Statement by Professor Calvin B. DeWitt to the
Commissioners of the Capitol Area Planning Commission
October 9, 2014

Dear Members of the Commission,

I am Calvin B. DeWitt, Professor Emeritus, and an environmental scientist at the University of Wisconsin-Madison, whom you know from my earlier presentation to the Commission on August 8, 2014 on "Waubesa Wetlands in Scientific Context." Thanks to you, my PowerPoint presentation on the science of this ecosystem is now accessible on your website (www.capitalarearpc.org/).

As you know, for three decades I have researched Waubesa Wetlands with my graduate class, Field Investigations in Wetland Ecology, at UW-Madison. Spencer Black's column in the *Capital Times* on August 20, summarized our research finding well as he wrote, "the Waubesa wetlands have retained their remarkable ecological value. The area has been protected by the Nature Conservancy because of its biological importance and has been designated as a State Natural Area by the Wisconsin Department of Natural Resources." And "The Wisconsin Wetlands Association names it as one of our state's "wetland gems."

I appreciate greatly the opportunity you already have given me to put this jewel in the landscape into scientific context. I also appreciate the times the City of Fitchburg has provided me in describing the larger system of which Waubesa Wetland is a part—a system we are coming to now and understand as "the Fitchburg-Waubesa Artesian Basin." I also appreciate Bill Horns' response to Spencer Black in the *Capital Times on* August 28, and especially our shared appreciation of the time and attention Fitchburg has given this. But I counter his suggestion that development of the NEN poses no greater threat than current agricultural practice. Paving over poorly cared for soil with urban development is not a solution to poor soil stewardship.

At one of the two CARPC hearings during your last meeting on September 11, one of the two applicants said they took seriously the work of the Wisconsin Initiative on Climate Change Impacts (WICCI) and not develop right up to their borders, leaving space available for adaptation to foreseen and unforeseen climate change. This is an expression of the wisdom we need tonight.

I am speaking in opposition to the proposed revision of the Urban Service Area, identified by Fitchburg as the "Northeast Neighborhood" (NEN), for reasons of climate and related factors.

First, I believe it unwise and unnecessary to press urban development right up to the north and east boundaries in a city of some 36 square miles whose central core is miles away, because this would compromise and eliminate the possibility of climate change mitigation for intensified rainfall and flood events—and also, consequential ecological and financial losses for the City of Fitchburg, its neighbors to the east, to Holtzman Marsh and the Waubesa Wetlands gem, and, very significantly, to the water quality of Lake Waubesa and its hundreds of shoreline residents and their expensive lakeshore properties.

In stating my case to you, I need first to describe how the World Meteorological Organization (WMO) defines what they have been calling "climate normals"—used "as reference points by climatologists to compare current climatological trends to that of the past." The WMO "climate normal" is defined as "the arithmetic average of a climate element"—like rainfall—over a 30-year period. A 30-year period is used, because it is long enough to filter out inter-annual variation, and short enough to be able to show longer climatic trends. The current "climate normal" period is calculated from 1 January 1961 to 31 December 1990.

It is a common practice of engineering and planning firms to use this same "climate normal" from an earlier 30-year period for sizing the needed capacity of rainwater detention and processing systems—systems they design for what they often call "stormwater management." This was the procedure used here for Fitchburg. It is important to note that the WMO uses this "a reference point to compare current climatological trends with the past." The firms we employ, however, uses this for another purpose: to determine the size of retention and treatment systems.

1. What this means is that planning for floodwater and stormwater for this site does not take into account the actual experience—from what we actually *measure*—about the increased intensity of rainfall events over the past one or two decades. At typically-used "climate normal" for the Madison area for the month of June is *4.54* inches for the Madison area.

However,

- In 1996 June rainfall was 2.1 times higher at 9.69 inches.
- In 2008 June rainfall was 2.4 times higher at 10.93 inches, and...
- In 2013 June rainfall was 2.4 times higher at 10.86 inches.
- In 2014 June rainfall was 2.1 times higher at 9.55 inches.

But this is not all.

Usually the design is not only based on a 30-year average, it is also based on only 80% of that figure—according to what is called "best management practice." This means that rainfall would have exceeded the capacity of designed retention by 2.7 times for June, 1996. For 2008 and 2013 June rainfall would exceed the design capacity by a factor of three. And for 2014 June rainfall would have exceeded 2.6 times the designed capacity.

If we move from the Madison to Baraboo region for a 10-day period of rainfall that totalled 17 inches in June 2008—as reported by WICCI—in contrast to the 4.54 inch 30-year average design capacity, we would have rainfall 4.7 times greater than could be handled.—more than 4 and half times! These means that 21 per cent of the rainfall would be retained. And what would happen to the other 79 per cent?

For the proposed NEN area, it moves downstream, runs beneath Larsen Road into the Holtzman Natural Resources Area and the Holtzman Marsh. There it joins run-off from the Meadowview subdivision that floods Holtzman Marsh, backing up water from the west and north. And then in time it moves south along the east side of Larsen Road to enter Swan Creek near the junction of

Larsen and Goodland Park Roads. From there it moves on through Waubesa Wetlands and into Lake Waubesa, carrying with its load of dissolved and suspended materials and nutrients.

2. The plan for the NEN does not explicitly address the increased intensities in rainfall, as I have illustrated here for the month of June. The city and the engineering firms, advisory and planning agencies at a minimum must use *measured* rainfalls of the past two decades in doing their design of rainwater retention and treatment. And it is vitally important for these entities to hold in reserve enough land area between them and downstream human and natural communities for probable future mitigation.

3. Finally, it is necessary to recognize and confront the problem that current rainwater detention and processing ponds been designed based upon rainfall records of earlier decades. During high rainfall events in September of this year, Swan Creek at Lalor Road and County Highway MM had opaque, coffee-colored flows, and these went on its course into Waubesa Wetlands, continuing to nourish wide borders of invasive Reed Canary grass along its banks, and then on into Lake Waubesa. These systems—designed for an earlier climate with less intense precipitation events—now also are failing, and their increasing contribution to the degradation of things downstream needs to become a priority.

Spenser Black in his column on Waubesa Wetlands reminded us that Dane County is growing because it is attractive to people and business and that we need to preserve that attractiveness. And, saying, “We don't have an alternative for the biological richness of the Waubesa wetlands,” he concluded:

We should conclude at this point that the far northeast corner of Fitchburg should have its landscape functions restored, including its prime agricultural land and the wetland area within it that has been put into agriculture. It should not become a new Urban Service Area but enhanced for the ecosystem services it once, and can again, provide.

In the early morning of Thursday, September 4, an intense thunderstorm dropped some three inches of rain onto the Swan Creek watershed in eastern Fitchburg. That evening, at 7 pm, I photographed Swan Creek at Lalor Road, south of Goodland Park Road, and 10 minutes later at County Hwy MM near its junction with Haight Farm Road. Swan Creek was in flood stage; its moving water an opaque chocolate-brown color, with no transparency. A month ago in my Power Point on August 8, I presented a photo of Swan Creek at Lalor Road in similar conditions—conditions of high turbidity and heavy sediment load.

A few weeks earlier I canoed from Lake Waubesa up Swan Creek into Waubesa Marsh, on water whose turbidity was so great that visibility ranged from 1 inch to zero depth. This time there had been no flood, but turbidity was extremely high and visibility extremely low. As I progressed up stream a photographer captured the scene. Swan Creek, as this video documents, is nearly totally bordered by Reed Canary Grass—a strong indicator of heavy nutrient loading. A short while later we entered Murphy Creek, that enters from its largely natural and agricultural watershed, also in Fitchburg. The contrast was great: its water was clear, and it was bordered mostly by native vegetation such as BlueJoint Grass, with very little Reed Canary.

These observations, and much more, brings me to conclude, reluctantly, that the current practices for managing stormwater and maintaining reasonable water quality of Swan Creek by Fitchburg, are not doing what they are intended to do. I have little reason to question here the good intentions of the city, with its good record of environmental stewardship. My assessment however, is that the city's current practices are seriously short of their stated goals of responsible and effective watershed and stream stewardship.

The consequences of the ongoing discharge of these heavily-silted and nutrient-rich waters into Waubesa Wetlands and Lake Waubesa are unacceptable. The continued attractiveness of Waubesa Wetlands and Lake Waubesa are being seriously threatened under existing practices. To allow an extension of these and similar practices even while existing practices are ineffective is unconscionable and it neglects viewing the watershed in the context of its receiving lands and waters, insults the wider community's four and more decade stewardship of Waubesa Wetlands and Lake Waubesa, and is scientifically ungrounded.

The Definition of the Standard WMO Climate Normal

The Key to Deriving Alternative Climate Normals

BY ANTHONY ARGUEZ AND RUSSELL S. VOSE

The World Meteorological Organization (WMO) and its predecessor, the International Meteorological Organization (IMO), have been coordinating the publication of global climate normals at the monthly scale for about 75 years. Member nations of the IMO/WMO were first mandated to compute climate normals for their respective countries for the 1901–30 period, and are required to update these climate normals every 30 years, resulting in the 1931–60 normals and the 1961–90 normals. Since 1956, the WMO has recommended that each member country recompute their 30-year climate normals every 10 years. Although some member countries do not update their climate normals every decade, for ease of comprehension we hereafter refer to the recommended decadally updated 30-year average as the standard WMO climate normal.

Given substantial evidence (e.g., Solomon et al. 2007; Milly et al. 2008) indicating that the stationarity of climate statistics can no longer be (and never should have been) taken for granted, the justification for using a 30-yr normal for describing current and future climate conditions has increasingly been called into question (e.g., the 2007 *Journal of Applied Meteorology and Climatology* article by Livezey et al., hereafter referred to as L07). The key problem is that climate normals are calculated retrospectively, but are often utilized prospectively. Specifically, climate normals are calculated using data from a recent 30-yr period, but one of their primary utilities is to provide stakeholders and decision makers with a metric of future climate conditions that can be taken into account in long-term planning considerations. The utilization of climate normals in this manner adheres to the well-known maxim, "The best predictor of future behavior is past behavior." Implicit in this link between the calculation and the utilization of climate normals is the notion of stationarity. Weak stationarity assumes that the expectation (i.e., the mean value) of a variable is time invariant, and that second-moment statistics are a function of lag only. Significant trends in a time series (as opposed to natural fluctuations about a mean state) violate the weak stationarity assumption. In turn, if stationarity is violated, a retrospective 30-yr average becomes considerably less useful as an indicator of current and future climate conditions.

As discussed by WMO (2007), climate normals are not only used as predictors of future climate conditions, but are also used to provide a reference value for the computation of climate anomalies. For placing current climate conditions in a historical perspective (i.e., real-time climate monitoring), there are compelling statistical reasons to use climate normals that are rarely updated—if at all—so that the meaning of a particular anomaly value will be consistent across time. This is true whether there are significant trends in climate time series or not. Similarly, for stationary climate time series, there would be little reason to update climate normals because, by definition, a stationary climate's mean does not change in time. The 30-yr climate normal under the stationarity assumption could be interpreted as the true background state, offset by decadal and longer-term tendencies, and further tweaked by interannual variability (e.g., ENSO-related variations) as well as random and systematic errors. Thus, for stationary time series, the standard WMO climate normal is a reasonable

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DOI: 10.1175/2010BAMS2955.1

metric with respect to both of its primary utilizations. Conversely, if climate conditions are deemed to be nonstationary, the standard WMO normal still retains its utility for placing current conditions in a historical context, but the predictive value is compromised.

Climate scientists have been concerned with the definition of climate normals since before the WMO mandate was put in place, with renewed interest in the last 30 years due in large part to observed climate change. To address the shortcomings of traditional climate normals in a changing climate, L07 and others have been advocating for the development of alternative normal products that are better indicators of current and future climate conditions. We contend that the most straightforward approach for creating alternative climate normals is to alter the generalized definition of the standard WMO climate normal. Arguably, every possible alternative climate normal that can be devised is the result of altering one or more of five fundamental attributes. Below, we describe these five attributes, formulate a generalized equation for WMO-type climate normals, and briefly consider a few ways to alter the standard WMO definition to arrive at alternative climate normals.

FIVE KEY ATTRIBUTES OF THE STANDARD WMO CLIMATE NORMAL. Although climate normals are simply 30-yr averages, the computation of climate normals is a nontrivial, multifaceted process. The WMO provides member nations with considerable leeway on the methodology employed in computing climate normals, such as quality control, the handling of missing data values, etc. Here, we ignore these methodological specifics and restrict ourselves to the statistical definition of the standard WMO climate normal (i.e., the metric of "typical" climate conditions). There are five important attributes of the normals metric:

- it is a temporal average;
- the average is unweighted;
- the averaging period is 30 consecutive years;
- it is a causal filter (using past and current values only); and
- it is updated once per decade.

Considering these five attributes, the generalized equation form for this class of average-based normals metrics is as follows:

$$y(t_0 + k\Delta t) = \sum_{i=t_0+k\Delta t-N+1}^{t_0+k\Delta t} w(i)x(i) \qquad (1)$$

Here, y is the climate normal, x is the observed annual time series, w is a weighting function, k is an integer, Δt is the update frequency, t_0 is a reference year, and N is the number of years averaged. For the standard WMO climate normal, $N = 30$, w is set to a constant value of 1/30, $\Delta t = 10$ years, and t_0 is a multiple of 10 years. Substituting, the standard WMO climate normal metric is defined as follows:

$$y(t_0 + 10k) = \frac{1}{30} \sum_{i=t_0+10k-29}^{t_0+10k} x(i) \qquad (2)$$

For the case of the 1971–2000 climate normals (setting $k = 0$, presuming $t_0 = 2{,}000$), Eq. (2) reduces further to an even more familiar form as follows:

$$y(2000) = \frac{1}{30} \sum_{i=1971}^{2000} x(i) \qquad (3)$$

Alternative normals products can be created by changing one or more of the five attributes listed above. In the remainder of this section, we provide additional details for each of the five attributes, and briefly describe how the attributes can be modified to arrive at alternative normals.

Temporal average. The defining characteristic of traditional climate normals is that they are based on averages. The average, or mean, is ubiquitous in weather and climate applications as an indication of central tendency. Specifically, climate normals are temporal averages, and can be considered running averages of sorts, although they are only updated once per decade. In time series filtering theory, a running average is a very simple low-pass filter, which means it smoothes out high-frequency variations (e.g., year-to-year to interannual fluctuations such as those associated with the El Niño–Southern Oscillation) to highlight a background state. Assuming stationarity, the rationale is that these higher-frequency fluctuations are superimposed on the mean background state; this background state is precisely what the WMO climate normal metric attempts to quantify.

There is no natural law mandating that "typical" weather conditions be represented as an averaged value. The median is a viable alternative that also provides a measure of central tendency. Further, a strong trend in a climate time series renders a temporal average an unsuitable choice for describing a background climate state. A temporal average essentially undermines the predictability inherent with a trend, since it involves simply taking the arithmetic mean of 30 values without regard to their temporal ordering, effectively smoothing out relative outliers in the first and second halves of the time series.

Truly time-dependent normals exist that do not rely on averaging. For example, L07 shows that a simple regression line can be considered a time-dependent normal. The point in time through which the regression line passes is the normal value for that year. Specifically, L07 proposes a Hinge Fit regression consisting of a constant value through 1975 and a linear fit thereafter. Similarly, the relatively new technique known as Empirical Mode Decomposition (EMD) has been used to define a normals metric. The lowest-order residual time series resulting from EMD analysis of climate time series is purported to represent a climate normal function. Both of these methods may be particularly useful for defining "normal" conditions for time series that exhibit large trends (either positive or negative).

Unweighted. The WMO climate normal is an unweighted average. Every single year in the averaging period imparts the same influence on the normal value. Therefore, the first year of the period has the same influence as the last year. Similarly, the first half of the period exerts the same influence as the second half. As an example, consider the 1971–2000 normals. The 1971–85 subperiod has the same impact as the 1986–2000 subperiod, whereas the individual contributions of the 1971 value and the 2000 value are equivalent. For a climate series that exhibits neither a significant trend nor positive serial autocorrelation, there is little incentive to use a weighted average. However, observations do indicate that significant trends in temperature, for example, exist over many parts of the world. Therefore, it is conceivably advantageous to provide greater weight to more recent data and limit the influence of the earliest values. This could be imposed via the function w in (1). Presumably, w would take the form of a monotonically increasing function (i.e., each successive year would be assigned a greater weight than the previous year). The weights could be determined based on theoretical techniques developed for filtering near endpoints, such as those described by Mann (2004, 2008) and Arguez et al. (2008). Alternatively, empirically determined weights could be utilized based on individual time series characteristics, analogous to the empirical weight exercise employed by Arguez et al. (2008).

Thirty years. Arguably the most intuitive and practical alternative to a 30-yr normal is to average over a different number of years (N). Basing climate normals on 30-yr averages has been standard practice for almost a century now, since the IMO first mandated that member countries provide climate normals for their respective countries. Interestingly, elementary statistics texts often state that a sample size of 30 is the "rule of thumb" threshold for which reliable estimates can be determined.

Considering climate change (e.g., the warming that has occurred over much of the U.S. since the 1970s), one would expect a shorter time interval average would be more representative of the current state of the climate, at the time of reporting, than a 30-yr average. Changing the value of N in (1) results in a simple alternative normal. Technically, this can also be accomplished by fixing N to a large value and removing unwanted years by setting the corresponding values of w to zero, essentially imposing a filtering window. However, we include both parameters N and w to highlight the distinctions between weighted averages and unweighted N-yr averages.

An abundance of anecdotal evidence suggests that the U.S. energy industry, particularly with respect to load forecasting by utilities and rate setting by state agencies, is moving to shorter-term averages for determining "normal" weather (McMenamin 2008; J. Sanderson 2007, personal communication; C. Marple 2007, personal communication; A. Heinen 2007, personal communication; T. Hennessey 2008, personal communication). It is not uncommon for industry representatives to utilize 10-, 15-, and/or 20-yr normals, although the number of years to average over (N) is sometimes determined somewhat arbitrarily and/or a posteriori.

In a 1996 *Journal of Climate* article, Huang et al. developed a method for computing normals based on an "optimal" averaging period (N). These so-called Optimal Climate Normals (OCN) are based on the predictive skill of normals for a 1-yr lead time. Citing practical reasons for choosing fixed averaging periods for the entire United States, their analysis determined that the optimal averaging period is 10 years for temperature normals and 15 years for precipitation normals over the United States. More recently, L07 argued that the N values for computing OCN should be computed separately for each of a station's annually sampled time series. It is easily shown that for stations exhibiting near-zero trends, the N value determined by the OCN technique is typically greater than 30 years. This is because, for a seemingly stationary time series, the best estimate results when the largest possible sample is included in the average. For time series with very large trends—regardless of sign—the OCN technique as described in L07 can result in N values much smaller than 30 (in practice as low as 5 years) for U.S. monthly temperatures.

Causal filter. Time-series filtering is used to extract salient time scales from time series, often to "smooth out" high-frequency variations. A causal filter is a filter in which the output value—the filtered value—is a function of past and/or present values only. The implication is that the current filtered value was "caused" by the previously recorded conditions. The standard WMO climate normal is essentially computed as a causal filter, since it is calculated retrospectively. This is inferred from (1) because the index of y is identical to the upper summation limit, meaning that the normal value is a function of past and present values only.

This stands in sharp contrast to acausal filters, which depend on "future" values. Acausal filtering, such as using conventional running means, typically results in filtered values that depict the midpoint of the filtering range. Thus, acausal filters are often referred to as *centered* filters. For example, a 5-month running average of August–December 2010 temperature values represents a smoothed value for October 2010. Consequently, the filtered value for October cannot be computed until data for December are available.

Following this alternate convention, it is reasonable to regard the 1971–2000 climate normals as indications of typical climate conditions for 1985/1986, which is the midpoint of the averaging range. The next recommended installment of WMO climate normals (covering 1981–2010) will be released no sooner than 2011. Until this product release, the "current" climate normals will be, arguably, up to ~25 years out-of-date. However, note that even when a new product is released every decade, the *centering* aspect of filter theory implies that standard WMO climate normals will always be *at least* 15 years out-of-date.

There are several ways to alter the normals metric definition such that the output value is indicative of the time of computation, rather than indicative of the middle of the averaging range. One indirect option was discussed earlier: using filter weights, determined either empirically or theoretically, to allow more recent observations to exert more influence on the average. However, a truly centered, acausal solution requires extrapolation, inevitably injecting some degree of prediction error. Predicting future values can either be accomplished via statistical methods (such as autoregressive models) or via downscaled climate model projections. A 30-yr average centered on today could be computed from the most recent 15 years of observations, along with the forecast for the next 15 years. In work commissioned by the U.K. energy industry, the Met Office Hadley Centre has used an analogous approach to update the climatological temperature baselines used in energy demand planning. A dynamical decadal prediction system was used to "extend" observed historical temperature records into the future. The long-term temperature average centered on the current year, or any year in the forthcoming decade, was then calculated using a mix of observed and predicted temperatures (personal communication, Richard Graham).

Decadal updates. The WMO mandates member countries to compute 30-yr normals once every 30 years (1901–30, 1931–60, 1961–90, 1991–2020, etc.), but recommends that member countries create decadal updates as well. Presuming stationarity, the true mean background state (μ) would not fluctuate from one decade to another (or from one 30-yr period to another), yet differences between decadal updates would mostly highlight long-term variability (and shorter-term variability to a lesser extent) superimposed on a constant background state. Conversely, if we presume a trend exists in the data record, then decadal updates become essential for monitoring such a trend's effects on what is considered "normal." In fact, a prominent trend would warrant that updates be initiated as frequently as possible. The obvious alternative to a decadally updated climate normal is to update the 30-yr average annually—setting Δt equal to 1 yr in (1)—as recommended in L07. Simple calculations using monthly mean temperature data demonstrate that for station-month time series exhibiting strong relative trends, annually updated climate normals can outperform decadally updated normals over 90% of the time as the decadal average becomes more out-of-date during the intervening decade between calculations of standard WMO climate normals. This effect is magnified for member nations that only compute normals every 30 years.

CONCLUSIONS. The standard WMO climate normal is a useful, albeit imperfect, metric. Indeed, no metric can be perfect by definition. Climate change, and in particular significant nonzero trends in climate time series, renders the standard WMO climate normal less useful. For use as a reference period average for computing climate anomalies, climate normals retain their usefulness despite climate change, although updating the reference period can lead to dramatic changes in the anomaly values (and their interpretations). Climate monitoring centers should proceed with caution if and when base periods are changed for computing real-time anomalies. If we accept that climate conditions are indeed nonstationary, then for the purposes of providing more accurate depictions of current and future climate conditions, climate normals should be 1) updated as frequently as possible (i.e., annually); and/or 2) computed in an alternative manner. Alternative approaches include choosing $N \neq 30$, computing climate normals as an acausal filter, using a weighted average, and/or redefining "normal" as some quantity other than an average.

Note that we have focused on the definition of the climate-normals metric, which is a statistical construct. While the statistical definition is universal, the real-world applicability of a particular alternative is not. For example, it is highly likely that the best alternative for monthly temperature normals will differ for monthly precipitation normals; consider the possibility of defining "normal" as a 15-yr average for the former and a 40-yr median for the latter. Further, varying underlying time series characteristics, such as trend and residual autocorrelation (L07), result in seasonal and regional disparities in the performance of particular alternative techniques. These issues need to be considered in any evaluation of alternative techniques.

Clearly, the standard WMO climate normal is not ideal in an era of observed climate change. Future work should be undertaken to identify a thorough list of alternative climate normals, conduct an evaluation of all viable techniques, and recommend and provide specific alternative normals products to stakeholders and decision makers. It is our contention that accurate depictions of current and future climate conditions necessitate the development of alternative climate normal products.

ACKNOWLEDGMENTS. The authors kindly thank R. Graham, T. Peterson, P. Thorne, and T. Karl for fruitful discussions on this topic, as well as M. Kruk and M. Squires for reviewing earlier versions of this manuscript. The authors also appreciate the instructive comments of several anonymous reviewers. Partial support for this work was provided by the Office of Biological and Environmental Research, U.S. Department of Energy (Grant number DE-AI02-96ER62276).

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The Integrated Surface Database

Recent Developments and Partnerships

BY ADAM SMITH, NEAL LOTT, AND RUSS VOSE

Hourly surface-based meteorological observations are the most-used, most-requested type of climatological data, but historically they have been scattered across multiple repositories worldwide in a variety of disparate formats. This greatly complicated the life of the end user and significantly increased the cost of data usage. To address this problem, in 1998 NOAA's National Climatic Data Center (NCDC) initiated the Integrated Surface Database (ISD) project. The goal of the project was to merge numerous surface hourly datasets into a common format and data model, thus providing a single collection of global hourly data for the user that was continuously updated and available. Additional benefits of integration include the reduction of subjectivity and inconsistencies among datasets that span multiple observing networks and platforms; standardized quality control (QC) based on reporting time resolution (e.g., a QC methodology for hourly temperature data independent of network); and products that are more easily developed and improved by collective experience and expertise.

The outcome of this effort is a dataset containing data from more than 100 original data sources that collectively archived hundreds of meteorological variables. The primary data sources include the Automated Surface Observing System (ASOS), Automated Weather Observing System (AWOS), Synoptic, Airways, METAR, Coastal Marine (CMAN), Buoy, and various others, from both military and civilian stations including both automated and manual observations. "Summary of day" parameters such as maximum/minimum temperature, 24-h precipitation, and snow depth are also included in ISD, to the extent that they are reported in the hourly data sources. Also, for ASOS sites, the daily summaries transmitted by each station are now being ingested into ISD. Some of the most common meteorological parameters include wind speed and direction, wind gust, temperature, dew point, cloud data, sea level pressure, altimeter setting, station pressure, present weather, visibility, precipitation amounts for various time periods, and snow depth. Total data

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CORRESPONDING AUTHOR: Adam Smith, NOAA's National Climatic Data Center, Federal Building, 151 Patton Avenue, Asheville, NC 28801-5001
E-mail: Adam.Smith@noaa.gov

DOI:10.1175/2011BAMS3015.1

Stewardship of the Fitchburg-Waubesa Artesian System

Significance of the

Buried Bedrock Valleys & the *Eau Claire Sea*

Further Research

Calvin B. DeWitt
Gaylord Nelson Institute
University of Wisconsin-Madison

The Groundwater System
What do we believe so far?

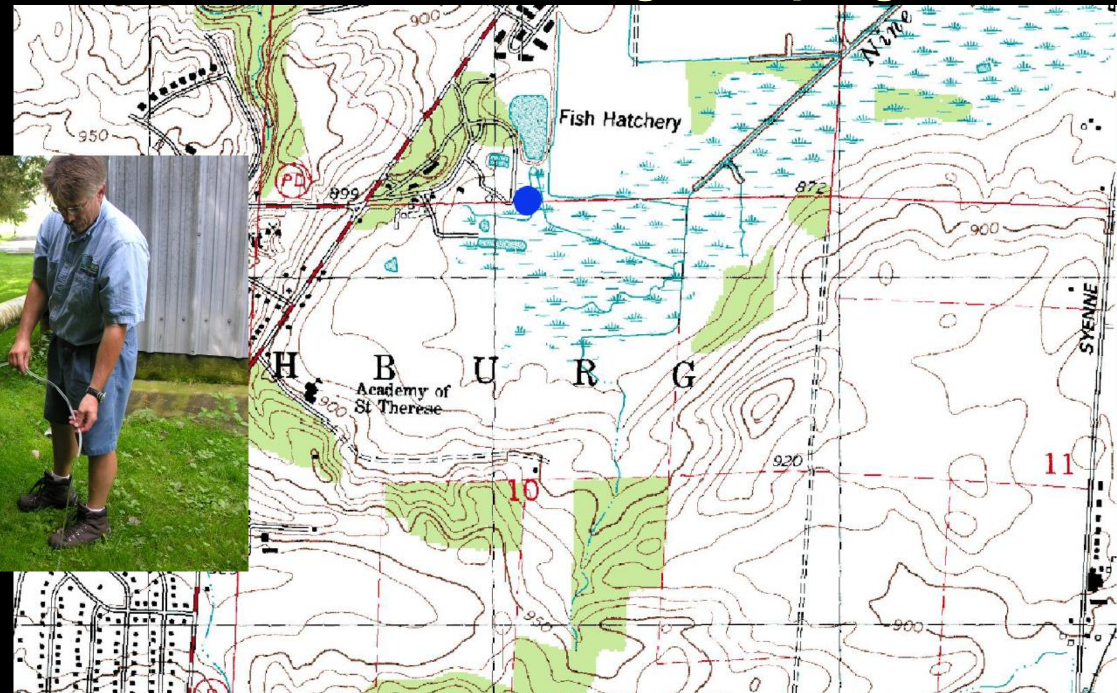
At this point we believe that:

- Two aquifers lie below us, with an aquitard between.
- This aquitard limits vertical water flow, except in cracks.
- Both aquifers ultimately get their water from above.
- Municipal wells pump at 800-1000 feet from the lower aquifer.
- Rural wells pump at 50 to 200 feet from the upper aquifer.

