depth to the water table varies from location to location, depending on the local topography, soil type, and subsurface geology. As such, the observation well water level data cannot be compared directly from site to site in the network or elsewhere.

Local precipitation is the source of shallow groundwater recharge at network locations. Groundwater levels fluctuate in response to variations in recharge, evapotranspiration, and natural groundwater runoff, and because monitoring sites have been selected purposefully to be remote from the effects of pumpage, fluctuations will be most closely defined by precipitation or lack thereof. Due also to a variety of undefined local soil attributes, seasonal fluctuations as much as 10 feet are possible.

The objective of this monitoring activity is the development of a shallow groundwater level (water table) database that will provide an indication of shallow groundwater recharge and its response to climatic variables. Shallow groundwater elevation varies from site to site and is dependent upon the hydrogeology of the specific location. Viewing these data, along with streamflow and climatic data such as soil moisture and precipitation, provides a more complete picture of the water resource conditions within an area and their response to climatic variations. These measurements are designed to improve our understanding of the effects of climatic phenomena such as droughts and floods on the state's water resources, and in particular, their lingering impacts.

**3.2.4.3. Number and Locations of Monitoring Sites**. The SGWN 17-station network WARM well locations are shown in Figure 3.4. Geographic locations, well depths, and starting dates of monitoring operations are given in Table 3.5. Some wells within the SGWN have been constructed for water level monitoring purposes, but many are old, privately owned, large-diameter (2 to 6 feet), typically brick-lined wells that are no longer used for water supply. All observation wells are finished in the shallow unconsolidated alluvium glacial drift deposits above bedrock. Scant detailed information (stratigraphy, well log, etc.) is available for most of the wells and well sites; however, a recorder installation record exists for each well and resides with the SGWN manager as well as the WARM Program Manager.


Figure 3.4. Shallow Groundwater Well Network

**Table 3.5. Site Locations and Start Dates of the Shallow Groundwater Well Network**

| *ISWS Number* | *Well name* | *County* | *Town-ship* | *Range* | *Section* | *Latitude (deg)* | *Longitude (deg)* | *Start date of record* | *Well Depth (feet)* |
|---|---|---|---|---|---|---|---|---|---|
| 11 | Cambridge | Henry | 15N | 3E | 8.4c | 90.17 | 41.30 | Oct 1961 | 42.0 |
| 21 | Galena | Jo Daviess | 28N | 1W | 24.4h | 90.43 | 42.42 | Sep 1963 | 25.0 |
| 31 | Mt. Morris | Ogle | 42N | 9E | 34.1c | 89.44 | 42.03 | Nov 1960 | 55.0 |
| 41 | Crystal Lake | McHenry | 43N | 8E | 6.5b | 88.44 | 42.23 | Sep 1950 | 18.0 |
| 53 | Fermi Lab | DuPage | 39N | 9E | 19.5e | 88.26 | 41.85 | Nov 1988 | 15.0 |
| 61 | Coffman | Pike | 4S | 6W | 26.5d | 91.06 | 39.69 | Feb 1956 | 28.0 |
| 72 | Good Hope | McDonough | 7N | 2W | 6.8c | 90.67 | 40.53 | June1980 | 30.0 |
| 91 | Snicarte | Mason | 19N | 10W | 11.8b | 90.20 | 40.11 | Mar 1958 | 42.0 |
| 132 | Greenfield | Greene | 11N | 10W | 28.3a | 90.21 | 39.36 | Apr 1965 | 22.0 |
| 143 | Janesville | Cumberland | 11N | 9E | 18.7d | 88.25 | 39.40 | Apr 1969 | 11.0 |
| 153 | St. Peter | Fayette | 5N | 3E | 17.1h | 88.88 | 38.88 | May 1965 | 15.0 |
| 171 | Sparta | Randolph | 5S | 5W | 5.4f | 89.67 | 38.21 | Nov 1960 | 27.0 |
| 181 | SWS #2 | St. Clair | 2N | 9W | 26.8f | 90.07 | 38.60 | Jan 1952 | 80.0 |
| 191 | Dixon Springs | Pope | 13S | 5E | 3.5d | 88.65 | 37.42 | Jan 1955 | 8.6 |
| 202 | SE College | Saline | 9S | 7E | 9.4b | 88.44 | 37.75 | Jul 1984 | 10.2 |
| 221 | Boyleston | Wayne | 2S | 7E | 17.7b | 88.46 | 38.34 | Feb 1984 | 23.0 |
| 1120 | Bondville | Champaign | 18N | 7E | 2.6g | 88.38 | 40.14 | Mar 1982 | 21.0 |

Most of the shallow observation wells are finished in glacial tills and outwash deposits, typically containing thin strips or lenses of discontinuous water-bearing silt, sand, or gravel. However, the Snicarte and SWS #2 observation wells monitor the water table in two shallow, extensive sand and gravel aquifers that, on a regional basis, are important sources of groundwater.

The ICN wells were attached to the climate stations without regards to local stratigraphy, but simply to view water table conditions at the site as additional information associated with the other weather and soil conditions being monitored. Wells currently exist at 18 ICN sites. The Champaign site has no well attached to the ICN, but instead maintains a shallow groundwater well not attached to the WARM Program.

**3.2.4.4. Siting Criteria.** Siting criteria for the WARM wells were established at the onset of the network (circa 1960), and have been maintained in the event that a well is moved or substituted. They are as follows:

1. At least one well should be located within each physiographic region of the state (later identified as a Crop Reporting District).
2. The network should possess a reasonable geographic distribution across Illinois.

3. Wells should be located near a timely source of precipitation data, such as National Weather Service (NWS) Cooperative Observer stations.
4. Wells should be easy to access by field personnel for required monitoring and service.
5. Locations should provide a limited opportunity for vandalism.
6. Water levels of wells should reflect changes in the shallow water table in areas remote from pumping centers.

No siting criteria existed for the installation of wells established at ICN locations. Siting criteria for shallow groundwater wells at new ICN stations can be found in Appendix IIB.

**3.2.4.5. Instrumentation.** Each well is equipped with a Steven's Type-F recorder. This type of device measures groundwater levels on a horizontal chart drum through float action proportional to changes in groundwater levels. The stylus is moved to the right across the width of the chart at a constant speed controlled by a clock. The combined movements of the chart drum and stylus produces a graphic record of water levels versus time.

Weight-driven and battery-operated clocks are used throughout the network and are set to record water levels for one month per recorder chart. Water levels are recorded on the chart at a scale ratio set to one revolution of the drum, which is 1 foot in circumference. Staff checks the recorded water level accuracy every month when changing the chart with a hand-measured water level using a chalked steel tape or an electric water level meter (also known as an electric drop line). Generally, groundwater level measurements are deemed acceptably accurate when repeated measurements are within ±0.01 feet.

Groundwater levels in the drilled wells at the ICN sites were manually monitored using a steel tape or electric drop line until automated sensors were installed and connected to and reported within the ICN data stream. Druck Inc. model 68 pressure transducers are polled once an hour, yielding data to the hundredth of a foot.

**3.2.4.6. Calibration Procedures and Calibration Verification.** The Type-F recorder calibration is a factor of the water level gauge scale, which is determined by the ratio of gears installed on the shafts of the drum and float pulley of each recorder and the clock movement. The majority of the network recorders are set to the 1:5 gauge scale, meaning there is 5 feet of water level change per one rotation of the chart drum. The drum has a 1-foot circumference. The smallest water level chart division for this device ranges from 0.01 feet for the 1:1 scale setup to 0.10 feet for the 1:10 scale setup. The manufacturer has calibrated the recorder gears and clocks. Each gear is stamped with the number of teeth it contains, which can then be used to set the gear ratio to the proper drum rotation for the given situation. A table containing these gear ratio and drum water level change determinations can be found within the Stevens Type-F recorder Instructions booklet (or SOP No. GWL-01.1, see 3.2.4.9).

Conscientious use of a chalked steel tape or electric water level meter should result in measurements accurate to ±0.01 feet. The recorder clocks are set to traverse the chart horizontally in 32 days. Clocks are replaced when this rate cannot be maintained with routine maintenance.

**3.2.4.7. Data Quality Objectives.** Since most of these wells are privately owned and constructed with a large concrete slab set on brick below the ground surface, the integrity of the data is dependent upon the Water Survey's ability to maintain the well. General maintenance is conducted monthly with major repair work performed on an "as needed" basis immediately upon discovery.

These data inherently contain a bias because the actual monitored water table levels are site specific, but can provide a relative indication of the regional water table levels, seasonal fluctuations, and hydrologic response to climatic conditions. Deviations from long-term normal, previous-month, and same-month-previous-year water levels give an indication of the regional water table trend. The precision of the data is to the nearest 1 hundredth of a foot. Monthly manual measurements are compared to the recorder elevation for accuracy. If a large difference is observed, an attempt is made to determine the cause of the difference. If the cause is determined, the chart is corrected with comments written on the chart. Departures less than 3 hundredths of a foot are deemed acceptable. If a departure of greater than 3 hundredths of a foot is observed, the depth to water is manually taken a second time to ensure an accurate reading. If it concurs with the first measurement, it is entered as the monthly measurement. The discrepancy is noted on the chart. Every effort is made to ensure a complete record of monthly water-level fluctuations from each well.

**3.2.4.8. Sampling Schedule and Procedures.** Each well is visited monthly to measure the groundwater level and to change the paper recorder chart. A detailed description of this procedure is further documented in the reference cited in Section 3.2.4.9. A brief description follows.

The shelter is opened and the recorder is checked for repair and maintenance needs and to verify that it is running properly. The recorder drum is removed from the shelter and the paper recording chart is removed from the drum. A manual groundwater level for the well is measured using a steel tape or electric drop line calibrated in 0.01-foot increments. Typically, the measuring point for the manual reading is the top of the recorder shelter at the opening for the float.

The manual groundwater level measurement, along with the current date and time, are recorded on the paper chart and in the field log book. The recorder and manual water level measurements are checked for agreement, and a second manual measurement is made if they differ by more than 0.03 feet. A continued difference of greater than 0.03 feet is noted in the log book and a decision is made whether to further investigate the installation to determine the reason for the discrepancy.

The location, date, time, water level, and gauge scale information are recorded on a new paper chart. This chart is securely wrapped on the recorder drum and the drum is reinserted on the recorder. The recorder pen and drum are adjusted to synchronize the pen position to the current time and measured groundwater level. The recorder cover is replaced and the shelter is secured.

**3.2.4.9. Written Standard Operating Procedures.** These procedures have been documented in *Standard Operating Procedure (SOP) for Groundwater Level Measurements* (Wehrmann, 2001, SOP #GWL-01.1).

**3.2.4.10. Quality Control Practices.** The quality of the data is checked when the chart is changed, i.e., the measured reading is checked against the chart reading. Should the two measurements be different, the staff member attempts to identify the problem and writes any conclusions on the chart.

**3.2.4.11. Data Users.** Data are presented in the monthly *IWCS*. Agencies use these data for water resources evaluation when planning responses to events caused by climatic extremes such as droughts and floods. Engineers, scientists, the public, governmental planners, drillers, etc. also use these data to estimate shallow water table fluctuations that can significantly impact agricultural practices, construction activities, existing structures, and water supply development.

**3.2.4.12. Data Reduction and Archival Protocols.** Data are entered into the Center for Groundwater Science's GWINFO computer system. The data entry program allows the water level measurement and the date to be entered. An analysis program calculates the deviations from long-term normal, previous month, and same-month-previous-year water levels for inclusion into the monthly *IWCS* report. At the end of each calendar year, the recorder charts for each well are compiled chronologically and individually scanned for the archives. After scanning, paper copies are organized into a cardboard bank box for long-term storage within Building 7 at the ISWS complex. The scanned images are maintained on CD media as well as included within the GWINFO "projects" application for storage and access.

**3.2.4.13. Data Quality Assessment Procedures.** The data are graphed for inspection. Data points producing unusual fluctuations are checked for errors. If any are found, the data are corrected within the main database.

**3.2.4.14. Personnel Qualifications and Training.** The personnel qualifications are non-technical; however, the staff member must be trained in water-level measuring procedures and recorder servicing by an experienced staff member. Training is usually conducted in the field. An understanding of basic mechanical measuring devices is beneficial, but not required. The standard operating procedure (SOP) for groundwater level measurements (GWL-01.1) also details the water level measuring procedure and recorder servicing process.

### *3.2.5. River Stage and Streamflow Monitoring*

The approximate peak stages (water level) of the month at selected stations along the largest rivers of Illinois are compiled in the monthly *IWCS*. Also, monthly averages of computed streamflow at selected river gauge locations throughout the state are reported each month in the *IWCS.* Finally, monthly statistics of the mean level of Lake Michigan are also included.

River stage and streamflow data are obtained from federal agencies; they are neither measured or computed by ISWS staff, nor obtained by ISWS-maintained equipment. The river stage and streamflow data presented in the *IWCS* are provisional and are not archived by ISWS as a dataset. The respective data are ultimately reviewed, adjusted if necessary, and archived by the providing federal agencies.

**3.2.5.1. History.** The U.S. Geological Survey (USGS) is the primary agency responsible for the operation and recordkeeping of the cooperative streamgaging network throughout the United States. The USGS streamflow gauging program was first organized in the western U.S. in 1889 (USGS 1998). The USGS eventually developed and continues to develop standardized methods for measuring river stage, discharge (flow), and other parameters. In 2007, the USGS operated and maintained about 7,400 streamgages nationwide (Blanchard 2007). As of 2005, USGS operated about 200 stream stage and/or discharge gauging stations in Illinois, over 150 of which transmit real-time discharge data (USGS 2005, 2009).

The streamgaging network maintained by USGS is supported in significant part by funding from cooperating agencies and organizations. As of 2008, cooperating agencies that support one or more of the streamgaging stations for which data are reported monthly in the *IWCS* include U.S. Army Corps of Engineers (USACE), IDNR Office of Water Resources (OWR), National Weather Service, the Danville Sanitary District, and the cities of Decatur, Monticello, and Springfield. In 2008, ISWS cooperatively funded four Illinois streamgages.

Some other agencies also measure river levels and flows. Most significantly, the USACE operates some of their own gauges, particularly on navigable waterways and major tributary rivers, in addition to being a primary cooperator in the USGS streamgaging program. The data record for some of the USACE gauges is maintained directly by the USACE and is not available from USGS. Other parties, including OWR, operate streamgage equipment or record water level observations, but do not publish the data or submit data to the USGS network. ISWS, as a research agency, has collected stage and flow data for specific periods as part of studies of particular watersheds. However, ISWS does not itself operate a long-term monitoring network of streamflow conditions or, in general, serve as a provider of streamflow data to other agencies.

River and stream discharge and stage data reported in the monthly *IWCS* are obtained from gauging stations operated by the USGS or USACE. With the increase of Internet connectivity and computer processing capability, particularly since 2000, source data from USGS and USACE have become more readily and directly available.

The ISWS has compiled some form of monthly surface water conditions report since at least 1967. At that time, staff engineer W. J. Roberts compiled selected reservoir water level reports from lake operators each month (see Section 3.2.6, following), and in 1974 began including water level reports relative to flood stage for various river locations, particularly during flood conditions. From 1985 to 1994, the *IWCS* included an evolving list of monthly stage statistics at about three dozen river gauging locations statewide. Thereafter, only monthly peak stages and dates at selected USACE gauge locations on the Illinois, Mississippi, and Ohio Rivers (currently 14 stations) have been reported in the *IWCS*.

For many years USGS has prepared monthly streamflow assessments comparing recent conditions to long-term observation statistics for three to four "index" stations representing different regions of the state. The monthly ISWS water condition reports reflected this information, beginning in 1976 with the Sangamon River at Monticello, and including the three present USGS Illinois index stations after 1983. Later, the monthly streamflow summary report in the *IWCS* was gradually expanded, from about a dozen stations in 1988 to the current total of 26 stations by 2000.

As of 2002, the monthly provisional mean streamflow values of the 26 *IWCS* stations, as well as the 10 percent exceedence, 90 percent exceedence, and median (50 percent exceedence) flow values for the month, as ranked in the period-of-station record used for the *IWCS*, have been made available graphically and in a table format on the WARM Web site *http://www.isws.illinois.edu/warm/pmfd/*. The *IWCS* streamflow statistics are available in these formats on the Web site for the past month and for each month within the past two Water Years (i.e., October to September).

Since 2004, the Illinois Water Science Center staff of the USGS has provided a private Web site for ISWS that normally displays the USGS-calculated provisional daily and monthly mean streamflows for each of the *IWCS* stations for the past few months. Daily mean values are added to this posting daily. For stations with a complete record for the month, the monthly average is posted following the last observation of the month.

The National Oceanic and Atmospheric Administration (NOAA) measures and computes mean water levels for each of the Great Lakes by averaging readings from a network of water level gauges around the perimeter of each lake by the Great Lakes Information Network (GLIN 2009). The USACE Detroit District archives and distributes the data, as well as publishing it in a long-running monthly newsletter (USACE 2008a). Lake Michigan levels from USACE have been reported in the ISWS monthly surface water resources reports from 1973 to 1982 and from 1986 to the present.

**3.2.5.2. Monitoring Objectives.** Generally, a variety of users share multiple objectives in monitoring water quantity in streams and rivers (USGS 1998; Wahl et al. 1995). Real-time and long-term stage records are used in major part for determining safe navigation conditions, identifying risk of safety and damage hazards due to flooding, and operating active flood controls such as pumps and floodgates. River stage is also important to determine suitable conditions for recreational use of water resources and for timing of construction activities along waterways. Furthermore, stage is the primary measure used to calculate streamflow.

Streamflow—the volume of water flowing past a location on a stream per unit of time, and more formally referred to as discharge—is recorded as an important parameter in predicting water availability for users, in general, as well as specifically predicting flood and drought conditions, both short-term and long-term. Discharge is also a "denominator" for assessing water quality, including effluent absorbing capacity.

Surface water resource conditions have many impacts, both for humans and wildlife, directly and indirectly, locally and regionally. Surface water is readily observable and accessible. Monitoring of surface water resource conditions is a fundamental societal need.

The objectives for *reporting* the selected surface water conditions monthly in the *IWCS* are limited by the nature of the product. Peak stages of major rivers, along which flooding can be extensive and long, are reported for general interest in reference to respective flood stage levels. Lake Michigan level is reported mainly for general and water supply interest.

Rankings of the reported mean streamflow values for the month relative to historic observations are provided as part of the WARM Program primarily for use by ISWS hydrologists involved in drought monitoring cooperatively with other state agencies. In addition, a statewide mean streamflow metric for the month is estimated for the *IWCS* overview, as a tool to qualitatively assess and compare trends among water resource measures over the past year in Illinois.

**3.2.5.3. Number and Locations of Monitoring Sites.** Figure 3.5 displays the geographic locations of both the stage and streamflow gauge stations reported in *IWCS* since 2000. Representative monthly peak stage values are reported at 14 sites along the Illinois, Mississippi, and Ohio Rivers. Station names, location descriptions, and the local reference flood stage for each site are listed in Table 3.6. Mean monthly discharge values are reported in the *IWCS* for 26 USGS streamgage sites located throughout Illinois. Station names and location descriptions are listed in Table 3.7.

For Lake Michigan, a single monthly average level is reported in the *IWCS*, as provided by the USACE's Detroit District (USACE 2008a). The nine source gauge locations around Lake Michigan are documented in detail at *http://tidesandcurrents.noaa.gov* (via GLIN 2009).

