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APPENDIX E:

Over-land Meteorology

Introduction

Over-land meteorological observations provide information and data crucial in understanding the hydrologic processes within a specific sub-watershed unit, as well as within the entire Great Lakes basin. The over-land meteorological parameters consist of precipitation, temperature, solar radiation, dew point, pan evaporation, soil temperature and moisture, among others. On the scale of the Great Lakes basin, these parameters influence or are a component of the hydrologic inflows (water going into the system) and outflows (water going out of the system) of the Great Lakes water balance. Currently, most these parameters are being used as inputs to a computer model developed by Croley (1989) to calculate evaporation from the surface of the Great Lakes.

Data for these parameters are measured at hundreds of weather station locations around the Great Lakes basin. These parameters are also assessed by satellite and radar imagery. The National Climate Data Center, in the United States and the National Archives and Data Management Branch, Atmospheric Monitoring and Water Survey Directorate, Meteorological Service of Canada collect, store and disseminate historical and current data.

Precipitation

Precipitation directly on the Great Lakes-St. Lawrence River basin a large part of each Great Lake's inflow. The percentage varies from one lake to another, and is largely a function of land-to-lake surface ratio in each lake basin. For example, Lakes Superior, Michigan-Huron, and Erie receive approximately 55 percent, 54 percent, and 53 percent of their total inflow as precipitation, respectively. Over-land precipitation can be used indirectly to estimate runoff in areas where stream gauging is incomplete.

Precipitation over land areas is reasonably well known due to the density and quality of data from precipitation gauge networks. Precipitation is measured or gauged at hundreds of locations in the Great Lakes basin. Conventional weather stations measure precipitation directly at one point. Data from multiple stations may be combined using various methods to calculate estimates of precipitation falling over a large area. Doppler radar is also used to estimate precipitation. Doppler radar permits the direct measurement of precipitation over a large area without the need to extrapolate observations made at single sites.

Precipitation in the form of lake-effect snow is a common cold season phenomenon in the Great Lakes region, occurring most frequently in late autumn and early winter. This type of snow results from the rapid warming and moistening of Arctic air masses that pass over lakes that are still relatively warm. The Arctic air becomes unstable and the resulting convection forms clouds and precipitation. The precipitation falls over and downwind of the lakes. For very cold air masses, temperatures remain below freezing even after passage over the warmer lakes, causing the precipitation to fall as snow. Lake-effect snow causes considerable enhancement of snowfall in narrow snowbelts along the downwind lakeshores (Figure E-1). For example, Detroit, Michigan, on the western (upwind) shore of Lake Erie receives an average of 42 inches per year, while Buffalo, New York, on the eastern (downwind) shore of Lake Erie, receives an average of 92 inches per year.

On 5 December, 2000, a storm swept across the Great Lakes and dropped "lake effect" snow along the southern shore of Lake Superior and western shore of Lake Michigan. This image shows how the big lakes can affect local weather and influence regional ecosystems. This image was made available by *NASA Visible Earth website:* http://visibleearth.nasa.gov/

Figure E-1 NASA Visible Earth imagery of the Great Lakes.

Snow depths at Canadian climatologic stations are measured with a ruler at a number of representative points and averaged. In the United States, snow is measured in gauges just like other forms of precipitation.

The water-equivalent of snow pack is measured by weighing samples of snow extracted along snow course stations using a special sample tube. Water equivalent of snow is the average amount of water existing as snow (i.e., the mass of snow per area unit). The water equivalent of snow is determined by snow course measurements. A snow course is a 2 to 4 km long trail through various terrains typical of the locality. Along the snow course, the number of snow depth measurements, made by using a measuring stick is usually 80. For obtaining the density, the snow is weighed at 8 points along the snow course. Snow water equivalent estimates are also derived from daily snow fall at many meteorological stations by measuring the new snowfall depth and dividing by a factor, usually 10. Snow caught in the gauge is also sometimes melted and measured for its water content. The use of the airborne gamma radiation attenuation technique to estimate mean areal snow-water equivalent of snowpack is currently being evaluated over the Great Lakes basin.

Meteorological Parameters
In addition to precipitation, the meteorological parameters listed below are measured by weather stations throughout the Great Lakes basin.

- Air Temperature
  Air temperature is measured by a thermometer placed in a sheltered but well-ventilated box located about 1.4 meters above the ground.

- Wind Speed and Direction
  Wind speed is measured by an anemometer, having either rotating cups or a pressure tube. The wind direction measuring system is comprised of precision positional motor, controlled by a wind vane, which in turn reacts to the ambient wind direction. The instrument is normally paced at height of about 10 meters.