The aquitard is sedimentary rock---Eau Claire shale formed layer by layer in bedded sediments that settled under an ancient sea

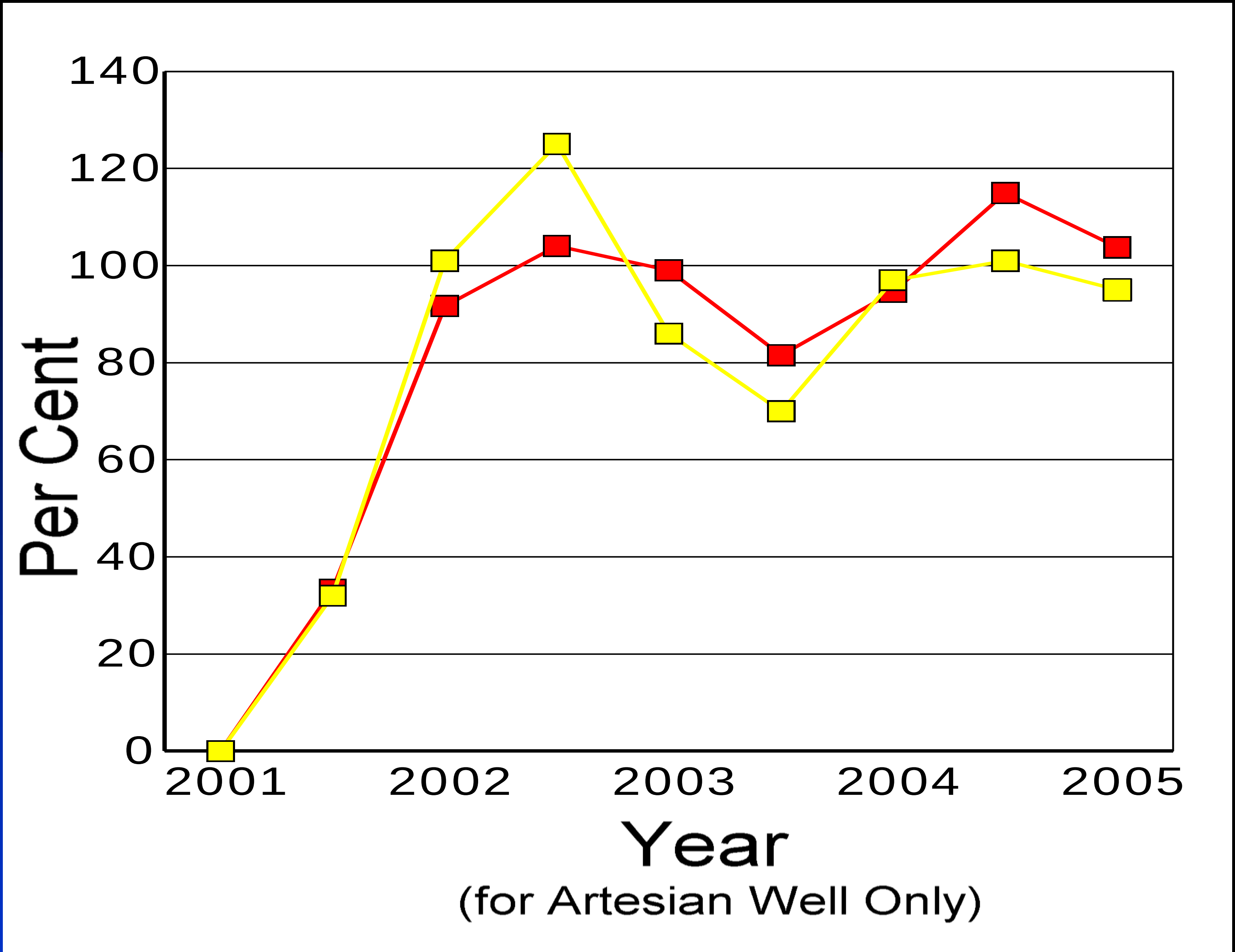
…….But we also have found that…

…there is a connection between DNR Artesian Well #8 …and Fitchburg Pumping Well #10.



Relationship of Wells #8 & 10

- The outflow of DNR Well #8 corresponds with the pumpage of Fitchburg Well #10.
- At first this lag is about 18 months, then after half a year it is about 12 months, and after another half year about 6 months.
- When these lags of 18, 12, and 6 months are used, we get the following graph
- (#8 is in yellow, #10 in red):

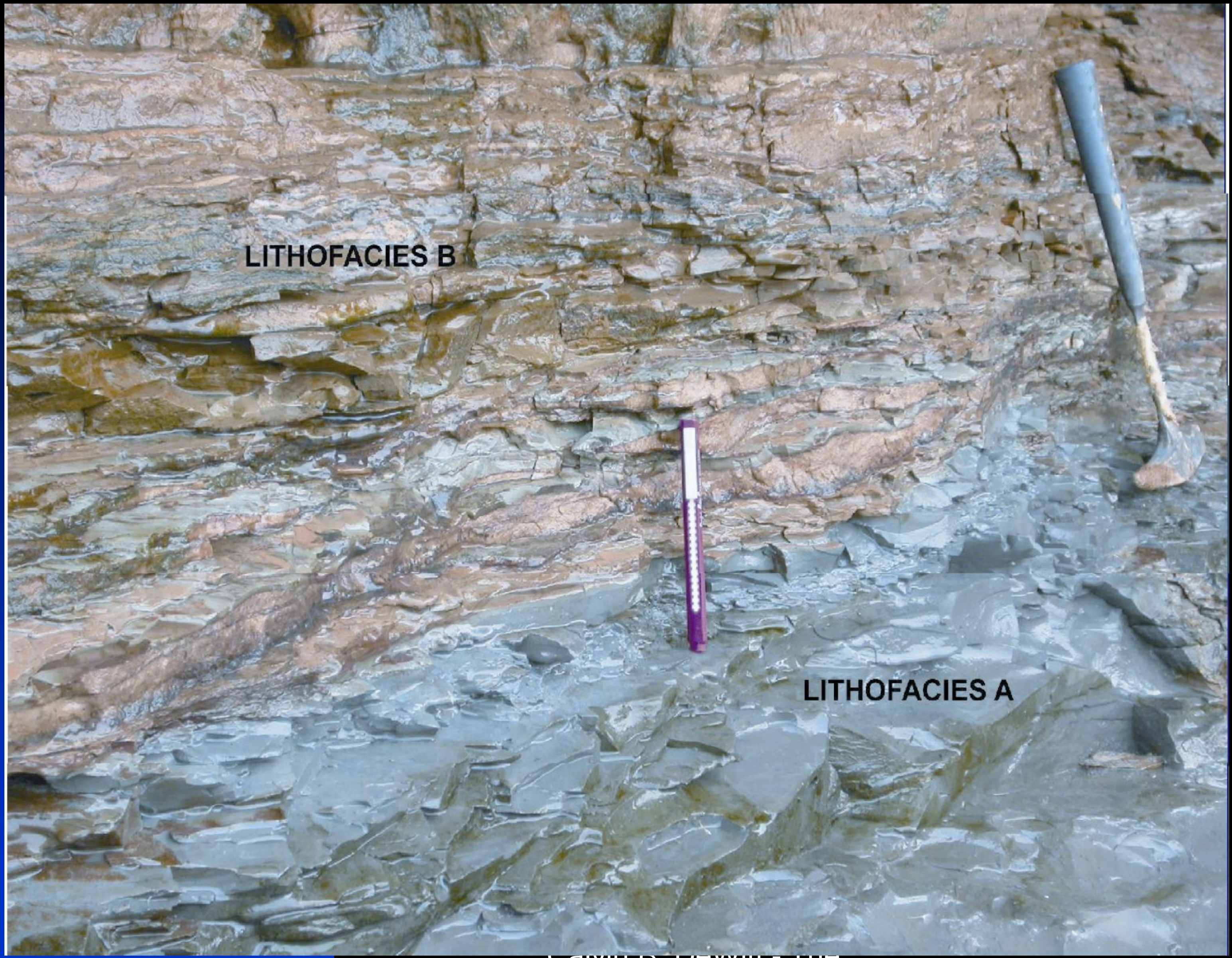

140
120
100
80
60
40
20
0
Per Cent
2001
2002
2003
2004
2005
Year
(for Artesian Well Only)

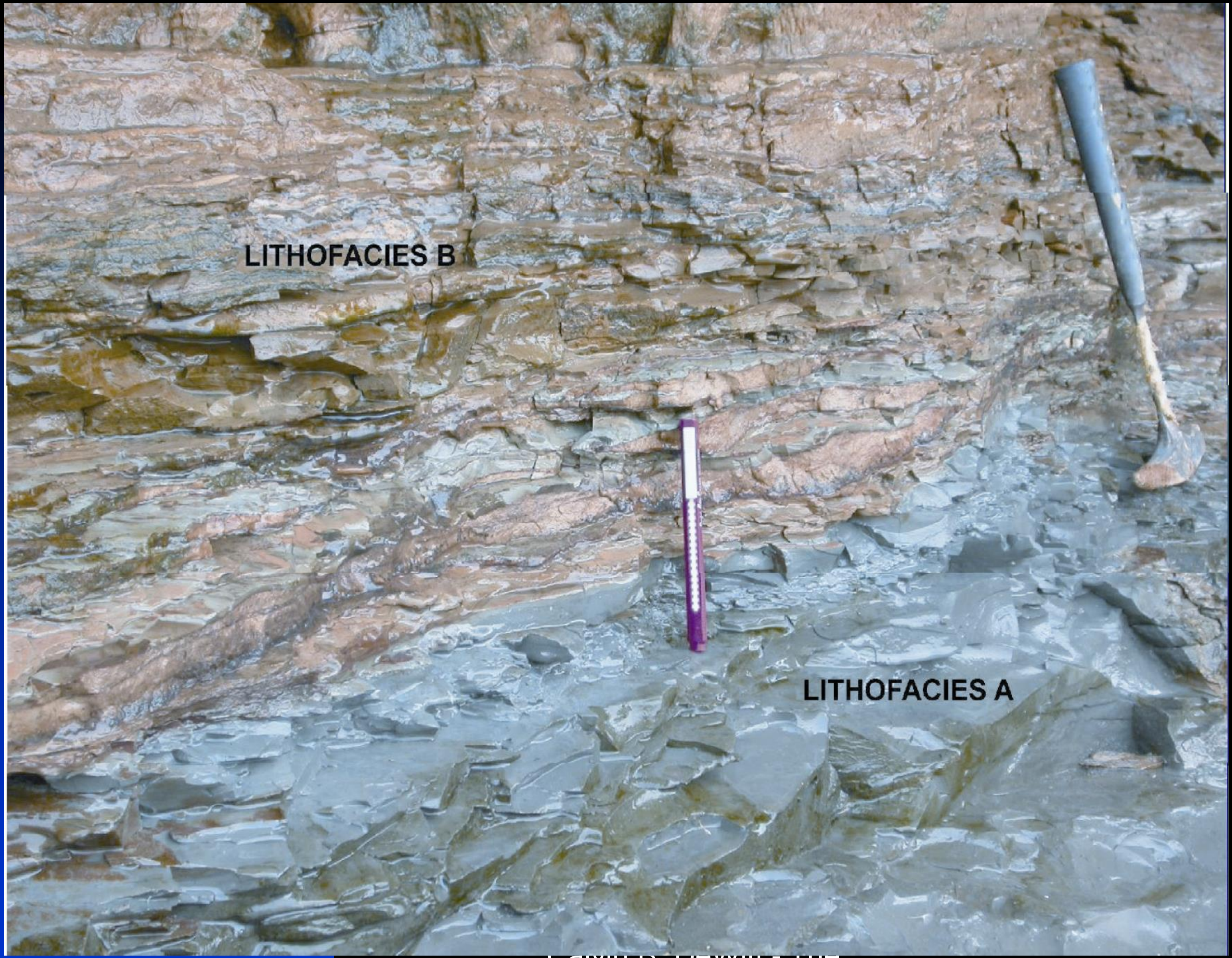
We therefore have discovered:

- There is a connection between Municipal Well #10 and Nevin Artesian Well #8
- Since the Nevin Artesian Well is 180 feet deep, there is a connection between the upper and lower aquifers
- The lag of the effect of Well # 10 on Nevin # 8 was at first about 18 months and now is about 6 months;
- The distance between wells is about 5505 feet.
- This means that the flow rate between these two wells is approximately 5505 feet per 365 days or approximately 30 feet (9.1 meters) per day.

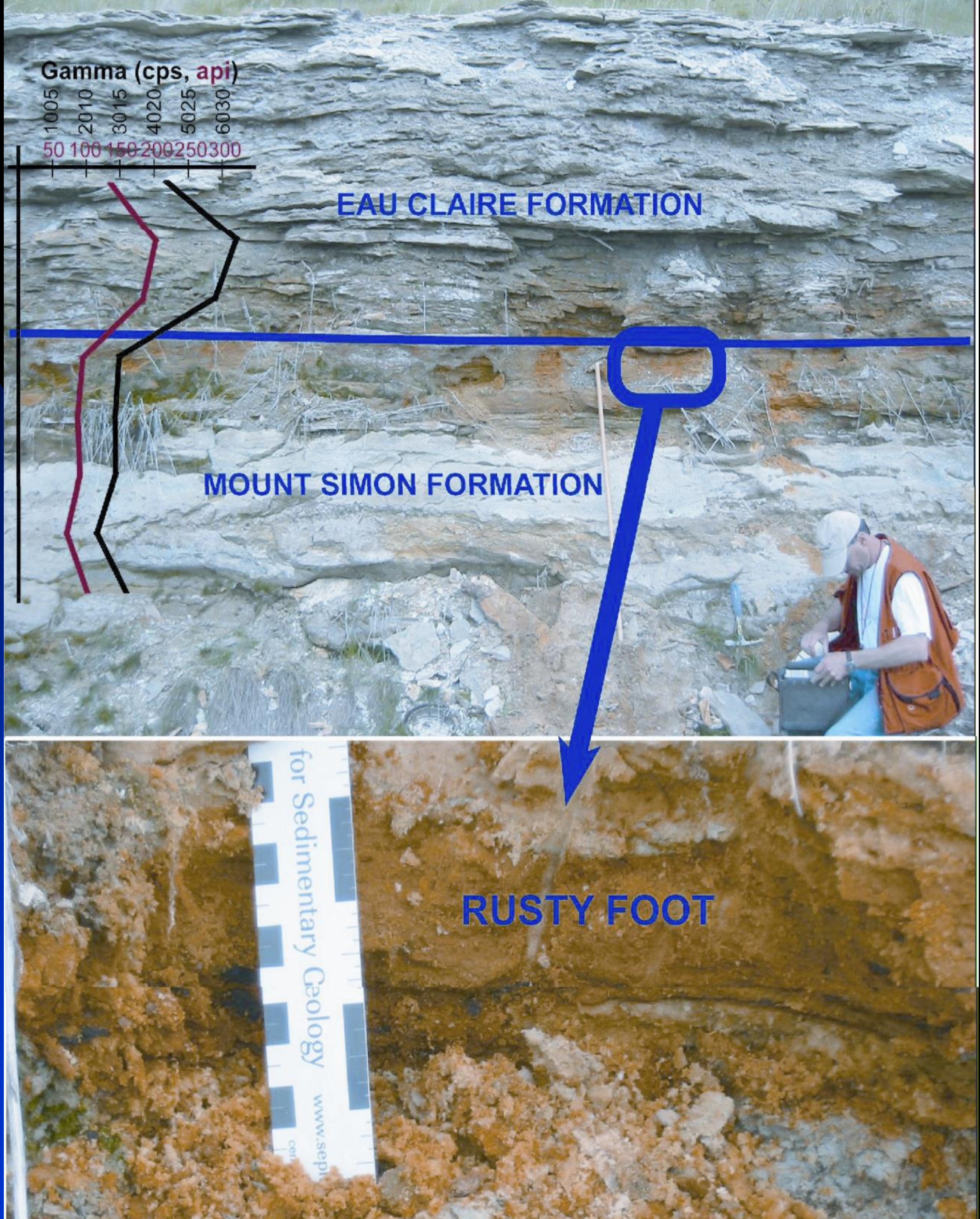
"…there is a connection between the upper and lower aquifers."

- This is our conclusion from our seeing that Well #10 pumpage corresponds with Well # 8 flowage.
- Does this mean that the Eau Claire Aquitard might be missing?
- Has the Eau Claire Aquitard been cut through?
- Let's find out….

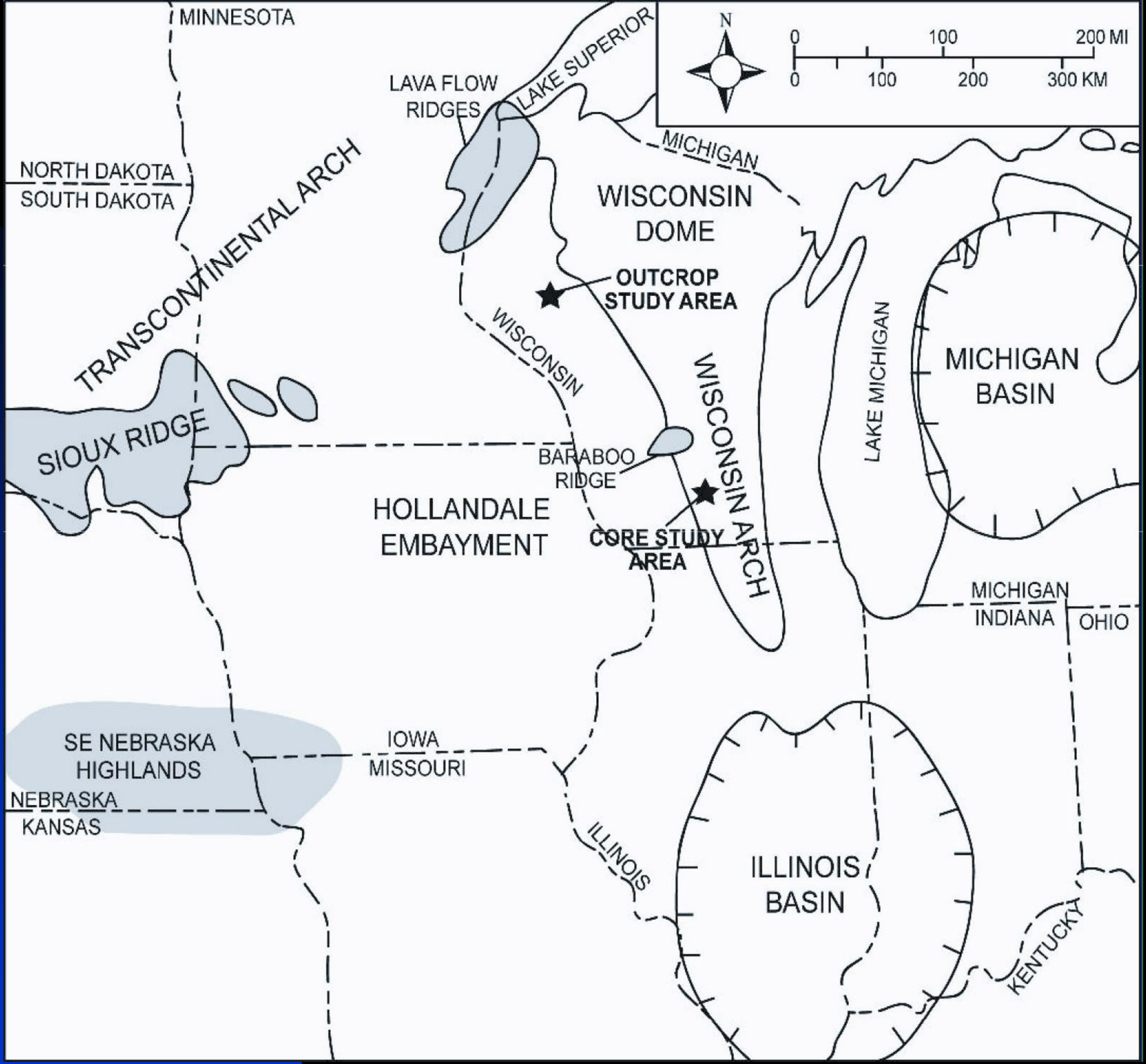

LITHOFACIES B
LITHOFACIES A

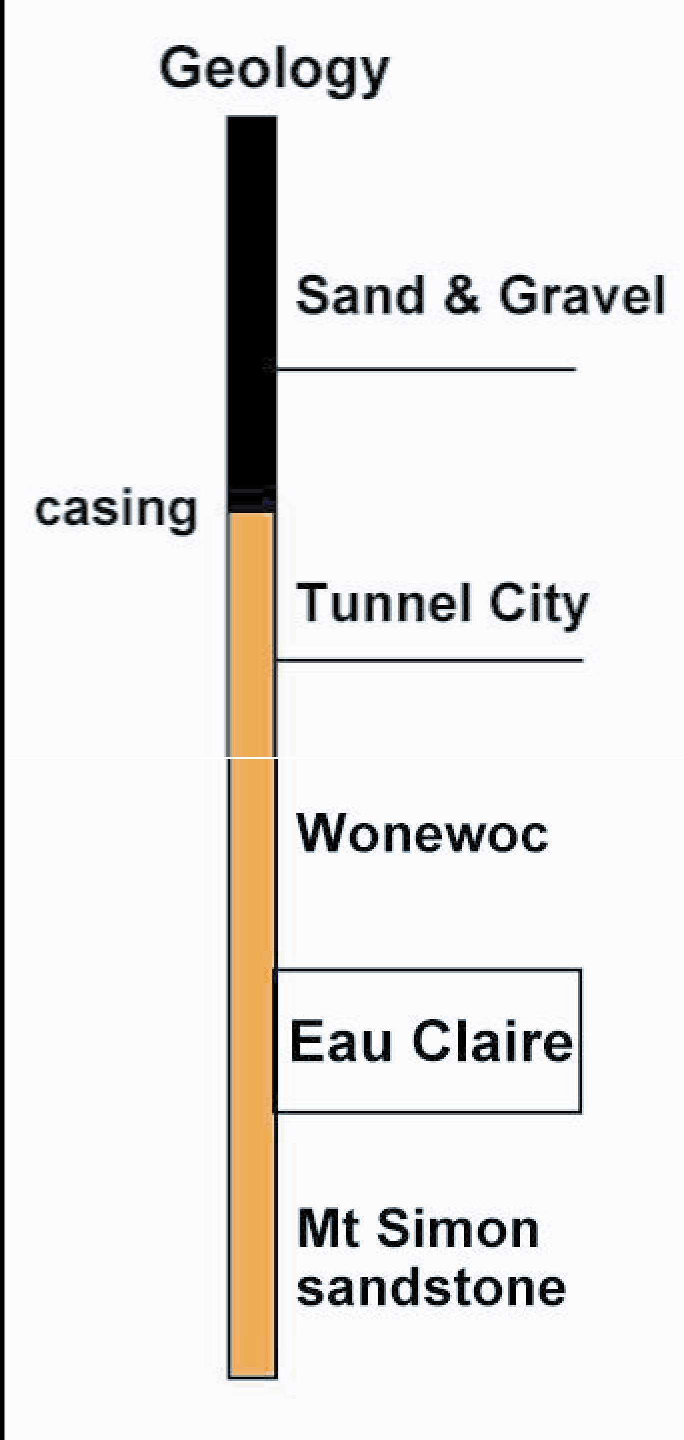

LITHOFACIES B
LITHOFACIES A

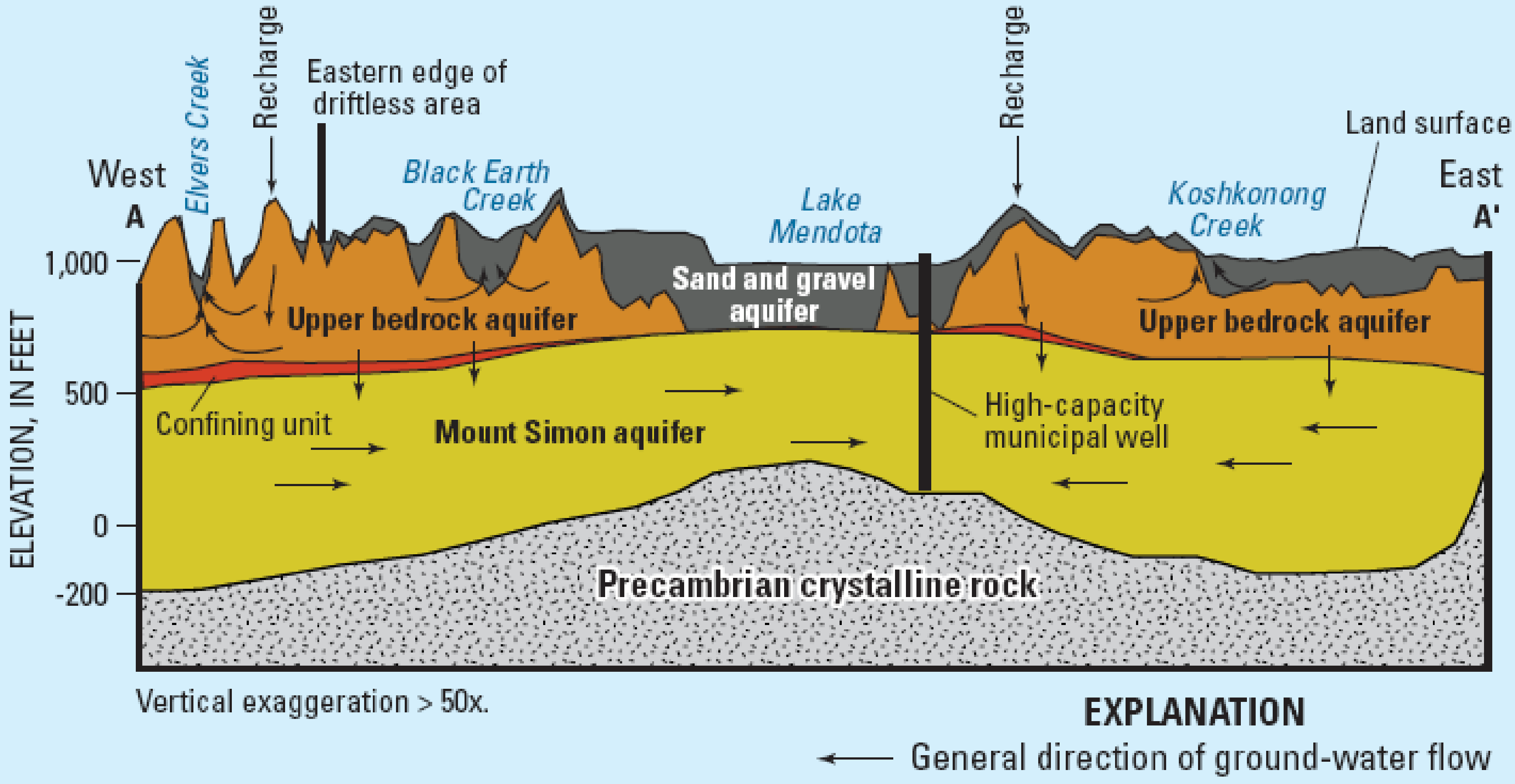

Sharpie



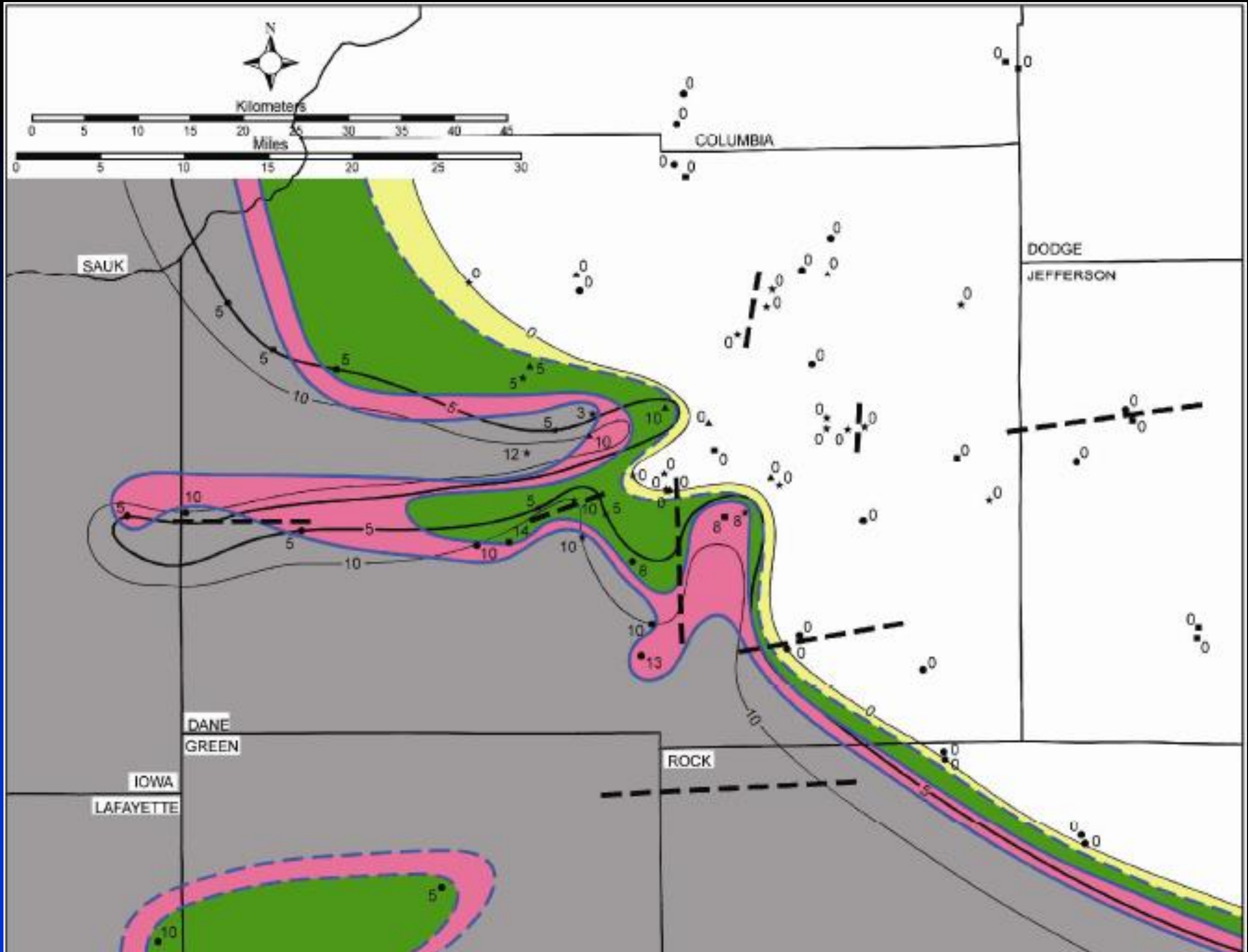
Gamma (cps, api)
1005
2010
3015
4020
5025
6030
50 100 150 200 250 300
EAU CLAIRE FORMATION
MOUNT SIMON FORMATION
RUSTY FOOT
for Sedimentary Geology