**3.2.5.4. Siting Criteria.** In general, gauges used to obtain river stage are sited only where it is suitable to obtain the desired monitoring objective(s) and where the equipment can be securely installed and operated. Stage gauges used to determine stream discharge are subject to more restrictive siting criteria. Ideally, streamflow gauge locations should be chosen away from the influence of backwater effects (the impeding of conveyance by high water levels on a receiving stream), at locations not prone to debris blockages, and in reaches where the streambed and channel cross section are relatively stable and hydraulically simple to allow for simpler calibration and calculation of discharge. However, many existing gauge locations do not fully meet these criteria.

The USGS has developed techniques for appropriate assessment, recalibration, and revision of data. Streamgage siting criteria and data processing methods are detailed in USGS Water Supply Paper 2175 (Rantz et al. 1982). For practical considerations, including site access and cross-sectional stability, streamgages are typically located on a bridge or other hydraulic structure. Gauges used to assess inflow to a receiving reach or lake or to predict conditions in a particular reach are often sited upstream of the reach of interest.

Selections of *IWCS* river stage and streamflow stations were made from existing gauging networks of federal agencies. On the major rivers represented by peak stage reports, USACE operates stage gauges at each lock-and-dam facility, and some gauges at intermediate locations. The peak stage stations selected for reporting are dispersed along the represented rivers and have had accessible real-time data. Most are at intermediate locations between dams and major tributary inflows.


Figure 3.5. WARM peak stage sites (green) and discharge stations [river (city)]

**Table 3.6. Locations and Flood Stage of IWCS Peak Stage Stations on Major Illinois Rivers**

| ***River*** | *Station Name* | *USACE Station Code* | *Location* | *Latitude (deg. N)* | *Longitude (deg. W)* | *County* | *River mile* | *Flood stage (feet)* |
|---|---|---|---|---|---|---|---|---|
| **Illinois R.** | | | | | | | | |
| | Morris | MORI2 | 0.3 mi downstream of IL 47 bridge | 41.35 | 88.43 | Grundy | 263.1 | 16 |
| | La Salle | LSLI2 | Near IL 351 bridge | 41.31 | 89.09 | La Salle | 224.7 | 20 |
| | Peoria | PIAI2 | At foot of Grant St. | 40.70 | 89.56 | Peoria | 164.6 | 18 |
| | Havana | HAVI2 | 100 ft downstream of US 136 bridge | 40.29 | 90.07 | Mason | 119.6 | 14 |
| | Beardstown | BEAI2 | 0.3 mi downstream of Burlington Northern Railroad bridge | 40.02 | 90.44 | Cass | 88.6 | 14 |
| | Hardin | HARI2/ILHA | Near IL 16/100 bridge | 39.16 | 90.61 | Calhoun | 21.5 | 25 |
| **Mississippi R.** | | | | | | | | |
| | Dubuque [IA] | DBQI4 | Railroad bridge at 4th St. [0.75 mi. downstream of Wisconsin state line] | 42.50 | 90.64 | (opposite Jo Daviess) | 579.9 | 17 |
| | Keokuk [IA] | EOKI4 | Lock & Dam 19 (tailwater) | 40.40 | 91.37 | (opposite Hancock) | 364.2 | 16 |
| | Quincy | UINI2 | Quincy Water Works, 3 mi. upstream of Lock & Dam 21 | 39.93 | 91.42 | Adams | 327.9 | 17 |
| | Grafton | GRFI2/MIGR | 0.2 mi. downstream of the confluence of the Illinois River | 38.97 | 90.43 | Jersey | 218.0 | 18 |
| | St. Louis [MO] | EADM7/MISL | At foot of Market St. [at the Arch] | 38.62 | 90.18 | (opposite St. Clair) | 179.6 | 30 |
| | Chester | CHSI2/MICH | IL 150/MO 51 bridge | 37.90 | 89.83 | Randolph | 109.9 | 27 |
| | Thebes | THBI2/MITH | Union Pacific Railroad bridge | 37.22 | 89.46 | Alexander | 43.7 | 33 |
| **Ohio R.** | | | | | | | | |
| | Cairo | CIRI2/OHCA | Near 4th St. | 37.00 | 89.16 | Alexander | 2.0 | 40 |

* (IDNR OWR 2004, 2007; USACE 2008b, 2008c)

## Table 3.7. USGS Streamflow Gauging Stations Reported in the Monthly IWCS

| Streamgage | USGS gauge Number | Drainage area (sq. mi.) | Years of record WY2009* | Latitude (decimal degrees N) | Longitude (decimal degrees W) | Posted observation interval | Hydrologic Unit Code | Accuracy of daily record** |
|---|---|---|---|---|---|---|---|---|
| Rock River at Rockton | 05437500 | 6363 | 73 | 42.449 | 89.070 | 15 min. | 07090005 | Good |
| Rock River near Joslin | 05446500 | 9549 | 65 | 41.556 | 90.185 | 15 min. | 07090005 | Good |
| Pecatonica River at Freeport | 05435500 | 1326 | 89 | 42.303 | 89.620 | 15 min. | 07090003 | Good |
| Green River near Geneseo | 05447500 | 1003 | 70 | 41.489 | 90.158 | 15 min. | 07090007 | Good |
| Edwards River near New Boston | 05466500 | 445 | 70 | 41.187 | 90.967 | 15 min. | 07080104 | Good |
| Kankakee River at Momence | 05520500 | 2294 | 91 | 41.160 | 87.669 | 15 min. | 07120001 | Good |
| Iroquois River near Chebanse | 05526000 | 2091 | 84 | 41.009 | 87.823 | 15 min. | 07120002 | Poor to fair |
| Fox River at Dayton | 05552500 | 2642 | 89 | 41.384 | 88.789 | 15 min. | 07120007 | Poor to fair |
| Vermilion River at Pontiac | 05554500 | 579 | 64 | 40.878 | 88.636 | 15 min. | 07130002 | Fair to good |
| Spoon River at Seville | 05570000 | 1636 | 91 | 40.490 | 90.340 | 15 min. | 07130005 | Fair |
| La Moine River at Ripley | 05585000 | 1293 | 85 | 40.025 | 90.632 | 15 min. | 07130010 | Poor to good |
| Bear Creek near Marceline | 05495500 | 349 | 64 | 40.143 | 91.337 | 15 min. | 07110001 | Fair |
| Mackinaw River near Congerville | 05567500 | 767 | 59 | 40.624 | 89.242 | 15 min. | 07130004 | Good |
| Salt Creek near Greenview | 05582000 | 1804 | 66 | 40.132 | 89.736 | 15 min. | 07130009 | Fair to good |
| Sangamon River at Monticello | 05572000 | 550 | 96 | 40.031 | 88.589 | 15 min. | 07130006 | Good |
| South Fork Sangamon River near Rochester | 05576000 | 867 | 59 | 39.742 | 89.567 | 15 min. | 07130007 | Fair |
| Illinois River at Valley City | 05586100 | 26,743 | 69 | 39.703 | 90.645 | 30 min. | 07130011 | Fair |
| Macoupin Creek near Kane | 05587000 | 868 | 79 | 39.234 | 90.395 | 15 min. | 07130012 | Poor to good |
| Vermilion River near Danville | 03339000 | 1290 | 86 | 40.101 | 87.597 | 15 min. | 05120109 | Poor to fair |
| Kaskaskia River at Vandalia | 05592500 | 1940 | 38 | 38.961 | 89.089 | 15 min. | 07140202 | Fair to good |
| Shoal Creek near Breese | 05594000 | 735 | 64 | 38.610 | 89.495 | 15 min. | 07140203 | Poor to good |
| Embarras River at Ste. Marie | 03345500 | 1516 | 94 | 38.936 | 88.023 | 15 min. | 05120112 | Good |
| Skillet Fork at Wayne City | 03380500 | 464 | 88 | 38.358 | 88.585 | 60 min. | 05120115 | Good |
| Little Wabash below Clay City | 03379500 | 1131 | 93 | 38.635 | 88.297 | 15 min. | 05120114 | Poor to fair |
| Big Muddy at Plumfield | 05597000 | 794 | 37 | 37.901 | 89.014 | 15 min. | 07140106 | Poor to good |
| Cache River at Forman | 03612000 | 244 | 84 | 37.336 | 88.924 | 15 min. | 05140206 | Poor to good |

Notes:
* Using published data through Water Year 2007.
** See text.
Sources: USGS 2005, 2007, 2009

The 26 streamflow gauge locations presented in the *IWCS* were selected from among the available USGS real-time access stations to represent general flow conditions throughout the state, accounting for most major watersheds while minimizing duplication of represented watersheds. In order to present monthly statistics in context with long-term data, other factors considered in the selection of *IWCS* stations included length of continuous station record, stability of the stage-discharge relationship of the gauge, reliability of gauge operation, and reporting consistency over time. (Those stations with relatively short years of record reported in the *IWCS* are located on rivers whose flow is physically regulated by major impoundments or other facilities upstream. For those stations, the data record considered in calculating the long-term statistics for *IWCS* presentation is truncated to consider only the record after construction of those facilities.) Also, all rivers and streams for which mean streamflow data are reported in the *IWCS* have a watershed area (at the gauge location) of more than 200 square miles.

**3.2.5.5. Instrumentation.** A standard installation for measuring stage (water surface level) of a river consists of a stilling well, which is a wide, vertical pipe hydraulically connected to the river flow containing a floating weight that is connected to a recorder and records the height of the float relative to a reference level. Other automated methods are used that have similar accuracy, such as a pressurized-air line calibrated to measure the depth above its outlet based on water pressure (Rantz et al. 1982; Wahl et al. 1995; USACE 2008c).

Streamflow, or discharge, is translated mostly from stage observations, typically using a stage-discharge rating table (also known as a rating curve) for the subject gauge location. At some gauges where a single-location stage-discharge relationship cannot be uniquely determined, discharge is calculated by more complex methods using data from a second gauge at another location (Rantz et al. 1982).

A stage-discharge rating curve is established by performing measurements specifically of the flow at the gauge location at different stage levels. Calculation of flow itself is usually based on detailed measurement of the velocity of the water flowing at representative points through a cross-sectional area of the river. Standard instrument types that measure velocity of water include mechanical current meters with receptive propellers, and more recently, reflective acoustic Doppler meters that are placed into the water (Wahl et al. 1995; Blanchard 2007). The geometry of the cross section is obtained by a physical transect survey across the stream valley, using standard survey practices.

Real-time gauge data are transmitted from the gauge by radio telemetry equipment first to NOAA's Geostationary Environmental Observational Satellite system (GOES) and subsequently to the USGS National Water Information System (NWIS) servers via a "domestic" satellite (Blanchard 2007; Wahl et al. 1995).

None of the instrumentation providing stream stage or discharge data reported in the *IWCS* is selected, operated, or maintained by ISWS. Identification of specific instrument models that were used to obtain discharge or stage values for any given period would require requesting the information from the individual gauge record from the USGS Illinois Water Science Center in Urbana, or the respective USACE District water control office, accordingly.

**3.2.5.6. Calibration Procedures and Calibration Verification.** Stage recorders as well as instruments used to measure discharge for the rating reference require calibration. USGS publishes standard calibration methods that are used in addition to manufacturers' specifications (Rantz et al. 1982). River stage recorders are typically calibrated by comparison with a second observation using separate equipment, such as a marked staff gauge (ruler) at the gauge site that is read visually. Stilling well gauges may have such auxiliary or reference gauges both inside and outside the well enclosure. In addition to standard calibration, auxiliary gauges can be used to verify or adjust automated measurements recorded during unusual conditions (Rantz et al. 1982).

Calibration of stage recorders, flow meters, or other streamgaging equipment that provide the data reported in the *IWCS* is controlled and implemented by the federal agency (USGS or USACE) that maintains the particular gauge station. ISWS does not control or maintain any of the equipment used to provide river stage or discharge data in the *IWCS*.

Stage-discharge rating tables for discharge stations are occasionally reviewed and adjusted based on discharge measurements obtained in the field both periodically and during infrequent flow events. Occasional rating table revision is necessary to account for evolving geomorphologic and vegetation conditions, and to make use of a larger sample of observations (Rantz et al. 1982). In the USGS network, this function is performed by USGS.

**3.2.5.7. Data Quality Objectives.** The WARM Program does not independently measure river stage or streamflow. The sole ISWS use of the river stage and discharge data is the monthly *IWCS* newsletter to present an approximate summary of recent surface water conditions for readers. The only data quality objective is to report reasonably representative conditions in relation to the long-term archived data published by the providing agencies as externally available real-time data may support.

The river stage and discharge data reported in the *IWCS*, obtained from non-ISWS sources, are strictly provisional, meaning, in part, that the data and summaries thereof are not appropriate for research, technical analysis, or citation. ISWS does not archive the river stage and discharge data reported in the *IWCS*; the providing agencies archive the source data after their own quality review and corrections.

The following is a description of the data quality objectives of the source monitoring programs. Generally, accuracy of instantaneous measurements inherent to properly maintained automatic gauge height recorders on rivers are reported to be ±0.01 feet (Rantz et al. 1982). USACE and USGS post stage readings for most gauges to 0.01 feet. Accuracy of discharge reports can vary considerably across different flow conditions and from location to location. Posted discharge values may vary from the "true" values of streamflow (actual volume of water passing the station per unit time) due to conditions that vary from the last-determined free-flow stage-rating curve for a given station. Such conditions might include:

- backwater (obstructed flow) from ice jams or debris jams
- erroneous stage readings due to ice
- vegetative growth, sediment movement, or other changes to the cross-sectional area
- equipment failure, transmitter outage, or other unforeseen events

Accuracy typically decreases at relatively extreme low and high flows, especially those beyond the limits of the established stage-discharge rating curve and those estimated by methods alternative to measurement during the event. Also, in general, because streamflow is non-uniform through a cross-sectional area, its derivation from practical measurements involves many inherent assumptions (Rantz et al. 1982).

USGS qualitatively ranks daily average discharge values and overall discharge records at each gauge as follows (representing 95 percent of data values) (USGS 2007):

within ±5% = excellent
±5-10% = good
±10-15% = fair
greater than ±15% = poor

USGS denotes as "poor" any daily mean flow values that are estimated due to missing or less reliable data. USGS reports most instantaneous discharge values to two significant figures for flow observations less than 10 cubic feet per second (cfs) and three significant figures for flows above 10 cfs (USGS 2007).

The typical accuracy of the *published* (not provisional) data record for each streamgage reported in *IWCS*, as determined and published by USGS, is given in Table 3.7 for each gauge (USGS 2005, 2007). The ranges shown in Table 3.7 are summarized from remarks in the station records published by USGS for Water Years 2005 and 2007. Note that regardless of the accuracy assessed for most conditions at each gauge, gauges experience periods during a given year when the accuracy of the published flows is not better than "poor" (> ±15%), most typically due to winter conditions, seasonal low flows, high backwater from receiving streams, or an equipment outage.

**3.2.5.8. Sampling Schedule and Procedures.** River stage observations at USACE gauges are made at least hourly; top-of-the-hour values are posted within two hours via satellite to the Web site *http://rivergages.com*, which is maintained nationally by the USACE Rock Island District in Illinois. The Web site interface provides graphs and tables of stage values for user-selectable periods, including a preset for the past 31 days. For some gauges, the interface can display pre-selected daily morning readings in particular, which for most Illinois stations are the 0600h CST observations. The user can view data by hovering the mouse pointer over a data point on a graph, allowing for easy manual retrieval of monthly peak stage and date (USACE 2008b). Similar USACE retrieval Web sites were available prior to the development of *Rivergages.com*. (A morning peak reading for the Ohio River at Cairo for the past 31 days is generated automatically on the NWS Web site *http://www.lrl.usace.army.mil/wc/reports/ohiorep.txt*. This is usually the source of the Ohio River at Cairo *IWCS* value, in conjunction with other sources when necessary.)

Automated stage (or other) measurements used to determine streamflow at the selected USGS real-time stations reported in the *IWCS* are recorded every quarter hour on the quarter hour at most stations. Real-time data are transmitted to the USGS via satellite. Generally, data are transmitted from each station at intervals of between one to three hours and are loaded onto the NWIS and local USGS Illinois Water Center Web sites. USGS also performs field measurements at gauges every several weeks to evaluate and eventually adjust the automated results; the national USGS real-time streamflow Web site (*http://waterdata.usgs.gov/il/nwis/sw*) includes these field measurements as well (USGS 2009).

Streamflow values for extremely high flow conditions that are not immediately measureable may be estimated by hydraulic computations using surveyed geometry and high water mark elevations identified and measured in the field by trained observers after the event. The USGS Illinois Water Center posts peak flow and recurrence interval estimates (and field crew notes) for some notable flood events during or shortly after the event (*http://il.water.usgs.gov/flooddata/*). Prior to 2004, provisional streamflow data for each *IWCS* station were accessible by direct computer subscription access to the USGS ADAPS system. The *IWCS* statistics for the month for each gauge were manually processed by the *IWCS* surface water staff member.

In 2004, Terry Ortel of the USGS constructed an automated retrieval product for direct ISWS Web access that gives daily and monthly average discharge values for all *IWCS* stations for each of the past several months (*http://il.water.usgs.gov/data/isws/*). ISWS staff established a spreadsheet file to automatically retrieve reports for these data from the USGS Web site and compile the monthly average values calculated by the USGS routine. If any daily average is not calculated, the USGS service does not calculate a monthly mean for the month. This occurs if one or more regularly scheduled samples during the day are missing, or if withheld by USGS as spurious. In such case, the *IWCS* surface water reporter investigates the detailed stage and discharges records for the month available on the USGS and USACE Web sites to determine which data gaps can be reasonably estimated and whether a monthly mean can then be reasonably estimated from available information. (See Section 3.2.5.13.)

Lake Michigan level data, both current and long-term, are copied directly from the monthly USACE source report (USACE 2008a). Great Lakes station water level readings are taken every six minutes, and transmitted hourly to a GOES satellite. (*http://glakesonline.nos.noaa.gov/faqglin.shtml*)

**3.2.5.9. Written Standard Operating Procedures.** Standard streamgaging and data control procedures are documented by USGS in USGS Water-Supply Paper WSP 2175 (Rantz et al. 1982) in *Techniques of Water-Resources Investigations of the United States Geological Survey* (TWRI) Books 3 and 8 (see references in USGS 2007) and in subsequent USGS procedural memos.

Documents explaining steps for retrieving the stage and discharge data reported in the monthly *IWCS* and examples of files used can be obtained by *IWCS* staff. These are stored in PC directories *\\HickoryCreek\data \data\Mclimate* and *\\HickoryCreek\data\wcspub35* in the Water Survey Research Center (WSRC) Room 512 and copied to *\\Shoalcreek\ infosvcs\swfpi_db\WARM_bak* in WSRC Room 510. Reference paper files containing the history of methodology since about 1996 are also retained by ISWS staff.

**3.2.5.10. Quality Control Practices.** The monthly stage and discharge data used for the *IWCS* are posted automatically by the providing agencies (USACE and USGS) with little review and filtering, and are subject to significant subsequent revision, as expressly stipulated by the providers (e.g., see *http://waterdata.usgs.gov/nwis/help/?provisional* [2009]). The providing federal agencies are responsible for QC, correction, and archiving of the data from their respective gauge networks. While these sources sometimes withhold some clearly erroneous readings from real-time posting, full QC of the data is performed months after observation (which is well after appearance in each monthly *IWCS*). USGS may later correct field-recorded data, may estimate data values to account for many varied conditions, and in general uses detailed discharge measurements obtained over several months, among other data, to update stage-discharge rating curves (Wahl et al. 1995).

Standard procedures employed by USGS to inspect and maintain equipment and to review and adjust recorded streamgage data (in particular in processing discharge data prior to publication as final in the annual Water Resources Data report, but in rare instances revising published data) are detailed in USGS Water Supply Paper 2175 (Rantz et al. 1982) and in different, separately published chapters of USGS TWRI Book 3 (see references in USGS [2007]). A principal QC practice performed by USGS for river stage and discharge measurement is occasional manual field measurement of stage and discharge at automated gauging stations using additional methods. Correction methods include transposition of hydrograph data temporally or geographically. USGS notes approximate error ranges of the results accordingly. (See preceding discussions.)