- Solar Radiation
  The short wave radiation incident to the outside of the earth's atmosphere comes primarily from the sun. As this radiation passes through the earth's atmosphere, it is absorbed by gases of the air, water vapor, clouds, and dust. As a result of these complex

processes, the short wave radiation arrives at the earth's surface partly as direct radiation and partly as diffuse radiation. This short-wave radiation can be evaluated by direct measurement by instrumentation or indirect evaluation in terms of easily measurable quantities. When direct measurements of solar radiation are not available, mathematical formulae may be used to estimate the value.

- Evaporation
  The evaporation pan is the most widely used instrument for evaporation measurement. Evaporation is measured in inches from a standard Weather Bureau Class A pan.

- Dew Point Temperature
  Dew point temperature is defined as the temperature at which the air becomes saturated when cooled under constant pressure and with constant water-vapor content.

- Soil Moisture
  Soil moisture refers to the water that occupies the voids of the soil located above the water table. It is determined by either weighing the soil samples before and after drying, or using instruments permanently or temporarily set within a given horizon of the soil. It can also be sensed by gamma radiation attenuation.

- Soil Temperature
  The soil temperature measuring systems consist of probes installed inside a tube in a 60 inch deep hole bored into the ground that record temperatures at six depths (2, 4, 8, 20, 40, 60 inches).

- Evapotranspiration
  Evapotranspiration is commonly considered to be evaporation from all water, soil, snow ice, vegetation, and other surfaces plus transpiration (the release of water as a byproduct of photosynthesis). It can be determined in controlled experiments, or by estimation methods. The Midwest Regional Climate Center collects potential evaporation data for select sites on a daily, monthly, and annual basis.

United States Data Collection Agencies

Several federal, regional and state agencies are involved in meteorological data collection, storage, analysis and dissemination. In the United States, National Climatic Data Center (NCDC), National Resource Conservation Service (NRCS), Regional Climatic Data Centers, and state climate offices are all involved in supporting these data services.

National Climatic Data Center
NCDC is the largest active archive of weather data. NCDC archives weather data obtained by the National Weather Service (NWS), Military Services, Federal Aviation Administration (FAA), and the U.S. Coast Guard, as well as data from voluntary cooperative observers. NCDC archives 99 percent of all NOAA data, including over 320 million paper records; 2.5 million microfiche records; and over 1.2 pedabytes (each pedabyte is a million gigabytes) of digital data residing in a mass storage environment. NCDC has satellite weather images back to 1960. NCDC maintains over 500 digital data sets, receives almost 2,000,000 requests each year, and records over 100 million hits per year on the website.

Over the years, the NCDC began to grow to meet the processing demands of ever-increasing data. In the 1960s, the Defense Department's Air Force and Navy climatological centers co-located with NCDC to form the federal Climate Complex. The National Climate Services System that coordinates climate activities at all levels of government evolved during the 1980s. This system is a three-tiered support program with the NCDC as its center and Regional Climate Centers and state climate offices as partners.

NCDC collects new data streams such as Next Generation Weather Radar System (NEXRAD) and Automated Surface Observing System (ASOS). The system from which these NEXRAD data are collected is the Weather Surveillance Radar-1988 Doppler network (WSR-88 Radar) which began operation at a few sites in 1991.WSR-88D sites are throughout the United States and selected overseas locations. This system is a joint effort of the United States Departments of Commerce (DOC), Defense (DOD), and Transportation (DOT). The controlling agencies are the NWS, Air Weather Service (AWS) and FAA, respectively. The data sent to the National Climatic Data Center (NCDC) for archiving and dissemination include the following NEXRAD data parameters:

- Base Reflectivity (R)
  A display of echo intensity measured in dBZ. This product is used to detect precipitation, evaluate storm structure, locate boundaries and determine hail potential.

- Base Velocity (V)
  A measure of the radial component of the wind. This parameter is used to estimate wind speed and direction, locate boundaries, locate severe weather signatures and identify suspected areas of turbulence.

- Hail Index Overlay (HI)
  Designed to locate storms which have the potential to produce hail.

- Mesocyclone Overlay (M)
  This parameter displays information regarding the existence and nature of rotations associated with thunderstorms.

- One-hour Precipitation (OHP)
  A map of estimated one hour precipitation accumulation on a 1.1 X 1.1 nmi grid. This product is used to assess rainfall intensities for flash flood warnings, urban flood statements and special weather statements.

- Severe Weather Probability Overlay (SWP)
  A measure of a storms relative severity as compared with those storms around it. The values are directly related to the horizontal extent of vertically integrated liquid (VIL) values greater than a specified threshold. This product is used as a quick identification of the strongest storms.