MINNESOTA
LAKE SUPERIOR
N
0
100
200 MI
0
100
200
300 KM
LAVA FLOW
RIDGES
MICHIGAN
NORTH DAKOTA
SOUTH DAKOTA
TRANSCONTINENTAL ARCH
WISCONSIN
DOME
OUTCROP
STUDY AREA
WISCONSIN
WISCONSIN ARCH
LAKE MICHIGAN
MICHIGAN
BASIN
SIOUX RIDGE
BARABOO
RIDGE
HOLLANDALE
EMBAYMENT
CORE STUDY
AREA
MICHIGAN
INDIANA
OHIO
SE NEBRASKA
HIGHLANDS
IOWA
MISSOURI
NEBRASKA
KANSAS
ILLINOIS
ILLINOIS
BASIN
KENTUCKY

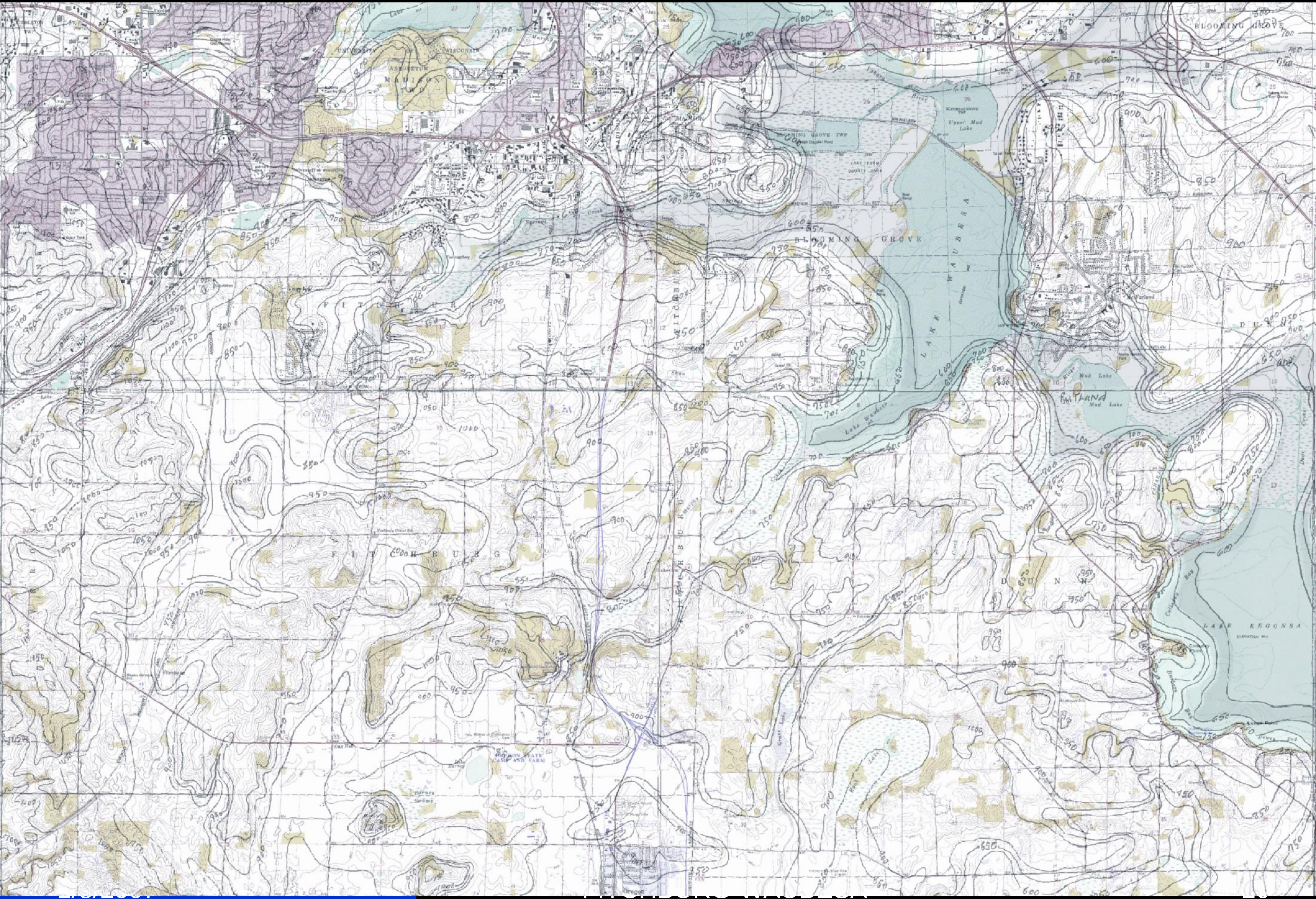

Geology
Sand & Gravel
casing
Tunnel City
Wonewoc
Eau Claire
Mt Simon sandstone



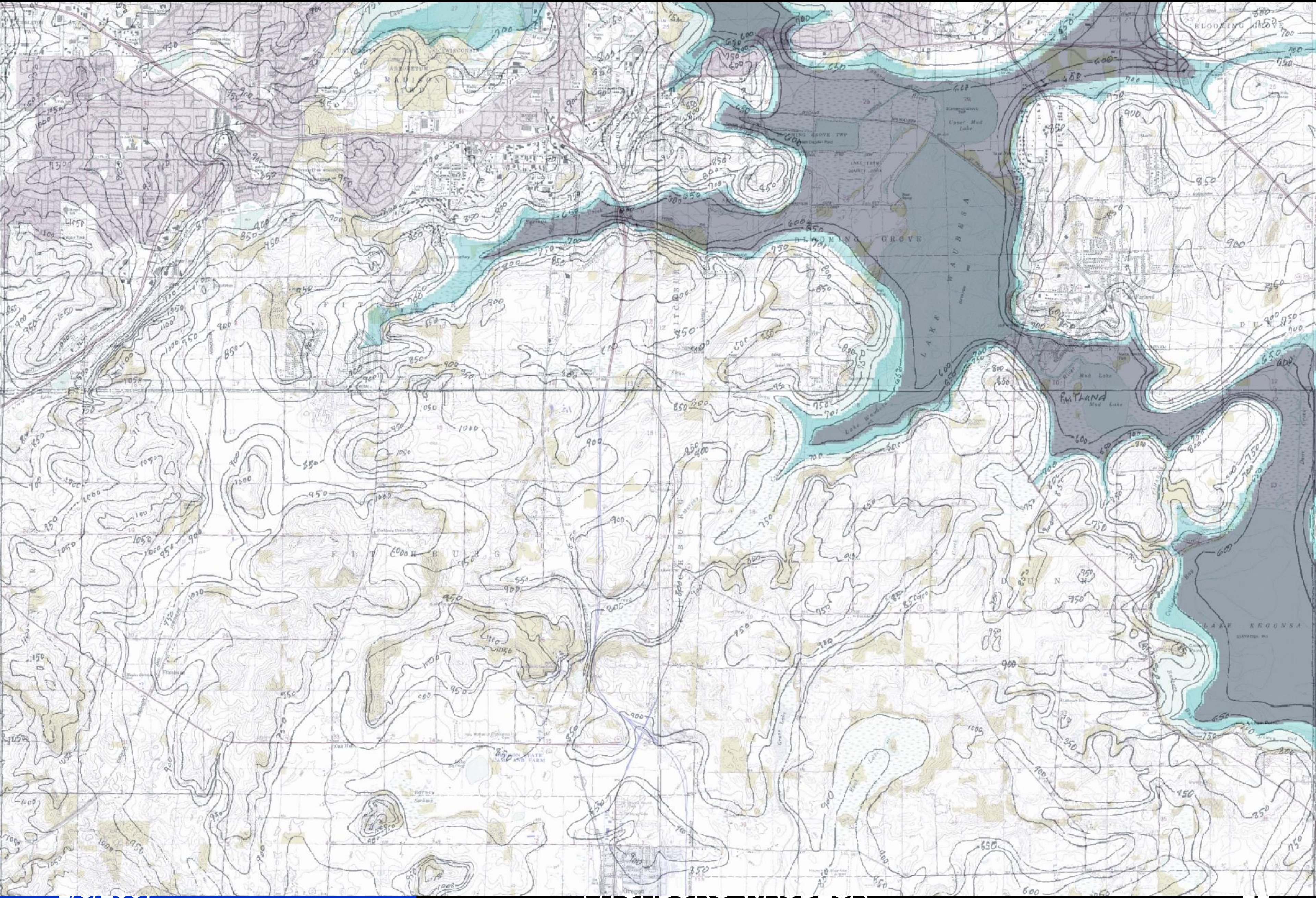
West-East cross section showing the upper aquifers and the lower (Mount Simon) aquifer. Schematic flow-lines also are included to illustrate the local and regional ground-water flow that occurs in the county.

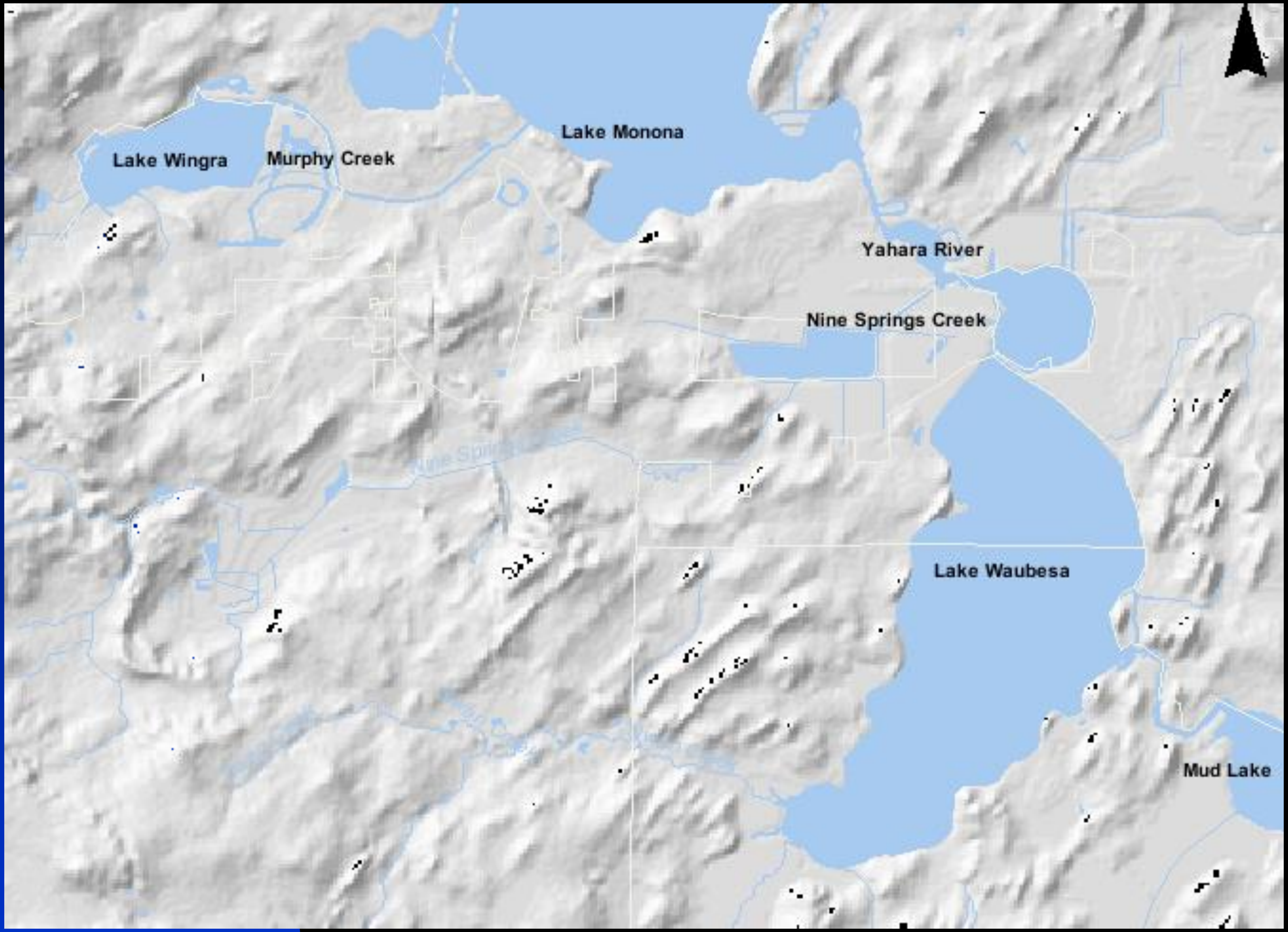


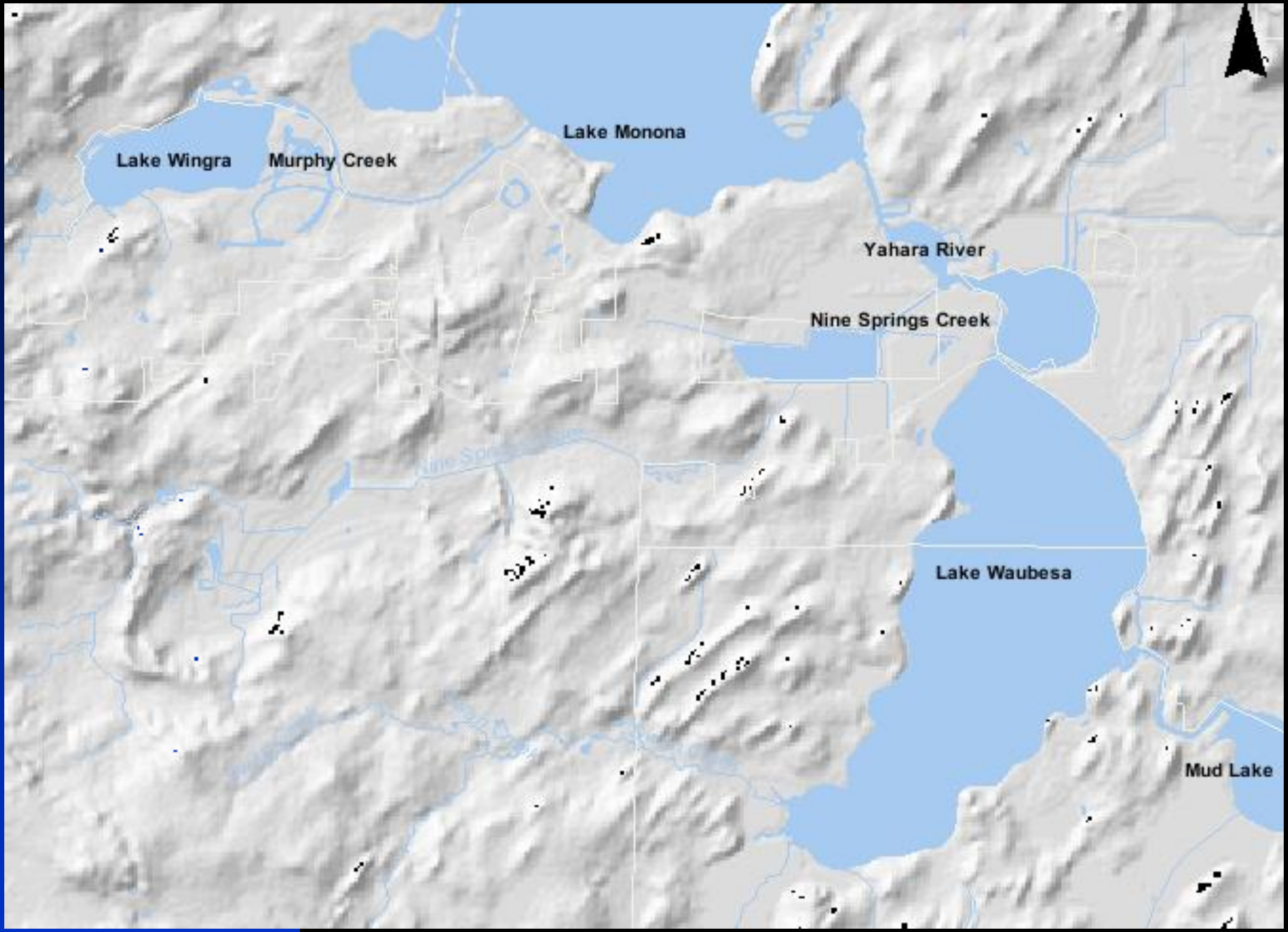
ARTESIAN SYSTEM

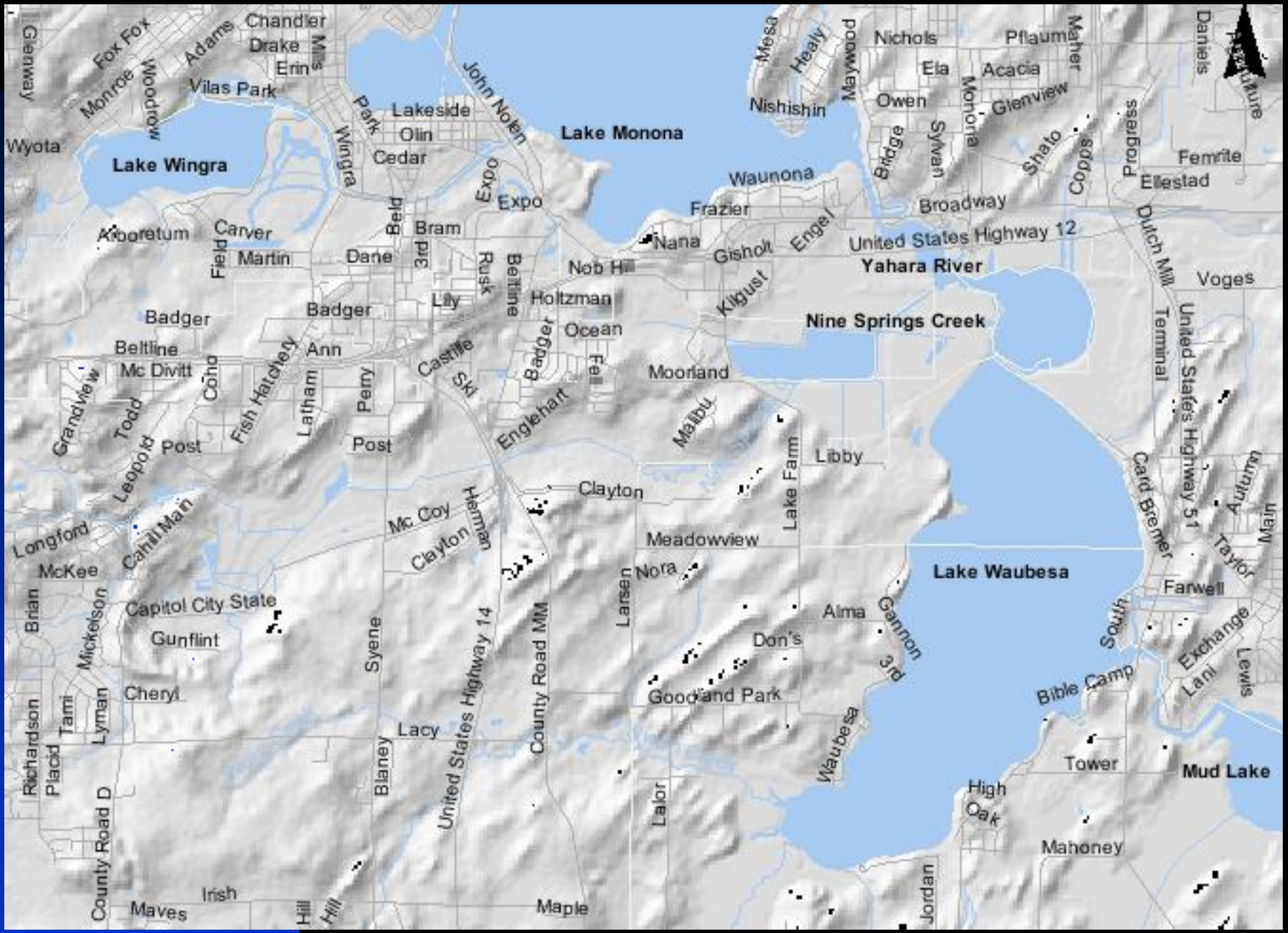


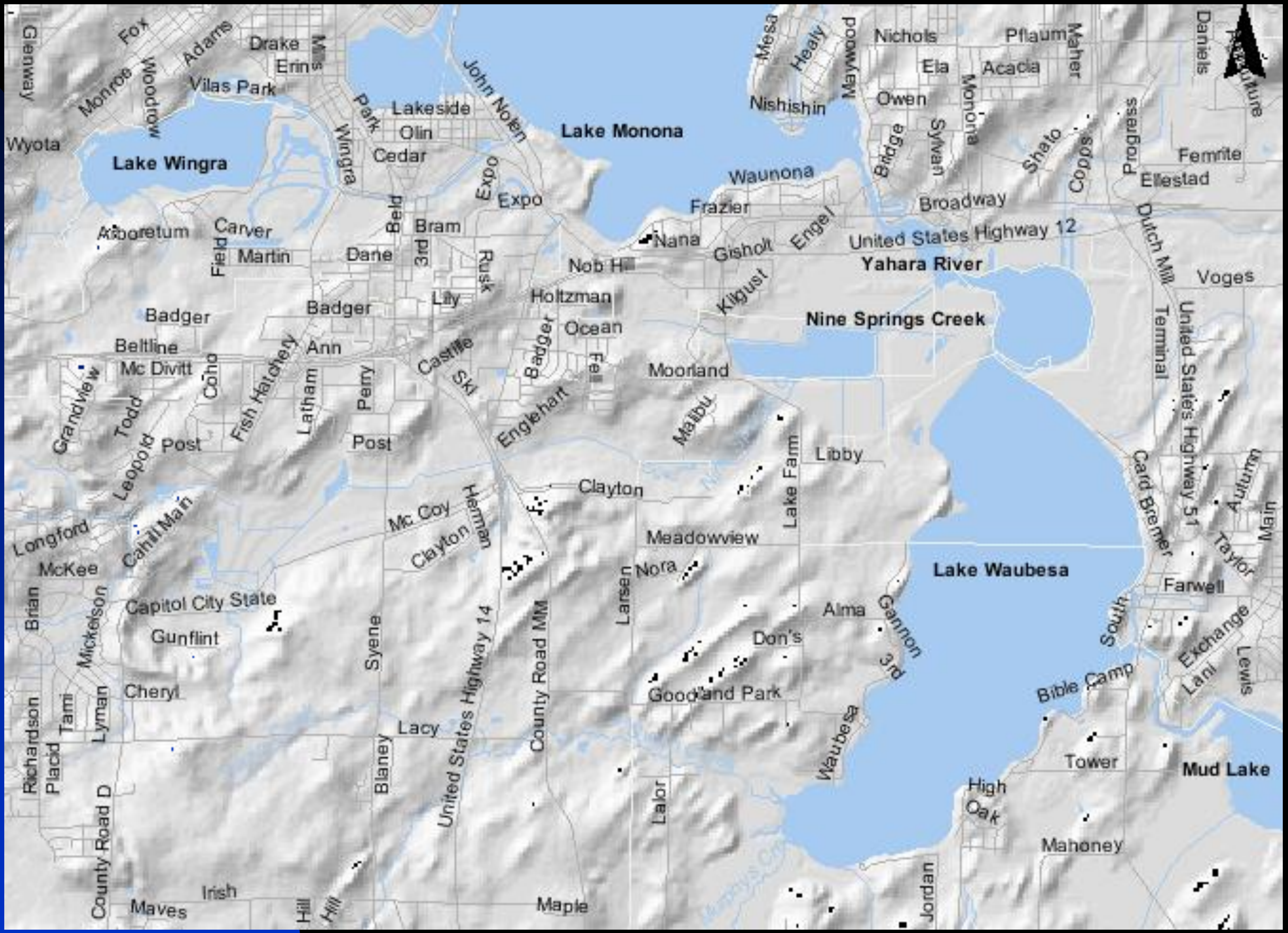
ARTESIAN SYSTEM


BLOOMING GROVE
LAKE WAUBESA
Mud Lake
LAKE KEGONSA


Lake Monona
Lake Wingra
Murphy Creek
Yahara River
Nine Springs Creek
Lake Waubesa
Mud Lake


Lake Wingra
Murphy Creek
Lake Monona
Yahara River
Nine Springs Creek
Lake Waubesa
Mud Lake


Lake Monona
Lake Wingra
Yahara River
Nine Springs Creek
Lake Waubesa
Mud Lake
United States Highway 12
United States Highway 14
United States Highway 51
County Road MM
County Road D


Lake Monona
Lake Wingra
Lake Waubesa
Mud Lake
Yahara River
Nine Springs Creek
United States Highway 12
United States Highway 14
United States Highway 51
County Road MM
County Road D
Glenway
Fox
Adams
Drake
Erin
Mills
Monroe
Woodrow
Vilas Park
Wyota
Park
Lakeside
Olin
Cedar
Wingra
John Nolen
Expo
Beld
Bram
3rd
Rusk
Arboretum
Carver
Martin
Field
Dane
Badger
Lily
Holtzman
Ocean
Beltline
Mc Divitt
Coho
Fish Hatchery
Ann
Latham
Perry
Castle
Ski
Englehart
Fell
Grandview
Todd
Post
Leopold
Moorland
Malibu
Mesa
Healy
Maywood
Nishishin
Nichols
Ela
Acacia
Owen
Monona
Pflaum
Maher
Daniels
Bridge
Sylvan
Shato
Copps
Progress
Femrite
Ellestad
Waunona
Frazier
Broadway
Nana
Gisholt
Engel
Nob Hill
Kilgust
Dutch Mill
Voges
Terminal
Libby
Lake Farm
Clayton
Mc Coy
Herman
Longford
Cahill Main
McKee
Meadowview
Nora
Card Bremer
Autumn
Main
Taylor
Farwell
Capitol City State
Gunflint
Brian
Mickelson
Syene
Larsen
Alma
Gannon
Don's
South
Exchange
Lani
Lewis
Cheryl
Goodland Park
3rd
Bible Camp
Richardson
Placid
Tami
Lyman
Lacy
Blaney
Waubesa
Tower
High Oak
Lalor
Mahoney
Maves
Irish
Hill
Maple
Jordan


Lake Monona
Lake Wingra
Lake Waubesa
Mud Lake
Yahara River
Nine Springs Creek
United States Highway 12
United States Highway 14
United States Highway 51
County Road MM
County Road D
John Nolen
Chandler
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Goodland Park
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Bible Camp
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Maves
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Maple
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Lake Monona
Lake Wingra
Lake Waubesa
Mud Lake
Yahara River
Nine Springs Creek
Nine Springs
Swan Creek
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United States Highway 14
United States Highway 51
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Capitol City State
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Wingra
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Arboretum
Carver
Field
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Nob Hill
Holtzman
Lily
Badger
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Beltline
Mc Divitt
Coho
Fish Hatchery
Castille
Ski
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Fen
Moorland
Grandview
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Malibu
Libby
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Pflaum
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Dutch Mill
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Bible Camp
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Tower
High Oak
Mahoney