**3.2.5.11. Data Users.** The monthly mean streamflow conditions report in the *IWCS* is used and shared by ISWS hydrologists participating in State Water Plan Task Force (SWPTF) assessments of prospective or acknowledged drought. (Note: other agencies, and sometimes ISWS, also make additional assessments of water conditions during drought periods.) Other uses of the monthly mean streamflow summaries have not been identified.

Major river stages are included in the *IWCS* only for general interest. More pertinent and timely river stage data are available from data sources. Lake Michigan levels are reported for both purposes. Specific use of the WARM Provisional Monthly Flow Data Web site, presented in a slightly different format, is undetermined, but likely available from the ISWS's Webmaster.

**3.2.5.12. Data Reduction and Archival Protocols.** The river stage and discharge contents of each month's *IWCS* are strictly provisional and are not used by ISWS beyond summarizing the recent month's conditions in the monthly report. ISWS does not reduce or archive the river stage or streamflow values compiled from sources. Final analysis, archiving, and selected publication of the data are performed by the providing agencies—USGS or the respective USACE District, accordingly.

River stage data are reported in the *IWCS* as posted by the provider, and only in reference to the current emergency management flood stage defined locally to the gauge. USACE source Web sites direct that "[a]ll critical data should be obtained from and verified by the United States Army Corps of Engineers" District water control engineering office that maintains the gauge equipment and record (USACE 2008c).

Monthly mean streamflow values used to determine the long-term period-of-record statistics for the *IWCS* streamflow condition reports are obtained from the annual Water Resource Data reports for Illinois published by USGS (e.g., USGS 2005). At the start of each Water Year, for the October *IWCS*, ISWS staff copy and sort the USGS-published monthly mean values from data for the Water Year two years prior (the most recently published) into a compilation of monthly mean values for each *IWCS* station. Because this sorting has been performed manually in a spreadsheet grid, this ISWS analysis does not retain the dates associated with each year's monthly mean flow values, and thus it is not an archive of the obtained data. (Presently, users can access final published USGS daily and monthly mean values directly from USGS usually four to six months following the end of each Water Year.)

The provisional monthly mean streamflow assessments and major river peak stage values of the month just ended are due to the *IWCS* editor (WARM Program Manager) by the fifth calendar day of each month. Normally this compilation can be completed on the first day of each month, but are delivered together later when the other *IWCS* surface water content is completed. Thereafter, ISWS does not use the provisional monthly river stage and streamflow data collected for the *IWCS*.

**3.2.5.13. Data Quality Assessment Processes.** In the WARM Program, river stage and discharge data, provided by other agencies, are assessed in the monthly *IWCS* only for the purpose of presenting a summary of approximately representative conditions of monthly mean streamflow and major river stage peaks. Because river stage and discharge data used in the *IWCS* are obtained as provisional and are not archived by ISWS, ISWS' effort to correct for missing or spurious data for use in the *IWCS* is of limited scope. However, because sources provide the provisional data with little quality control, ISWS exercises some review to minimize incorporation of likely misrepresentative information in the *IWCS*.

Primarily for the *IWCS* surface water data, staff examine the following sources to check reasonableness of automated stage and discharge summaries:

- station stage and/or discharge hydrograph throughout and preceding the subject month
- the ranking (flow condition) of stations by region within the state for the subject month, also considering different watershed characteristics
- precipitation patterns including major storms in the subject month (mostly by radar rainfall estimates available at the U of I Department of Atmospheric Sciences' weather Web site *http://www.atmos.uiuc.edu/weather/* ).

River stages (and Lake Michigan levels) are generally reported as provided. However, where part of the month's stage record of an *IWCS* river stage station is missing, the *IWCS* reporter checks upstream, downstream, and/or associated auxiliary stations to determine whether the monthly peak would likely have occurred during the period of missing data. If it cannot be reasonably determined that it did not occur, a monthly peak is not reported in the *IWCS* for that station.

Provisional monthly mean streamflows are reported for a station as provided if calculated by USGS (which is the case if no posted output is missing during the month) unless it is visually evident from the month's hydrograph that either (a) the gauge output was temporarily not functioning for whatever reason, or (b) the stage exceeded the upper limit of the established stage-discharge rating curve in a flood condition, and discharge output is posted but artificially capped at that value. In such cases the evidently erroneous period of data are withheld from the *IWCS* analysis and interpolation is considered as follows.

If automated streamgage output is missing at any regularly scheduled sample time for any reason, USGS does not provide an automated monthly mean streamflow calculation or respective daily mean flow calculation for that station. In such case (or if suspect data were discarded), ISWS staff will manually calculate a monthly mean flow for the *IWCS* report from the available daily mean flows, if reasonably possible. Such estimation is considered reasonable for use in the *IWCS* only if the resulting mean is not qualitatively sensitive to the range of missing values that could be construed given other information. The staff member interpolates discharge values if the data gap between reliable observations is relatively small (i.e., less than eight hours per date), if the slope of the missing hydrograph is likely to have been relatively gradual, and if it can be deduced from hydrographs from other area gauges and from precipitation reports that fluctuating flow conditions did not occur at the station during the period subject to estimation. If reasonable, the staff member typically estimates a linear discharge value for each missing sample time between the last and resumed available discharge values, then calculates the daily mean discharge by the same technique employed by USGS in its automated report. Because of their limited use and since the USGS updates missing data at later times, these estimations are not retained in ISWS records.

For the *IWCS*, ISWS staff manually calculate the monthly mean streamflow for a station with missing values, if similarly reasonable, by averaging the daily mean values including any added daily estimates. If an estimate of the monthly mean flow value cannot be calculated (e.g., too many missing days of data that cannot be reasonably estimated, or undetermined extreme or highly fluctuating flow conditions likely occurred during the period of missing data), the month's mean streamflow for the station is listed as "Not Available" in the *IWCS* and the station is excluded from the statewide flow condition calculation in that issue. For the purposes of *IWCS*, ISWS may graphically estimate the value of daily mean streamflow that exceeded the station's rating curve during flood conditions, if USGS posted a separately estimated instantaneous peak discharge and time for the station for the flood event and/or if neighboring streamgage hydrographs, also subject to the event, support a reliable estimation of the hydrograph shape. If a reasonable estimate of the hydrograph peak cannot be deduced in this manner, top-of-rating curve values may be retained as the data values and the resulting monthly mean in the *IWCS* denoted as a minimum estimate, by "<".

The number of days of data reported in *IWCS* for each streamflow station represents the total number of days of the subject month with daily means represented in the monthly mean calculation (including any partial-data days estimated as above).

Shifting (adjustment) of automated USGS discharge output data, for instance on the basis of detailed field measurements showing different actual values than the automated output, is not performed by ISWS and is not performed for the *IWCS*.

**3.2.5.14. Personnel Qualifications and Training.** Review and downloading of the provisional river stage and streamflow data require a cursory knowledge of surface water hydrology and of the USGS and USACE water control data Web services. ISWS staff reporting for the IWCS should be oriented on checking reasonableness of streamflow data by an experienced hydrologist, but this may be less necessary if a supervisor will be reviewing the same source data each month.

### *3.2.6. Illinois Reservoir Monitoring*

With the exception of some lakes in far northeastern Illinois and in some historical floodplain areas of larger rivers, almost all lakes in Illinois are man-made, created by structural impoundments and/or excavation (such as former quarries). Most impoundments are dams across a stream. Even many naturally-occurring lakes in Illinois today are defined by some type of hydraulic control structure, and in some cases excavation of a shallower or original wetland area. Urban stormwater detention ponds and lakes have become a standard development practice in the past 30 years; conversely, few large lakes have been built in Illinois since 1970.

Surface water reservoirs have been constructed mainly throughout central and southern Illinois to provide water reserves in particular for public and industrial water supplies, as well as flood control and recreation. Public water supply lakes in Illinois are typically in-stream impoundments that fill from natural inflow from upstream. However, many water supply lake systems also have the infrastructure to divert water from auxiliary sources into the lake, including from streams or lakes in other watersheds, and in some cases from groundwater pumped from wells. Lakes that are not built directly on a stream channel but are designed to hold and pass flow diverted from a nearby stream are called side-channel reservoirs. Some public water supply systems consist of more than one lake, where during normal operation water is pumped from an auxiliary lake as needed to maintain a desired operational level in the lake from which the water is drawn for treatment and distribution.

Reservoirs in Illinois typically have a single operational control outlet consisting of an earthen dam with a concrete spillway at a fixed elevation. When the water surface level of the lake rises above the spillway elevation due to the volume of inflow, water exits the lake simply by flowing over the dam. Many larger lakes (and large river dams) have an additional structural mechanism that can be used to vary the operational spillway level, either on a seasonal or temporary basis. In a water supply system, of course, some volume is pumped out of the lake, and later returned out of the system downstream, sometimes into a different stream.

Structures placed in a stream affect sediment flow. Sediment gradually deposits and accumulates in a lake. Without mechanically dredging sediment out of the lake, the volume of water that a reservoir can hold decreases over time.

**3.2.6.1. History.** Since at least 1967, water levels at various water supply reservoirs have been reported in monthly ISWS surface water condition reports, based mainly on reports obtained by calling local observers, usually water supply operators. Water level reports at the three large USACE reservoirs in Illinois (Shelbyville, Carlyle, and Rend) were added to ISWS reports by 1973. Regular reporting of levels at 10 specific reservoirs began in 1983, increasing to two dozen during the 1988 drought. As part of the IWCS WARM product, the number of reservoirs reported was increased to 45 in 1993, and in 1995 reports of monthly system pumpage totals (system water usage amounts) were first requested from as many of the reporting water supply operators as were willing and equipped to furnish pumpage volume data.

Subsequently, some reporting systems have transferred their primary water supply to another source (such as the Rend Lake Intercity Water distribution system) and no longer use their local reservoir for water supply. For this or other reasons, some operators have discontinued reporting.

By 2008, the *IWCS* monthly reservoir level reports listed 36 reservoirs, of which 24 lakes are used primarily for water supply.

Reporting of reservoir information to ISWS is strictly voluntary, and the method of lake level observation is at the discretion of the volunteer observer. ISWS subscribes volunteer participants to the monthly printed *IWCS*, and offers to distribute the collected data to requesters.

Some minor effort has been made to collect reports of lake level observations made more frequently than monthly at some lakes. These are not reported and have not yet been systematically archived at ISWS. From 2002 to 2007, the monthly reservoir monitoring data reports from individual lakes were withheld from the Web-posted pdf version of the *IWCS* out of potential security concerns.

**3.2.6.2. Monitoring Objectives.** Water level is a necessary metric for predicting the yield capacity of a reservoir (how much water can sustainably be drawn, at what times). Water level alone is not a sufficient metric to determine yield capacity, but it is the most observable indicator of the supply status of a reservoir, and is a necessary input to estimate its near-term use capacity.

A critical consideration in water supply and use planning is the minimum "safe yield" that a source can provide during prolonged periods of drought. Water levels in reservoirs fluctuate, especially seasonally, but water levels much lower than are typical for a particular time of year may serve as a warning of declining supply or capacity. Water levels and water withdrawals need to be systematically monitored to provide the proper context to evaluate water level variations and projected water availability. Long-term monitoring of water surface levels of a lake provides a historical perspective on lake conditions and, to an extent, the hydrologic behavior of the watershed.

Inherently, a lake holds water and tempers flow through the system. Relative to streamflow and precipitation, water level changes in a lake are gradual, even with pumped withdrawal or controlled outflow. Thus lake level sampling need not be frequent (with the exception of flood control design or operation, which is not within the scope of WARM). Considered additionally in the context of ISWS's monthly summary of water conditions, presently the *IWCS* reservoir monitoring for WARM is intended to illustrate month-end conditions for the subject month.

For the WARM Program, an objective of reporting monthly reservoir levels of a number of reservoirs is to provide a greater-than-local perspective of water supply conditions, in conjunction with the other WARM Program reports, to help researchers and decision-makers identify drought conditions and assess their severity. The ISWS is likely to be the only agency that monitors reservoir level reports regularly from a range of lake facilities in Illinois.

The objectives of collecting pumpage volumes by month within the WARM Program are (1) to have the data at that resolution immediately available at ISWS if desired for initial analysis, and (2) to show the relative size of the reporting systems.

In addition to lake levels and withdrawal amounts, other critical parameters in reservoir water supply analysis include bathymetric surveying of the lake bottom to calculate the full volume of the lake, which changes over the years due to sediment accumulation and selected removal, and assessment of inflow. The majority of public water supply reservoirs do not have streamgages upstream to monitor inflow (and some have multiple contributing sources). Neither of these metrics has been an objective of the WARM Program. It is also worth noting that considerable variability of the lake bottom surface, not captured in traditional bathymetric surveying, somewhat precludes the need for precision in lake level measurements in a volume or yield calculation.

In general, the predictable range of water level of a lake is also of interest in planning construction, maintenance, access for recreational opportunities, and at some lakes, for wildlife and habitat management. Real-time level monitoring of a flood control reservoir is of interest to emergency managers to determine near-term storage capacity as well as effects of lake operation downstream and upstream. However, these are not monitoring objectives of the WARM Program.

**3.2.6.3. Number and Locations of Monitoring Sites.** As of 2008, monthly water levels are collected by ISWS for 36 lakes. Attribute data for these sites are found in Table 3.8. Their locations are shown in Figure 3.6. Reference elevations have been translated to National Geodetic Vertical Datum (NGVD) 1929 datum, where available.

**3.2.6.4. Siting Criteria.** The voluntary cooperation of reservoir operators and the accessibility and availability of data dictate the scope of reservoir monitoring in the WARM Program. ISWS does not operate or maintain field equipment or obtain measurements directly from the field for the reservoir monitoring program. ISWS has obtained data from reservoir operators who are willing to report monthly within the production schedule of the *IWCS*, which means by the fifth of each month (or at the very latest by press time around the 10th of the month). Water supply lakes and the larger non-supply lakes in Illinois are those more likely to have active operators present who are available to obtain lake observations. Being directly related to public health and security, the sustainability of existing community drinking water supplies is obviously a relatively important assessment need.

Most public water supply reservoirs are located in central and southern Illinois. In northern Illinois, Lake Michigan water supplies, groundwater, or direct withdrawals from rivers are available to most communities and are more preferred water sources than surface impoundments. Therefore, most WARM reservoir monitoring locations are in central and southern Illinois.

At a given lake, specific facilities to measure lake levels need only be sited where accessible to the observer and easily relatable to consistent reference elevation. Some observers achieve this for the typical range of observations without a permanent instrument installation.

## Table 3.8. Locations of Reservoirs Monitored for the WARM Program

| *Site* | *County* | *Township* | *Range* | *Section* | *Principal Meridian* | *Normal pool (ft)* | *Approximate years of record* |
|---|---|---|---|---|---|---|---|
| Altamont | Effingham | 07N | 04E | 23 | 3 | 582.0 | 25 |
| Bloomington[3] | McLean | 25N | 02E | 01 | 3 | 719.5 | 22 |
| Canton | Fulton | 07N | 05E | 30 | 4 | 577.5 | 19 |
| Carlinville | Macoupin | 09N | 07W | 10 | 3 | 571.1 | 25 |
| Carlyle[1] | Clinton | 02N | 02W | 18 | 3 | 443.0-445.0 | 31 |
| Coulterville | Randolph | 04S | 05W | 11 | 3 | 515.9 | 13 |
| Decatur[1,3] | Macon | 16N | 02E | 22 | 3 | 612.25-614.5 | 25 |
| Evergreen[3,4] | Woodford | 25N | 01E | 12 | 3 | 720.0 | 18 |
| Glenn Shoals[2] | Montgomery | 09N | 04W | 36 | 3 | 590.0 | 16 |
| Greenfield | Greene | 10N | 10W | 03 | 3 | 566.2 | 15 |
| Highland | Madison | 04N | 05W | 30 | 3 | 500.0 | 20 |
| Hillsboro[2] | Montgomery | 09N | 04W | 36 | 3 | 589.0 | 16 |
| Jacksonville[2] | Morgan | 14N | 10W | 09 | 3 | 644.0 | 14 |
| Kinkaid | Jackson | 09S | 03W | 04 | 3 | 420.0 | 20 |
| Lake of Egypt | Williamson | 10S | 02E | 25 | 3 | 500.0 | 15 |
| Mattoon | Coles | 10N | 06E | 01 | 3 | 632.0 | 15 |
| Mauvaise Terre[2] | Morgan | 15N | 10W | 28 | 3 | 588.5 | 14 |
| Mt. Olive (new) | Macoupin | 08N | 06W | 28 | 3 | 600.0 | 6 |
| Mt. Olive (old) | Macoupin | 07N | 06W | 03 | 3 | 654.0 | 12 |
| Nashville[3] | Washington | 02S | 02W | 19 | 3 | 503.8 | 23 |
| Pana | Christian | 11N | 02E | 30 | 3 | 641.6 | 24 |
| Paradise | Coles | 11N | 07E | 08 | 3 | 685.0 | 19 |
| Paris (east) | Edgar | 14N | 12W | 31 | 2 | 660.0 | 24 |
| Paris (west) | Edgar | 14N | 12W | 25 | 2 | 660.1 | 14 |
| Pinckneyville | Perry | 05S | 03W | 14 | 3 | 445.0 | 15 |
| Pittsfield | Pike | 05S | 03W | 16 | 4 | 596.0 | 19 |
| Raccoon[1] | Marion | 01N | 01E | 08 | 3 | 477.0 | N/A |
| Rend | Franklin | 06S | 02E | 03 | 3 | 405.0 | 31 |
| Salem[3] | Marion | 02N | 02E | 02 | 3 | 546.5 | 14 |
| Shelbyville[1,5] | Shelby | 11N | 04E | 08 | 3 | 594.0-600.2 | 31 |
| Sparta[3] | Randolph | 05S | 05W | 06 | 3 | 497.5 | 12 |
| Spring[4] | McDonough | 06N | 03W | 15 | 4 | 654.0 | 25 |
| Springfield[1,3] | Sangamon | 15N | 05W | 12 | 3 | 559.6-560.0 | 25 |
| Taylorville | Christian | 13N | 02W | 36 | 3 | 590.0 | 16 |
| Vermilion[4] | Vermilion | 20N | 11W | 31 | 2 | 581.7 | 23 |
| Virginia[5] | Cass | 18N | 10W | 34 | 3 | 575.0 | 20 |

**Notes:**
Datum: NGVD 1929
Years of record = Total number of years included in month-end average. Total period of record may be longer.
(1) Target operating level varies seasonally.
(2) Instrumentation not available to measure height of water elevation above spillway.
(3) Natural inflow can be supplemented by other sources.
(4) Normal pool elevations have changed during period of record reported.
(5) Not a public water supply.


Figure 3.6. Locations of Illinois reservoirs monitored for the WARM Program

**3.2.6.5. Instrumentation.** Instrumentation used to measure water surface levels at lakes reported in IWCS include:

- a stilling well float gauge or air-pressure gauge (as described in 3.2.5.5)
- a fixed visual marker, such as a staff gauge with height demarcations
- some other form of ruler, mounted or not mounted (including a yardstick or tape measure)

Observations or measurements are typically made at or near the dam spillway, but some instruments are installed at a pump house or other structure. Reference points are usually related in some manner to spillway elevation by measurement or a level survey performed at installation.