The NWS develops several information products from NEXRAD data including:

- Storm Structure (SS)
  A table displaying information on storm attributes which include maximum reflectivity, maximum velocity at lowest elevation angle, storm overhang, mass weighted storm volume, storm area base and top, storm position and storm tilt.

- Storm Total Precipitation (STP)
  A map of estimated storm total precipitation accumulation continuously updated since the last one-hour break over the entire scope. This product is used to locate flood potential over urban or rural areas, estimate total basin runoff and provide rainfall data 24 hours a day.

- Storm Tracking Information Overlay (STI)
  A product which shows a plot of the past hours movement, current location, and forecast movement for the next hour or less for each identified thunderstorm cell. This product is used to determine reliable storm movement.

- Tornadic Vortex Signature Overlay (TVS)
  A product which shows an intense gate to gate azimuthal shear associated with tornadic-scale rotation. It is depicted by a red triangle with numerical output of location and height.

- VAD Wind Profile (VWP)
  A graphic display of wind barbs plotted on a height staff in 500 ft or 1000 ft increments. The current (far right) and up to 10 previous plots may be displayed simultaneously. This product is an excellent tool for meteorologists in weather forecasting, severe weather and aviation.

- Vertically Integrated Liquid (VIL)
  The water content of a 2.2 X 2.2 nmi column of air which is color coded and plotted on a 124 nmi map. This product is used as an effective hail indicator, to locate most significant storms and to identify areas of heavy rainfall.

National Operational Hydrologic Remote Sensing Center
The NWS OHRSC conducts experimental Remote Sensing Analyses (RSA). RSA provide daily maps of snow cover, derived from National Oceanic and Atmospheric Agency's GOES and AVHRR satellites, for the coterminous United States and Alaska. The RSA include rough estimates of snow water equivalent based on ground and airborne observations combined with snow cover information from the satellite maps. Also included in the RSA are estimates of the percentage of normal snow water equivalent, and analyses of freezing and thawing degree days. RSA product formats include maps, text summaries, and downloadable data files.

Automated Surface Observing Systems
The ASOS program is a joint effort of the NWS, the FAA and the DOD. The ASOS serve as the nation's primary surface weather observing network. ASOS are designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities.

With the largest and most modern complement of weather sensors, ASOS has significantly expanded the information available to forecasters and the aviation community. The ASOS network has more than doubled the number of full-time surface weather observing locations. ASOS works non-stop, updating observations every minute, 24 hours a day, every day of the year. With this near real-time data update ASOS information has helped the NWS move toward its goal of modernization and increase the accuracy and timeliness of its forecasts and warnings. ASOS detects significant changes, disseminating hourly and special observations via the networks. ASOS observes, formats, archives and transmits observations automatically. ASOS reports basic weather elements:

- Sky condition: cloud height and amount (clear, scattered, broken, overcast) up to 12,000 feet
- Visibility (to at least 10 statute miles)
- Basic present weather information: type and intensity for rain, snow, and freezing rain
- Obstructions to vision: fog, haze
- Pressure: sea-level pressure, altimeter setting
- Ambient temperature, dew point temperature
- Wind: direction, speed and character (gusts, squalls)
- Precipitation accumulation

Within the National Climate Services System, six region climate centers exist. Two of the regional climate centers, the Midwestern Regional Climate Center (MRCC) and the Northeast Regional Climate Center (NRCC), collect and process weather data for the Great Lakes states. Major funding for their operations is provided by a grant from the National Oceanic and Atmospheric Administration.

Midwestern Regional Climate Center
The MRCC is a cooperative program of the Illinois State Water Survey and the National Climatic Data Center. The Center serves the nine-state Midwest region that includes Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio and Wisconsin. It services and research help to better explain climate and its impacts on the Midwest, provide practical solutions to specific climate problems, and to develop climate information for the Midwest on climate-sensitive issues such as agriculture, climate change, energy, the environment, human health, risk management, transportation and water resources.

Northeast Regional Climate Center
Established in 1983, the NRCC is located in the Department of Earth and Atmospheric Sciences at Cornell University. It serves the 12-state region that includes: Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont and West Virginia. The NRCC conducts research studies that focus on the development of new climate information products, data analysis techniques, and applications of climate data. Studies are also directed toward understanding and characterizing regional climate and climate variability as it may affect the economic or societal well being of the northeastern United States. Examples of work in progress or recently completed include: the development of methods to estimate soil frost depths,

monitor water resources, predict agricultural crop development and characterize extremes of snow pack water equivalent in the Northeast.