Lake Monona
Lake Wingra
Lake Waubesa
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Yahara River
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United States Highway 12
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County Road MM
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Arboretum
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Nine Springs Creek
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United States Highway 12
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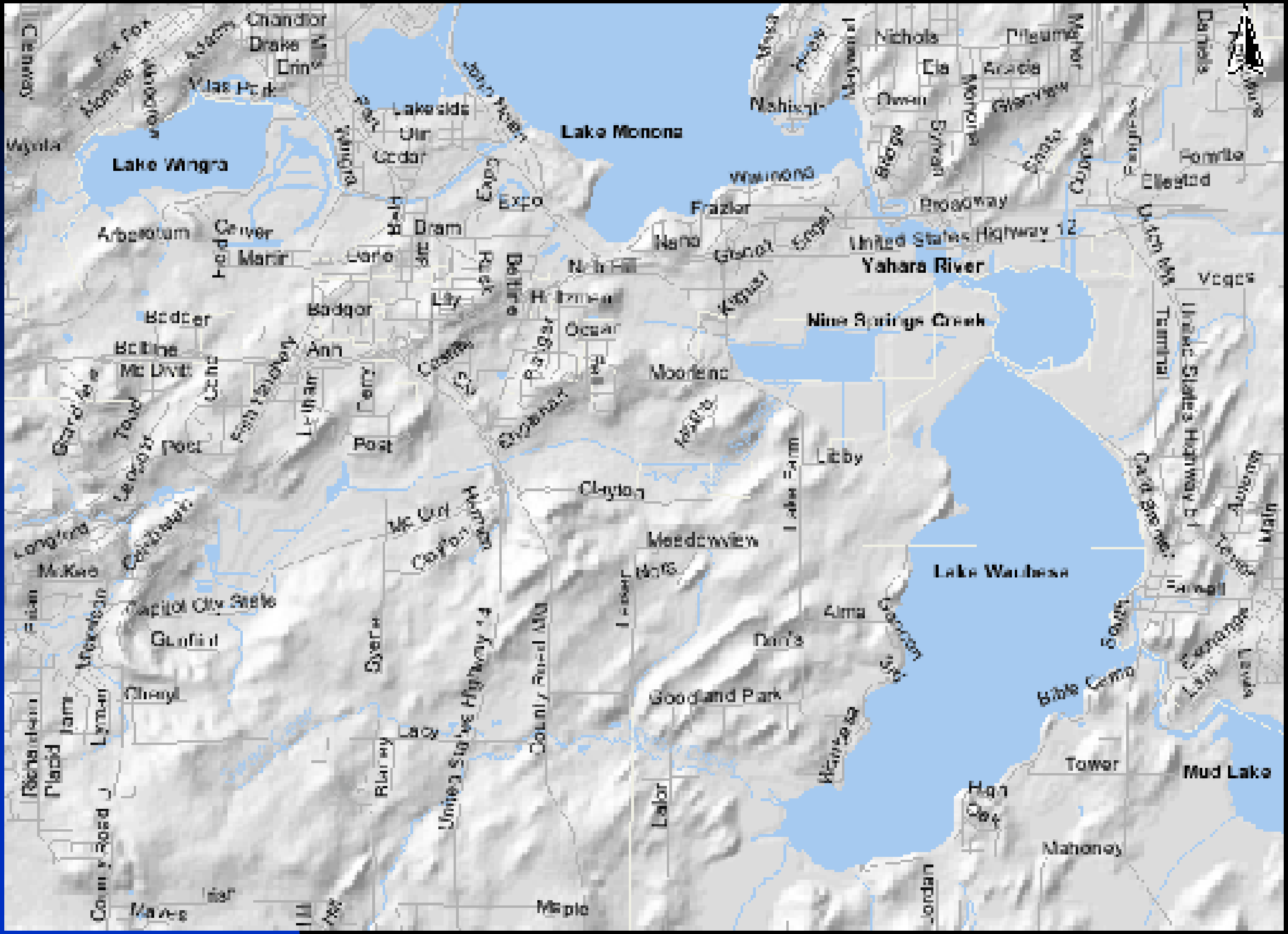
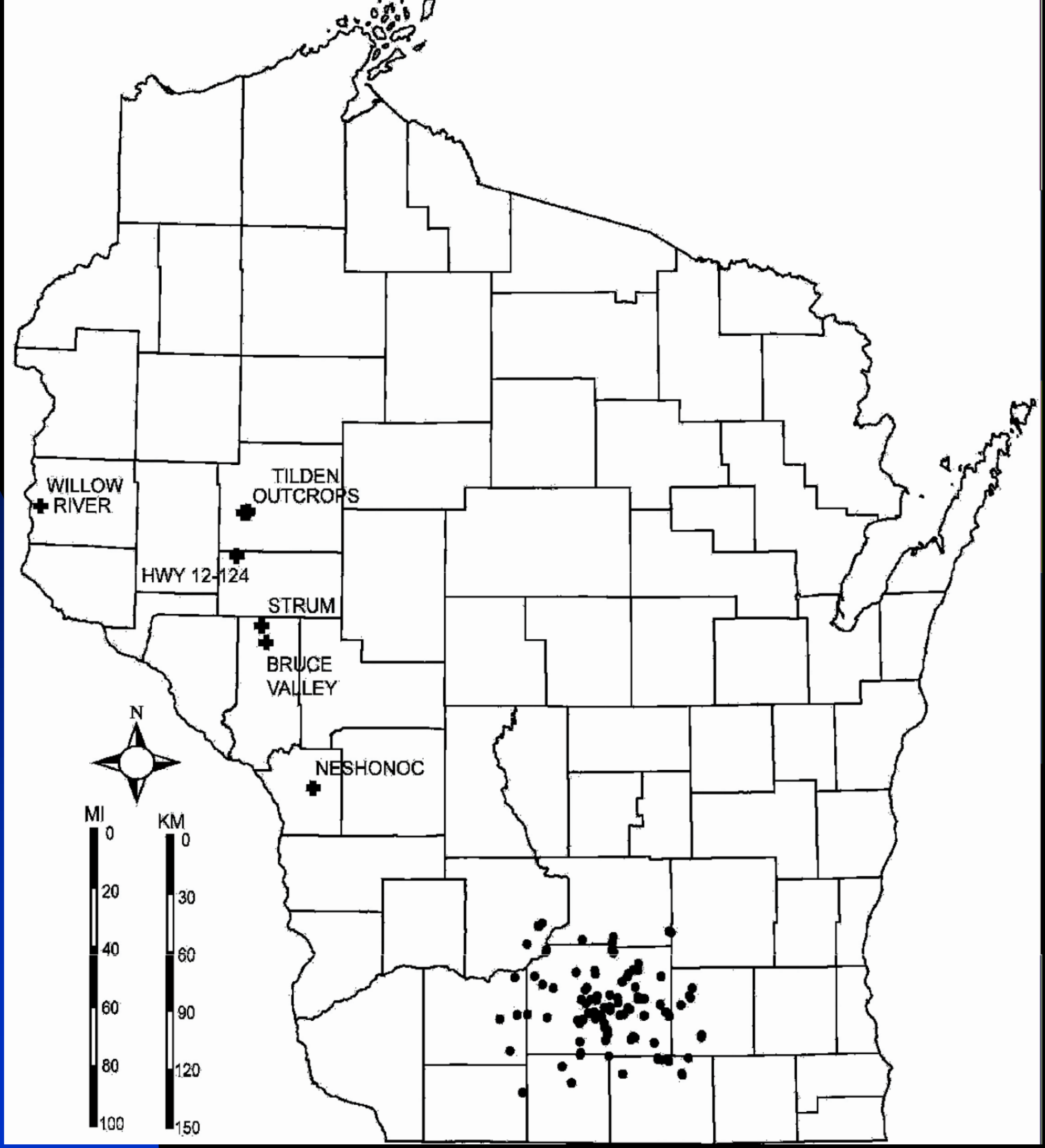
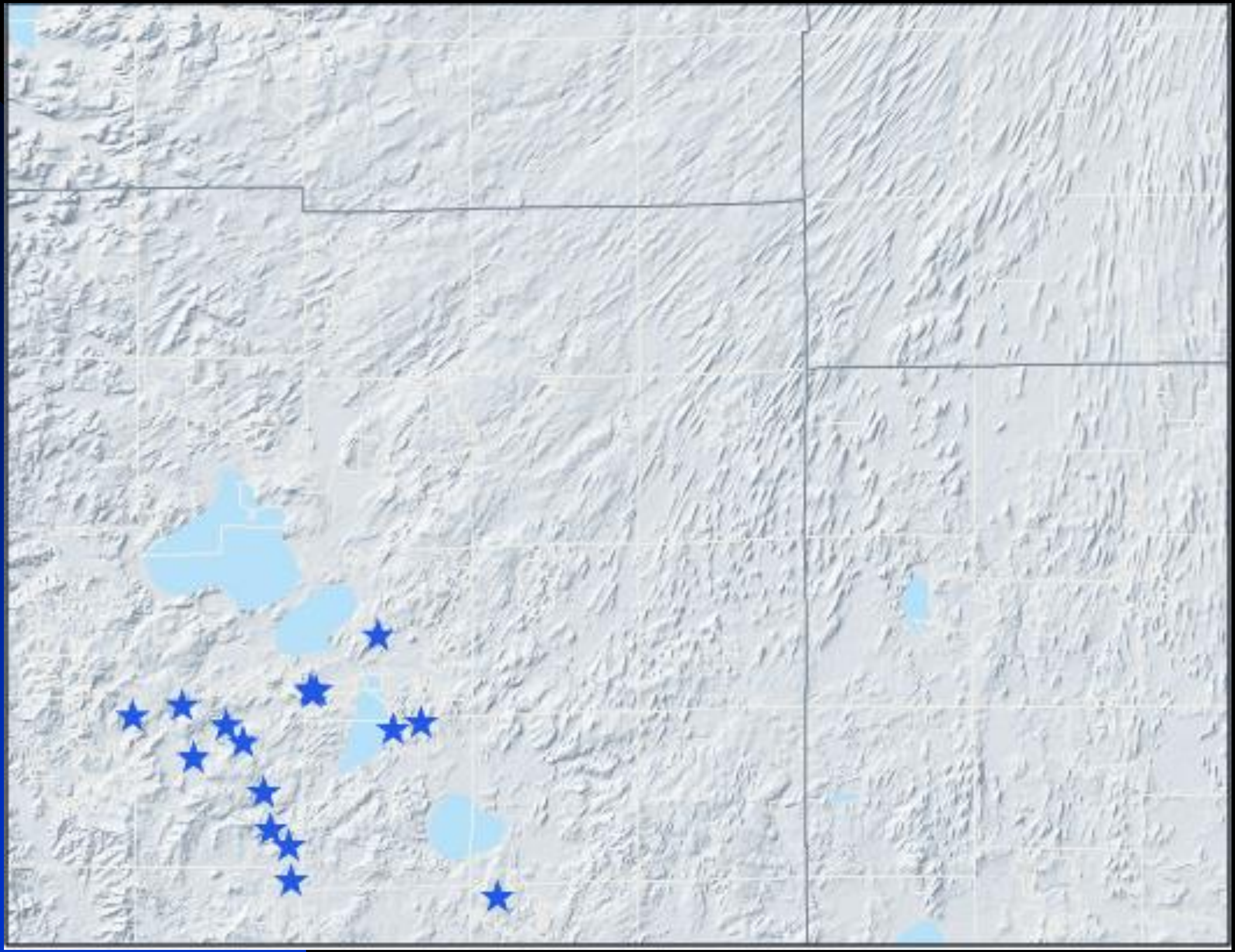
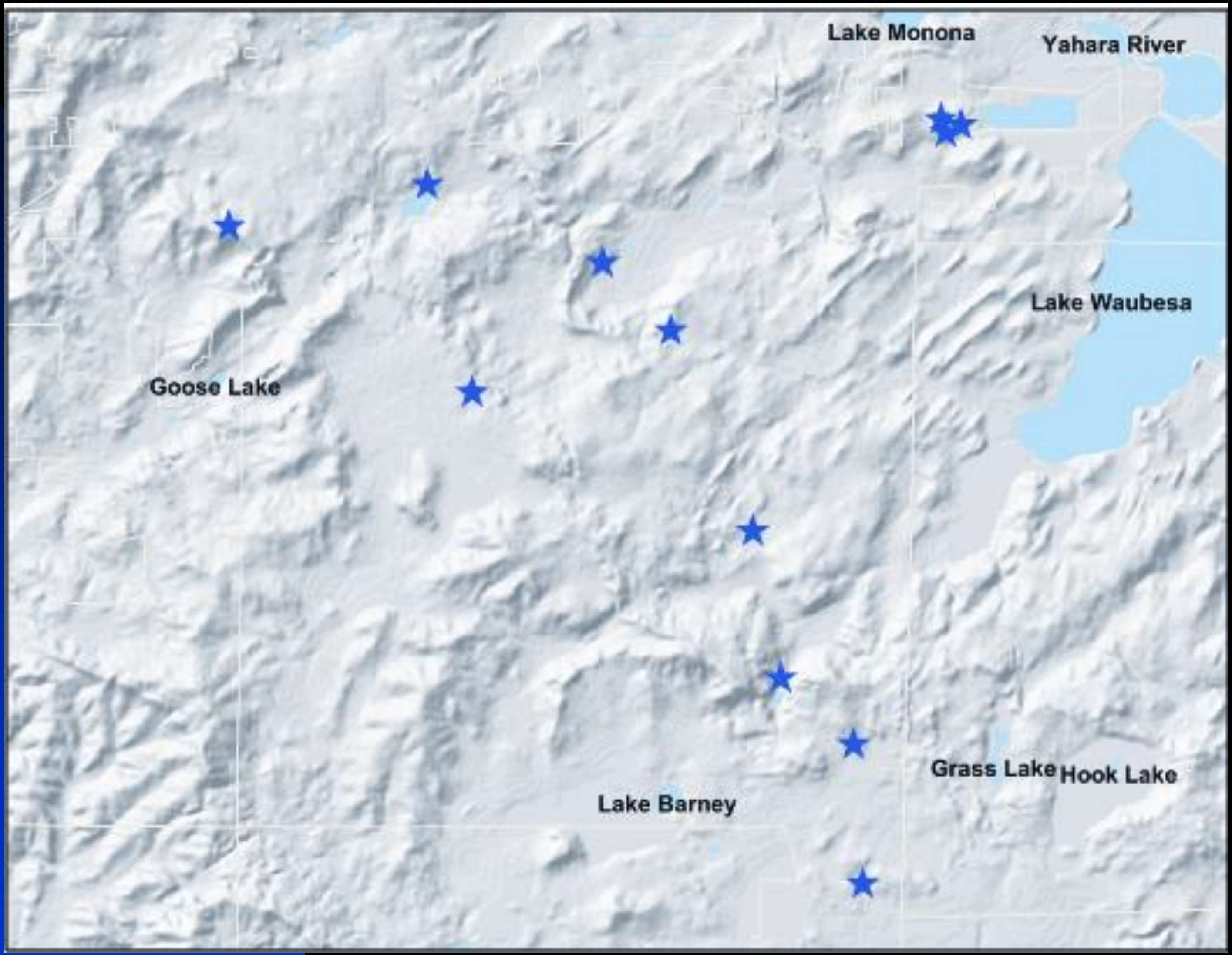
County Road MM
County Road D



Lake Monona
Lake Wingra
Yahara River
Nine Springs Creek
Lake Waubesa
Mud Lake


WILLOW RIVER
TILDEN OUTCROPS
HWY 12-124
STRUM
BRUCE VALLEY
NESHONOC
N
MI
0
20
40
60
80
100
KM
0
30
60
90
120
150

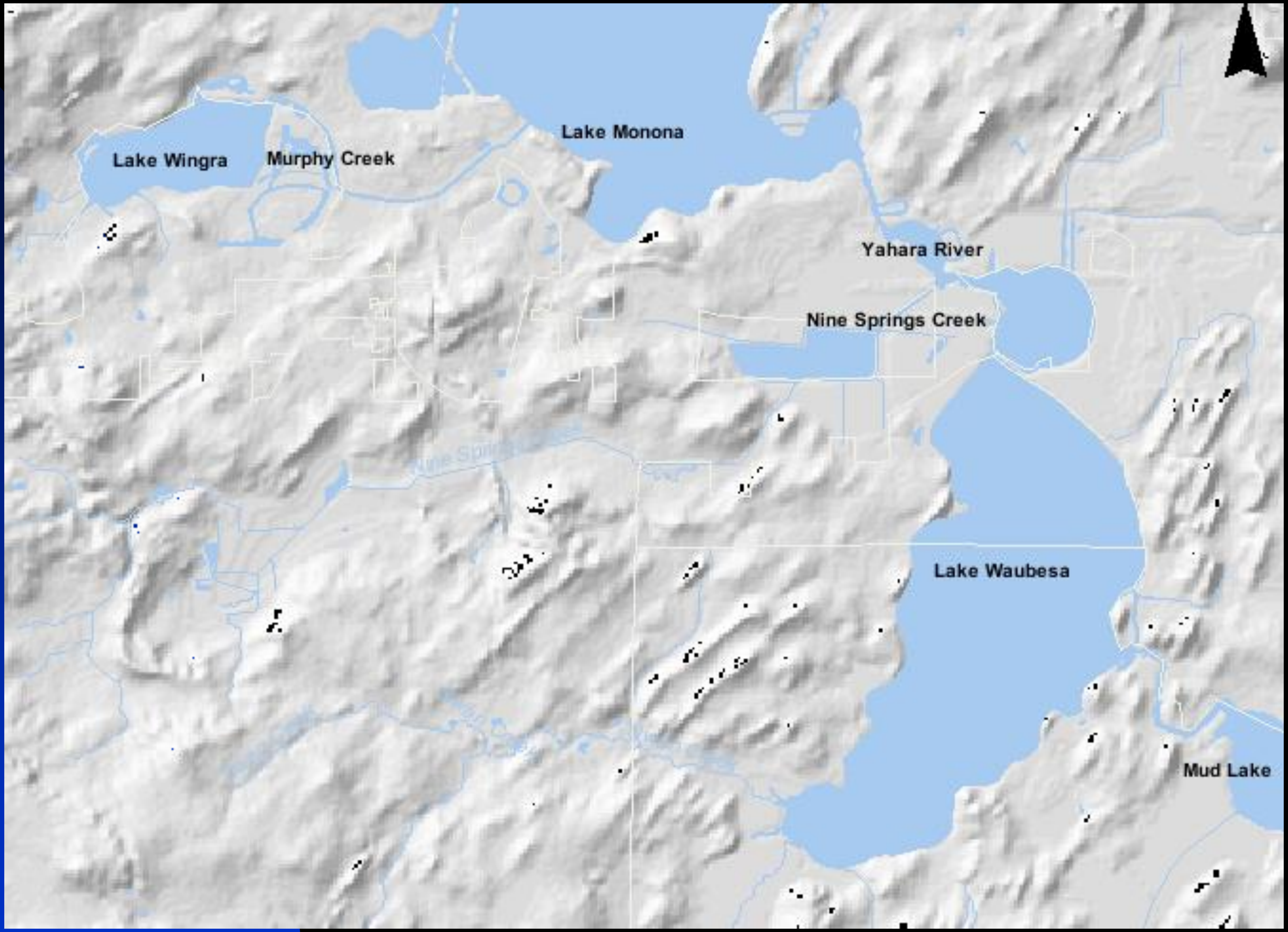


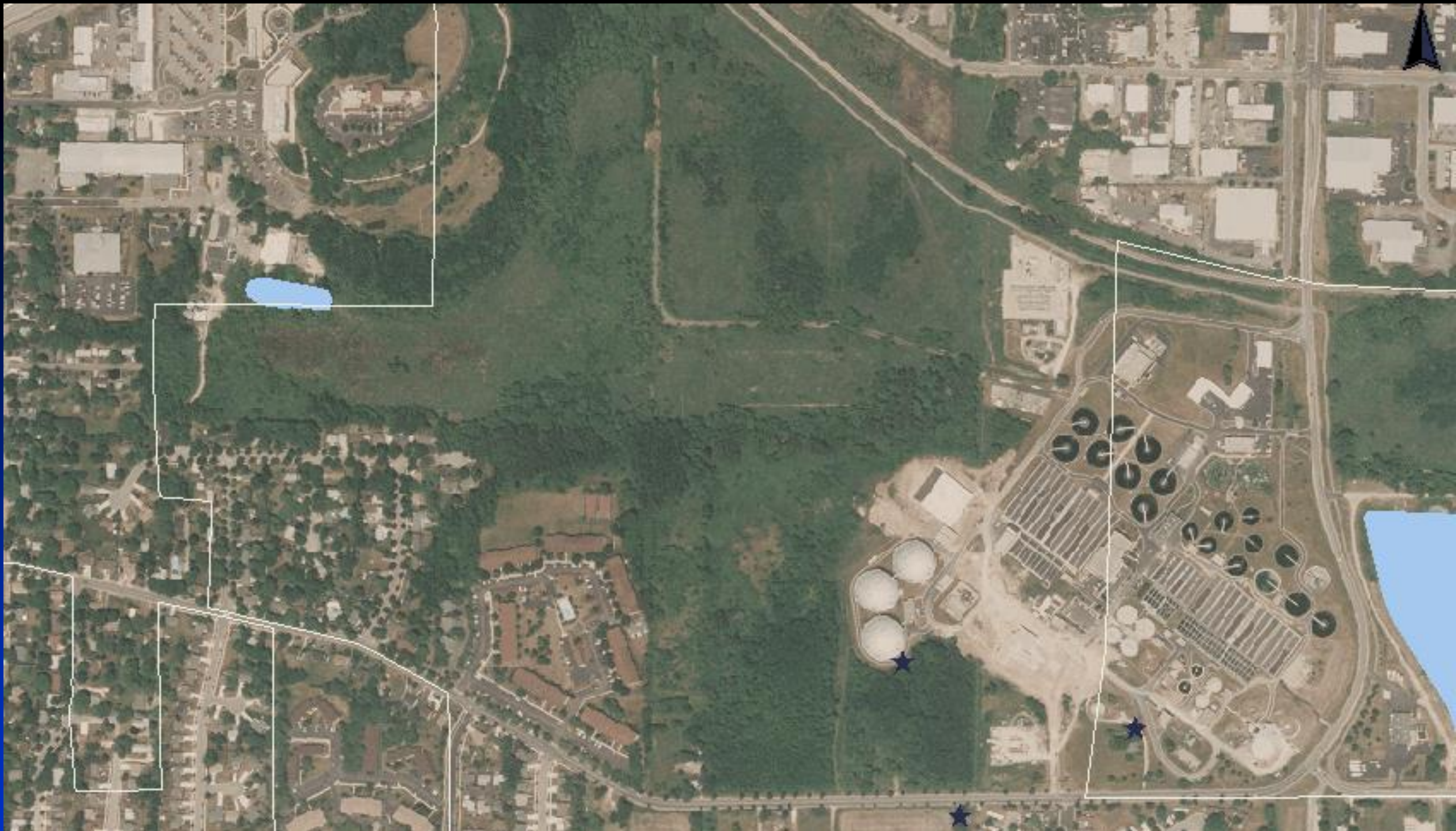

Lake Monona
Yahara River
Lake Waubesa
Goose Lake
Grass Lake
Hook Lake
Lake Barney

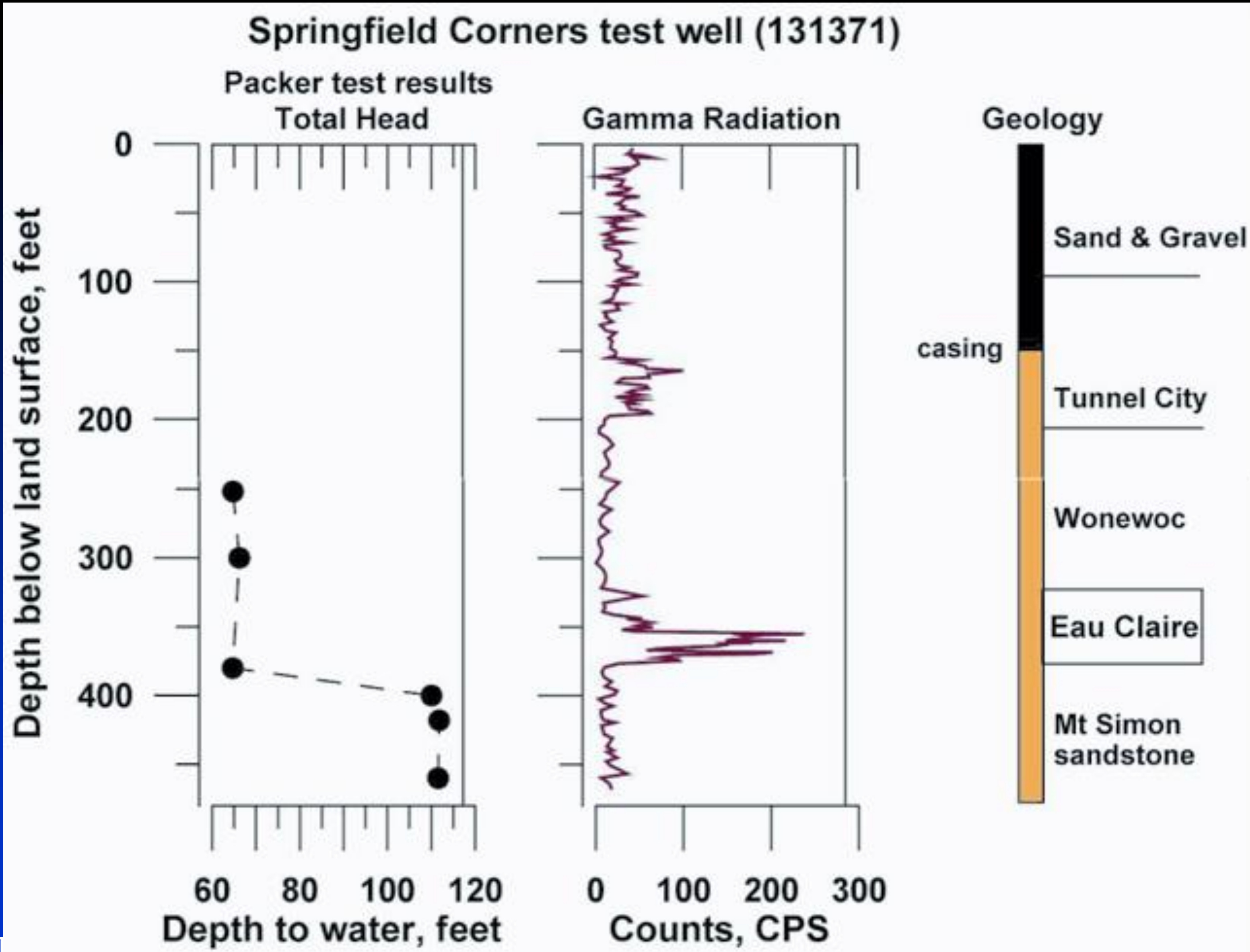

Lake Wingra
Murphy Creek
Lake Monona
Yahara River
Nine Springs Creek
Nine Springs Creek
Lake Waubesa
Swan Creek
Mud Lake

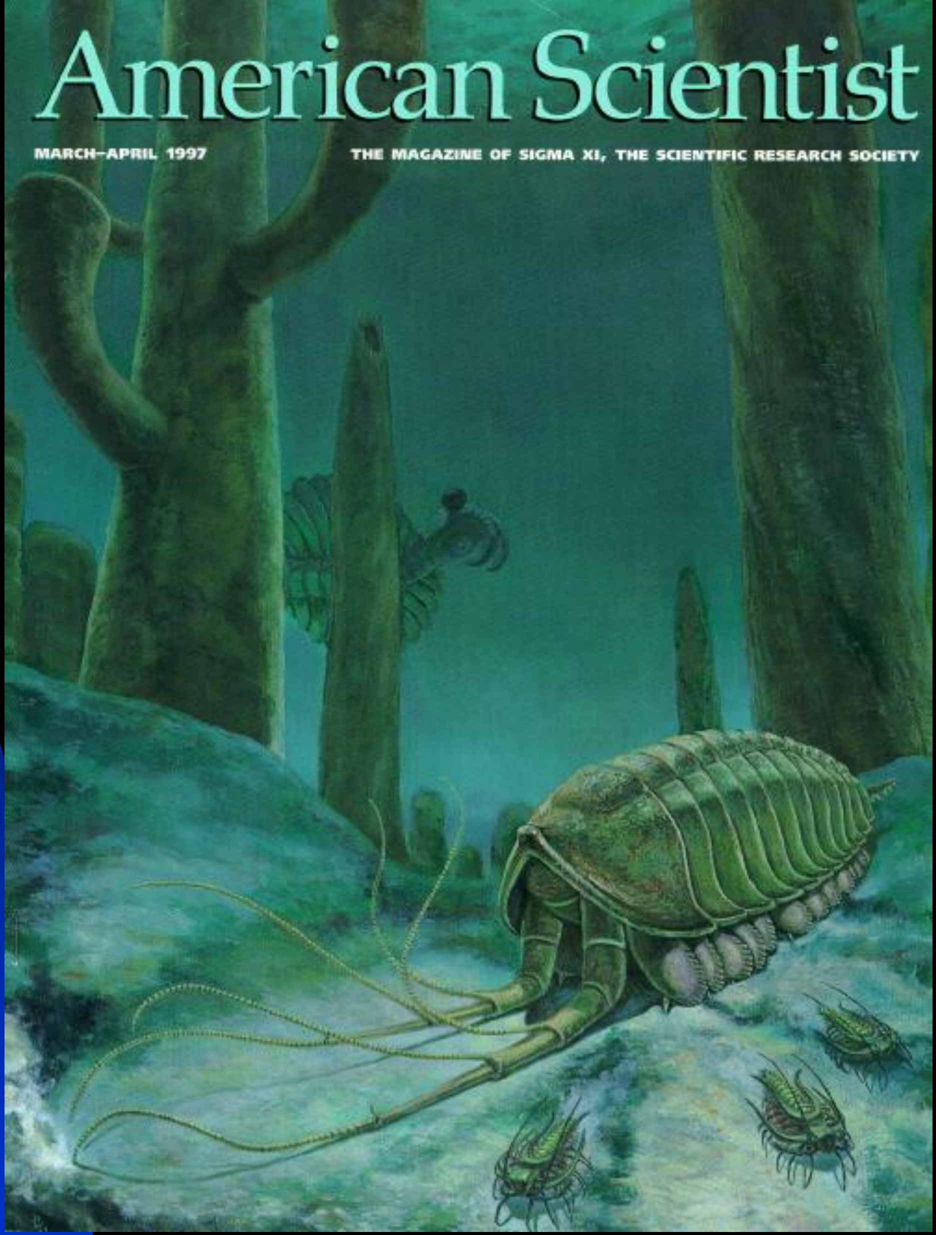

Lake Wingra
Murphy Creek
Lake Monona
Yahara River
Nine Springs Creek
Nine Springs Creek
Lake Waubesa
Swan Creek
Swan Creek
Swan Creek
Mud Lake