In 2001, ISWS personnel installed eight staff gauges at selected participating lakes chosen by ISWS as desired stations with no gauge. A Memorandum of Understanding was conducted with the operators receiving the gauges, detailing our agreement (Appendix VIII). These devices are simply stick gauges (rulers), with 0.02-foot markings in black printing on white background, bolted to a structure and read visually by an observer. The vertical position of a staff gauge is set arbitrarily at each location; ISWS staff recorded the staff gauge height value corresponding to full pool (normal operating spillway elevation) at each installation. In addition, ISWS left blank recording forms with these operators (Appendix IX) with a request that they verify the spillway level staff gauge value over time and provide ISWS-enhanced information on conditions during reservoir level observations. In practice, participation with the form and enhanced observations varies among operators.

Measurements of system pumpage are made at a point at the water control or distribution facility using standard industry meters installed as part of the system. Installation, operation, and reading of pumpage metering are outside the purview of the ISWS.

**3.2.6.6. Calibration Procedures and Calibration Verification.** Calibration of float or pressure gauges is assumed to be performed by the gauge installer or operator. Installation of a staff gauge normally involves leveling to a reference elevation, typically the lowest normal operating spillway elevation, as mentioned above. Any reference elevations at lake structures normally have been determined by standard surveying techniques to a benchmark (translated to NGVD 1929 datum), but in some cases are unverified or assumed.

No other calibration process is performed for measurement by visual marker or ruler. Any further site verification of the data is the responsibility of and at the discretion of the reservoir operator.

System pumpage metering requirements at public water supply systems are specified by public water system regulators (and equipment manufacturers). Operation is the responsibility of the licensed lake operator.

**3.2.6.7. Data Quality Objectives.** Because the purpose of WARM reservoir monitoring is strictly to monitor and assess drought trends and long-term water level patterns at each reported lake rather than to obtain data sufficient for technical water budget analysis, and also because lake volume assessments are not particularly sensitive to small differences in lake levels, data quality objectives for WARM reservoir monitoring are not specified. Good-faith reports from lake operators who are volunteering to report observations, and in most, but not all cases, are already obtaining the data for their own purposes, have been considered sufficient for the purposes of the WARM reservoir monitoring program and *IWCS* presentation.

In practice, the quality of lake level data differs considerably from location to location, and may differ between operators or observers, both long-term and monthly, at a given location. Generally, the accuracy of reported water levels of *IWCS* lakes is within 0.25 feet, and at many facilities is within 0.5 inches. However, at some locations, observations become much more approximate under certain conditions, particularly at low lake levels and in winter.

Most participating operators do not report the height of the water level when water is pouring over the spillway. Operator reports for this condition are typically "full" or "over," meaning relative to the spillway level. Absent other description, "full" is translated as at spillway level. Since 1998, absent more specific description, "over" is recorded by ISWS as 0.1 feet over spillway level. In general, reports of water surface levels over uncontrolled spillways should be considered less accurate than reports of levels below spillway level in the same dataset. The accuracy of measurements made via an automated gauge can be ± 0.01 feet. At most mounted and properly referenced staff gauges, accuracy is estimated to be ± 0.1 feet. *IWCS* pumpage values are reported as provided. Among different systems, pumpage values may represent different system components.

**3.2.6.8. Sampling Schedule and Procedures.** Sampling method, sampling frequency, local recording procedures, and reporting format are chosen by each volunteer operator at his or her own discretion. Again, most are obtaining the reported data already for their own purposes. A few operators read and record the output of automated gauge equipment if installed. Most operators interpret the lake level from a visual reading of the water level against a marker (such as a staff gauge). Those using an unmounted instrument such as yardstick or ruler lower the ruler to or into the water and measure the distance to a reference point that it is placed against at the measurement location. Methods of recording visual observations are not specified, except that ISWS provided recording forms at locations where staff gauges were installed to encourage the observer to note local weather conditions (including wave action) concurrent with lake level observation if using the form.

Most lake operators reporting lake levels to ISWS perform and record their own routine lake level observations at least weekly, and some daily. Conversely, a few obtain observations monthly or occasionally, but not regularly. Some lakes are inaccessible for observation in winter conditions.

The ISWS collection frequency of operator reports is normally monthly, reporting observations representative of month's end in each issue of the *IWCS*. In severe drought periods (e.g., 1988, 2000), ISWS has sometimes requested observations more frequently than monthly, for use by the DRTF.

To obtain most of the monthly lake reports, a regularly assigned ISWS employee telephones the participating water plant offices each month on working days some time from the 1st through the 5th of each month. ISWS staff records the verbal report as later described. A small number of operators either fax or e-mail their reports to ISWS; these may arrive at ISWS after the 5th of the month, after the operator can complete the finished month's pumpage totals.

USACE St. Louis District Water Control posts daily midnight lake levels from automated gauges at Lake Shelbyville, Carlyle Lake, and Rend Lake at: *http://mvs-wc.mvs.usace.army.mil/dresriv.html*. NWS Lincoln posts lake levels almost daily from two of the larger city supply reservoirs, Springfield and Decatur, in its Hydrologic Summary at: *http://www.weather.gov/water/textprods/view.php?wfo=ilx&prod=RVA&extra=HYD*. ISWS contacts Springfield and Decatur (and Bloomington) operators directly every other month to obtain monthly pumpage data, because the water levels and pumpage data for these facilities are provided by different contacts.

Some water plant supervisors share the task of lake level observation with selected assistant staff, while some supervisors retain this function solely for themselves. Also, some supervisors leave the data with the receptionist or other staff for ISWS's monthly call, but many need to be contacted directly to obtain the report each month.

While a few water plant supervisors complete their monthly pumpage totals (which they must report to a regulatory agency in a more detailed report) on the first of the month, most need several work days after the end of the month before they can tally the just-ended month's pumpage totals due to day-to-day operational obligations. Because of this schedule for many volunteer cooperators, ISWS has reported the pumpage for the month preceding the subject month in the *IWCS* instead of the month just ended. However, it is easier month-to-month for operators to report to ISWS the just-completed month's pumpage totals rather than the prior month after they have filed it, regardless of the date of its completion. Therefore, the ISWS staff member compiling the reports tries to accommodate this schedule when collecting month-end reports from water supply operators, within the constraints of the *IWCS* production schedule.

The ISWS recording staff generally obtains the levels for the daily-observed lakes in the WARM Program as close to the 1st of the month as is possible, to represent end-of-month lake levels, given the various considerations described previously. At lakes with less frequent observations, reports obtained by the 5th of the month usually suffice.

For those lakes that operate at different spillway elevations seasonally, the ISWS compiler verifies the target elevation as needed by the information posted on the USACE Web site (Shelbyville, Carlyle), and by the context of the record and/or by asking the operator (Decatur, Springfield). In addition, the Raccoon Lake operator reports if their variable outflow gates are activated when the lake level is obtained; however, their gate is operated on an occasional temporary basis. The ISWS recorder also notes any other information provided by the operators, such as periods of deliberate lake level drawdown to accommodate maintenance activities, periods of supplemental inflow pumped from a source other than natural inflow, approximate precipitation or lake outflow peaks noted during recent storms, ice cover, and, if provided, the date of the reported lake level observation.

**3.2.6.9. Written Standard Operating Procedures.** In general, instructions for the ISWS recording staff person are embedded in the working electronic files and in the computer directory containing the working files. Reference paper files containing the history of methodology since about 1996 are also retained by the ISWS recorder.

The standard operating procedure (SOP) for WARM reservoir monitoring can be summarized as follows:

> The ISWS staff recorder calls the participating lake operator's office or otherwise receives the lake level and the last available monthly pumpage values, if applicable. Since 1998, the ISWS recorder has transcribed on a printed spreadsheet for the month the lake level reports from the operator in the format reported by the operator, which may be different from spillway, a staff gauge stage value, or an already-translated elevation, and may be in feet or inches and in different fractional formats. (Pumpage is transcribed in millions of gallons, as reported, which is usually to three decimal places.) Prior to 1998, the ISWS recorder often translated the operator's report to an elevation or stage relative to an assumed reference before writing down the value.
>
> The ISWS recorder keeps the previous month's reports on hand during calls to operators as a reference and as a reminder to request any data missed the previous month.
>
> The ISWS recorder enters the values written on the month's paper log into an MS Excel (2000) working spreadsheet file; since 1998 this entry by formula literally reflects the operator's report. The reported value is then converted by formula in the spreadsheet file to units of feet, unrounded, relative to the confirmed reference level for the month. (As a convention for *IWCS* reporting, the reference level for the representative month-end reports at reservoirs whose target elevations change by a schedule is considered to be the level on the first day of the next month [i.e., the next day's higher or lower target], with the intent of illustrating water availability.) Since 2002, the resulting value is calculated as feet difference from spillway, or from target pool level, if applicable; prior *IWCS* tabular reports displayed lake levels as elevation.

For the monthly *IWCS*, lake level values are rounded to 0.1 feet, and pumpage values rounded to 0.1 million gallons. These values, along with current reference level elevation and years of past available WARM level records for the month and their average value for each lake, are copied unformatted into a table in a working MS Word (2000) document. The working Word file contains instructions and template formatting rows used to format the pasted monthly values (not-available (N/A) entries require separate formatting). After formatting, a clean Word document is saved separately and submitted to the *IWCS* editor usually by the fifth of each month. Late reports received by press time are edited into an Adobe pdf proof *IWCS* document. (From 1999 to 2005, the most recent version of WordPerfect was the standard ISWS word processing software.) The ISWS recorder adds any notes of significance to interpreting the tabular report to the *IWCS* narrative.

Locations of monthly reservoir monitoring recording files:

Working spreadsheet files:
\\HickoryCreek\data\data\Mclimate\wcsYYYY\table5\Res-YYMM.xls

Working document files:
\\HickoryCreek\data\data\Mclimate\wcsYYYY\table5\TB5_YYMM.doc

Submitted document files:
\\HickoryCreek\data\wcspub35\table5\TB5_YYMM.doc and
\\HickoryCreek\data\wcspub35\swtext\swYYMM.doc

Past monthly files are saved in subdirectories by year.

Files on PC *\\HickoryCreek* are normally backed up to tape in WSRC Building 5 weekly. The updated archive files and most recent work files are occasionally backed up to a floppy disk or CD.

**3.2.6.10. Quality Control Practices.** ISWS does not control or direct the observation and reporting practices of the volunteer water plant operators. Values are accepted as provided. If the only available reported lake level value was obviously (as reported) observed too long before or after the end of the subject month to be representative of month-end conditions relative to recent precipitation, the value is not used in the *IWCS* and is not archived as a month-end observation.

Where automated gauge equipment is installed, operation is assumed to be implemented by the gauge operator (e.g., lake levels at USACE lakes).

**3.2.6.11. Data Users.** In the past, the reservoir data reported in the *IWC*S were reviewed routinely by members of the SWPTF. ISWS hydrologists have brought the WARM reservoir reports to the DRTF, when this group has been activated, along with other WARM meteorological and climatological staff reports. Until recent years, print versions of the monthly *IWCS* newsletters were provided to participating lake operators and to the director of the OWR. With total accessibility now available over the Internet, these reports reach these users on press day.

Occasionally (once or twice a year), a community or consulting engineer requests the WARM reservoir record that ISWS has compiled for a particular lake or lakes, in order to review the operation and/or estimate the yield of the subject water supply, sometimes in relation to a prospective project (that may or may not have been revealed to the community). ISWS has responded to these requests by providing a clean copy of the monitoring data compiled for specific subject lakes in the current spreadsheet archive format (see below) with customized disclaimers describing the limitations and context of the particular data record.

Use of the reservoir data included in the monthly *IWCS* issues posted on the ISWS Web site is unknown.

**3.2.6.12. Data Reduction and Archival Protocols.** Preparation of the reservoir monitoring data for the monthly WARM product (the *IWCS*) is described in section 3.2.6.9.

Late-arriving reports are added to the month's working spreadsheet file, if appropriate. This includes any reports received with the following month's reports that were not originally obtained within the *IWCS* production schedule, or that supersede *IWCS*-reported values because they were observed closer to the end of the subject month than the observation that was reported within the particular *IWCS* production schedule.

At least annually, the monthly lake level and pumpage data for the year are copied from each month's working spreadsheet file and pasted into a spreadsheet file maintained for each lake in the WARM Program. The format of the spreadsheet is a month-by-year grid for each lake level and for pumpage. The lake level data are currently saved unrounded in their inherently "native" format (e.g., as elevation, stage, or difference from spillway). Prior to 1998, values were entered in the archive reservoir files as they appeared in the printed *IWCS* issues, as translated to 0.1-foot elevation based on the assumed reference elevation. (A few ISWS reservoir level record files were extended using earlier sources, including the USACE lake records distributed by USACE or USGS.) As needed, values from different periods in each reservoir archive spreadsheet are copied elsewhere in the sheet to a common format, and the long-term average of the ISWS-recorded values prior to the current year (and number of such observations per month, representing years of record) is calculated for use in the current year's *IWCS* issues. These reservoir archive files are maintained in the *\\HickoryCreek\data\data\RESVOIR* directory and copied to *\\Shoalcreek\infosvcs\swfpi_db\WARM_bak*.

Consistent with the monitoring objective, only a month-end representative lake level value for each month and a representative monthly reported pumpage for each month as available are entered in the WARM reservoir archive files. Dates of observations are not requested, in most cases are not necessarily provided by the reporting operator, and are not saved by ISWS with the recorded lake-level values representing end-of-month conditions. When corresponding dates are provided, the ISWS recorder writes down the date on the paper worksheet, but the date is not further archived. Similarly, other supplemental information that is written on the recorder's worksheet is not recorded in the reservoir archive file. Limited site information is recorded in the reservoir archive spreadsheets, including spillway or target elevation by month (and year if the spillway was permanently raised during the period of record), as well as the typical accuracy, format, and method of measurement reported by the operator.

Updated observer point of contact information for collecting monthly reports is retained in each working monthly spreadsheet file. Mail addresses of water system supervisors can be obtained from the Illinois Water Inventory Program (operated by ISWS’s Center for Groundwater Science).

The original paper worksheets on which the ISWS recorder wrote the operator's verbal reports each month have been retained since 1998 in the ISWS recorder's files in WSRC Building 5. The recorder's working sheets from 1984 to 1990 are mostly on file, grouped but not all marked by year. A fair proportion of the recorder's sheets in the interim are lost.

Some lake operators provide ISWS with a written record of lake level observations by recorded date several times per month. These more detailed data have not yet been systematically archived. (Usually these records are provided from the operator's own local spreadsheet record.) Written communication from the operators is retained in the ISWS recorder's files in WSRC Building 5.

**3.2.6.13. Data Quality Assessment Processes.** Operator-reported values are generally accepted as valid observations as-is, except for precise values (other than full pool) that are exactly equal to the previous month's value. In this case, primarily for pumpage, the ISWS recorder will ask the reporting operator to confirm the time frame represented by the value(s).

Examining the change in level from the previous month and comparing the reported level to the average for the available record is also a check of the reasonableness of the reported water level.

More specifically, the ISWS recorder keeps the previous month's reports on hand when collecting the following month's data as a very approximate gauge of reasonableness, also considering generally the precipitation events during the month and the monthly WARM streamflow summary which is completed before most of the reservoir reports are obtained.

If the reported lake level value is obviously, by the nature of the report, not a recent observation, particularly relative to subsequent precipitation before the end of the month, the value is not used in the *IWCS* or archived in the reservoir monthly record archive files.

Dates and values of permanent and seasonally scheduled changes in spillway elevations are recorded by ISWS in the WARM reservoir data archive files, to the extent known to ISWS. Water elevation values from past ISWS reports whose reference elevation (or actual subject location) is deemed uncertain during a certain period due to lack of documentation may be excluded from the long-term average calculation for the particular lake.

**3.2.6.14. Personnel Qualifications and Training.** The cooperating reservoir operator obtains the measurements or performs the observation, and determines the report. No training or guidance is provided by ISWS. In general, public water supply operators are subject to considerable training and oversight in water plant operation by their regulating agency, the Illinois EPA.

The ISWS staff member compiling and archiving the data for the *IWCS* should have functional knowledge of MS Excel formula behavior. In addition, some hydrology experience or education is beneficial to be able to assess reports for possible errors or inconsistencies and to provide useful and accurate supplemental information in the *IWCS* text. However, no specialized experience is required to collect lake reports from cooperating operators.

### *3.2.7. Illinois Benchmark Sediment Monitoring Program*

**3.2.7.1. History.** The ISWS initiated the Benchmark Sediment Monitoring Program (BSMP) in 1981 to collect data on suspended sediment transport in Illinois rivers and streams. It was recognized at the time that information on this aspect of the state's water resources was substantially lacking. A long-term database was developed to assess the impacts of sediment and sediment transport on the state's water resources. The 1984 Illinois SWPTF identified erosion and sediment control as the number one water resources issue for Illinois waterways. The 1984 plan stated that "excessive soil erosion on 9.6 million acres of Illinois farmland is threatening their productive capacity, degrading water quality, accelerating eutrophication of reservoirs, silting of streams, and degrading fish and wildlife habitat" (SWPRF 1984). Discussions in later years on the impacts of erosion and sedimentation on the Illinois River Valley have kept the issue in the forefront of concerns to the state (Bellrose et al. 1983; Bhowmik et al. 1986; Bhowmik and Demissie 1989; Demissie, Keefer, and Xia 1992).

The BSMP collects weekly suspended sediment samples on a group of selected rivers and streams in the state. The sediment sample concentrations are matched with water discharges at the same location to obtain instantaneous sediment loads at each monitoring site. The BSMP began in 1981 with 50 monitoring stations around the state. Subsequent budget cutbacks and assessments of data quality pared the program to its present status of 15 sites. Since the inception of the program, more than 23,000 suspended sediment samples have been analyzed, creating a substantial database of sediment transport in Illinois waterways. The current design of the program was documented by Allgire and Demissie (1995).

**3.2.7.2. Monitoring Variables and Objectives.** Data collection in the BSMP occurs on a regular basis in two phases. The sediment program trains local observers to collect samples for suspended sediment for concentration analysis. Secondly, a Water Survey technician takes cross-section samples that are alternately analyzed for concentration or for a sand/fine split of particle size.

Monitoring objectives are to measure and quantify the long-term changes in suspended sediment transport in Illinois waterways. The long-term database can be used to:

- Identify watersheds with high erosion rates
- Evaluate the effectiveness of watershed protection programs
- Identify watersheds of potential degradation of surface water supplies
- Estimate sediment loads in nearby unmeasured streams
- Determine long-term trends in sediment transport

**3.2.7.3. Number and Locations of Monitoring Sites.** The BSMP currently consists of 15 sampling sites located throughout Illinois. Figure 3.7 shows the location of the program's monitoring sites. Table 3.9 lists the stations, the size of the upstream watershed drainage areas, and period-of-record at each sampling site. In addition, the USGS identification number has been added for ease of reference to concomitant streamflow data from the USGS. One site in northern Illinois, formerly owned by USGS, was suspended and given to ISWS when the BSMP was initiated.

**3.2.7.4. Siting Criteria.** BSMP stations are located at the USGS continuous recording streamgaging sites with the exception of #513, Cache River at Ullin station, which is an ISWS streamgaging station. Co-locating the sampling stations at continuous recording streamgaging sites allows for a reading of the river gauge height at the time the sample is collected. The USGS furnishes copies of the discharge rating tables for all streamgaging monitoring stations in the BSMP each Water Year, except for the ISWS streamgaging station Cache River at Ullin. The ISWS develops the discharge rating for the Cache River at Ullin. This discharge value, combined with the suspended sediment sample concentrations, yields the instantaneous suspended sediment load transported by the river past that gauging station at that particular moment (Porterfield 1972).