Soil Climate Analysis Network

Besides National Climate Services System that is operated mainly under the NOAA, the USDA NRCS, is leading a cooperative nationwide, comprehensive soil moisture and climate information system called Soil Climate Analysis Network (SCAN) that is still in its development phase.

This system, if funded, will add 1,000 or more new remote sites and integrate existing cooperator networks to develop the first nationwide soil-climate network. SCAN will integrate information from existing soil-climate data networks and establish new data collection points through partnerships with federal, state, local and tribal entities.

The long-term soil/information complied through SCAN could be used for:

- Monitoring drought development and trigger plans and policies for mitigation.
- Classifying soil.
- Inputs to global circulation models.
- Developing new soil moisture accounting and risk assessments.
- Predicting regional shifts in irrigation water requirements which may affect reservoir construction and groundwater levels.
- Predicting shifts in wetlands.
- Verifying satellite and soil moisture model information.

Currently the ability of NRCS and its partners to make sound resource assessments and watershed decisions has been severely limited by the lack of quality, historic and real-time soil-climate information. Existing data from other networks are essentially inadequate for most purposes, as they tend to be application specific, short-term, incomplete, limited in area of coverage, and often include non-standard data that are difficult to access. The Figure E-2 below is a map of the current network.

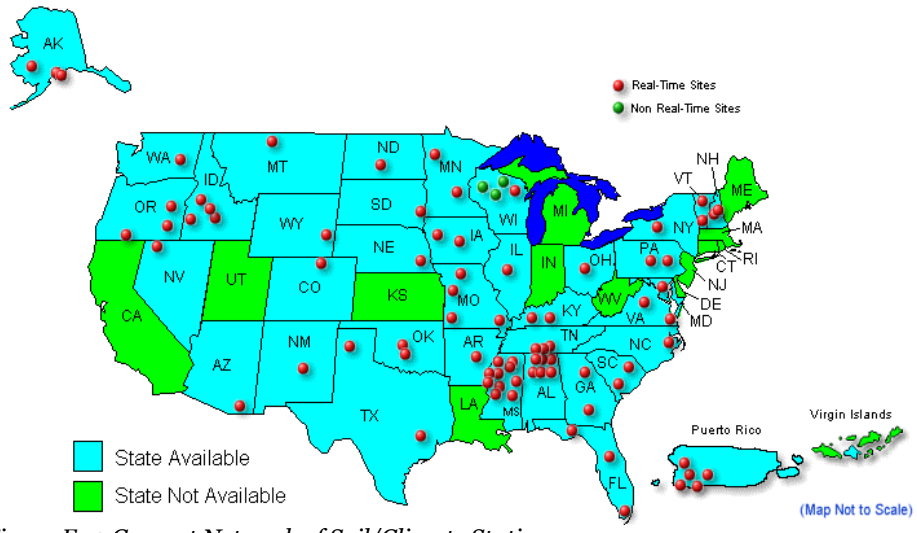

Figure E-.2 Current Network of Soil/Climate Stations

Besides soil moisture, SCAN sites measure the following parameters:

- precipitation,
- air temperature,
- relative humidity,

- wind speed and direction,
- solar radiation,
- barometric pressure,
- snow-water content,
- snow depth,
- and soil temperature.

Canada

In Canada, the Meteorological Service of Canada (MSC) and Ontario Ministry of Natural Resources (OMNR) are Canada's source for meteorological information.

Meteorological Service of Canada
The MSC monitors water quantities, provides information and conducts research on climate, atmospheric science, air quality, ice and other environmental issues.

The MCS:
- provides weather forecasts and warnings of extreme weather events and hazardous air quality
- monitors atmospheric conditions and the quantity of water in Canadian lakes and rivers
- forecasts ice and wave conditions on navigable oceans and inland waters
- monitors and predicts the state of the climate
- leads the development of atmospheric science and related environmental prediction in Canada

MSC's radar network of conventional and Doppler radars covers 95 percent of Canada's population. The National Radar project will convert all weather radars to Doppler and is MSC's number one priority for capital investment. When finished, 31 Doppler radars will be in operation.

MSC's National Climate Data and Information Archive contains official climate and weather observations for Canada. Climate elements, such as temperature, precipitation, relative humidity, atmospheric pressure, wind speed, wind direction, visibility, cloud types, cloud heights and amounts, soil temperature, evaporation, solar radiation and sunshine as well as occurrences of thunderstorms, hail, fog or other weather phenomena are warehoused in a digital database.