Lake Monona
Lake Wingra
Murphy Creek
Yahara River
Nine Springs Creek
Nine Springs Creek
Lake Waubesa
Swan Creek
Swan Creek
Swan Creek
Mud Lake


Lake Monona
Lake Wingra
Murphy Creek
Yahara River
Nine Springs Creek
Lake Waubesa
Mud Lake




Springfield Corners test well (131371)
Packer test results
Total Head
Gamma Radiation
Geology
Depth below land surface, feet
0
100
200
300
400
Sand & Gravel
casing
Tunnel City
Wonewoc
Eau Claire
Mt Simon sandstone
60
80
100
120
Depth to water, feet
0
100
200
300
Counts, CPS


American Scientist
MARCH–APRIL 1997
THE MAGAZINE OF SIGMA XI, THE SCIENTIFIC RESEARCH SOCIETY

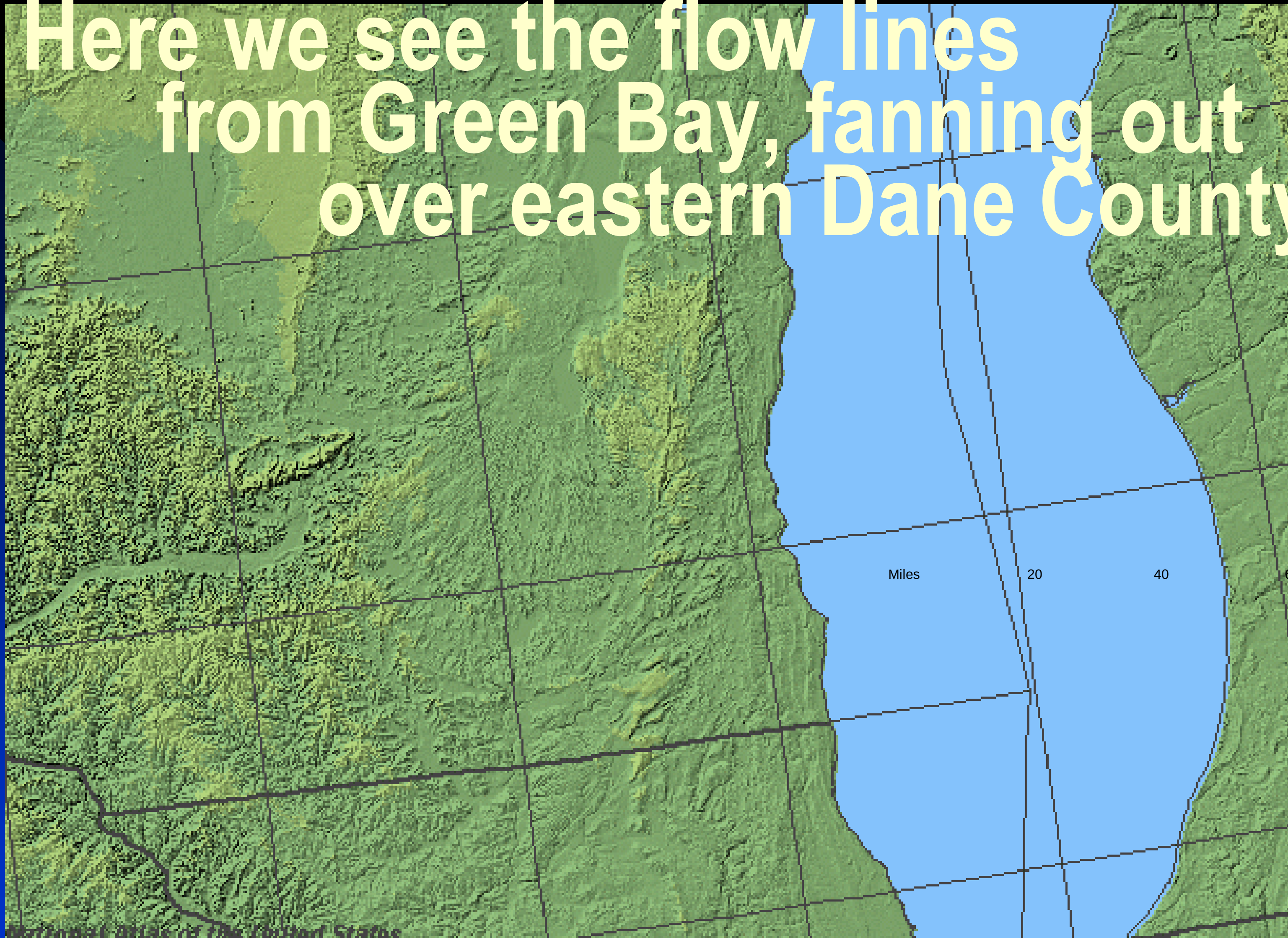
The U.S. National Atlas – – can help us find the answer.

This a LIDAR image….

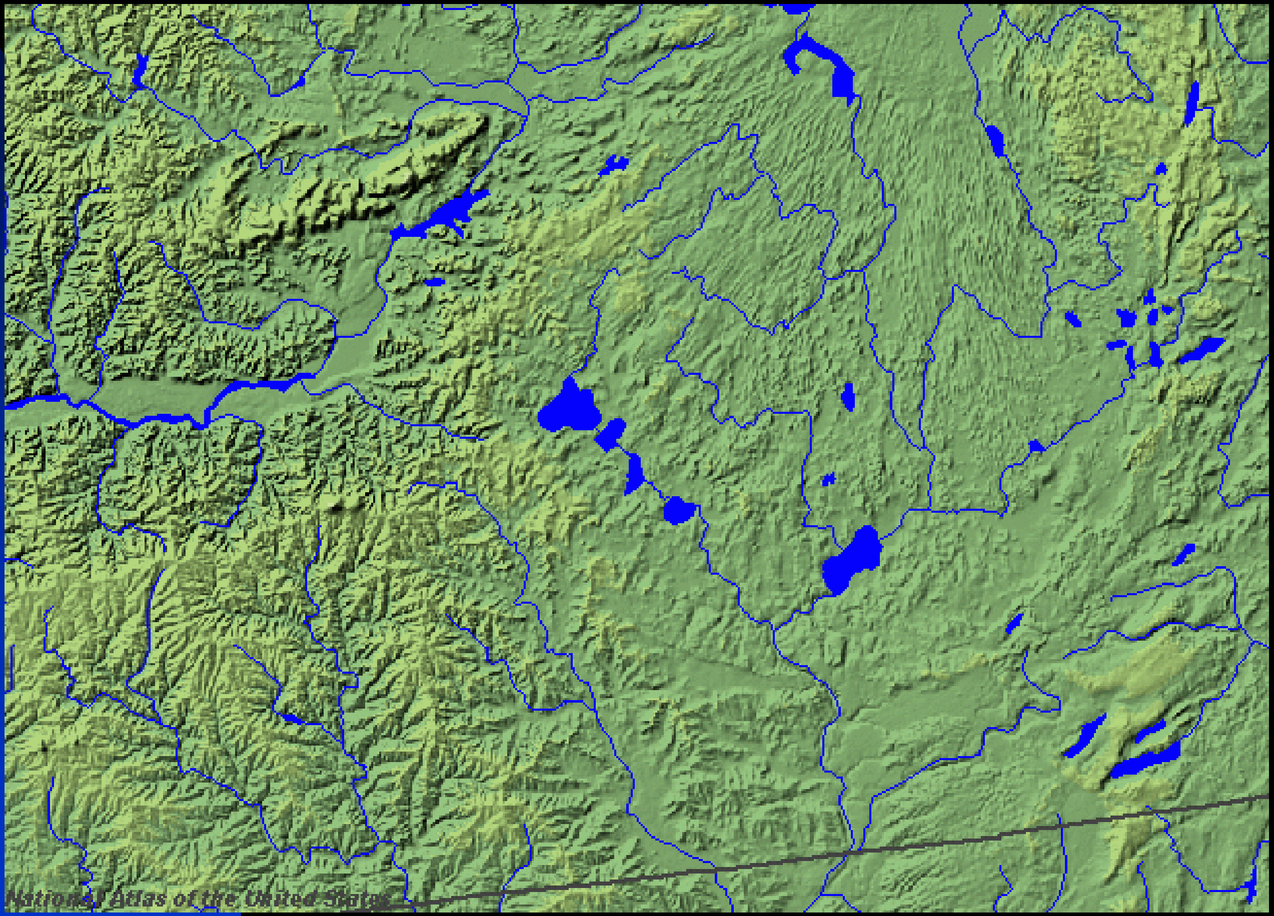
It shows surface features beautifully…

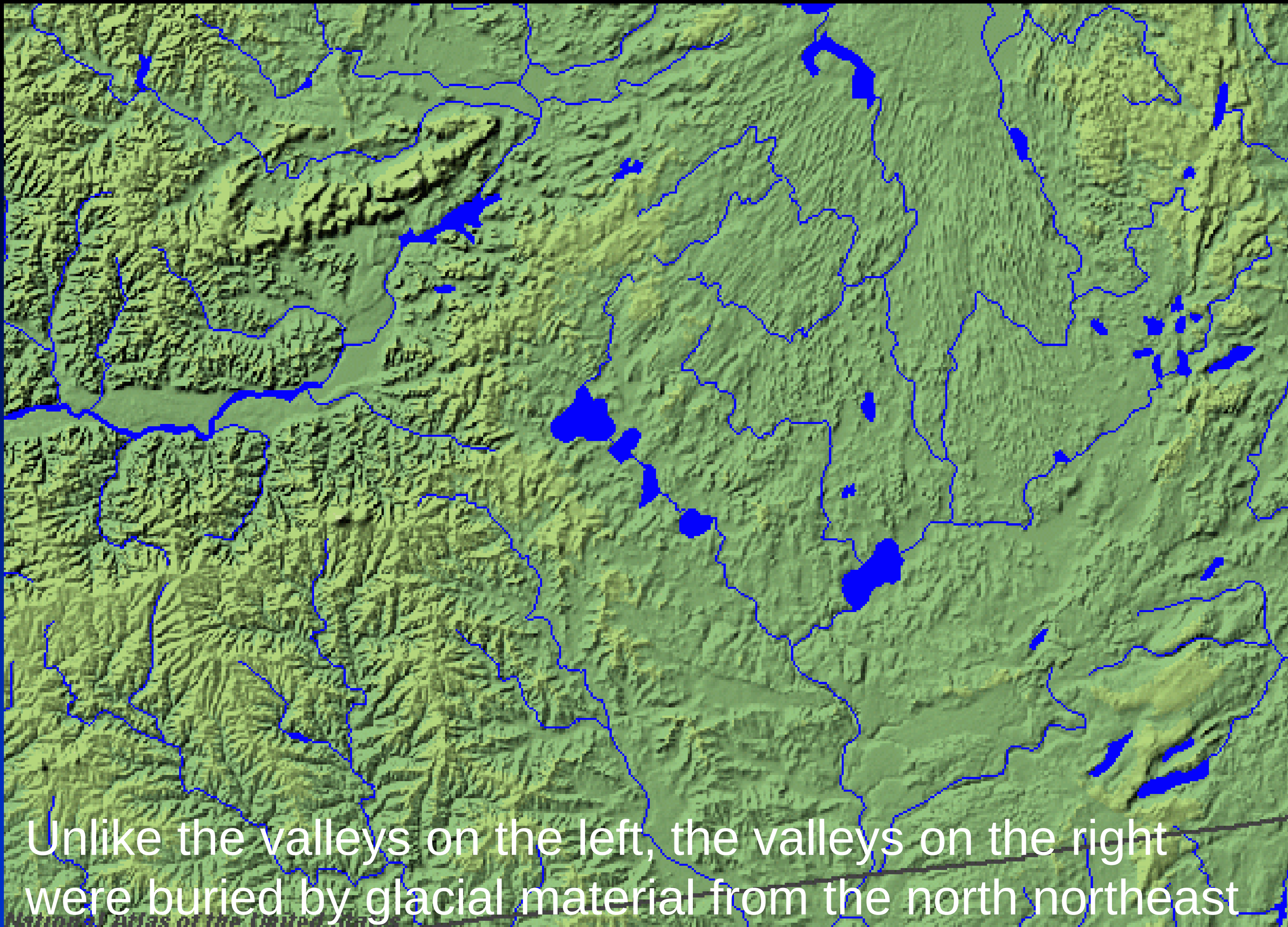
TAKE SPECIAL NOTE OF THE UNGLACIATED DRIFTLESS AREA

Here we see the flow lines from Green Bay, fanning out over eastern Dane County.



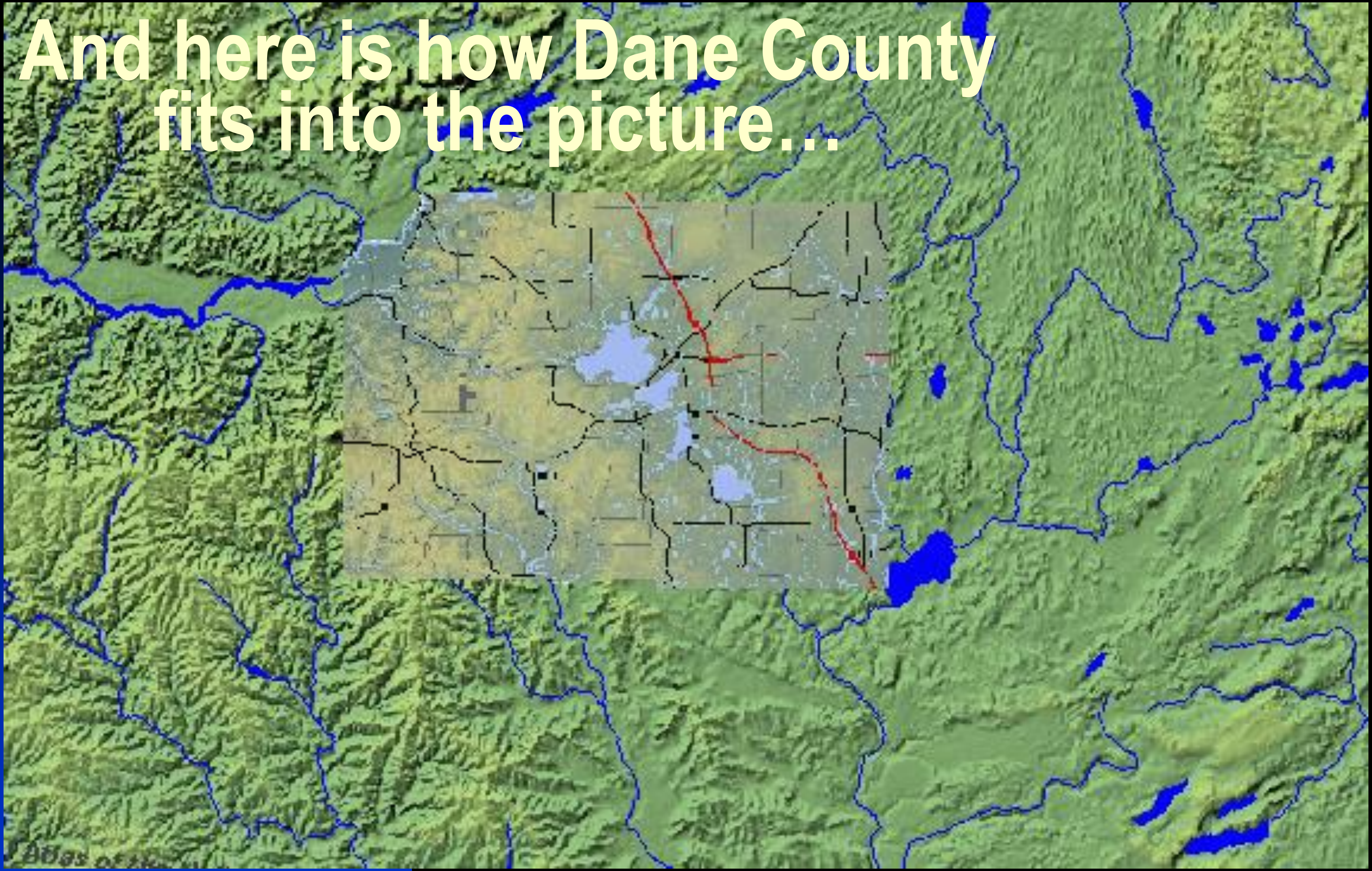
- And this flow of glacial material buries the eastern bedrock Valleys including the Yahara Valley.
- But it stops before it otherwise would have filled the valleys further west.

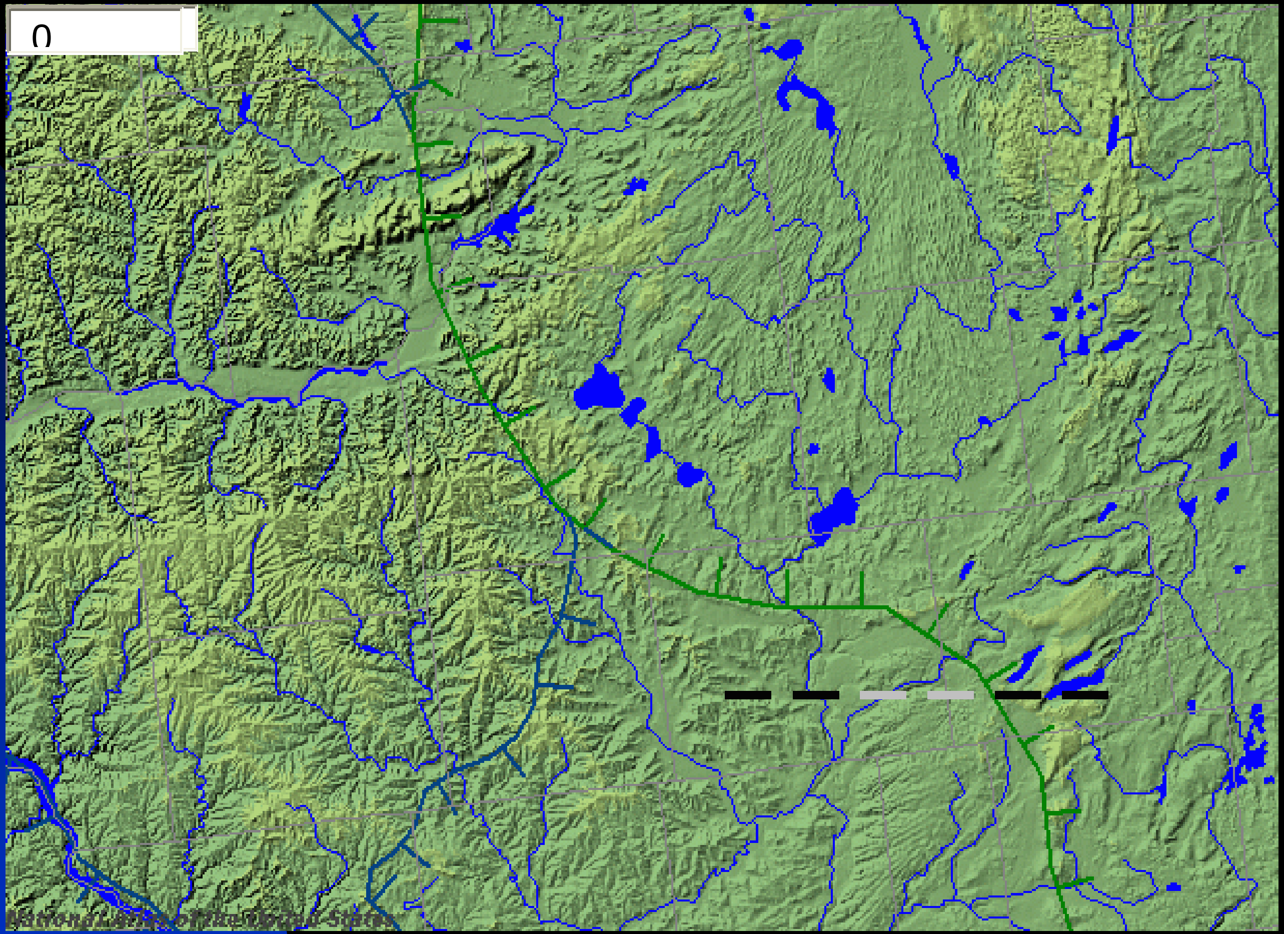


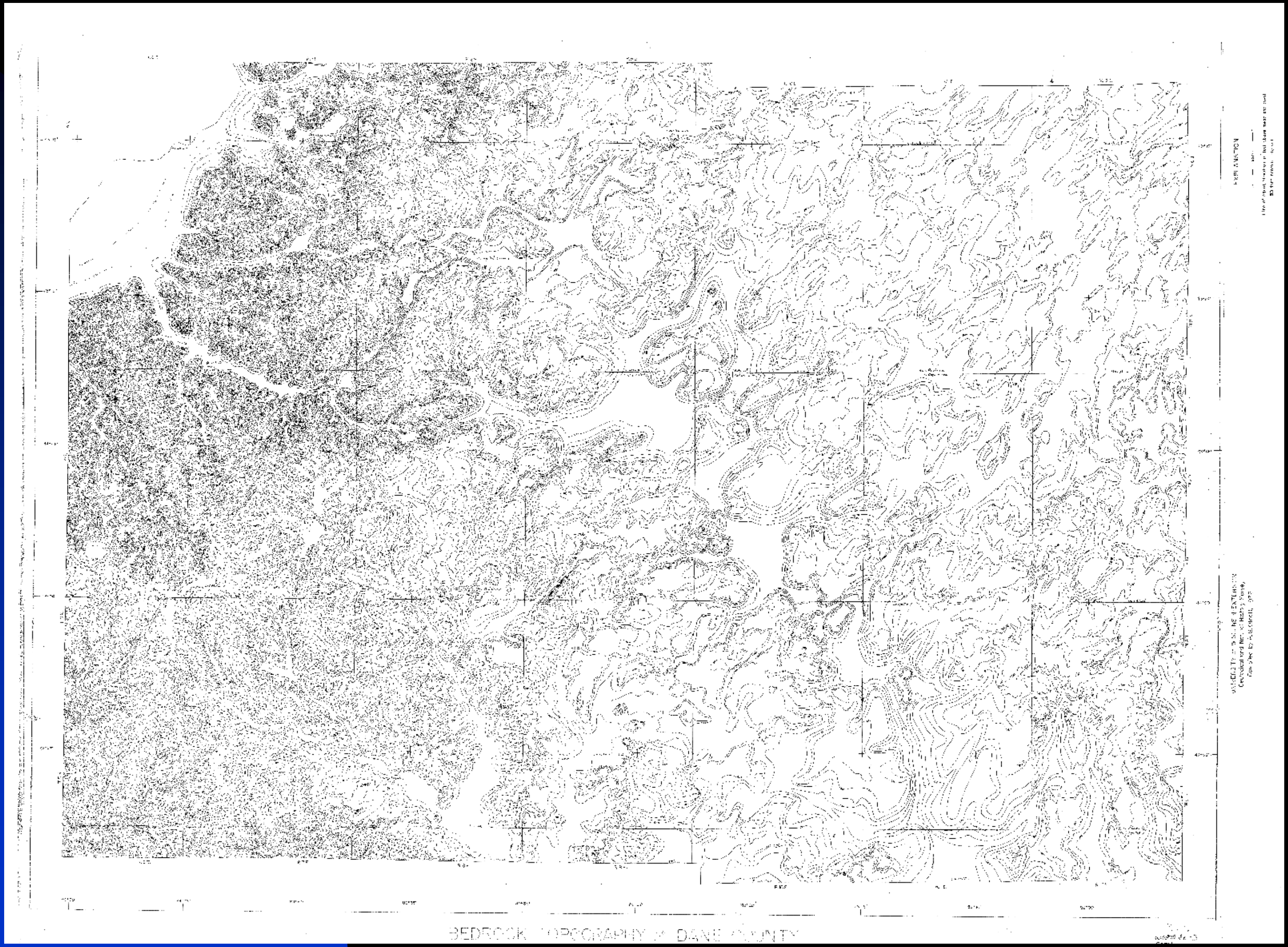


- Unlike the valleys on the left, the valleys on the right
- were buried by glacial material from the north northeast

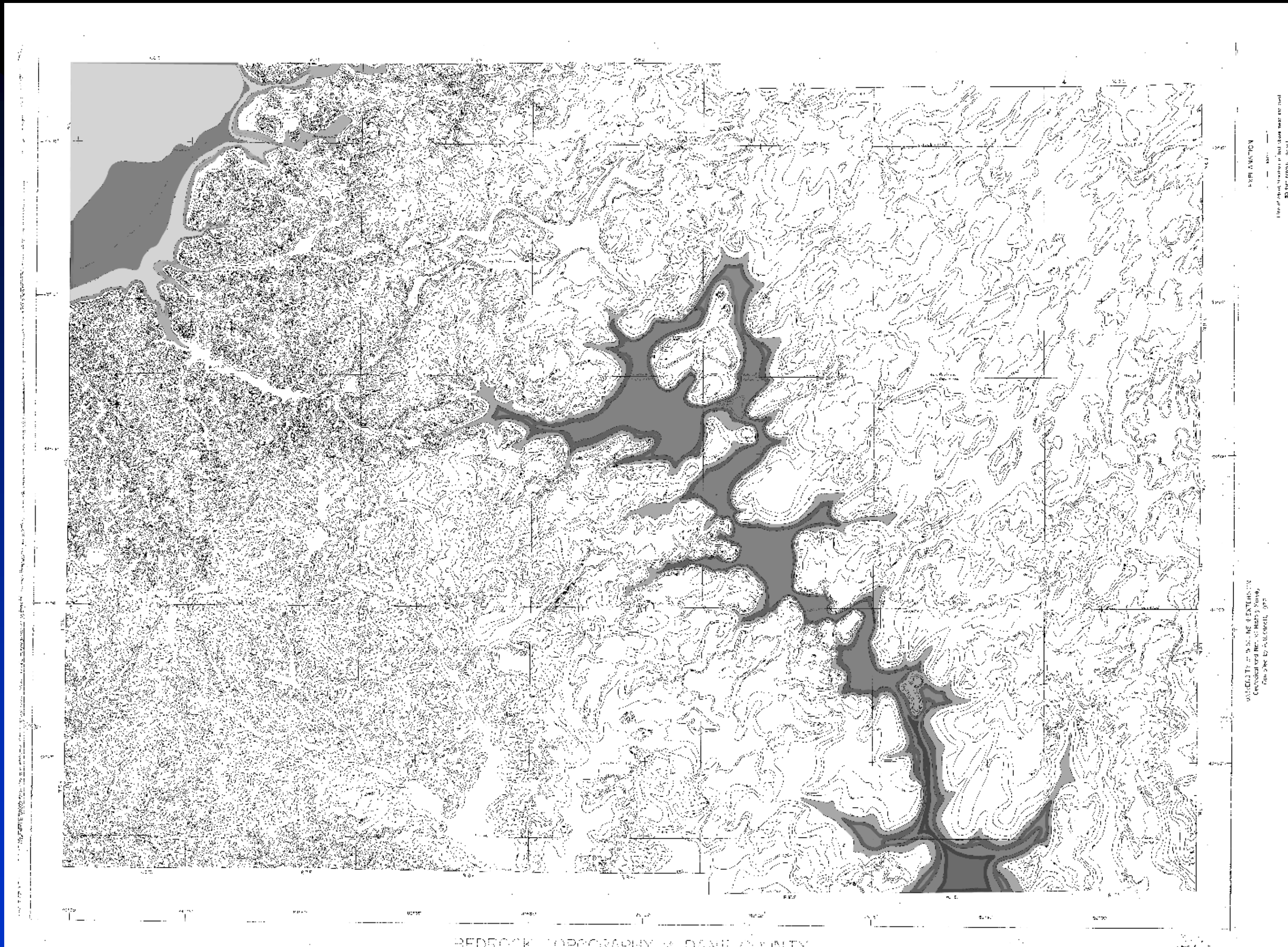
And here is how Dane County fits into the picture…