During the site selection process, streamgaging stations statewide were analyzed for suitability of quality sediment data collection. A strong effort was made to locate monitoring stations on small, medium, and large drainage areas in order to provide researchers with information on an array of sediment transport observations under various surface watershed characteristics. High emphasis was placed on site locations in rather stable streamflow regimes. Streamgaging stations found immediately downstream from control features such as lakes, dams, or confluences with tributaries or other streams were not considered appropriate data collection locations.


Figure 3.7. Benchmark Sediment Monitoring Program sites

**Table 3.9. Locations and Dates of Benchmark Sediment Monitoring Program Sites**

| *ISWS ID* | *Station Name* | *USGS ID* | *Period of record (Water Years)* | *Drainage area (sq mi)* |
|---|---|---|---|---|
| 102 | Pecatonica R. at Freeport | 5435500 | 1981 - Present | 1326 |
| 103 | Rock R. at Rockton | 5437500 | 1981 - Present | 6363 |
| 122 | Vermilion R. near Leonore | 5555300 | 1984 - Present | 1251 |
| 123 | Mazon R. near Coal City | 5542000 | 1981 – 1997, 2002 - Present | 455 |
| 124 | Kankakee R. near Wilmington | 5527500 | 1983 - Present | 5150 |
| 125 | Kankakee R. at Momence | 5520500 | 1982 - 1985, 1988 - 1990, 1993 - Present | 2294 |
| 229 | Spoon R. at London Mills | 5569500 | 1981 - 1987, 1994 - Present | 1062 |
| 242 | La Moine R. at Colmar | 5584500 | 1981 - 1988, 1993 – Present | 655 |
| 245 | La Moine R. at Ripley | 5585000 | 1983 - 1990, 1993 – Present | 1293 |
| 249 | Sangamon R. at Monticello | 5572000 | 1981 - 1994, 1996 – Present | 550 |
| 361 | Kaskaskia R. at Vandalia | 5592500 | 1981 - 1988, 1990 – Present | 1904 |
| 367 | Silver Creek near Freeburg | 5594800 | 1981 - 1988, 1990 – Present | 464 |
| 370 | Little Wabash R. at Carmi | 3381500 | 1981 - 1985, 1993 – Present | 3102 |
| 378 | Cache R. at Forman | 3612000 | 1981 - Present | 244 |
| 513 | Cache R. at Ullin | none | 1986 - 1989, 1995 – Present | 164 |

**3.2.7.5. Calibration Procedures and Calibration Verification.** The depth-integrated samplers used in BSMP require no post-manufacturing calibration. Jenway and Labcraft conductivity meter calibration, used in the sediment laboratory for analyses of suspended sediment, is described in the "Standard Operating Procedure for Suspended Sediment by Filtration Method", Sediment Laboratory SOP Number 1, Version 1.5, Section 11.0.

**3.2.7.6. Data Quality Objectives.** It is the objective of BSMP to collect quality samples representative of the suspended sediment transported in Illinois streams. Streams around the state vary greatly in their drainage areas, watershed characteristics, and the composition of their bed and bank material. Sampling a variety of stream sizes and types in different regions of the state yields estimates of the sediment transport that can be expected for watersheds with similar parameters.

The quality of the suspended sediment analytical results is expressed as precision and bias for three ranges of sediment concentrations. These can be found in Sediment Laboratory SOP Number 1, Version 1.5, Section 13.0.

**3.2.7.7. Sampling Schedule and Procedures.** Sediment data collection in the BSMP is based on the techniques used by the USGS. Detailed descriptions of these and other techniques can be found in a series of publications by the U.S. Department of the Interior (Guy 1969; Guy and Norman 1970; Porterfield 1972).

Illinois is divided into three sampling regions headed by an ISWS technician who maintains the network in each specific area. These regions are divided roughly by geography: southern, central and northern Illinois. Sites in southern Illinois (5) and central Illinois (6) are handled identically; the remaining four sites in northern Illinois are monitored on a semi-annual schedule due to the distance required for travel to each location.

The field sampling performed by BSMP consists of three types:

1) weekly samples,
2) cross-section samples, and
3) particle-size cross-section samples.

Data at most sites have not been continuous through the years due primarily to reconstruction of the bridges on which they reside. Data collection at these times is suspended.

*3.2.7.7.1. Weekly Sampling.* A weekly sample is taken at each sampling station by a local citizen hired to serve as the observer for that site. These observers are trained by ISWS staff in the proper data collection methods and techniques of the program (Appendix X). Each observer is supplied with a case of 20 clean sample bottles to use for his/her data collections over a period of several months. Every 15 to 20 weeks, observer samples are collected by the Water Survey staff member responsible for that sampling region, and a set of clean bottles is left with the observer for the next sampling period. The samples are transported to the Water Survey Sediment Laboratory in Champaign for analysis.

The monitoring process dictates that the observer collect a sample of river or stream water at a fixed location, or vertical, in the stream cross-section at a location on the bridge referred to as the "box site." The box site, containing the depth integrated sampler, is usually located near the center of the main channel flow of the river. An open collection bottle is placed inside the sampler and the device is lowered into the stream below.

Proper depth integration sampling involves lowering the sampler to the riverbed at a constant speed, or transit rate. A transit rate is determined by the speed a sampler is lowered and raised through a water column, where the sample bottle is not under- or over-filled (less than 200 milliliters [mL] or greater than 400 mL). When the sampler contacts the riverbed, the direction is immediately reversed and the sampler is raised at the same transit rate until it clears the water surface. Water is thus allowed to flow continuously into the collection bottle from the moment the sampler is submerged until it is raised above the water surface.

After retracting the sampler back to the box site, the collected bottle is removed from the sampler, and a water temperature measurement is made. This is accomplished with an alcohol-filled, 76-mm immersion thermometer placed into the sample bottle. The collection bottle is capped. The observer records the river name, date, and time the sample was collected, the gauge height obtained from the on-site USGS streamgage, and the water temperature of the sample onto the bottle cap. Samples are stored in a dark room, closet, basement, or a USGS gauge house, where samples are not exposed to any light.

The identical information is logged onto a Chain of Custody log sheet kept by the observer with the case of sample bottles (Appendix XI). Log sheets serve as an important cross check of the sample information in the event the information on the sample bottle cap becomes unreadable between the time of sample collection and delivery to the laboratory for analysis. The observer's copies of each sample's log sheets are added to the site file when samples are collected by the Water Survey staff member.

BSMP guidelines are for observers to sample on the same day each week, barring circumstances that would necessitate a temporary change in the observation schedule, such as vacation, illness, or dangerous conditions due to weather. Observers choose the day of the week on which they would prefer to sample their respective rivers based on their personal schedules. In those instances when observation days need to be altered, samples are to be taken on the next available day. If an observer plans to be gone for a period of one week, sampling is to be performed as soon as is practical just prior and subsequent to the observer's absence. A longer absence will require a substitute observer or a special trip by the regional technician.

A general guideline for observers is that when circumstances dictate a sampling schedule change, sample days should be kept to between five to nine days apart. This prevents samples being collected on consecutive days, and provides sample data under as many different flow conditions as that of a weekly schedule. Observers are compensated for each weekly sample they collect.

*3.2.7.7.2. Cross-Section Sampling.* The second type of sampling is cross-section sampling. This consists of collecting suspended sediment samples at multiple verticals across an entire river channel. Cross-section sampling can be used as a check that a single box sample accurately represents average sediment concentration of a stream. This is accomplished by computing the ratio of the box sample concentration with the average concentration of the entire river channel cross section. This ratio can then be used to adjust the box site concentration measurement to reflect the actual suspended sediment concentrations in the stream. This calibration can also be used to relocate the box site in the cross section to obtain a more representative sample if inadequacies are revealed in this analysis. All of the cross-section samples for the BSMP are collected using the Equal-Transit Rate (ETR) method. The ETR method collects samples using the same transit rate both upwards and downwards at equally spaced verticals across the entire width of the channel cross section. That is, each sample is proportional in volume to the partial streamflow and sediment load of that particular vertical. Together, all samples in a cross section yield a gross sample proportional to the total streamflow and sediment load at the time of sampling (Guy and Norman 1970).

The ETR method necessitates that the same size sampler nozzle be used for an entire cross section. Samplers come with three different size nozzles: 1/8 inch, 3/16 inch, and 1/4 inch diameter. The different size nozzles can be used under various flow conditions within each stream. The smaller size nozzles can be used at sampling locations with a greater depth and/or rivers and streams possessing increased stream velocities, thereby allowing a more comfortable sampling transit rate without overfilling the sample bottle.

The number of verticals required for an ETR sediment cross-section measurement depends on the streamflow and sediment characteristics at the time of sampling. The staff member collecting samples makes a determination of sample spacing by dividing the stream width by the desired number of verticals. As a general guideline, the BSMP uses 10 to 20 verticals in a cross section as sample numbers for each stream.

The sampling schedule for cross-section observations in the BSMP is approximately every six weeks. However, due to staff limitations, the northernmost sites in the BSMP (#102, #103, #124, and #125) are visited only twice per year to collect observer samples, perform cross-section sampling, and conduct site maintenance.

*3.2.7.7.3. Particle Size Sampling.* The third scheme is particle size cross-section sampling. In general, sampling periods alternate between cross-section analysis and particle size analysis. The particle size sample data collection uses the same ETR method as that for cross-section sampling. However, for these collections, all samples from each vertical of a particular stream or river are compiled in the laboratory to form one sample for that location and observation time. This composite sample is analyzed for particle size. The particle size is reported as a sand/fine split analysis with a percent of the suspended sediment sample reported as finer than 0.0625 mm or 62.5 micrometers. A summary of the procedures used for cross-section sampling is in Appendix X.

**3.2.7.8. Written Standard Operating Procedures.** Standard operating procedures for observer sampling and the ISWS technician cross-section sampling are outlined in Appendix X. A detailed copy of the procedures is maintained in the BSMP office and sediment laboratory for reference. All observers and each ISWS technician in the BSMP have a copy of these procedures to follow.

**3.2.7.9. Quality Control Practices.** The collection of suspended sediment samples under varying hydrologic conditions results in large spatial and temporal variability. The best assurance for the collection of quality samples is standardized observer data collection training procedures. Ongoing comparisons of sample data collected by ISWS field staff versus the observer data yield insight into the quality of the observer data.

The suspended sediment samples are transported to the ISWS Sediment Laboratory in Champaign. The Sediment Laboratory performs QC procedures in accordance with the SOP for operations (Keefer and Shackleford 2001). The following is a summary of the data management and data QC steps that are taken for the analyses received from the laboratory.

- Upon receipt of samples from the field, the information on the cap of each sample is compared to the log sheet information that the observer and technician filled out when the sediment sample was collected. This ensures the correct date, time, gauge height, and water temperature were recorded in the data set for each sample.

- Each sediment sample’s recorded gauge height is crosschecked to the matching USGS streamgaging stations’ time and gauge heights to verify as accurately as possible the associated streamgage height.

- Each sediment sample concentration value is checked independently for concentration values that are outliers for the associated date and gauge height. These samples are flagged and the sample and its data sheet are scrutinized for possible explanations for the unusual value. The sample is compared to concentrations on the dates before and after the date in question to reveal whether a short-term trend could explain the sample data. Notes by the observer or technician are reviewed for pertinent information. Possible explanations include heavy precipitation events, construction or agricultural activities, drainage ways discharging into the stream near the site, etc. An occurrence of any of these events is noted with the sample documentation, as well as when no explanation for the atypical value is determined.

- Sediment concentrations for each site are plotted versus gauge heights to determine if there are any unusual concentration values that may warrant further investigation. Plotting these values often assists in rectifying questionable sample values. Some values often appear more reasonable when viewed in a complete yearly data set. Similarly, other samples may stand out when plotted and reveal questionable data, warranting further investigation.

- Sediment concentrations are added to the period of record data set for each network site. The sediment concentrations are plotted versus the date for the entire period of record for each site. This final plot allows for comparison of sediment concentration values over the entire sampling history for each site.

- Samples that have large variations in concentration as compared to adjacent data with no reasonable explanation for their value are declared as contaminated samples and are deleted from the sample file. Samples that are slightly outside of existing trends, but could in fact be viable data values, are left in the data set, but are flagged as such in the remarks column of the data set. While these data values are retained, the BSMP advises use of the flagged data in analyses of sediment transport trends to be performed with caution.

- Samples are matched with the corresponding stream discharge (in cubic feet per second) from the latest USGS rating table for each monitoring site, and instantaneous sediment loads are calculated for each sediment sample using the equation:

$$Qs = Cs\ (Qw)\ K$$

where Qs is the instantaneous suspended sediment load in tons per day, Cs is the suspended sediment sample concentration in mg/L, Qw is the instantaneous water discharge in cubic feet per second, and K is a coefficient with a value of 0.0027. As a final check for a sample's validity in the sediment transport curve, instantaneous sediment load data are plotted versus instantaneous water discharge for each site. If a sample data point stands out as problematic, that sample point is scrutinized as before and either corrected, flagged, or deleted from the final data set.

**3.2.7.10. Data Users.** The primary users of data from the BSMP are state and federal governmental agencies. Universities and various research organizations including private engineering companies also request data from the program. Data will become more accessible for users as the program Web site is fully operational. In general, the users of these data are researching sediment transport loads in specific streams and regions of the state. They are using specific sediment concentrations and sediment loads whether it is for engineering design, water use, or reservoir planning. The demand for sediment transport data is not generally driven by specific climate conditions, but rather, governed by regional environmental questions.

**3.2.7.11. Data Reduction and Archival Protocols.** Historically, completed analyses have been published in biennial data reports, such as Allgire (1997). Beginning with the Water Year 2000 data, data reports were no longer published. Instead, the water year sample data were added to the total period-of-record sample data set for concentration and particle size for each sampling site. The period-of-record sample data sets for all current sites in the BSMP are disseminated on the ISWS Web site. These data include the date that samples were collected, the time of sample collection, the stream stage at the sampling time, the water temperature, the sediment concentration, the stream discharge corresponding to the stream stage taken from the station discharge rating table (furnished by USGS), and the instantaneous sediment load for the concentration data sets or the percent finer than 0.0625 mm for the particle size data sets.

**3.2.7.12. Data Quality Assessment Procedures.** Data collected for the BSMP undergo a series of steps to scrutinize the quality of the samples being reported. Every aspect of the network from the sample collection through the laboratory analysis is checked to verify information is not inadvertently altered along the path to full acceptance. The nature of the sampling process occasionally results in a sampling error in which a sample has too high or too low sediment concentration. Other unusual conditions often occur during the data collection that will yield a sample concentration that may appear unusual standing alone. However, when looked at in the context of the seasonal, or period of record data set, that data point may accurately represent the sediment transport under certain hydrologic conditions.

**3.2.7.13. Personnel Qualifications and Training.** BSMP staff work on two project areas. One project area consists of the field data collection. This entails installing and maintaining the sampling stations, locating and training the observers, supervising the regional observers, collecting the observer samples, and cross-section sampling.

The data collection/field staff requires some basic knowledge of fabrication with materials for the equipment and equipment installations. Equally important is staff that can interact with members of the community that act as observers for the program. Understanding, communicating with, and meeting the needs of the observers is a major task of the regional staff. However, the most important aspect of this position is a good understanding of hydrology and sediment transport. Evaluation of the sampling site conditions for cross-section sampling as well as overseeing the observers' sampling is a primary responsibility towards collecting quality data for the program.

The second staff aspect of the program is the data analyses that are conducted. This aspect focuses on detailed knowledge and understanding of hydrology and sediment transport. Staff expertise requires the ability to work with large data sets and be able to perform QC analyses on the program data. Additionally, assigned staff must have the ability to assess program needs and be able to communicate with city, county, state, and federal agency personnel to accomplish the goals of the project.

The minimum qualifications for a laboratory technician to perform suspended sediment analyses are an associate’s degree in chemistry or a related field and knowledge of laboratory techniques. Technicians need to have experience with spreadsheet software and an ability to work independently and communicate effectively.

Laboratory technicians are trained by similar technicians or laboratory managers to fully understand the filtration apparatus and are expected to maintain it in good working order. Technicians receive the SOP and are trained using all listed procedures. Technicians analyze several dozen blind samples and must meet the established precision and bias criteria stated in the SOP.

## Section 4.0. Terms and Definitions (From Source Document 1.2)

**Assessment** - the evaluation process used to measure the performance or effectiveness of a system and its elements. As used here, assessment is an all-inclusive term used to denote any of the following: audit, performance evaluation, management systems review, peer review, inspection, or surveillance.

**Data quality assessment** - a statistical and scientific evaluation of the data set to determine the validity and performance of the data collection design and statistical test, and to determine the adequacy of the data set for its intended use.

**Data quality objectives** - the qualitative and quantitative measures of data quality that are desired from a specific activity or program. Data quality objectives may include characteristics of bias, precision, completeness, and representativeness.

**Environmental data** - any measurements or information that describe environmental processes, location, or conditions; ecological or health effects and consequences; or the performance of environmental technology. Environmental data include information collected directly from measurements, produced from models, and compiled from other sources such as databases or the literature.

**Graded approach** - the process of basing the level of application of managerial controls applied to an item or work according to the intended use of the results and the degree of confidence needed in the quality of the results.

**Inspection** - examination or measurement of an item or activity to verify conformance to specific requirements.

**Management** - those individuals directly responsible and accountable for planning, implementing, and assessing work.

**Management system** - a structured, non-technical system describing the policies, objectives, principles, organizational authority, responsibilities, accountability, and implementation plan of an organization for conducting work and producing items and services.

**Metadata** - information that describes the content, quality, condition, or other characteristics of data that aid the user in determining the applicability of a data set for a specific application.

**Quality assurance** - an integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the client. Such management programs generally entail a formal mechanism for encouraging worker recommendations with timely management evaluation and feedback or implementation.

**Quality assurance plan** - a formal document describing in comprehensive detail the necessary QA, QC, and other technical activities that must be implemented to ensure that the results of the work performed will satisfy the stated performance criteria.

**Quality control** - the overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements established by the customer; operational techniques and activities that are used to fulfill requirements for quality.

**Quality management** - that aspect of the overall management system of the organization that determines and implements the quality policy. Quality management includes strategic planning, allocation of resources, and other systematic activities (e.g., planning, implementation, documentation, and assessment) pertaining to the quality system.

**Quality management plan** - a document that describes the quality system in terms of the organizational structure, functional responsibilities of management and staff, lines of authority, and required interfaces for those planning, implementing, and assessing all activities conducted.

**Record** - a completed document that provides objective evidence of an item or process. Records may include photographs, drawings, magnetic tape, and other data recording media.

**Specification** - a document stating requirements and which refers to or includes drawings or other relevant documents. Specifications should indicate the means and the criteria for determining conformance.

**Standard operating procedure** - a written document that details the method for an operation, analysis, or action with thoroughly prescribed techniques and steps, and that is officially approved as the method for performing certain routine or repetitive tasks.

**Water year** - the 12-month period running from October of a given year through the following September designated by the ending year.

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# Appendix I.

## Selection of Measurement Sites in the Illinois Solar Weather Program

The criteria developed during the site selection process are listed below in order of importance (Hendrie 1981).

“(1) The sites should provide a reasonably homogeneous spatial coverage of the State, although this is difficult with only 6 sites to be established in the first year of the project. Consequently, consideration was also given to probable site locations for the anticipated additional sites to be established during the second year. It was determined that data from the Argonne National Laboratory at Lemont would be compatible with the network data, and permission was obtained for us to receive it, hence giving a seventh site in the first year. It was also decided that no attempt should be made to monitor solar radiation within Chicago because, due to large local variations in cloudiness, atmospheric moisture and aerosol concentrations, it is likely to be highly variable. Rather this should be studied independently in a future project.