Ontario Ministry of Natural Resources
The OMNR compiles snow data into bimonthly reports. The snow course data is gathered by Conservation Authorities, MNR Districts, Trent-Severn Waterway and Ontario Hydro Generation. These data are used by the Flood Forecasting and Warning Unit to access current snow cover and ground conditions across the province. Snow data is an important indicator for flood forecasting and is used in daily rainfall runoff calculations and modeling procedures. Yearly data are compiled for a year end summary that includes maps of snow depth, water equivalent of snow, snow density, and satellite imagery.

Climate Summaries, Projections and Climate Change Analyses

The climate of a place is the average over a number of years of the day-to-day variations in temperature, precipitation, cloud cover, wind and other atmospheric conditions that

normally occur there. Climate also includes the variability of individual climate elements, such as temperature and precipitation, and the frequency with which various weather conditions occur. In other words, climate is the combination of average weather conditions and weather patterns over time for a particular location.

The meteorological data discussed in the previous sections of the appendix are used to produce climate summaries, meteorological projections, and climate change analyses. These information products are often produced by the federal and state agencies that collect the primary meteorological data.

Climate summaries and projections, along with circulation models are important inputs to climate change models that are used to explore the impacts of climate on Great Lakes-St. Lawrence River basin hydrology and ecology. The primary driving factors to changes in the Great Lakes water supply are precipitation and air temperatures. Lower precipitation leads to lower runoff as does higher air temperatures. Higher air temperatures also result in higher evaporation. Since the fall of 1997, precipitation has decreased over the Great Lakes basin, particularly in the upper lakes and air temperatures have been significantly above-average. This has resulted in lower-than-normal water supplies. In addition during the past four winters, the ice cover has been much below average, also significantly contributing to the decreasing water levels. NOAA's Great Lakes Environmental Research Laboratory (GLERL) has the ability to make water supply and lake level forecasts 1-12 months into the future based on current basin hydrology and NOAA's long-term climate outlooks.

The MRCC produces regional climate summaries by state and by each Great Lake basin. The climate summaries for each Great Lake basin were developed through a joint project between GLERL and the MRCC. The summaries also forecast future climate for several important variables including:

- Over-lake air temperature
- Over-lake cloud cover
- Evaporation from lake
- Lake heat storage
- Ice area
- Latent heat flux
- Net long-wave radiation
- Precipitation
- Reflected radiation

Figure E-3 below is the sample of a Great Lakes probabilistic precipitation outlook created by the Great Lakes Environmental Research Laboratory of NOAA.

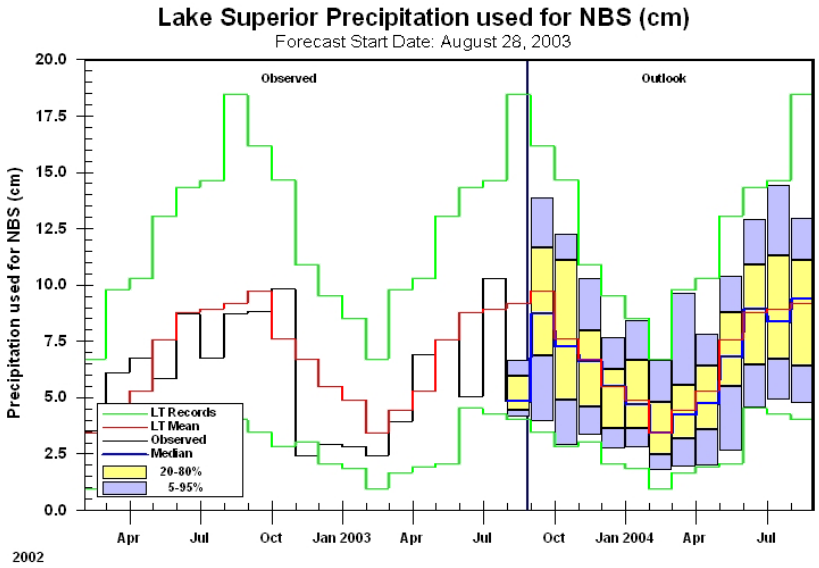

Figure E-3 Graph NOAA Probabilistic Precipitation Outlook

A more detailed discussion on climate change analyses is presented in Appendix D, *Open Lakes, Interconnecting Waterways, St. Lawrence River and Diversions.*

Data Needs Assessment

The inventory conducted on overland meteorological observations did not showcase any substantial short-comings in data needed to support water withdrawal impact assessments. This conclusion awaits confirmation. As such, no recommendations for additional federal investment in data collection or analysis are provided for these necessary components of the water resources management decision support system.