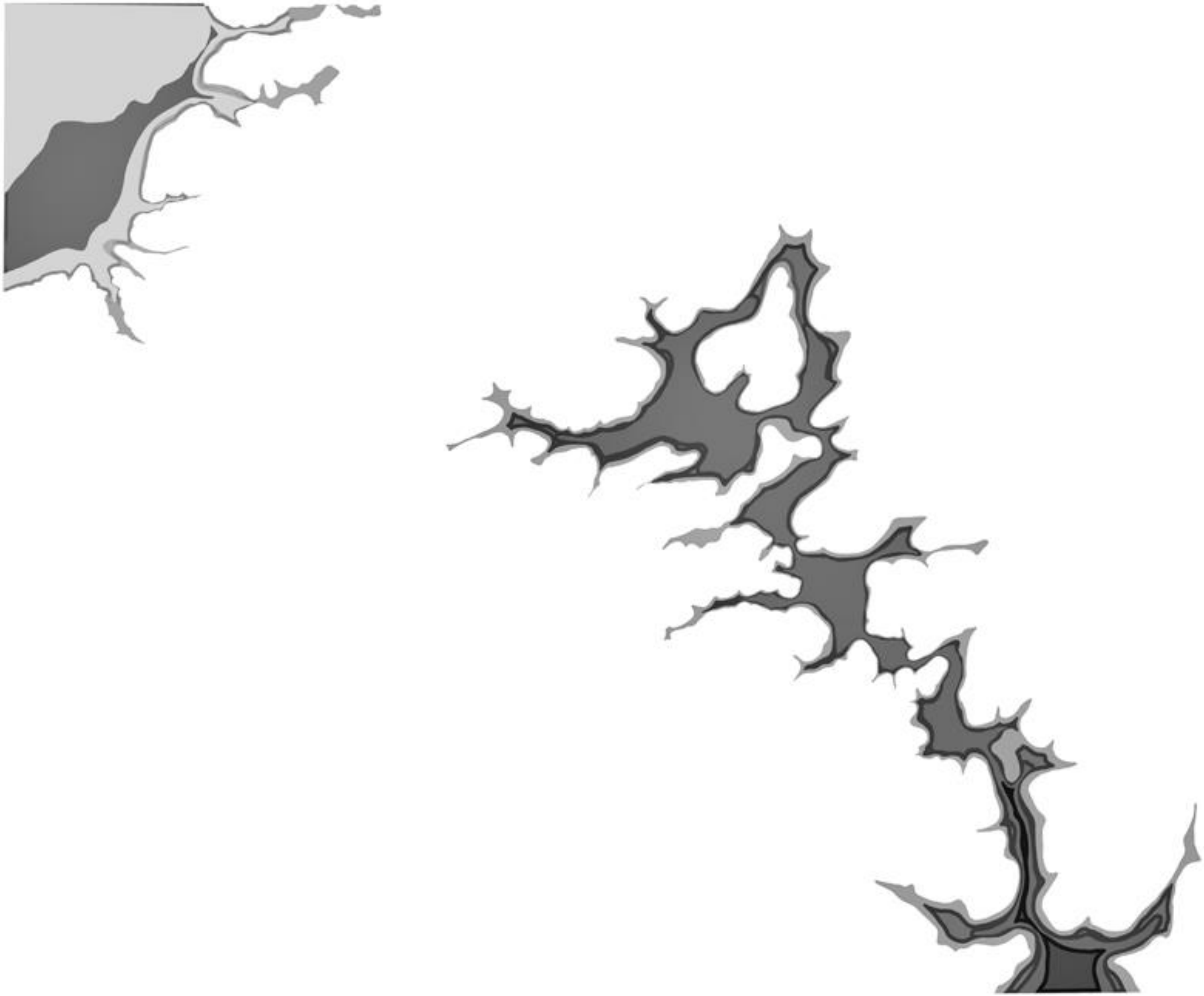


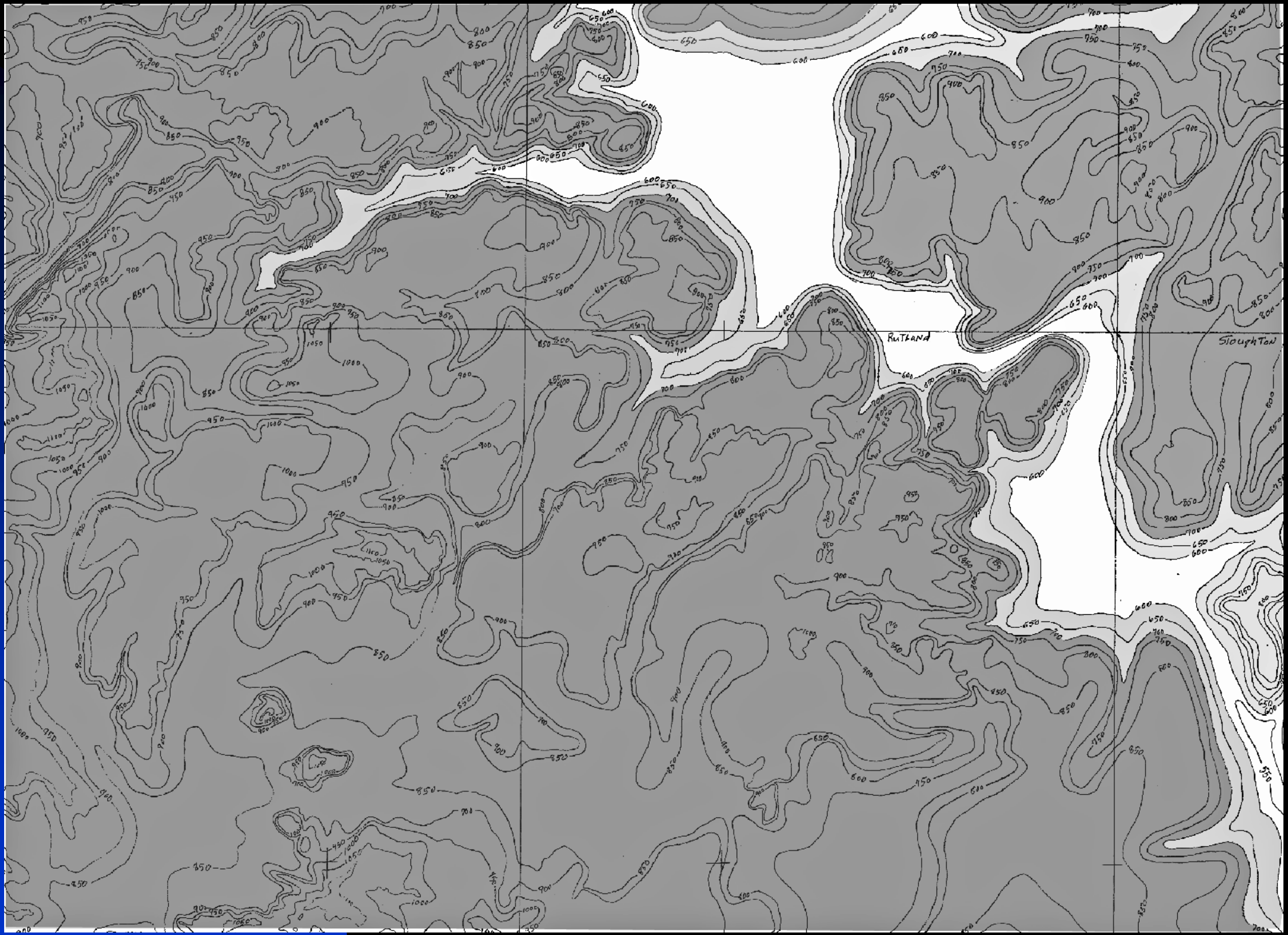

0
National Atlas of the United States


BEDROCK TOPOGRAPHY DANE COUNTY


EXPLANATION
Line of equal elevation in feet above mean sea level
50-foot contour interval
UNIVERSITY of WISCONSIN-EXTENSION
Geological and Natural History Survey
Compiled by P.G. Olcott, 1972
BEDROCK TOPOGRAPHY of DANE COUNTY







Rutland
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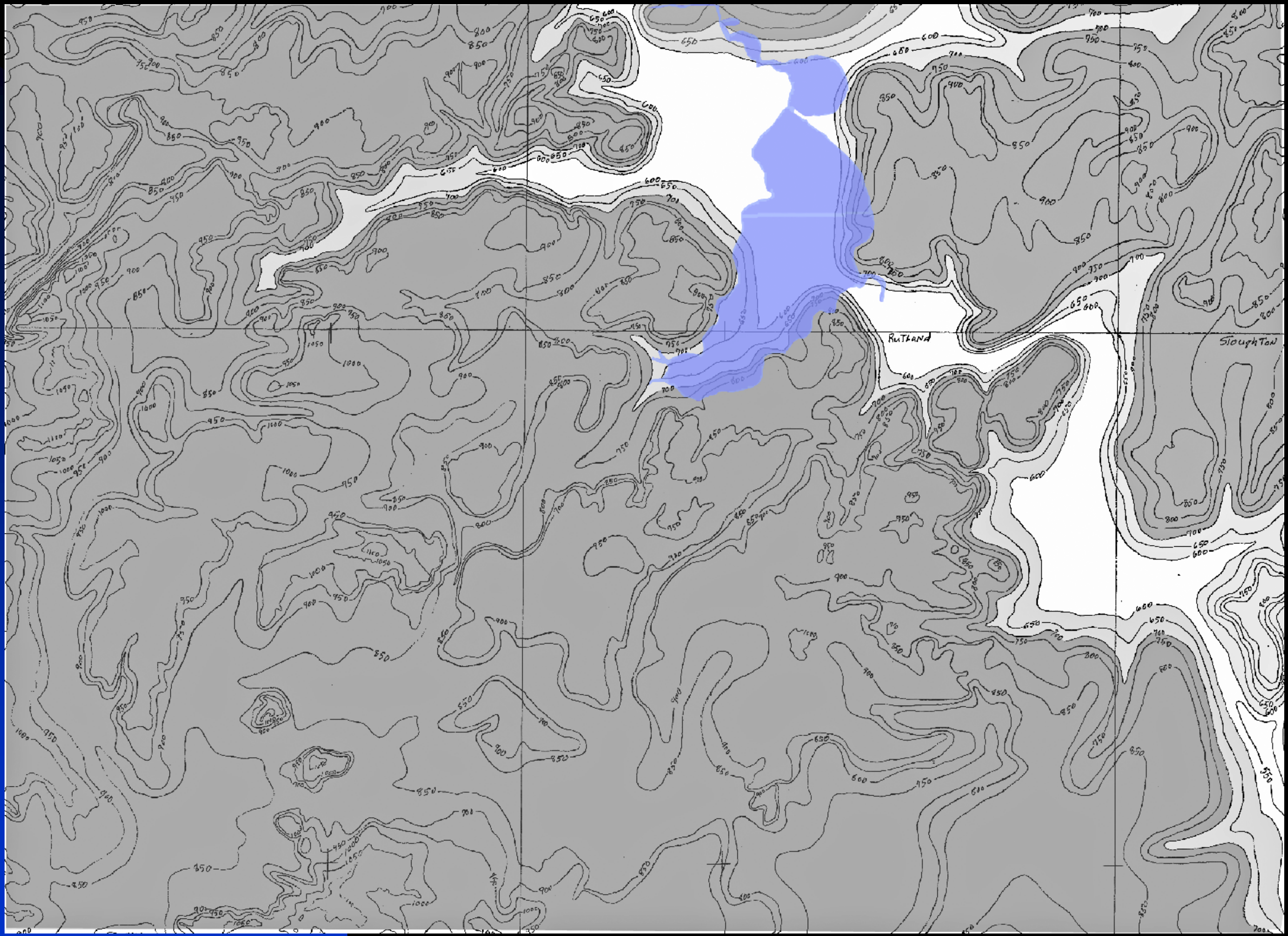
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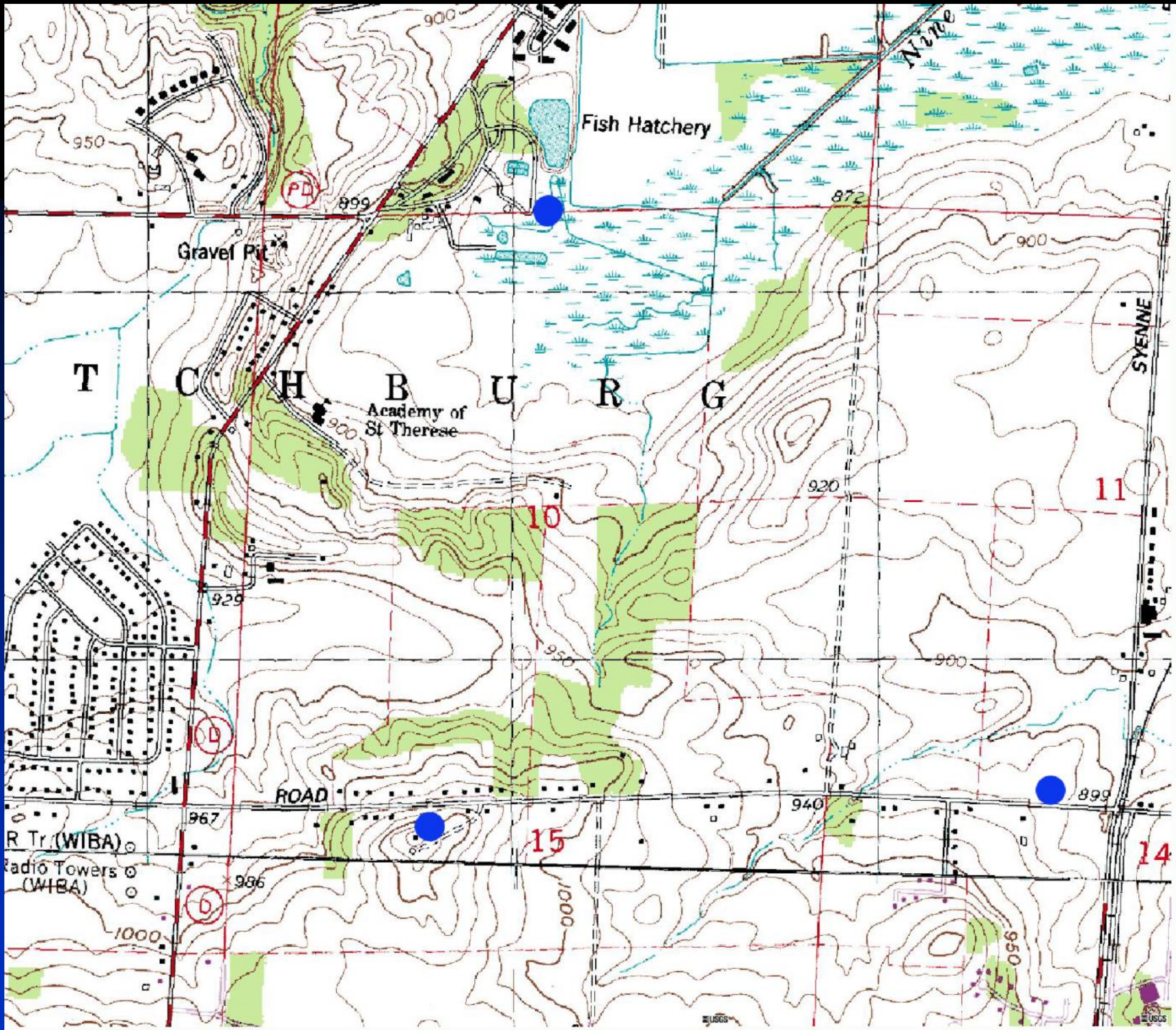
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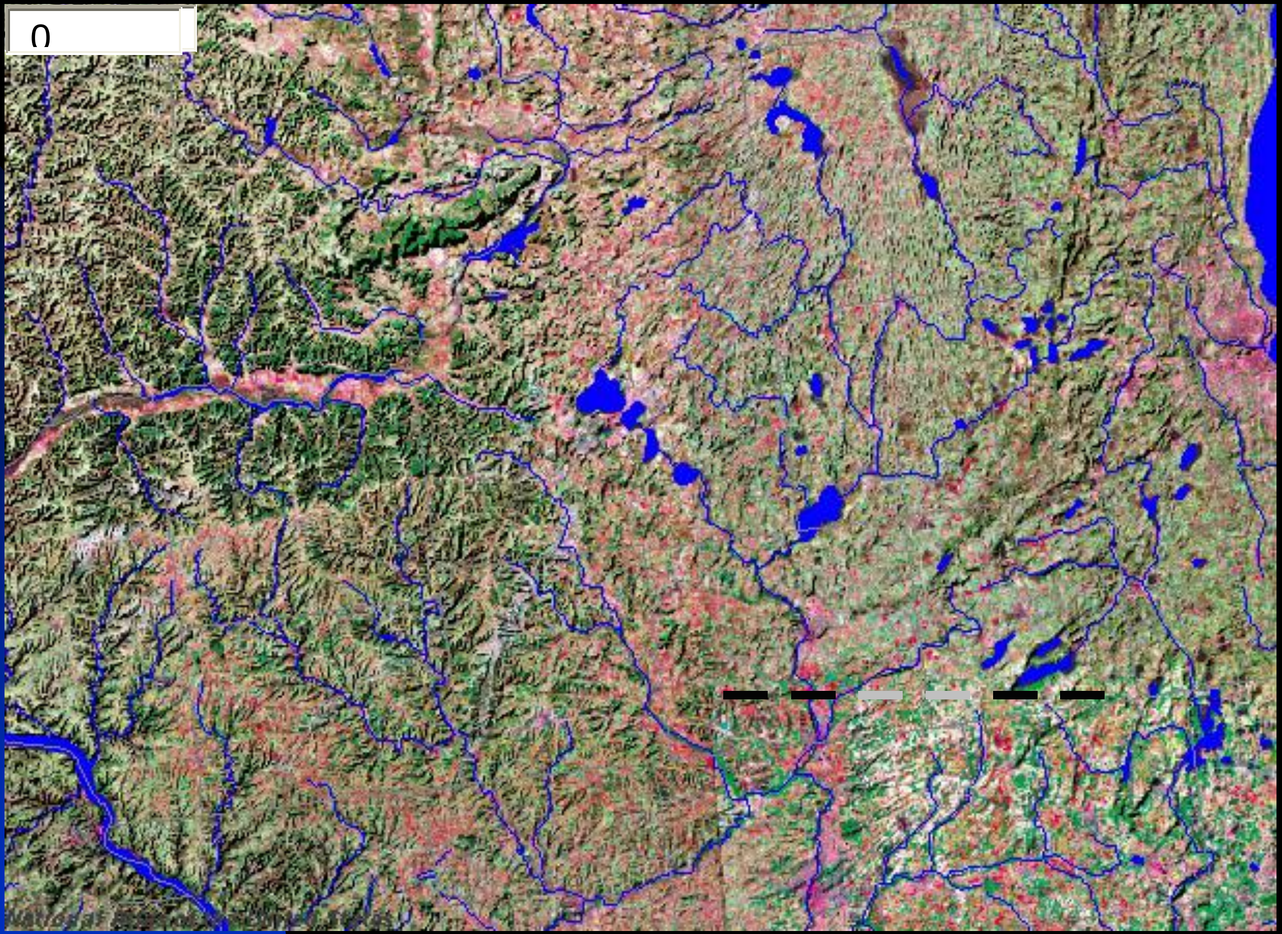
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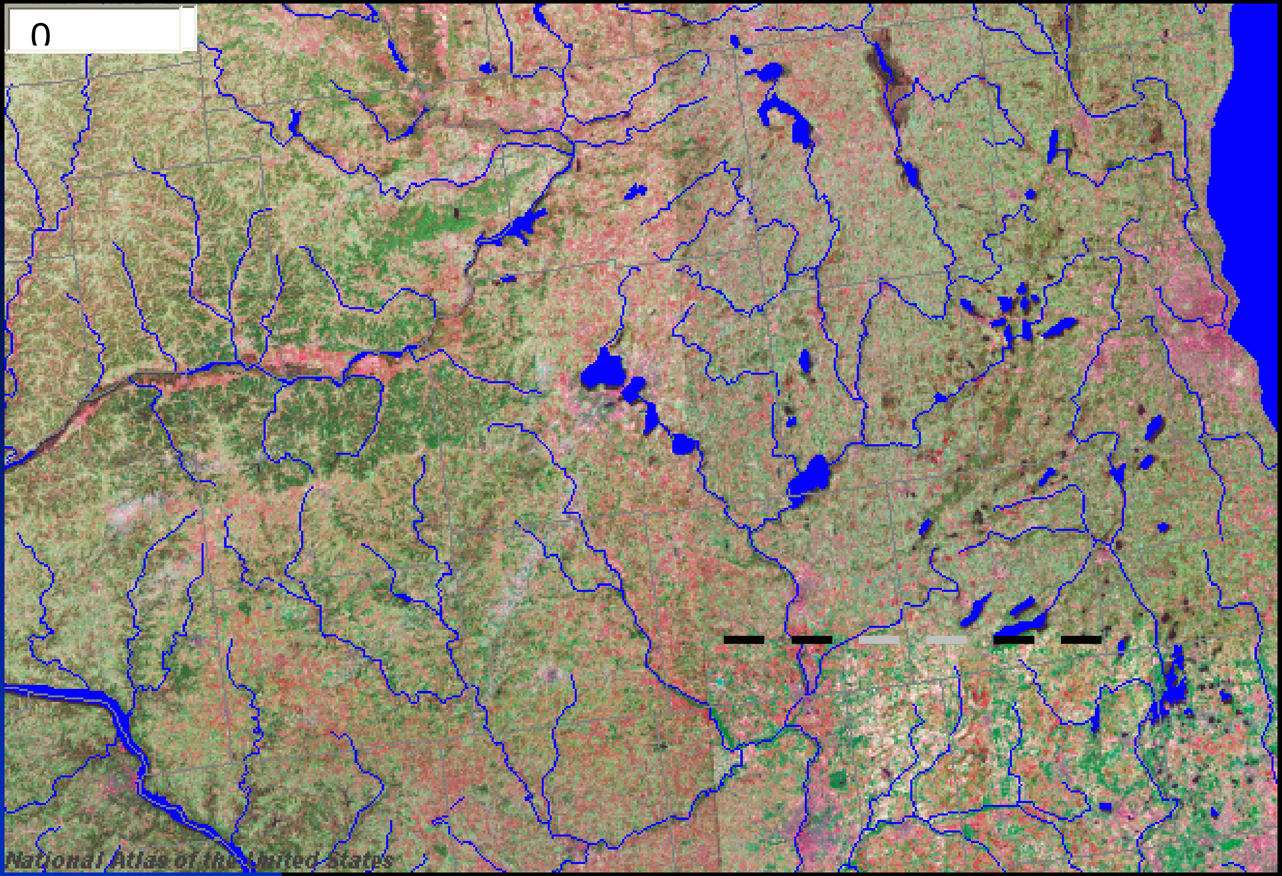
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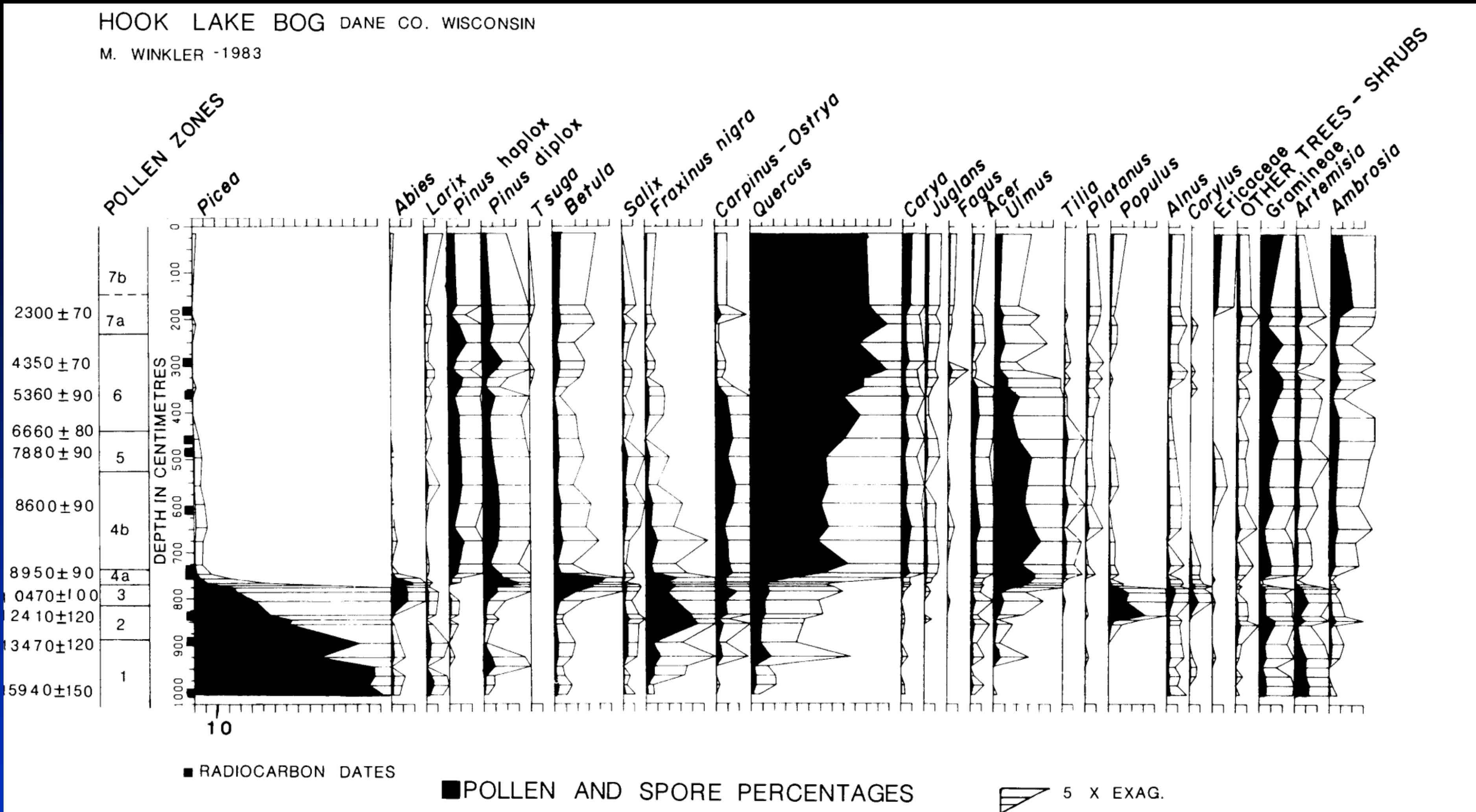
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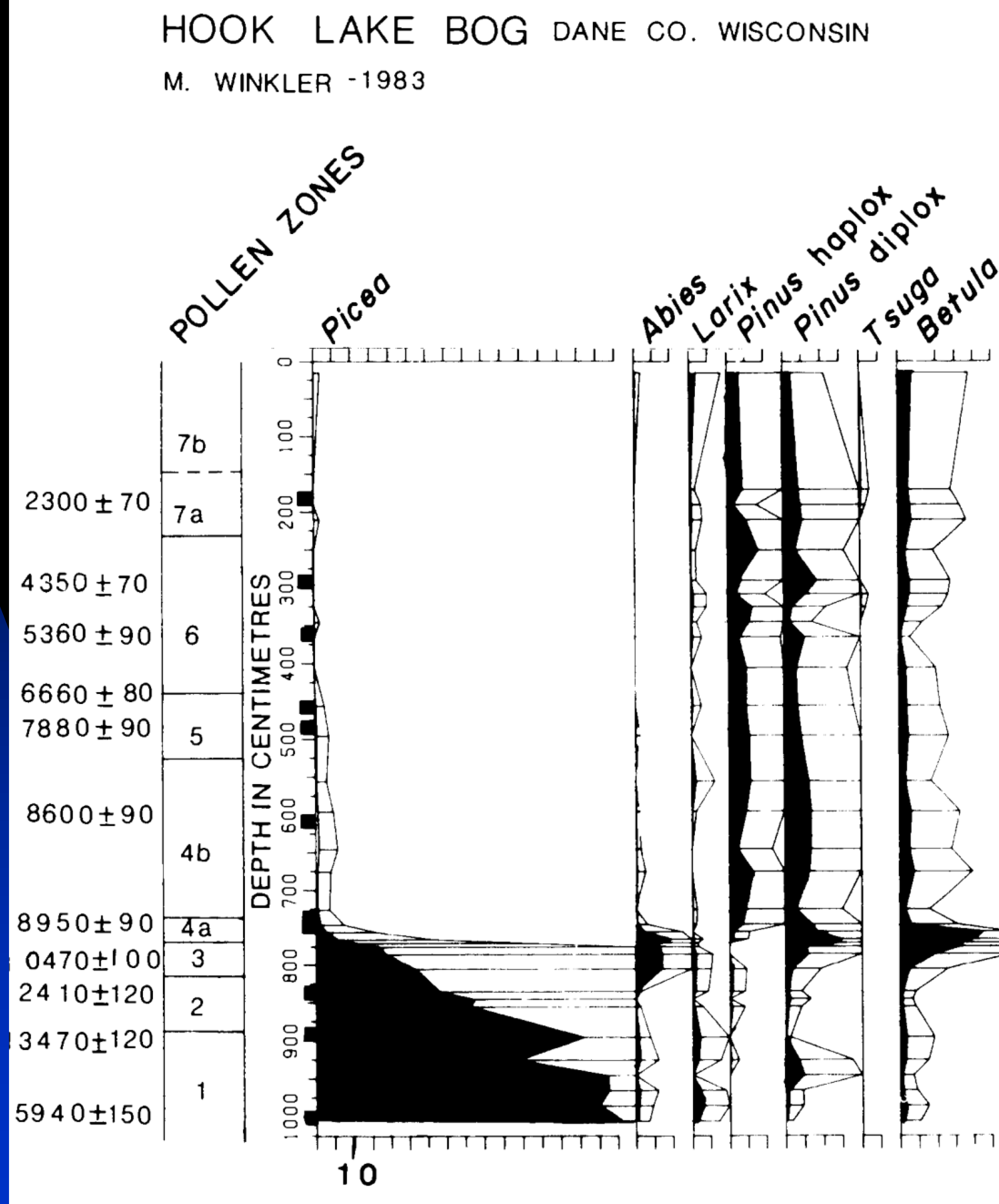
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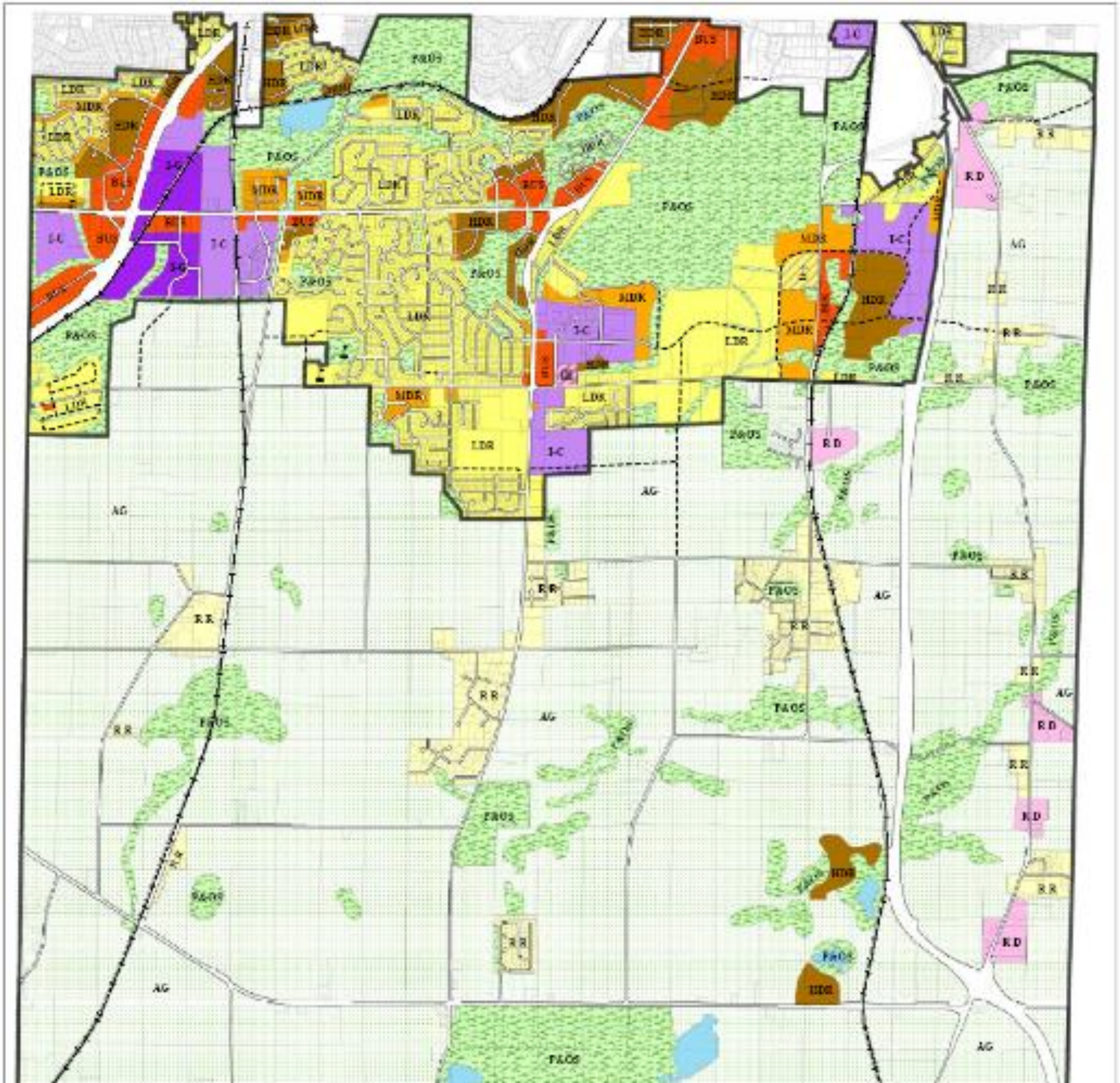