“(2) The pyranometers were to be mounted with their sensing surfaces positioned in a horizontal plane as is conventional in meteorological practice. Solar fluxes on surfaces of other orientation can be estimated from this data using appropriate empirical models. The instruments should be positioned at a height of at least 1 meter above the surface, but still be convenient for servicing.

“(3) The pyranometers should be located preferably in an open space in a relatively flat area and fairly unobstructed by buildings, trees and all other tall objects, particularly from the east through south to west. It is important that there be no shading of the sensor surface, and best if there is also little horizon obstruction. The limits imposed were that the top of any obstructions located from the east through south to west should have an angle of elevation from the sensor surface of less than 5° (2.5 meters above instrument at 30 meters distance), and that the location would be definitely unsuitable if the angle of elevation of any obstruction exceeded 10° (5 meters above instrument at 30 meters distance).

“(4) The site locations should be relatively accessible at all times of the year to facilitate Water Survey personnel in the initial installation of the delicate equipment, and in their routine visits for maintenance, calibration and checking of the instrumentation. However, the site should not be directly adjacent to high-use areas or traffic corridors where it may become subject to theft, vandalism and/or tampering.

“(5) It would be beneficial to have experienced and sympathetic personnel living and/or working near the site. This would greatly enhance the security of the instrumentation and provide an "on-site" observer who could notify Water Survey personnel promptly in the event of such abnormalities as equipment malfunction, damage or theft, thereby reducing periods of data loss.

“(6) It would be preferable to have a 115 V AC power source nearby to reduce distances through which cabling would have to be installed.

“(7) It was also considered preferable to locate these sites at places where the data could be utilized to assist with on-going operations or research.”

# Appendix II.

## Selection Criteria for New ICN Sites

### A. General Considerations (historic)

The following criteria serve as guidelines to aid in selecting new ICN sites for the WARM Program. These were adapted from Hendrie (1981) and Hollinger et al. (1994). The overall guideline structure is subjective, leaving room for discrimination at individual locations where regional site selection opportunities are limited. If multiple locations are considered for a prospective ICN monitoring site, guidelines may assist in selecting one site over another. More specific selection criteria follow in Section B of this appendix, classifying the data quality of monitored variables, and providing objective measures by which prospective sites can be accepted or rejected.

**1. Longevity and continuity of site.** Stations should have the potential for being located at the selected site for 50+ years with minimal expected development or modification of land use within the immediate area surrounding the station. Due to the lower frequency of ownership and use changes, rural and remote public property typically holds an advantage over private property and locations within urban or suburban settings.

**2. Spatial coverage across the state.** Station locations will be selected to collectively represent the entire state spatially. The addition of new stations should be placed in areas that reduce large gaps in the current ICN network. Spatial representation related to specific meteorological variables should be considered if station spacing is ever reduced substantially from the current ICN array of sites.

**3. Local terrain and regional surface and subsurface influences**. Stations should be selected in locations that have minimal topographic or surface cover variability in the surrounding region. The immediate area should possess a relatively flat terrain with similar vegetation in all directions. Documentation of surface roughness around stations during all seasons is required so that temporal and spatial comparisons of weather variables can be made as representative as possible. Potential sites shall not be unduly influenced by drainage or nearby surface water bodies. Distances to potential surface water influences should be noted. The site should not be subject to flooding. Proximity of operating wells (e.g., irrigation) and field tiles should be avoided.

**4. Obstructions**. All natural and man-made obstructions in the immediate area of a site must be at a minimum. Specific classifications of obstruction influences on all measured variables are defined in the next section. Locations of nearby features that could produce significant impacts on ambient climate elements, soil conditions, and water table elevations, unrepresentative of the general conditions in the broader region around the site, should be avoided. Man-made influences on site construction and impacts on all monitored variables shall be evaluated. Site documentation will include a map of the site drawn to scale, showing the location of all obstructions, noting their height, breadth, and distance from the tower. Site descriptions will be reviewed and revised as necessary when structures and semi-permanent vegetation in the area are added or removed. All sites should be at a safe distance from overhead utilities for well construction, tower erection purposes, avoidance of communication interferences, and staff safety. Underground utilities and obstructions will be identified prior to site selection.

5. **Readily accessible power and telecommunications**. Due to numerous cloudy days in winter, commercial power is a preference; however, solar power is a viable option. Cellular telephone service with Internet capabilities is preferred.

6. **Readily accessible servicing by staff.** Each site should be easy to access by field personnel for required monitoring and servicing. Each site should be accessible by a well-drilling rig.

7. **Minimal opportunity for vandalism.** All equipment and sensors should be protected from acts of vandalism and constructed so as not to be a hazard to site visitors or animals. Efforts should be taken to protect hosts and the Water Survey from liability concerns.

8. **Sympathetic personnel living/working near location.** It is desired that owners or local personnel responsible for the property on which a site is located should have a desire to use the weather data collected and/or possess an appreciation of its importance. In the most opportunistic sense, they should be willing to visually peruse the site in a simple manner and notify the ISWS of obvious problems with the station. Hopefully, they will be willing to perform light site servicing needs, such as emptying rain gauges, as well as maintaining site appearance. In certain agreements, they should be willing to provide resources such as funding to establish the site (not a requirement) and to cover the costs of power and local telecommunications.

## B. Specific Climate Variable Classifications

Site selection in Illinois is hampered by the fact that the best, most representative locations for atmospheric monitoring equipment within a region are generally unavailable. Flat terrain with unobstructed air flows in all direction usually are found only well inside the boundaries of agricultural fields. Thus, since sites must be located no closer than the edge of fields or in other open areas invariably closer to natural and man-made obstructions, objective criteria selected for acceptance or rejection of proposed site locations are problematic. In general, a classification scheme evaluating the potential to measure each meteorological variable sensor representatively, developed by the Climate Reference Network to observe temperature/relative humidity, precipitation, solar radiation, and wind speed, was taken from Leroy (1998). Criteria for additional ICN variables were developed using a similar structure.

Definitions for siting purposes:

Angular height - elevation (in degrees) of the top of obstacle from site location or instrument
Angular width - azimuthal width (in degrees) of obstacle from site location

**Classification for Temperature/Relative Humidity**

**Class 1 –** Flat and horizontal ground surrounded by a clear surface with a slope below 1/3 (<19º). Grass/low vegetation ground cover <10 centimeters high. Sensors located at least 100 meters from artificial heating or reflecting sources, such as buildings, concrete surfaces, and parking lots. Far from large bodies of water, except if it is representative of the area, and then located at least 100 meters away. No shading when the sun elevation is >3 degrees.

**Class 2 –** Same as Class 1 with the following differences. Surrounding vegetation <25 centimeters high. No artificial heating sources within 30 meters. No shading for a sun elevation of >5 degrees.

**Class 3** (error 1ºC) **–** Same as Class 2, except no artificial heating sources within 10 meters.

**Class 4** (error ≥2ºC) **–** Artificial heating sources <10 meters away.

**Class 5** (error ≥5ºC) **–** Temperature sensor located next to/above an artificial heating source, such as a building, roof top, parking lot, or concrete surface.

**Classification for Precipitation**

**Class 1 –** Flat, horizontal ground surrounded by a cleared surface with a slope below 1/3 (<19º). Any obstacle must be located at a distance of at least four times the height of the obstacle. An obstacle is an object seen from the precipitation gauge with an angular width of ≥10º.

**Class 2** (error 5%) **–** Same as Class 1, except an obstacle is located at a distance of at least 2 times its height.

**Class 3** (error 10% to 20%) **–** Ground with a slope ≥1/3 (≥19°) and below 1/2 (<30º). Any obstacle is located at a distance of at least its height.

**Class 4** (error >20%) **–** Ground with a slope > 1/2 (≥30º). Obstacles located at a distance less than their height.

**Class 5** (error > 50%) **–** Obstacles overhanging the gauge.

**Classification for Solar Radiation**

**Class 1 –** Flat, horizontal ground with a slope of the terrain <2º. No obstacles within 100 meters.

**Class 2** (error 10%) **–** Slope of the terrain ≥2° and <5º. Obstacles within 100 meters and an angular height of >7º but <10º.

**Class 3** (error 15%) **–** Slope of the terrain ≥5° and <7º. Obstacles within 100 meters and an angular height ≥10º.

**Class 4** (error 30%) **–** Same as Class 3 except no obstacles within 2.5 times the height of the obstacle (angular height ≥10° and <21.8º).

**Class 5** (error >40%) **–** Obstacles within 2.5 times the height of nearby obstacles.

**Class 6** (error >50%) **–** Obstacles with a height >10 meters, seen with an angular width greater than 60º, are within a 20-meter distance.

**Classification for Wind**

**Class 1 –** Sensor located at a distance of at least 10 times the height of an obstacle (angular height <5.7º). Object considered an obstacle if seen at angular width of >10º. Obstacle is below 5.5 meters in height within a 150-meter radius and 7 meters within a 300-meter radius. Wind sensor located a minimum distance of 15 times the width of thin nearby obstacles (i.e., mast, tree with angular width of <10º). Surrounding terrain relief change ≤5 meters within a 300-meter radius.

**Class 2** (error 10%) **–** Same as Class 1 except terrain change ≤5 meters within a 100-meter radius.
**Class 3** (error 20%) **–** Same as Class 1 except no obstacles within five times the height of the nearby obstacles (angular height <11.3º). Wind sensor located a minimum distance of 10 times the width of thin nearby obstacles. Terrain change of ≤1m within a 10-meter radius.
**Class 4** (error 30%) **–** Same as Class 3 except no obstacles within 2.5 times the height of the nearby obstacles (angular height <21.8º).
**Class 5** (error >40%) **–** Obstacles within 2.5 times the height of the nearby obstacles.
**Class 6** (error >50%) **–** Obstacles with a height of >10 meters, seen with an angular width greater than 60º are within a 20-meter distance.

**Classification for Pressure**
No restrictions.

**Classification for Soil Temperature**
**Class 1 –** Flat and horizontal ground surrounded by a clear surface with a slope below 1/3 (<19º). Grass/low vegetation ground cover <10 centimeters high. Sensors located at least 10 meters from artificial heating surfaces, such as buildings, concrete surfaces, and parking lots. No shading when the sun elevation is >3 degrees.
**Class 2 –** Same as Class 1 with the following differences. Surrounding vegetation <25 centimeters high. No shading for a sun elevation >5 degrees.
**Class 3** (error 1ºC) **–** Same as Class 2, except no artificial heating sources within 5 meters.

**Classification for Soil Moisture**
**Class 1 –** Flat and horizontal ground surrounded by a clear surface with a slope below 1/3 (<19º). Grass/low vegetation ground cover <10 centimeters high. No surface ponding or obvious drainage of rainfall towards sensor location. No nearby obstructions, including precipitation gauge and instrument tower, to cause heavy drifting of snow over immediate area of sensors.
**Class 2 –** Same as Class 1 with the following difference. Surrounding vegetation <25 centimeters high.
**Class 3 –** Same as Class 1 with the following difference. Surrounding vegetation ≥25 centimeters high.

***Addendum***
**Categories of Shallow Groundwater (Water Table Level) Observations**
For purposes of WARM data description (i.e., metadata), wells can be placed in one of the four following categories so a data-user has an understanding of the appropriateness of the data. Wells have not been sorted into "classes" in the manner used for ICN climate data because those classifications denote some loss in acceptability (accuracy) of the data due to the location of sensors relative to obstructions, terrain, etc., whereas all groundwater level data should be accurate to within ± 0.01 foot. In addition, a site determined as a poor location for a shallow groundwater well will likely never disqualify a site if all other criteria (especially those concerning exposure) are acceptable.

**Category 1 –** Shallow water table is remote from pumping centers (may not necessarily be in an "aquifer").

**Category 2 –** Shallow water table aquifer likely is influenced by pumping centers.
**Category 3 –** Confined local/regional aquifer is under natural conditions.
**Category 4 –** Confined local/regional aquifer likely is influenced by pumping centers.

## Appendix III.

## Example of Tracking Inventory for Instruments and Equipment at ICN Sites

Items are tracked by site location, serial numbers, property tag numbers, and installation dates.

| *Device* | *Location* | *Serial #* | *IDNR tag #* | *ISWS tag #* | *Installation or last calibration date* |
|---|---|---|---|---|---|
| Anemometer | Bondville | 15075 | E22065 | ----------- | 07/09/98 |
| Barometer | Bondville | 1004 | ----------- | | |
| data logger | Bondville | 5819 | W00414 | 9726 | 11/04/96 |
| heat flux plate | Bondville | H983322 | 419852 | ----------- | 04/12/99 |
| Multiplexer | Bondville | 5454 | ----------- | ----------- | 11/04/96 |
| multiplexer (soil moisture) | Bondville | 2440 | E20971 | 10746 | 07/20/98 |
| phone modem | Bondville | 1547 | ----------- | ----------- | 08/16/99 |
| Pyranometer | Bondville | 26756 | W00423 | 9737 | 08/26/96 |
| radiation shield | Bondville | ----------- | W00582 | ----------- | |
| precipitation gauge | Bondville | | ----------- | 5060 | 05/04/95 |
| RF modem | Bondville | 2129 | W00325 | 11659 | 03/24/00 |
| soil moisture (5 cm) | Bondville | 1022 | ----------- | ----------- | 07/20/98 |
| soil moisture (10 cm) | Bondville | 1021 | ----------- | ----------- | 07/20/98 |
| soil moisture (20 cm) | Bondville | 1019 | ----------- | ----------- | 07/20/98 |
| soil moisture (50 cm) | Bondville | 1020 | ----------- | ----------- | 07/20/98 |
| soil moisture (100 cm) | Bondville | 1018 | ----------- | ----------- | 07/20/98 |
| soil moisture (150 cm) | Bondville | 1023 | ----------- | ----------- | 07/20/98 |
| soil temperature (4 inch) | Bondville | | ----------- | ----------- | |
| soil temperature (8 inch) | Bondville | | ----------- | ----------- | |
| soil temperature (profiler) | Bondville | ----------- | ----------- | ----------- | |
| temperature/rel. humidity | Bondville | 65003 | ----------- | ----------- | 08/18/99 |

## Appendix IV.

## Example of Hourly and Daily Weather Elements Downloaded from ICN Sites

# ICN Hourly Weather Elements
# BONDVILLE - BVL - 1

| *FIELD* | *DESCRIPTION* | *IDENTIFICATION* | *UNITS* |
|---|---|---|---|
| 1 | STATION ID NUMBER | HSTNID | NA |
| 2 | YEAR | HYEAR | YYYY |
| 3 | DAY OF YEAR | HDOY | DDD |
| 4 | HOUR OF DAY (CST) | TIME | HHMM |
| 5 | MEAN WIND SPEED AT 10 M | WS10 | MPH |
| 6 | MEAN WIND VECTOR MAGNITUDE AT 10 M | WVM10 | MPH |
| 7 | MEAN WIND VECTOR DIRECTION AT 10 M | WVD10 | DEGREES |
| 8 | STD. DEV. OF MEAN WIND VECTOR DIRECTION AT 10 M | WVD10SD | DEGREES |
| 9 | STD. DEV. OF WIND SPEED AT 10 M | WS10SD | MPH |
| 10 | SOLAR RADIATION AT 2 M | SR | KWATTS $M^{-2}$ |
| 11 | STD. DEV. OF SOLAR RADIATION AT 2 M | SRSD | KWATTS $M^{-2}$ |
| 12 | AIR TEMPERATURE AT 2 M | AT02 | DEGREES C |
| 13 | STD. DEV. OF AIR TEMPERATURE AT 2 M | AT02SD | DEGREES C |
| 14 | RELATIVE HUMIDITY AT 2 M | RH02 | PERCENT |
| 15 | STD. DEV. OF RELATIVE HUMIDITY AT 2 M | RH02SD | PERCENT |
| 16 | PRECIPITATION SAMPLE ON THE HOUR AT GAUGE 1 | PC1 | INCHES |
| 17 | STD. DEV. OF PRECIPITATION SAMPLE AT GAUGE 1 | PC1SD | INCHES |
| 18 | SOIL TEMPERATURE AT 4 INCHES | ST4 | DEGREES C |
| 19 | SOIL TEMPERATURE AT 8 INCHES | ST8 | DEGREES C |
| 20 | STD. DEV. OF SOIL TEMPERATURE AT 4 INCHES | ST4SD | DEGREES C |
| 21 | STD. DEV. OF SOIL TEMPERATURE AT 8 INCHES | ST8SD | DEGREES C |
| 22 | BAROMETRIC PRESSURE | BP | MB |
| 23 | STD. DEV. OF BAROMETRIC PRESSURE | BPSD | MB |
| 24 | MAXIMUM (HOURLY) BAROMETRIC PRESSURE | XBP | MB |
| 25 | TIME OF MAXIMUM (HOURLY) BAROMETRIC PRESSURE | TXBP | HHMM |
| 26 | MINIMUM (HOURLY) BAROMETRIC PRESSURE | NBP | MB |
| 27 | TIME OF MINIMUM (HOURLY) BAROMETRIC PRESSURE | TNBP | HHMM |
| 28 | WELL LEVEL DEPTH | WLD | FEET |
| 29 | STD. DEV. OF WELL LEVEL DEPTH | WLDSD | FEET |
| 30 | SOIL TEMPERATURE AT 0 CM | ST000 | DEGREES C |
| 31 | SOIL TEMPERATURE AT 5 CM | ST005 | DEGREES C |
| 32 | SOIL TEMPERATURE AT 10 CM | ST010 | DEGREES C |
| 33 | SOIL TEMPERATURE AT 20 CM | ST020 | DEGREES C |
| 34 | SOIL TEMPERATURE AT 30 CM | ST030 | DEGREES C |
| 35 | SOIL TEMPERATURE AT 40 CM | ST040 | DEGREES C |
| 36 | SOIL TEMPERATURE AT 50 CM | ST050 | DEGREES C |
| 37 | SOIL TEMPERATURE AT 60 CM | ST060 | DEGREES C |
| 38 | SOIL TEMPERATURE AT 70 CM | ST070 | DEGREES C |
| 39 | SOIL TEMPERATURE AT 80 CM | ST080 | DEGREES C |
| 40 | SOIL TEMPERATURE AT 90 CM | ST090 | DEGREES C |
| 41 | SOIL TEMPERATURE AT 100 CM | ST100 | DEGREES C |
| 42 | SOIL MOISTURE AT 5 CM | SM0051 | VOLTS |
| 43 | SOIL MOISTURE AT 5 CM | SM0052 | VOLTS |