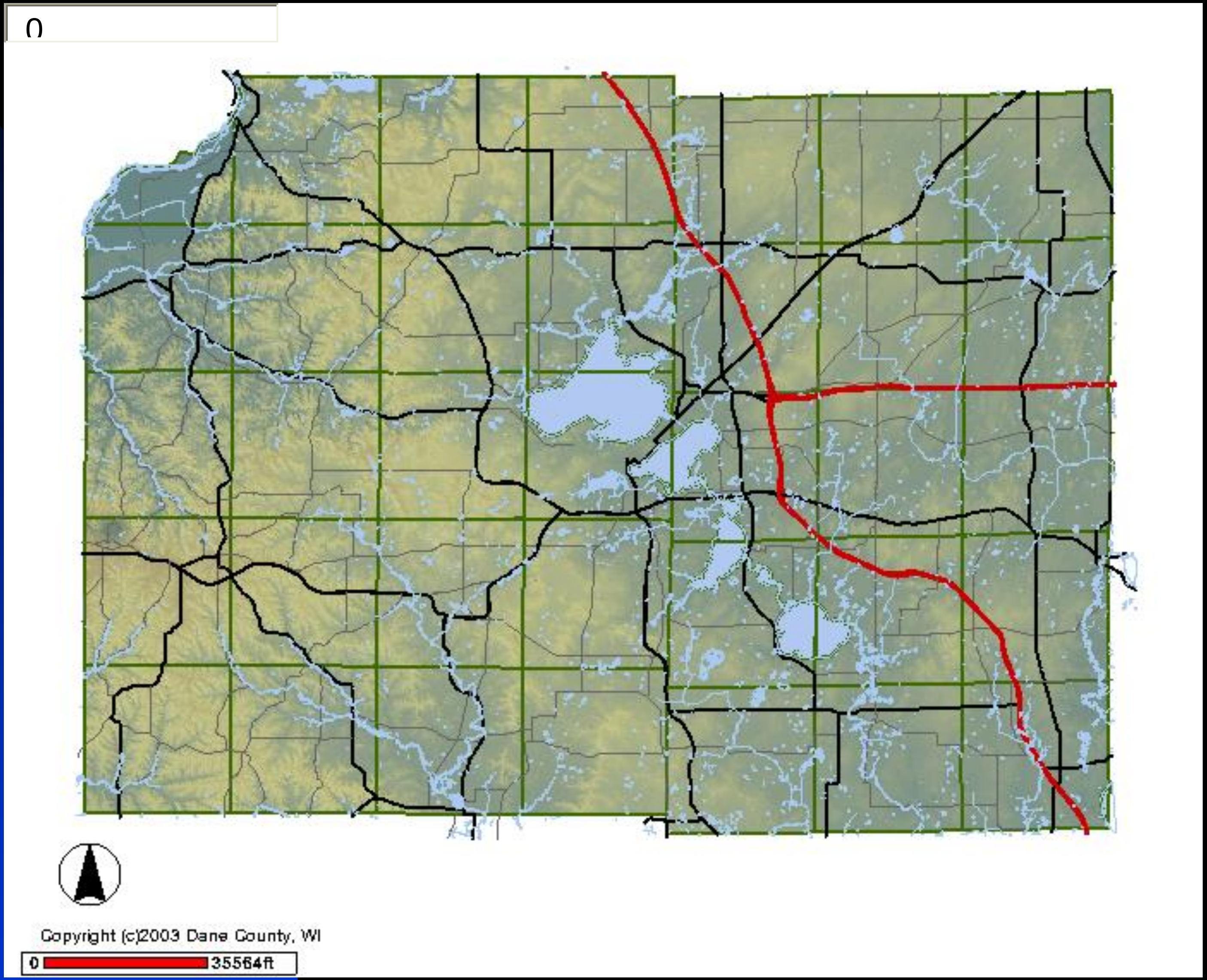
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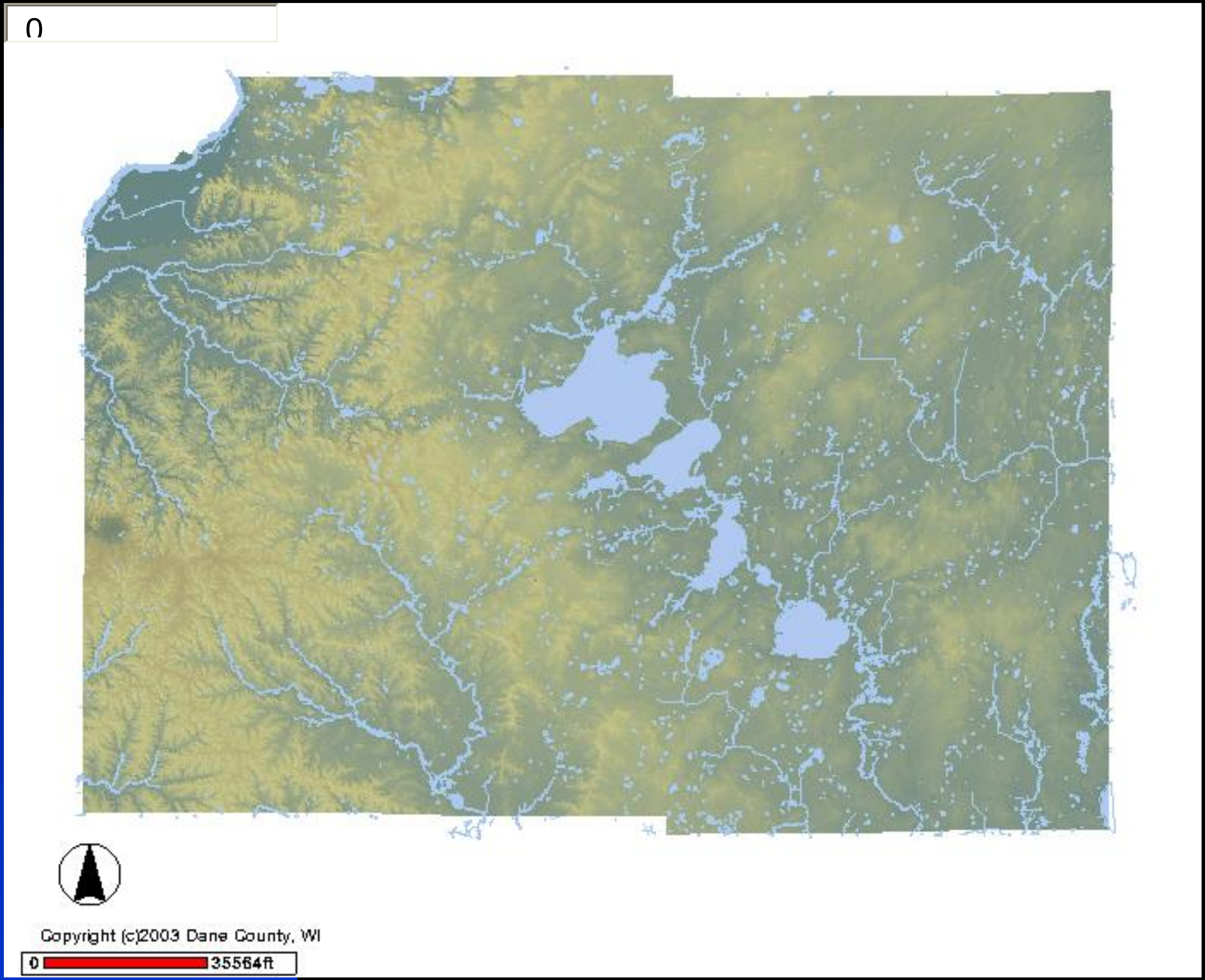
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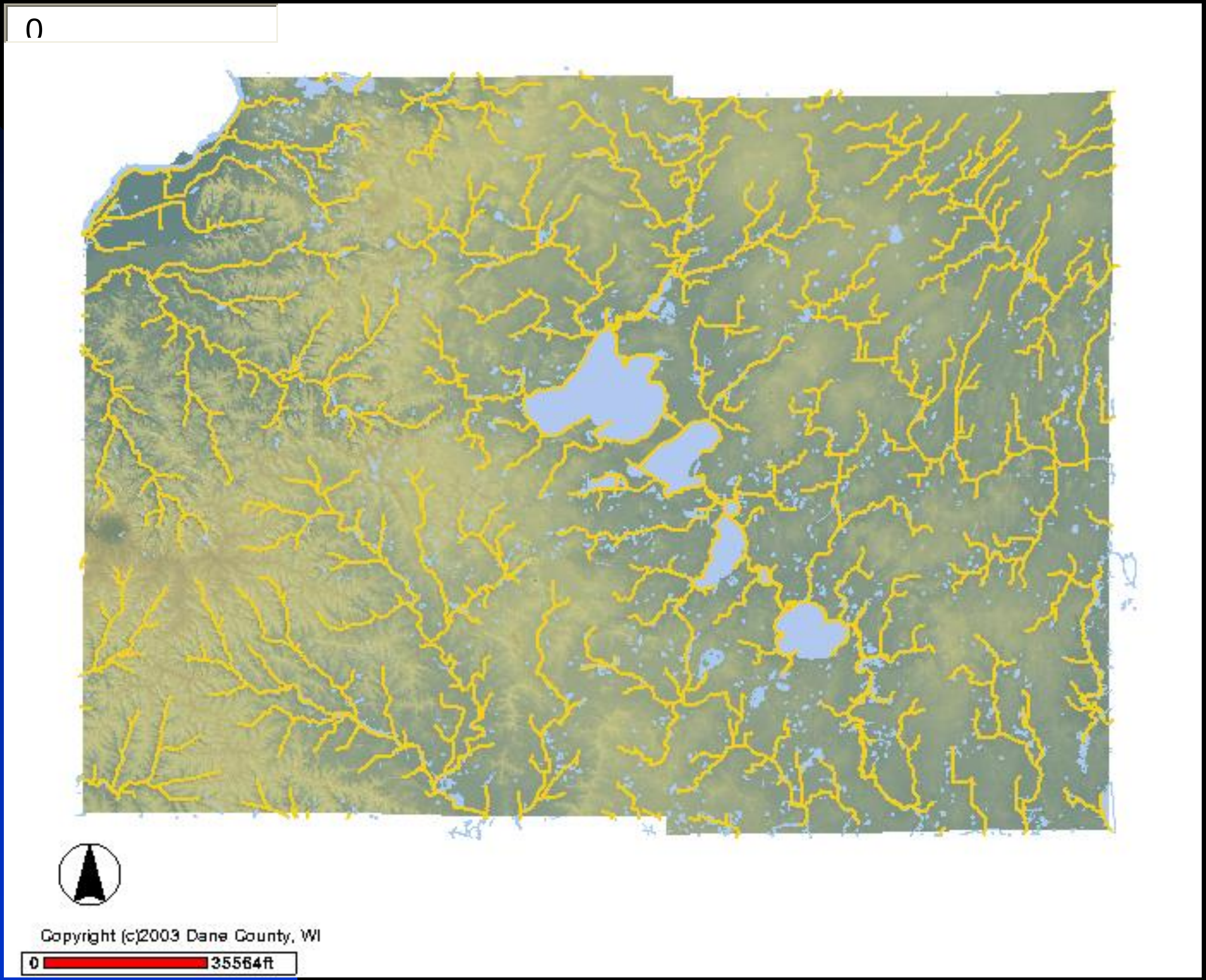
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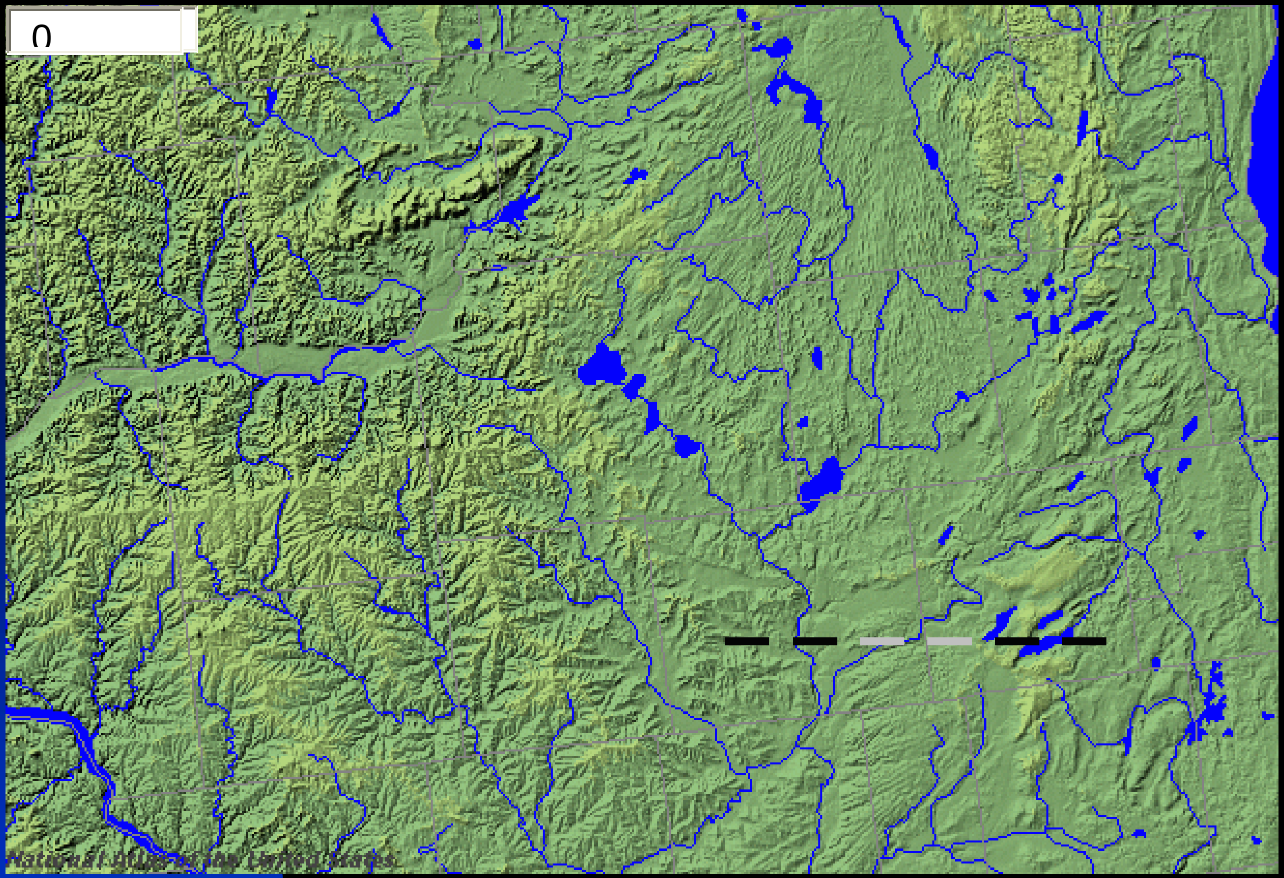
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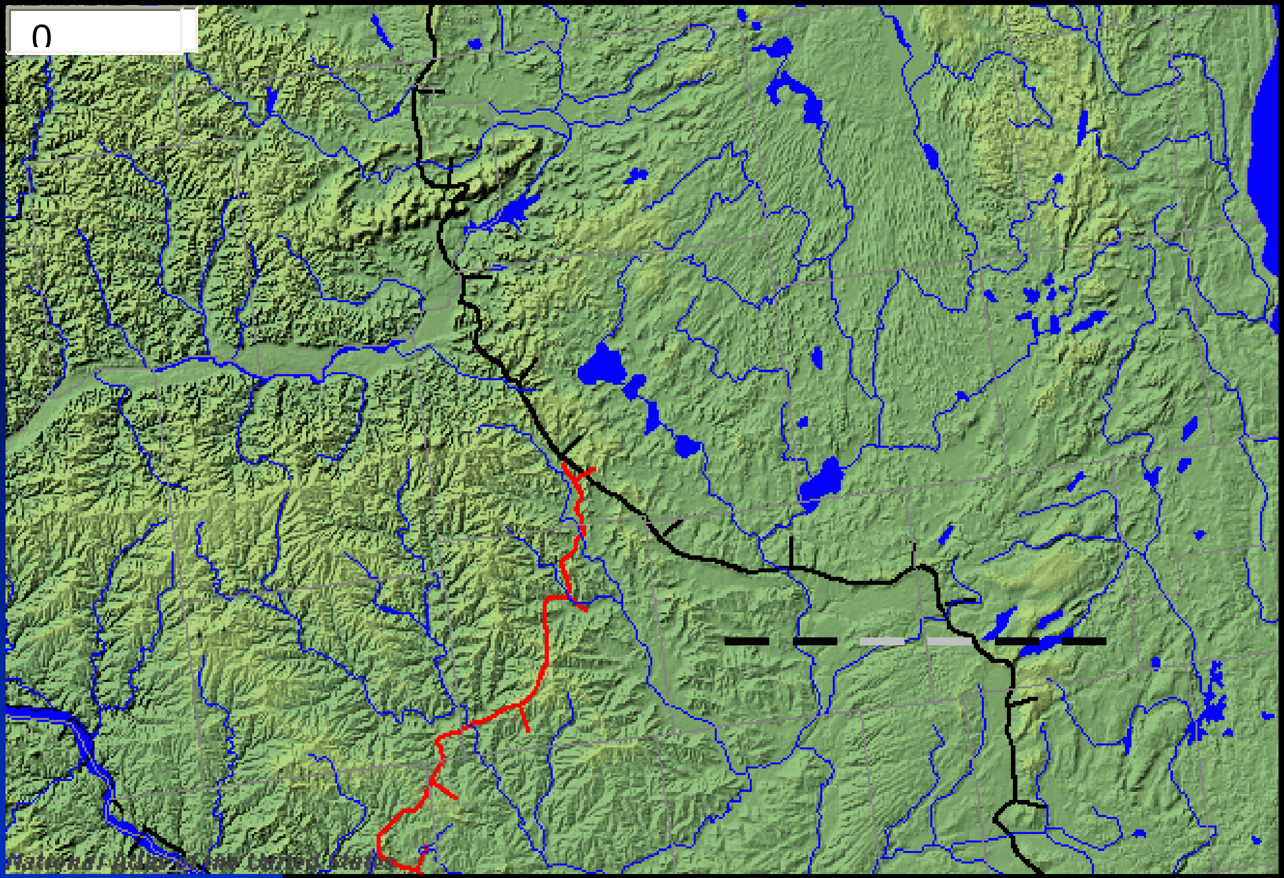
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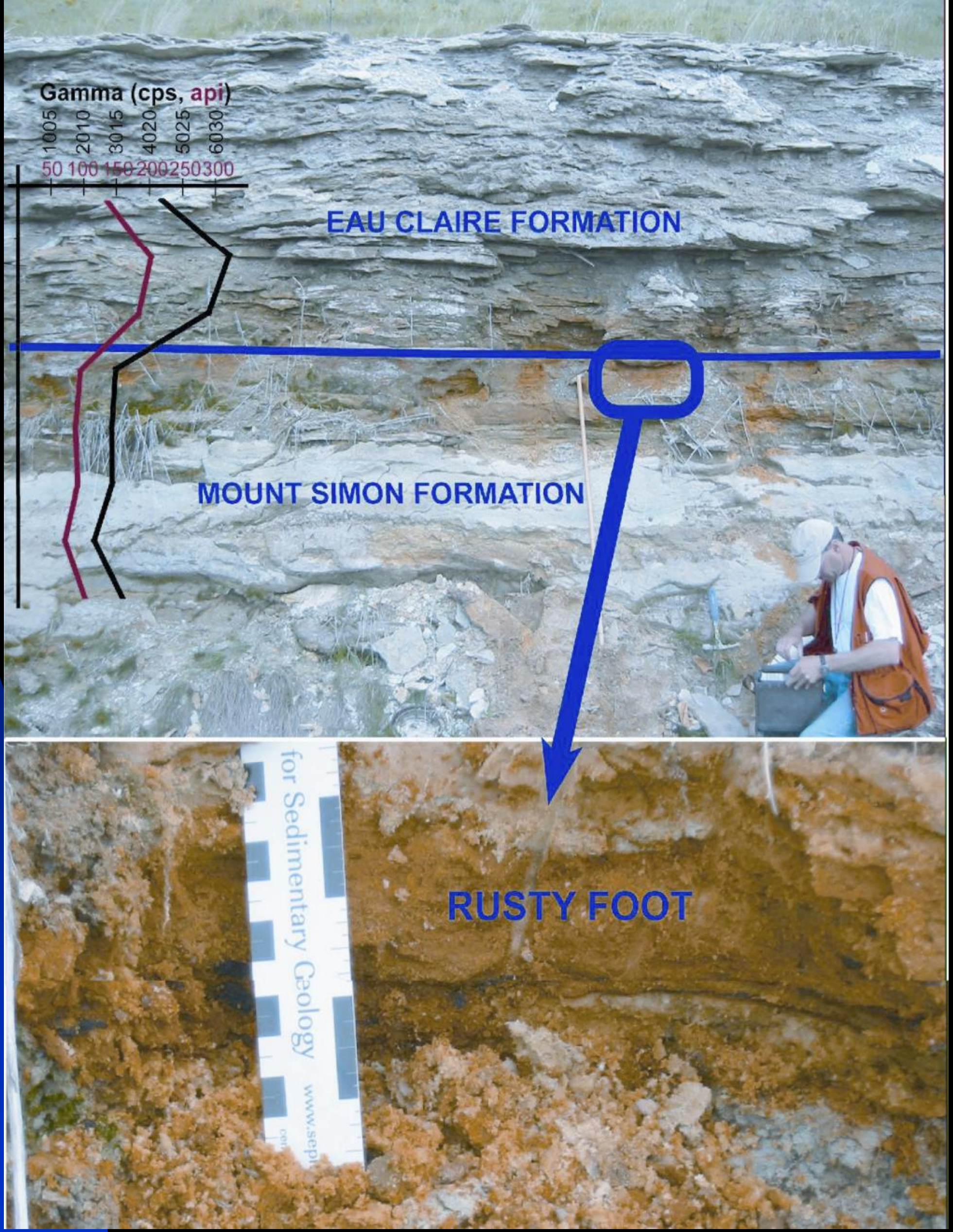
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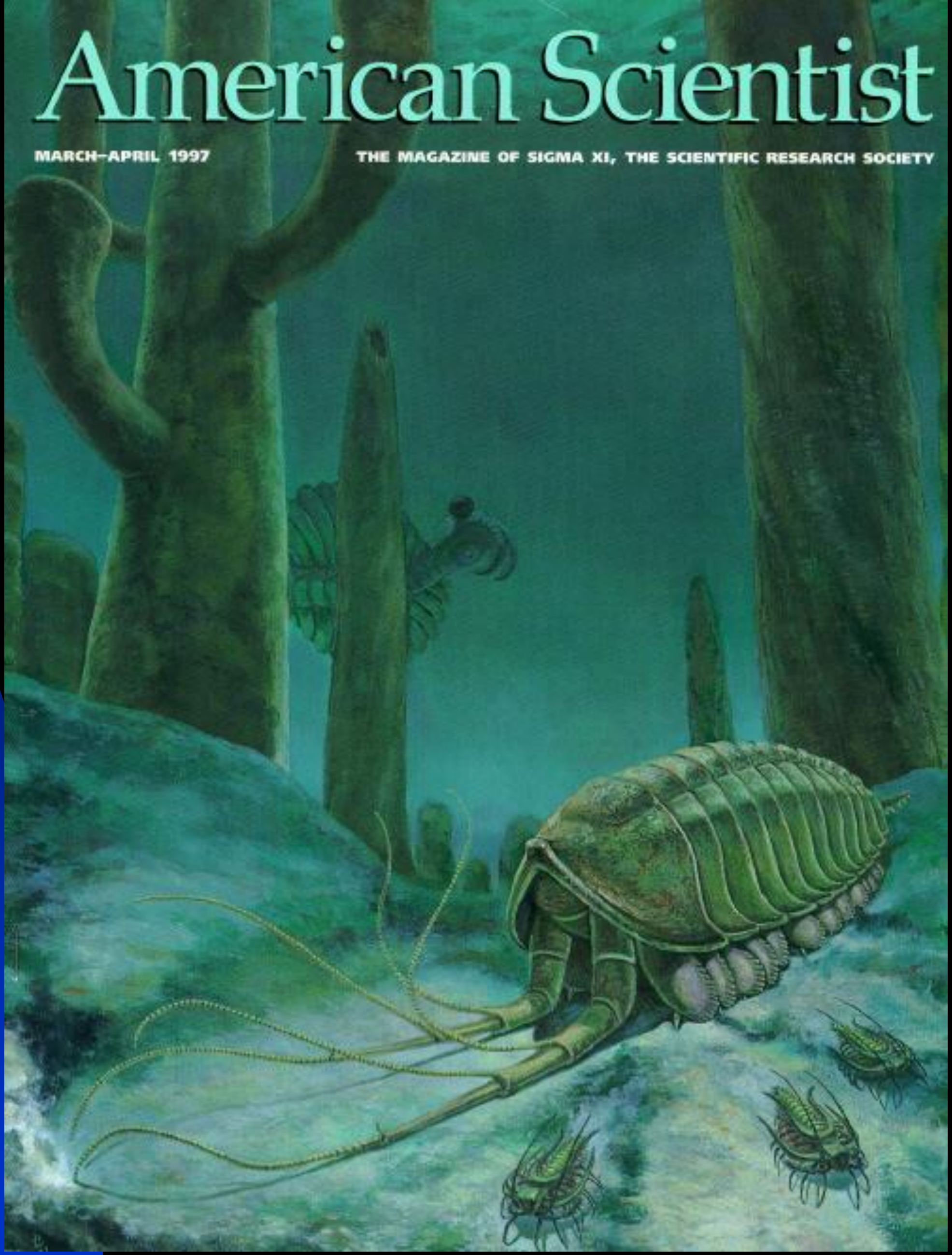
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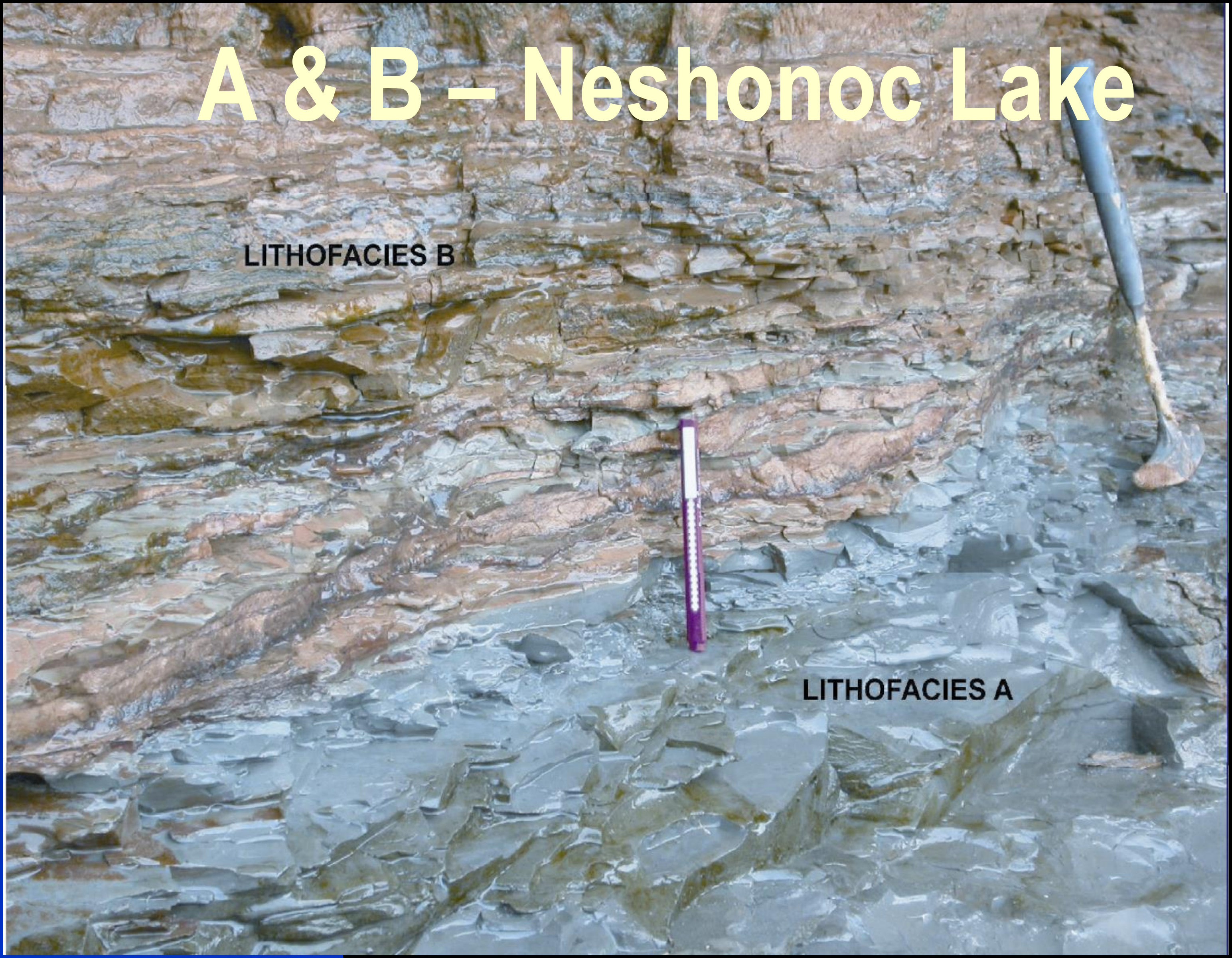