## ICN Hourly Weather Elements
# BONDVILLE - BVL - 1

| *FIELD* | *DESCRIPTION* | *IDENTIFICATION* | *UNITS* |
|---|---|---|---|
| 44 | SOIL MOISTURE AT 5 CM | SM0053 | VOLTS |
| 45 | SOIL MOISTURE AT 5 CM | SM0054 | VOLTS |
| 46 | SOIL MOISTURE AT 10 CM | SM0101 | VOLTS |
| 47 | SOIL MOISTURE AT 10 CM | SM0102 | VOLTS |
| 48 | SOIL MOISTURE AT 10 CM | SM0103 | VOLTS |
| 49 | SOIL MOISTURE AT 10 CM | SM0104 | VOLTS |
| 50 | SOIL MOISTURE AT 20 CM | SM0201 | VOLTS |
| 51 | SOIL MOISTURE AT 20 CM | SM0202 | VOLTS |
| 52 | SOIL MOISTURE AT 20 CM | SM0203 | VOLTS |
| 53 | SOIL MOISTURE AT 20 CM | SM0204 | VOLTS |
| 54 | SOIL MOISTURE AT 50 CM | SM0501 | VOLTS |
| 55 | SOIL MOISTURE AT 50 CM | SM0502 | VOLTS |
| 56 | SOIL MOISTURE AT 50 CM | SM0503 | VOLTS |
| 57 | SOIL MOISTURE AT 50 CM | SM0504 | VOLTS |
| 58 | SOIL MOISTURE AT 100 CM | SM1001 | VOLTS |
| 59 | SOIL MOISTURE AT 100 CM | SM1002 | VOLTS |
| 60 | SOIL MOISTURE AT 100 CM | SM1003 | VOLTS |
| 61 | SOIL MOISTURE AT 100 CM | SM1004 | VOLTS |
| 62 | SOIL MOISTURE AT 150 CM | SM1501 | VOLTS |
| 63 | SOIL MOISTURE AT 150 CM | SM1502 | VOLTS |
| 64 | SOIL MOISTURE AT 150 CM | SM1503 | VOLTS |
| 65 | SOIL MOISTURE AT 150 CM | SM1504 | VOLTS |
| 66 | MAXIMUM HOURLY WIND SPEED AT 10 M | HXWS10 | MPH |
| 67 | TIME OF MAXIMUM HOURLY WIND SPEED AT 10 M | THXWS10 | HHMM |
| 68 | DIRECTION OF MAXIMUM HOURLY WIND SPEED AT 10 M | DHXWS10 | DEGREES |
| 69 | MAXIMUM HOURLY AIR TEMPERATURE AT 2 M | HXAT2 | DEGREES C |
| 70 | TIME OF MAXIMUM HOURLY AIR TEMPERATURE AT 2 M | THXAT2 | HHMM |
| 71 | MINIMUM HOURLY AIR TEMPERATURE AT 2 M | HNAT2 | DEGREES C |
| 72 | TIME OF MINIMUM HOURLY AIR TEMPERATURE AT 2 M | THNAT2 | HHMM |
| 73 | MAXIMUM HOURLY RELATIVE HUMIDITY AT 2 M | HXRH2 | PERCENT |
| 74 | TIME OF MAXIMUM HOURLY RELATIVE HUMIDITY AT 2 M | THXRH2 | HHMM |
| 75 | MINIMUM HOURLY RELATIVE HUMIDITY AT 2 M | HNRH2 | PERCENT |
| 76 | TIME OF MINIMUM HOURLY RELATIVE HUMIDITY AT 2 M | THNRH2 | HHMM |
| 77 | BARE SOIL TEMPERATURE AT 4 INCHES | BST4 | DEGREES C |
| 78 | STD. DEV. OF BARE SOIL TEMPERATURE AT 4 INCHES | BST4SD | DEGREES C |
| 79 | PROM SIGNATURE | PROM | NA |
| 80 | SOIL HEAT FLUX PLATE | SHFP | VOLTS |
| 81 | PRECIPITATION SAMPLE ON THE HOUR AT GAUGE 2 | | INCHES |
| 82 | STD. DEV. OF PRECIPITATION SAMPLE AT GAUGE 2 | | INCHES |
| 83 | TEST SPACE | | |
| 84 | TEST SPACE | | |
| 85 | RAINGAUGE STATUS | | CODE |

# ICN Daily weather elements
# Bondville - BVL - 1

| *Field* | *Description* | *Identification* | *Units* |
|---|---|---|---|
| 1 | Station ID Number | DSTNID | NA |
| 2 | Year | DYEAR | YYYY |
| 3 | Day of Year | DDOY | DDD |
| 4 | Maximum Wind Speed at 10 m | XWS10 | MPH |
| 5 | Time of Maximum Wind Speed at 10 m | TXWS10 | HHMM |
| 6 | Direction of Maximum Wind Speed at 10 m | DXWS10 | DEGREES |
| 7 | Maximum Air Temperature at 2 m | XAT02 | DEGREES C |
| 8 | Time of Maximum Air Temperature at 2 m | TXAT02 | HHMM |
| 9 | Minimum Air Temperature at 2 m | NAT02 | DEGREES C |
| 10 | Time of Minimum Air Temperature at 2 m | TNAT02 | HHMM |
| 11 | Maximum Relative Humidity at 2 m | XRH02 | PERCENT |
| 12 | Time of Maximum Relative Humidity at 2 m | TXRH02 | HHMM |
| 13 | Minimum Relative Humidity at 2 m | NRH02 | PERCENT |
| 14 | Time of Minimum Relative Humidity at 2 m | TNRH02 | HHMM |
| 15 | Total Precipitation at Gauge 1 | TPC1 | INCHES |
| 16 | Maximum Soil Temperature at 4 inches | XST4 | DEGREES C |
| 17 | Time of Maximum Soil Temperature at 4 inches | TXST4 | HHMM |
| 18 | Maximum Soil Temperature at 8 inches | XST8 | DEGREES C |
| 19 | Time of Maximum Soil Temperature at 8 inches | TXST8 | HHMM |
| 20 | Minimum Soil Temperature at 4 inches | NST4 | DEGREES C |
| 21 | Time of Minimum Soil Temperature at 4 inches | TNST4 | HHMM |
| 22 | Minimum Soil Temperature at 8 inches | NST8 | DEGREES C |
| 23 | Time of Minimum Soil Temperature at 8 inches | TNST8 | HHMM |
| 24 | Maximum Soil Temperature at 0 centimeters | XST000 | DEGREES C |
| 25 | Time of Maximum Soil Temperature at 0 centimeters | TXST000 | HHMM |
| 26 | Maximum Soil Temperature at 5 centimeters | XST005 | DEGREES C |
| 27 | Time of Maximum Soil Temperature at 5 centimeters | TXST005 | HHMM |
| 28 | Maximum Soil Temperature at 10 centimeters | XST010 | DEGREES C |
| 29 | Time of Maximum Soil Temperature at 10 centimeters | TXST010 | HHMM |
| 30 | Maximum Soil Temperature at 20 centimeters | XST020 | DEGREES C |
| 31 | Time of Maximum Soil Temperature at 20 centimeters | TXST020 | HHMM |
| 32 | Minimum Soil Temperature at 0 centimeters | NST000 | DEGREES C |
| 33 | Time of Minimum Soil Temperature at 0 centimeters | TNST000 | HHMM |
| 34 | Minimum Soil Temperature at 5 centimeters | NST005 | DEGREES C |
| 35 | Time of Minimum Soil Temperature at 5 centimeters | TNST005 | HHMM |
| 36 | Minimum Soil Temperature at 10 centimeters | NST010 | DEGREES C |
| 37 | Time of Minimum Soil Temperature at 10 centimeters | TNST010 | HHMM |
| 38 | Minimum Soil Temperature at 20 centimeters | NST020 | DEGREES C |
| 39 | Time of Minimum Soil Temperature at 20 centimeters | TNST020 | HHMM |
| 40 | Maximum Panel Temperature | XPT | DEGREES C |
| 41 | Time of Maximum Panel Temperature | TXPT | HHMM |
| 42 | Minimum Panel Temperature | NPT | DEGREES C |
| 43 | Time of Minimum Panel Temperature | TNPT | HHMM |
| 44 | Maximum Battery Voltage | XBV | VOLTS |
| 45 | Time of Maximum Battery Voltage | TXBV | HHMM |
| 46 | Minimum Battery Voltage | NBV | VOLTS |
| 47 | Time of Minimum Battery Voltage | TNBV | HHMM |
| 48 | Maximum Bare Soil Temperature at 4 inches | XBST4 | DEGREES C |
| 49 | Time of Maximum Soil Temperature at 4 inches | TXBST4 | HHMM |
| 50 | Minimum Bare Soil Temperature at 4 inches | NBST4 | DEGREES C |

# ICN DAILY WEATHER ELEMENTS
# BONDVILLE - BVL - 1

| *FIELD* | *DESCRIPTION* | *IDENTIFICATION* | *UNITS* |
|---|---|---|---|
| 51 | TIME OF MINIMUM BARE SOIL TEMPERATURE AT 4 INCHES | TNBST4 | HHMM |
| 52 | FLUID IN PRECIPITATION GAUGE 1 | | INCHES |

## Appendix V.

## Procedures and File Locations for WARM Electronic Data

### A. Daily Automated Illinois Climate Network Data Operations

All data downloading, QC, and archival activities are performed by the reading and writing of ASCII data files, conducted on ISWS domain computers, **warm** and **warmer**, under the direction of the WARM Program Manager.

Data are transferred and arranged onto these various computers into easily recognizable names appropriate for each site. Currently (May 2010), beginning just after the start of each hour at six sites and just after midnight CST each day at 13 sites, new data are transferred from ICN field site data loggers via Internet or telephone modems to **warm** (a computer which remains on CST year round) using LoggerNet (version 3.4.1) download software from Campbell Scientific, manufacturer of the ICN data loggers.

The new data are stored on **warm** in the directory *c:\Campbellsci\LoggerNet* under the file names SiteName_Daily.dat and SiteName_Hourly.dat. SiteName is a varying-length name for each site shown in the table below. These files are termed the "raw" data files and include those variables displayed in the hourly and daily listings of Appendix II, now sorted into 19 site files of daily data and 19 site files of hourly data.

**Various computer names for ICN sites**

| *Site* | *3-letter ID* | *Prefix to computer file names "Daily.dat" and "Hourly.dat"* | *Site* | *3-letter ID* | *Prefix to computer file names "Daily.dat" and "Hourly.dat"* |
|---|---|---|---|---|---|
| Belleville | frm | Belleville_ | Kilbourne | sfm | Kilbourne_ |
| Big Bend | bbc | Big_Bend_ | Monmouth | mon | Monmouth_ |
| Bondville | bvl | Bondville_ | Olney | oln | Olney_ |
| Brownstown | brw | Brownstown_ | Orr (Perry) | orr | Orr_ |
| Carbondale | siu | Carbondale_ | Peoria | icc | Peoria_ |
| Champaign | cmi | Champaign_ | Rend Lake (Ina) | rnd | Rend_Lake_ |
| DeKalb | dek | DeKalb_ | St. Charles | stc | St_Charles_ |
| Dixon Springs | dxs | Dixon_Springs_ | Springfield | llc | Springfield_ |
| Fairfield | fai | Fairfield_ | Stelle | ste | Stelle_ |
| Freeport | fre | Freeport_ | | | |

These data are not modified during the transfer and include all properly stored information recorded by on-board site data loggers since the last successful download was completed, usually the prior hour (from sites with Internet or local telephones) or the prior day (from stations requiring long-distance telephone calls).

At 0230 (clock time) each day, data manipulation begins on **warmer** by activation of a series of MS-DOS batch routine scripts beginning with *d:\arcc\awdn\bldWarm.bat*. The process transfers and converts all daily and hourly ICN data files from **warm** and renames them into appropriate data files on **warmer** with the names *dat_xxx.dy and dat_xxx.hr*, in which xxx is a three-letter identification code for each site listed in the prior table.

The following scripts and procedures are operated daily by script *bldWarm*.

1. Script *d:\arcc\awdn\bldDail2.bat* is run. This script does the following:
   a. Sets *d:\arcc\autoicn* as the initial work directory for ICN data on **warmer**.
   b. Transfers and appends all site data files from the previous running of "*bldDail2*" (usually the day before) to similarly named files in directory *d:\arcc\icncheck\tmp*. This is performed by running script *d:\arcc\autoicn\striphead.bat*, which runs the program *d:\arcc\brendan files\striphead p*.
   c. Copies all new data files (from **warm**) to *d:\arcc\autoicn* and converts file names to the aforementioned file names: *dat_xxx.dy and dat_xxx.hr*.
   d. Transfers and appends original raw data files on **warm** in directory *c:\Campbellsci\LoggerNet* to data files in directory *c:\Campbellsci\LoggerNet\archive* with file names *xxx_dy_archive.dat* and *xxx_hr_archive.dat*, as appropriate.
2. Script *d:\arcc\awdn\getPrecip.bat* is run. This script:
   a. Runs programs *d:\arcc\brendan files\getPrecip daily* and *d:\arcc\brendan files\getPrecip hourly*, which generate e-mails sent to the WARM Program Manager and the WARM technician alerting them of current gauge totals in the Belfort and Pluvio2 rain gauges. This is primarily for the Belfort gauges to alert staff when these smaller 12-inch maximum capacity gauges need to be emptied.
3. Script *d:\arcc\awdn\makePest.bat* is run. This script:
   a. Runs program *d:\arcc\brendan files\QualCon*, which is the primary data management/data processing program for the ICN data. This program checks data for potential inaccuracies and malfunctioning sensors through basic data analyses. Subsequent to this process, data are appended to archives on the SQL *Datastorm* with a database name of *WARM*.
   b. Runs program *d:\arcc\brendan files\PestProj*. This program takes the updated current year's temperature data on *Datastorm* from every site and performs an analysis for specific, pre-loaded pest degree days and for crop degree days, creating daily degree day text tables, then places them on *\\h2odrop\warmpestdata$\text* for display on the WARM Web pages. (See the ISWS webmaster for assistance.)
   c. Runs program *scripter* with *d:/iwcs/icn/pestmapper.BAS* and again with *d:/iwcs/icn/cropmaps.BAS* to generate maps of current respective degree day totals. *Scripter* is located on *c:\Program Files\Golden Software\SURFER8\scripter*. New maps are placed on the WARM Web pages in the Pest Degree Day and Crop Degree Day areas.
4. Script *d:\arcc\awdn\newMaps.bat* is run. This script:
   a. Copies existing last six weather and soil temperature data tables on the WARM Web pages to the previous day's location on *\\H2odrop\wwwsoiltemp$*.
   b. Runs *d:\arcC\Brendan Files\WarmMap* on the newly stored (yesterday's) data.
   c. Copies new tables to *\\H2odrop\wwwsoiltemp$\text*.

d. Runs program *scripter* with *d:/iwcs/icn/dailyrun/dailytest.bas* to generate maps of current respective weather and soil temperature data. New maps are placed on the WARM Web pages in the Weather Data and Soil Temperature areas.

5. Data streams are generated and placed on the WARM Web pages for specific users. (Contact the ISWS webmaster for details.)

**B. Archival Operations for Other Processed Illinois Climate Network Data**

Besides the archival of raw ICN data on **warm** and processed ICN data on *Datastorm\WARM*, a final set of archived data is performed. One last batch routine is activated on **warmer**, d:\arcc\autoicn\doqc. This process operates on the *d:\arcc\autoicn\dat_hr*.xxx and *d:\arcc\autoicn\dat_dy*.xxx data files created in item 1.c. The following procedures are performed:

The program *d:\arcc\autoicn\mysplit* is run on all sites and creates hourly and daily files of selected data to strip off all header lines. Then files are appended to the appropriate data files *d:\arcc\icncheck\dat_hr.xxx* and *d:\arcc\icncheck\dat_dy.xxx*, respectively. At this point, all *d:\arcc\autoicn\dat_hr.xxx* and *d:\arcc\autoicn\dat_dy.xxx* files are deleted, readying that space for the next day's data download.

**C. Illinois Soil Moisture Network Data Archives**

All historic neutron probe data are archived on **warmer** in file *d:\FromC\PRIVATE\NP_SM_Illinois.txt*. Data from the Stevens-Vitel sensors are processed and stored on SQL *Datastorm\WARM* within the regular ICN data stream.

**D. Groundwater Data Archives**

See section 3.2.4.12

**E. Stream and River Stream Flow Archives**

See section 3.2.5.12. No data are maintained at ISWS because the data originate with USGS or USACE.

**F. Monthly Water Reservoir Compilations**

See section 3.2.6.12.

**G. Benchmark Sediment Archives**

See section 3.2.7.12

## Appendix VI.

## Electronic Work Order Form for ICN Repairs

Date: [ ] Order Number: [ ]

Station Requiring Service: [ ]

Items in question:

☐ Wind Speed ☐ Wind Direction ☐ Air Pressure ☐ Temperature/Relative Humidity
☐ Well ☐ Solar Radiation ☐ Rainfall [ ] " Soil Temperature ☐ Data logger ☐ Profiler
☐ Communications [ ] " Soil Moisture Other: [ ]

Description of Problem/Request:

[ ]

Order Submitted by: Robert W. Scott Send Order To: pfnelson@illino

OLD SENSOR SERIAL #: ________ NEW SENSOR SERIAL #: ________ PROPERTY TAG #: __________

OLD SENSOR SERIAL #: ________ NEW SENSOR SERIAL #: ________ PROPERTY TAG #: __________

OLD SENSOR SERIAL #: ________ NEW SENSOR SERIAL #: ________ PROPERTY TAG #: __________

ORDER COMPLETED BY (SIGNATURE): ______________________ DATE:___/___/

ICN COORD. SIGNOFF (SIGNATURE): ______________________ DATE:___/___/

# Appendix VII.

## Information from Section 3.2.3 on Decommissioned Neutron Probe Technology

This appendix provides information and procedures on the neutron probe data used to collect soil moisture data from 1981 to 2008 at ISMN sites across Illinois. In 2008, all neutron probe equipment was retired and stored within the Division of Research Safety at the U of I. The equipment is stored and not decommissioned in the event that the ISWS again sees a need for its use. Continued storage in that location will be reviewed on a five-year interval.

### 3.2.3.5. Instrumentation (description and performance attributes)

Instrumentation used in the measurement of soil moisture via neutron probes was manufactured by Troxler Electronics Laboratories. The full set of items included a model 3221 Troxler Neutron Depth Probe and a model 3411B Troxler Neutron Surface Probe (Troxler Electronics Laboratories, Research Triangle Park, North Carolina 1980), a 2-meter-long aluminum tube buried vertically in the ground, a film badge, and a radiation monitor. Due to the hazards involved with transporting radioactive elements, travel documents were required, describing the handling of these devices in the event of a driving accident, including operating procedures and leak test certificates provided by the radiation safety office at the U of I.

The Water Survey operated three sets of these instruments. Two sets were housed in Building 10 of the Water Survey Resource Center in Champaign, Illinois, and were available for use by the field technician responsible for observations taken across northern Illinois. One set was housed by the Water Survey's Southern Regional Offices in Carbondale, Illinois, and was available for use by the field technician taking soil moisture measurements across southern Illinois.

Neutron probes were used to measure water content in soils through the emission of high-energy neutrons from a radiation source lowered by the field technician into an aluminum tube buried into the ground for access to soils surrounding the tube. During this process, the emitted neutrons move into the ambient soil environment, colliding numerous times with various soil particles. When they collide with atoms of approximately their same size, they lose energy and tend to slow and reflect back in the opposite direction. At this point, they are available to be detected and counted by a second sensor in the access tube that tracks low-energy neutrons.

Individual neutrons have masses that are similar to that of hydrogen atoms, such that a hydrogen atom is an efficient element for reflecting and slowing neutrons. Although both water and organic matter in soils contain hydrogen, natural changes in organic matter occur over a period of many years, whereas hydrogen locked up into water molecules varies constantly due to the movement of water in the soil. Thus, there is usually a strong linear relationship between variations in soil water content and reflected neutron counts.

By manufacturer estimates, each data level measures a spherical soil volume within a radius of 10 to 15 cm, a volume of approximately 4,200 to 14,100 $cm^3$, with the variability in radius dependent on water content in the soil. Specifically, measurements involved obtaining a neutron count ratio. This is the number of slow neutrons reflected back to the counter from the soil, ostensibly by hydrogen molecules, divided by the number of slow neutrons reflected back to the counter from a dense plastic block within the sensor that serves as a calibration standard. Due to the high variability between sites from differences in organic matter and soil pH, the neutron probe was calibrated to gravimetric measurements of soil moisture at each site. This extensive procedure was performed and reported by Hollinger and Isard (1994).

#### 3.2.3.6. Calibration procedures and calibration verification

There were no direct instrument calibration procedures to be performed on neutron probes. At times, due to instrument failure, probes were sent back to the manufacturer for repair. Return documents usually indicated that a manufacturer calibration was performed as a matter of course.

As a check on proper mechanical operations, the ISMN technician noted when the depth standard from the depth probe and/or the surface standard from the surface probe varied outside a typical range for each instrument. Both of these observations were taken using a manufacturer-supplied block of plastic specific to the actual instrument being used. Some variability in output occurred with these readings due to the weather conditions present during the actual field observation. When a standard was outside a typical range for a specific probe, as judged by the field technician, the probe was removed from service and returned to the manufacturer for maintenance.

#### 3.2.3.7. Data quality objectives

Due to the nature of the historic manual soil moisture observations, the tasks of maintaining instrument quality, care in taking observations, and attention to detail during data reduction were essential actions to assure the highest data quality possible from the neutron probe observation platform. The only method used to maintain high quality with the non-repairable, non-calibration checked, continuous sensors was identifying unreasonable data output. In addition, the representativeness of quality data was impacted by factors, including the timing of observations in relationship to recent precipitation events (specifically with neutron probe observations taken 19 times a year on runs of 2 to 3 days each), the high variability of soil moisture over short distances below 1 meter of depth, soil properties including porosity and bulk density, and the existence of underlying impervious strata at soil moisture sites as found by Scott et al. (2010).

In reality, soil moisture observations likely represented only a small area near the site location (Scott et al. 2010). For that reason, ISMN historic (neutron probe) data are best used related to: (1) the observed moisture related to developed normal moisture levels for the time of year at each station and level, and (2) the local change in moisture levels since the previous observation.

#### 3.2.3.8. Sampling schedule and procedures

Soil moisture observations with neutron probes were made during site visits. These were undertaken twice a month in the growing season (March through September) and monthly during the fallow season (October through February). The day before each observation run, batteries used to power the Troxler depth and surface probes were charged.

At each observation site, the neutron surface probe was placed on a polyethylene reference standard (a heavy plastic block) and positioned parallel to the surface. From this orientation, neutrons were emitted and counts were taken of low-energy neutron reflections from within the plastic to obtain a surface standard. Then, the surface probe was placed directly on the turf and also in an adjacent tilled field (if nearby) where observations were made of the moisture content from within the top 10 to 15 cm of soil in both locations. Three sites, Champaign, Mason Tree Farm, and Freeport, had no nearby tilled fields.

Next, the neutron depth probe was placed on the top end of the aluminum ground tube so that the probe could be lowered into the tube without restriction. Measurements began by obtaining a depth standard with the probe initially contained fully within the base of the device. The base contains a polyethylene reference standard from which reflected neutrons were counted. Then, measurements of reflected neutrons from soil moisture were taken below the surface. With the probe fully extended into the tube, an initial reading was taken at 200 cm from the surface. The probe then was drawn upward at 20-cm intervals to obtain layered information progressively from 180 cm to 20 cm of depth for a total of 11 readings from the surface to 2 m (including the surface probe reading). When measurements were complete, a rubber stopper was placed on the top of the tube to keep the interior tube clean and dry between visits. Over time (since 1981), water occasionally intruded into the base of the tubes seasonally as the local water table rose. The general procedure was to siphon the water out prior to data collection.

All measurements from the neutron probe were recorded on a soil moisture form (shown at the end of this appendix), which was then provided to the ISMN data analyst for data entry. The form documented the data collected, plus other pertinent site information at the time of observation (the weather type; the ground condition at the time: wet, dry, etc.; the crop type and observed moisture condition in the neighboring field, if crops were present), as well as the serial numbers of the probes used. Each probe had known characteristics, which were available in the analyses program of the data and were specifically applicable to the reduced data at each observation.

During these site visits, other minor manual tasks applicable to other WARM network activities were performed, e.g., checking the pyranometer globe for cleanliness, emptying and/or recharging the rain gauge with antifreeze (if needed), taking a manual water table reading from the shallow water well, etc. This additional information was included on the soil moisture forms.

#### 3.2.3.9. Written standard operating procedures

A hard copy of step-by-step operational procedures of neutron probe observations, as well as manufacturer-supplied manuals on the equipment used (provided by Troxler), are housed in the offices of the ISMN technician and WARM Program Manager. Documents of procedures and the required handling of the radioactive materials in the equipment in the event of accidents also reside in the above locations, and during the years of neutron probe operations, within the WARM service vehicle transporting the instruments.

#### 3.2.3.10. Quality control practices

Quality control procedures for neutron probe observations included meticulous attention given to data collection and entry procedures. Data entry errors usually became apparent during data reduction or a review of computed and mapped data summaries. Errors more subtle in nature were more difficult to identify since entire regions of the state are observed on each data collection with usually the same sensors at each site, often encountering sites with recent heavy rainfall or none at all for many days.

#### 3.2.3.11. Data reduction and archival protocols

Raw data neutron probe logging sheets from the manual soil moisture observations covering northern Illinois locations were submitted directly to the ISMN office for data entry. Those collected from ISWS's Carbondale office in southern Illinois were faxed in a timely fashion to the ISMN office, and then mailed to the office as well.

As of the date of publication of this document, all analyses and computer software for neutron probe analyses are located on the ISWS computer: **warm3**. Data were entered into a pre-programmed *Paradox for Windows, version 5,* software, which structured entered data into appropriate files for subsequent analyses and archives. The software output a hard copy station report for each site's observations, as well as creating input files for further computational analyses performed in *QuattroPro for Windows, version 5,* and for map construction using *Surfer 8* software. Outputs from the latter software included a table for the *Illinois Soil Moisture Summary* report showing the change in soil moisture over the prior month within three layers of soil (0 to 6 inches of depth, 6 to 20 inches, and 20 to 40 inches). It also includes analyzed maps showing the current month's moisture level within four soil layers (the aforementioned levels plus 40 to 72 inches of depth) as a percentage difference from normal (currently based on each station's value between 1985 and 1995), respectively. Raw data entry sheets and output tables are stored within the office of the ISMN manager.

A more complete location and tracking of computer files is given in Appendix V.

#### 3.2.3.12. Data quality assessment procedures

The temporal consistencies between successive neutron probe readings using the same instrumentation each month lead heavily towards consistent data quality.

# Neutron Probe Soil Moisture Network Data Collection Form

**ILLINOIS STATE WATER SURVEY**
**WARM NETWORK SOIL MOISTURE MEASUREMENTS**

SITE NAME:____________________SITE NUMBER:___________DATE:______________

START TIME:_____________CST END TIME:_____________CST MEAN:_____________CST

TROXLER SURFACE PROBE S/N:____________ TROXLER DEPTH PROBE S/N:_______________

OBSERVER:_________________________

| MEASUREMENT LEVEL | MOISTURE COUNTS |
|---|---|
| DEPTH STANDARD | |
| 20 CM | |
| 40 CM | |
| 60 CM | |
| 80 CM | |
| 100 CM | |
| 120 CM | |
| 140 CRN | |
| 160 CM | |
| 180 CM | |
| 200 CM | |
| SURFACE STANDARD | |
| TURF SURFACE | |
| FIELD SURFACE | |

WEATHER TYPE: CLEAR PARTLY CLOUDY CLOUDY RAIN THUNDERSTORM HAIL SNOW

SURFACE CONDITION: DRY MOIST WET STANDING WATER FROZEN SNOW COVER

FIELD CROP: YES NO TYPE: ______________CROP CONDITION:___________________

PYRANOMETER: GLASS DOME: OK DIRTY CLEANED SILICA GEL: BLUE CHANGED LEVEL: OK ADJUSTED

WELL LEVEL: _________ RAIN GAUGE: EMPTIED RE-CHARGED

OTHER COMMENTS:______________________________________________________________

REPORT NUMBER:______________ DATE ENTERED:_______________ BY:_______________

## Appendix VIII.

## Memorandum of Understanding between ISWS and Public Supply Reservoirs Receiving ISWS Staff Gauges

**Parties:**

_____________________ Public Water Supply, __________________________, Date: ___________
(reservoir name) (name of authorizing agent)

Illinois State Water Survey, __________________________________________, Date: ___________
(ISWS, WARM Program Manager)

The Illinois State Water Survey will install a staff gauge* at the ___________________ public water supply reservoir and provide a rain gauge. The purpose of installing the gauges is to accurately monitor the water level of the reservoir and develop an accurate, long-term record of reservoir water levels and local precipitation. ___________________ public water supply will make gauge readings and regularly report them to the Illinois State Water Survey. The Survey will maintain historical files. The respective responsibilities of the ISWS and ____________________ public water supply related to gauge installation and monitoring are detailed below.

**The Illinois State Water Survey will perform the following tasks:**

1. Install a Ben Meadows staff gauge (or equivalent) at a mutually agreeable location in the reservoir (concrete wing wall, intake tower, bridge abutment, etc.) at no cost to ________________________ public water supply. Should damage occur to the gauge, the Illinois State Water Survey is not obligated to repair or replace the gauge.
2. Provide a Tru-Chek, wedge-style rain gauge (or equivalent) to be mounted by _______________ public water supply.
3. Provide directions for making staff gauge and precipitation observations and a ledger form for recording the data.
4. Conduct periodic site visits to adjust the gauge placement. Anticipated frequency of site visit is one time per year.
5. Maintain a complete record of all gauge readings and water supply withdrawals and other data provided by the forenamed public water supply. The compiled records of water levels and other relevant data will be of public record and available to the public water supply upon request.
6. Report the month-end water level of the reservoir in its monthly *IWCS*. A complimentary subscription to the *IWCS* will be provided.

**___________________ Public Water Supply agrees to conduct measurements and provide the following information to the Illinois State Water Survey.**

1. Conduct staff gauge readings on a regular basis and maintain a record of the water level. The suggested schedule of gauge readings is the 7$^{th}$, 15$^{th}$, 23$^{rd}$, and the last day of the month, plus or minus one day. A regular, weekly schedule of readings may be substituted. Daily water level gauge readings are preferable.
2. Conduct rain gauge readings once daily and maintain a record of precipitation.

3. Following a precipitation event of one (1) inch or greater during a one-day period, record reservoir water level every 4 daylight hours as practicable. This detailed series of readings will be continued for a period of 2 days or until the water level changes are less than 0.1 feet in a 24-hour period. If the water level is above the spillway level, this reading period should include the stage decline following the peak stage.
4. Conduct the staff gauge and rain gauge observations following the general directions provided by the ISWS. Maintain gauge readings in a ledger (paper and/or electronic) with date, gauge readings, observer, and any other pertinent data as shown on the ledger form provided.
5. Promptly report gauge readings to the ISWS at the end of each month. The preferred methods of reporting in order of desirability are: a) e-mail, b) fax, or c) by phone for end-of-the- month observation and U.S. mail for complete paper and/or electronic record. The ISWS will continue to phone at the end of each month for the water level unless other arrangements are made. The cooperator is responsible for submitting copies of the complete data ledger each month to the ISWS.
6. Report damage or shifting of the staff gauge to the ISWS.
7. Clean the gauges periodically with a brush or other equipment.
8. Provide data on daily or monthly total water withdrawals from the reservoir as possible with existing monitoring equipment. Finished water volumes are an acceptable substitute if raw water is not metered.
9. Notify the ISWS of changes in the reservoir operations, such as lowering of the reservoir for maintenance, augmenting inflows with water from an alternate source, irrigation or other unusual withdrawals, etc.

* Successful installation of the staff gauge presumes an acceptable mounting surface exists.

## Appendix IX.

## Enhanced Observations Requested from Reservoir Cooperators Receiving ISWS Staff Gauges

# Reservoir Stage and Precipitation Record

**Site:** Greenfield Reservoir

Staff Gage level: 0.0 = 561.0 ft NGVD 1929

Staff Gage level 5.2 feet = top of inlet, 566.2 ft NGVD 1929

Difference from top of inlet: staff gage level minus 5.2 feet.

| DATE (mm/dd/yy) | TIME hh:mm AM or PM | Staff gage water level, feet | Difference from spillway, +/- feet | Rain gage amount, inches | Raw water pumpage, gallons | Comments (wave action/calm) (weather conditions) note if more than 24 since last reading |
|---|---|---|---|---|---|---|
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Staff gage readings should be entered to the nearest tenth of a foot. Rain gage amounts should be entered to the hundredth of an inch (e.g. 0.01, 0.20, 1.13). If a rain gage measurement includes amounts for more than one day, indicate what days are included in the Comments section. For example, if you read the raingage on a Monday September 27, and it includes rain that fell on Saturday and Sunday, write the observation down for Monday and in the comments line write "includes 9/25 and 9/26".

## Appendix X.

## Benchmark Sediment Monitoring Program Observer Sampling Procedures

Collect one sample per week.
Acceptable sample is one from 200 to 400 mL as marked on sample bottle.
If the sample is less than 200 mL or greater than 400 mL, discard the sample and sample again.

### A. Sampling Guidelines

1. Check for clean nozzle in sampler; clean off/out if necessary.
2. Use clean sample bottle.
3. Lower sampler to water surface and align it with the flow, keeping nozzle above the flow of water.
4. Sample using a steady rate to and from the bottom.
5. Retrieve sampler; if there is spillage, discard sample and go back to #2.
6. If bottle contains less than 200 mL or more than 400 mL, go back to #2.
7. If mud is in or on the nozzle that means that the nozzle went into the streambed, contaminating the sample. Go back to #2.
8. Remove sample from sampler, take water temperature, and fill out bottle cap and log sheet.

**Never**:

Never pour out part of a sample in order to get desired amount.
Never align sampler with nozzle in the water.
Never allow the sampler to stop in one place while taking a sample.
Never allow the sampler nozzle to dig into the streambed.

**Instructions for filling out bottle caps and log sheets**

Date: Use numbers for month, day, and year. (ex: June 21, 1993 = 6-21-93)
River Name: Use river identification number; this number never changes.
Time: Write down the time sample is taken. If you know 0000 to 2400 hour, military time, please use it. If not, then please indicate if the time you wrote down was a.m. or p.m.
G. Ht.: Gauge height is found by lowering the wire weight to just touch the surface of the water and then reading the numbers on the dials. If a gauge house is at the bridge, then read the numbers inside the gauge house as well and write them on the log sheet in the comment space.
Sta.: Station always remains the same (Box).
Temp: After taking a sample, place the thermometer in the bottle; after one minute, record temperature on the bottle cap. Cap sample bottle.

### B. Cross-Section Sampling

*Purpose*

The calibration cross sections should be collected at approximately six-week intervals. The purpose of these calibration samples is to verify the accuracy of the weekly “box” samples that the observer collects. Ideally, the box sample will accurately represent the average sediment concentration in the river. However, since suspended sediment concentration will vary laterally across the flow regime, the box sample may not accurately reflect the average sediment concentration. Cross-section samples are collected to determine if the box samples are representative of the average suspended sediment concentration in the river.

Additionally, every other cross section should be labeled as particle size (PS) to determine the percentage of material less than 62.5 micrometers. This sample is generally referred to as a sand fine split.

*Cross-Section Method*

The cross-section sampling method in use on the BSMP is the Equal Transit Rate (ETR). The ETR method consists of a sample volume proportional to the amount of flow at equally spaced verticals in the stream cross section. A vertical is a sampling location within the stream cross section. The ETR sampling consists of lowering the sampler from the water surface to the river bed and returning to the water surface at the same rate or speed for all samples collected across the stream cross section. This equal spacing of sampling verticals and collecting all samples at the same up-and-down transit rate yields samples that are proportional to the total streamflow and sediment discharge.

The number of verticals needed depends upon streamflow and sediment characteristics. As a general rule, 15 verticals would be an average number, 10 verticals would be a minimum, and 20 verticals are usually more than adequate. To determine the distance between verticals, divide the width of the streamflow by the desired number of verticals. To locate the 1st vertical, add one-half of the vertical spacing to the left edge of water (LEW). Each subsequent vertical should be equally spaced along the cross section using the original distance between verticals.

For example, if the river width was 150 feet and a cross section with 15 verticals were desired then the vertical spacing would equal 10 feet. The first vertical would be taken 5 feet from the LEW. The second vertical would be taken 15 feet from LEW or 10 feet from the last vertical and so forth across the width of the river channel. More than one vertical location may be collected in a cross-section sample bottle as long as the total sample quantity in a sample bottle does not exceed 400 ml. If more than one vertical is composited into a sample bottle, care must be taken when moving between verticals so as to prevent sample spillage from the sampler nozzle. The box sample bottles always contain only a single vertical sample from the box location.

*Sample Labeling*

The labeling of the sample bottle caps is completed as below depending upon whether the cross section is analyzed for concentration or concentration and particle size.

Cross-section samples

- Date -- use numbers for month, day, and year
- River -- river identification code number
- Time -- time sample was taken (in military time)
- G. Ht. -- none or gauge house
    - Sta -- B-1 or B-2 -- the location of verticals in the cross section in feet
- Temp -- water temperature of the B-1 sample

Below the temp line, write the sample identification. The cross-section sample bottle I.D. will either be XS (cross section) or PS (particle size cross section) and a number/number. The first number is the sample bottle in order of occurrence and the second number is the total number of bottles in the cross section.

NOTE: The bottle number and total number of bottles for the cross section do not include box samples.

*Cross-Section Sampling Procedures*

1. Determine the spacing and location of sampling verticals.
2. Measure the gauge height with the wire weight gauge if available; if not, use the inside gauge height from the gauge house and write on the B-1 bottle cap.
3. Install a clean sample bottle and lower the box sampler to the water surface and allow the sampler to stabilize and orient itself into the current prior to allowing the nozzle to enter the flow.
4. Lower the sampler using a constant transit rate (the same for all verticals both descending and ascending) to the river bed. Immediately upon contacting the bed, reverse direction until the sampler nozzle clears the water surface. All verticals will be sampled at the same transit rate so remember your transit rate speed.
5. If there is spillage from the nozzle, go back to the start.
6. If the sample contains more than 400 mL or less than 200 mL, go back to the start.
7. Inspect sampler and sample. If there is mud on or in the nozzle, an obvious plug of sediment, or an unusual amount of sand in the sample bottle, go back to #3. If the sample is acceptable, cap with B-1 bottle cap and fill in the time the sample was collected.
8. Start at either edge of the river and sample at all the designated verticals using the above procedures. Label the bottle caps appropriately for that vertical station and bottle I.D.

NOTE: More than one vertical may be sampled into a cross-section sample bottle (but not B-1 or B-2 samples) as long as the 400 mL limit is not exceeded.

NOTE: Discard sample and resample any verticals for a sample bottle if the sample exceeds the 400 mL volume limit.

After collecting all cross-section samples, collect another box sample designated as B-2 in the same manner and the same transit rate as the B-1 sample.

Measure the gauge height again and add information to the B-2 bottle cap.

Log all of the sample information (box and cross-section samples) on a Chain of Custody log sheet, including any pertinent comments about stream and flow characteristics.

# Appendix XI.

## ISWS Sediment Laboratory Chain of Custody Record

PROJECT NAME ______________________ Collected by: ______________________ Date: __________
WATERSHED ______________________ Recorded by: ______________________ Date: __________
Lab Report to: ______________________ Relinquished by: ______________________ Date: __________
Received by: ______________________ Date: __________
Job / Batch # __________ Page _____ of _____ Analysis Starting Date: __________ Analysis Completion Date: __________

| | Sample Information | | | | | | | | | Analysis Requested | | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pan No. | SAMPLE ID | SITE ID | DATE (MM/DD/YY) | TIME CST (2400) | STATION (ft) | GAUGE HEIGHT | WATER TEMP (F OR C) | TYPE | XS or PS? | SSC | Pipette | Sieve | Fine/Sand Split | Unit Weight | Water Content | |
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