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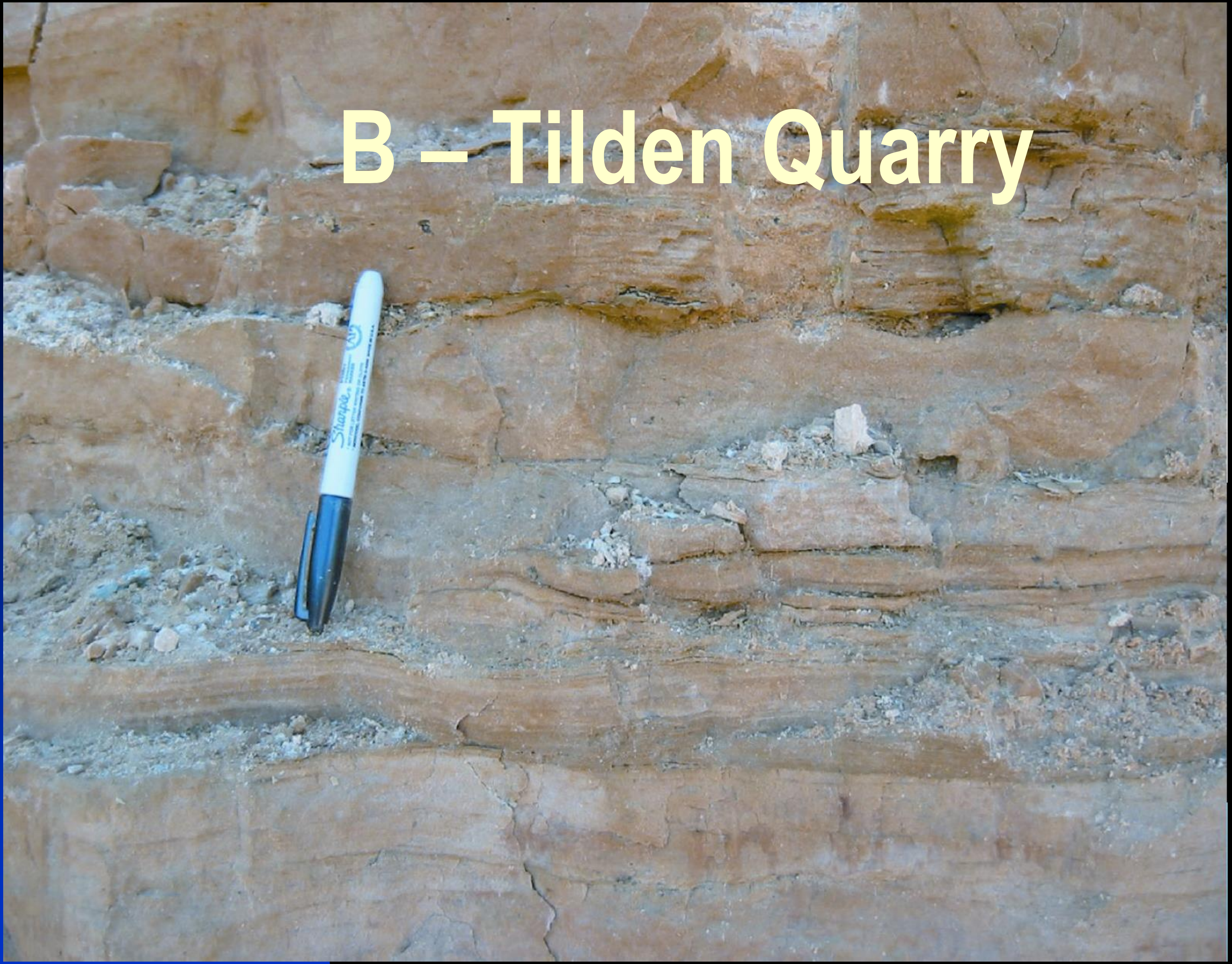


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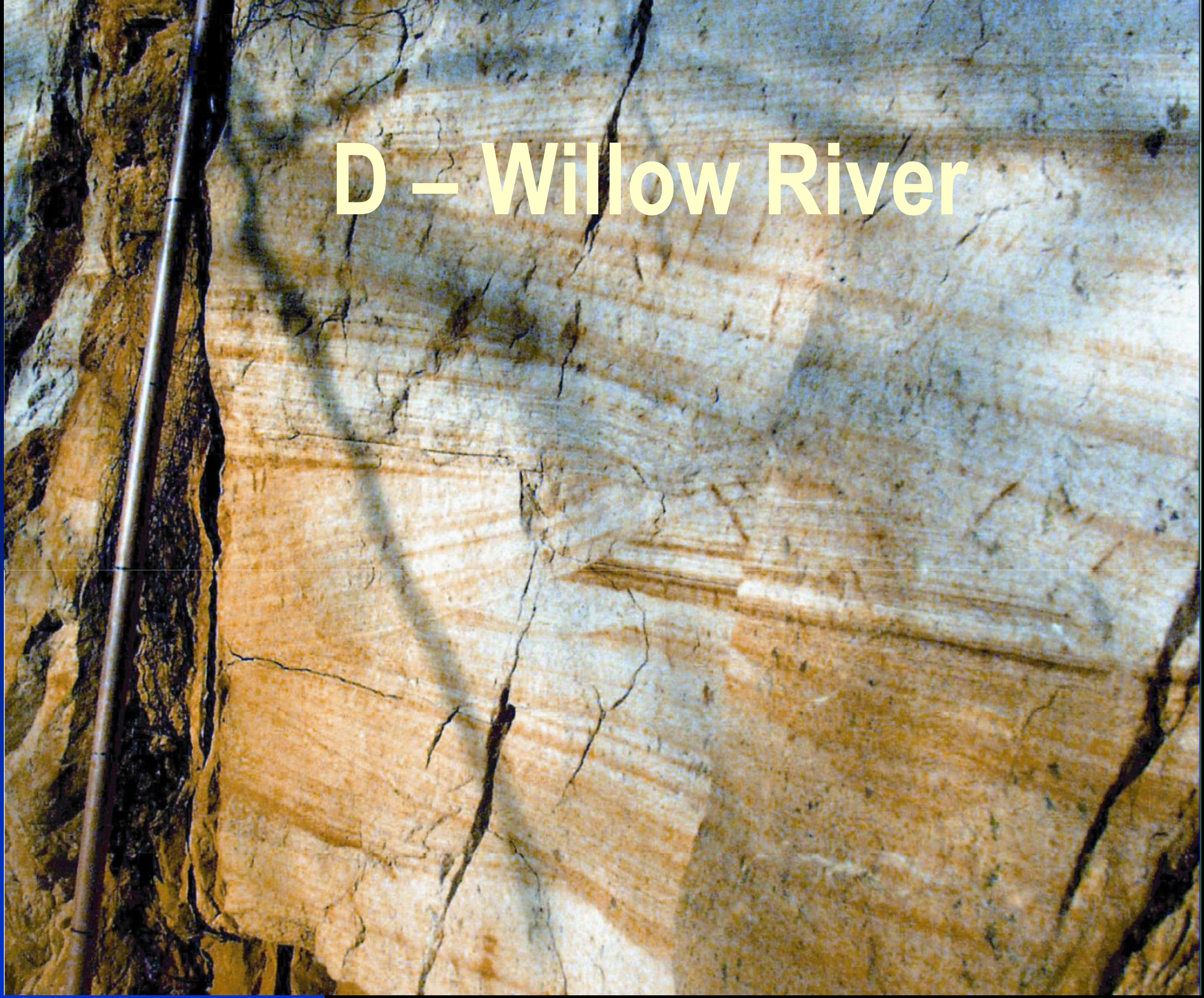
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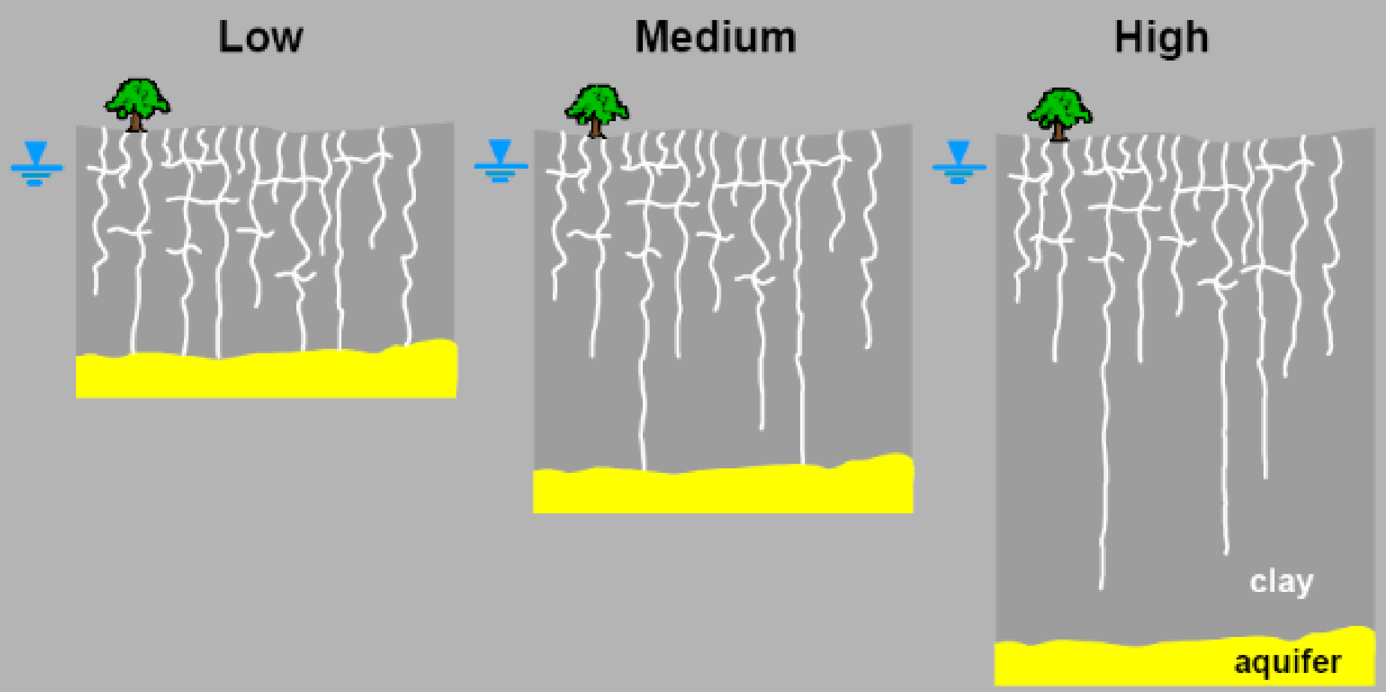

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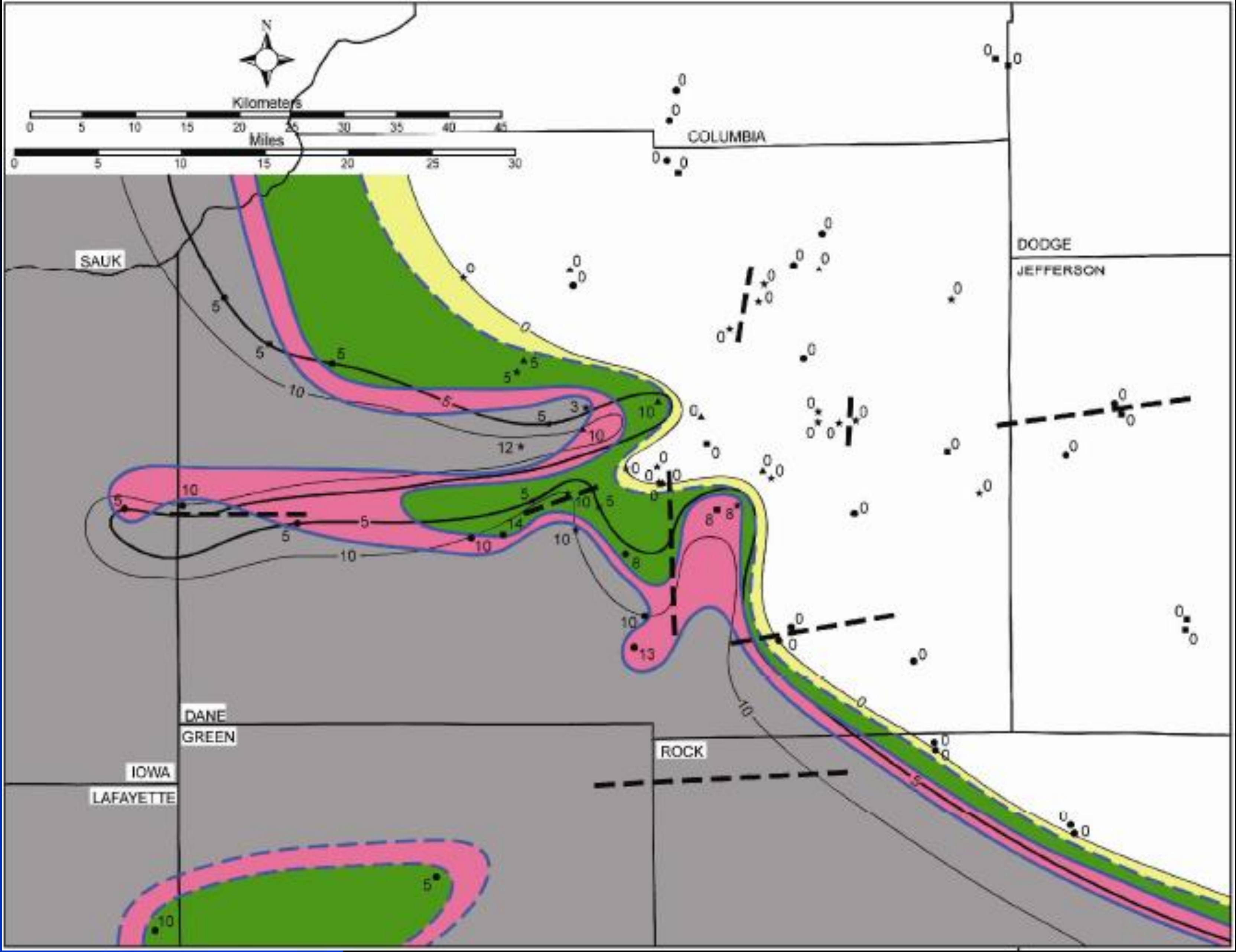
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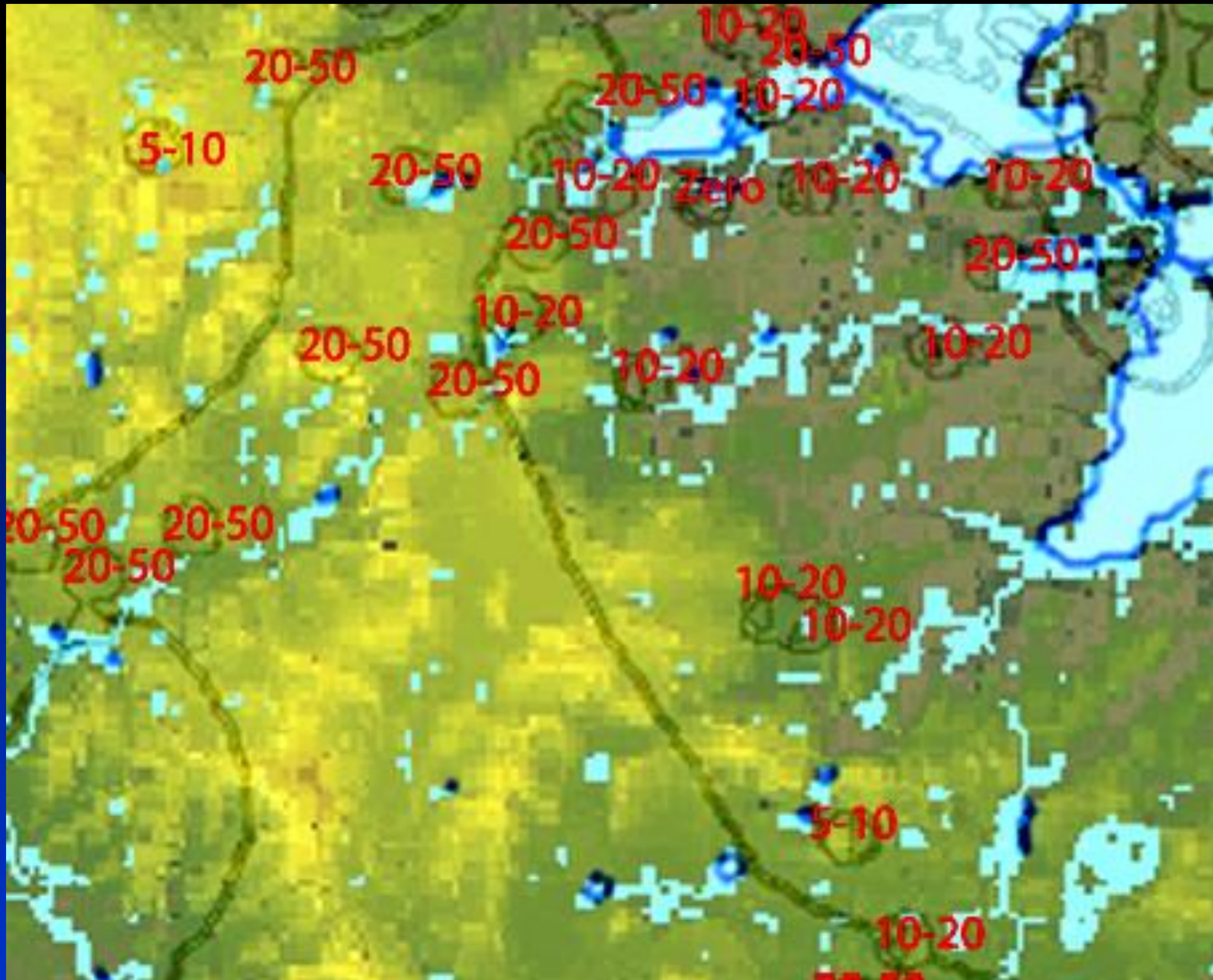
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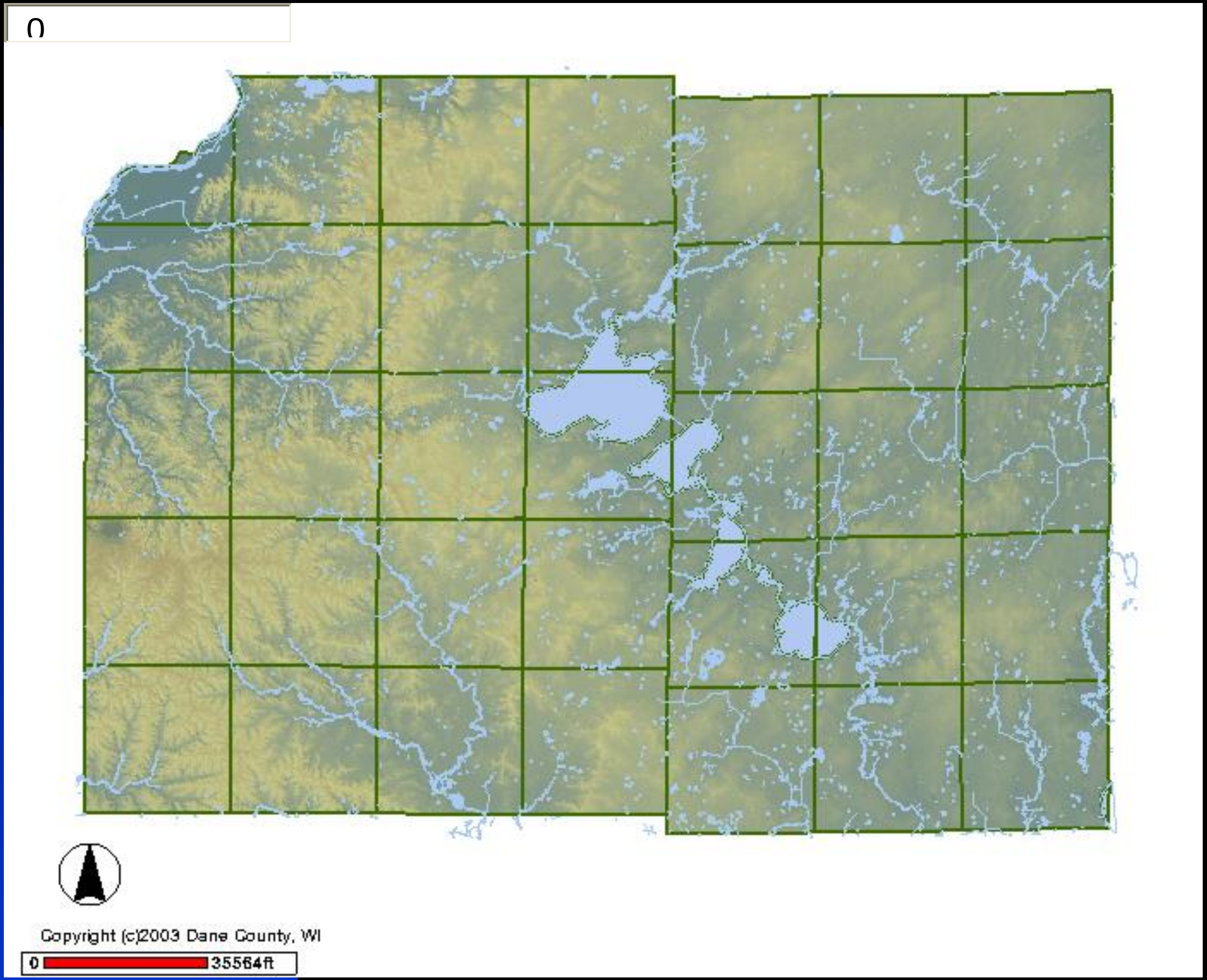
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The Economy of Cranes:
A Minder-of-Marshes Reflects on Sandhills and Whoopers

Calvin B. DeWitt

A few weeks after moving into our wetland home south of Madison in the Spring of 1972, I heard a loud wild-sounding call reverberating across the marsh. It was strangely familiar! Not my extensive work in the field, but from a recording of bird calls I had played repeatedly for a decade and more earlier as together with my students I learned by ear the birds of the midwestern U.S. The call, while familiar, came from a bird I had never seen. Not that I had not tried to find it! In the 1960s when we lived in eastern Michigan, I learned of a pair of them in the Waterloo Recreation Area west of Detroit, but I was unsuccessful in finding them. And Wisconsin? I knew that back in the 1930s—five years before I was born—that there were only 25 breeding pairs in the state. And now, some 40 years later at our new Wisconsin home, I heard it's marvelous call! It was an extremely power clangor—one that seemed to take charge of the great marsh. And it was one my family and I would continue to enjoy as it increasingly enlivened our marsh as their population increased. The marvelous wildness of their call would accompany our lives for decades to come on the glacial drumlin that holds us above water at the edge of the marsh! And what was it? It was the Sandhill Crane!

The decade of our move to Wisconsin—the 1970s—was remarkable for its remarkable innovative environmental legislation put into place by the U.S. Congress. Through it, the cranes and every other creature in America had been aided—especially by the U. S. Endangered Species Act, passed by both houses of Congress with but one dissenting vote, and signed into law by President Nixon in 1973. Its passage was not bi-partisan; it was *non-partisan*. Everyone knew that the great legacy of plant and animal species should be conserved as the heritage of our and future generations. The "name of the game" back then was pulling together to protect the blessed heritage of living creatures we believed we held in trust. We passed the ESA—and so many other pieces of environmental legislation—because we knew it was the right thing to do. Political ideology did not matter. Neither did the way we earned our livelihoods or practiced our beliefs. Even as the Sandhills were not officially endangered, they benefitted through preservation of wetland habitats of other species that were endangered. Wonderfully, the ESA was responsible for pulling back the Bald Eagle—our national symbol—and scores of other species, back from extinction's brink.

People across the land were inspired by the ESA and highly successful work in applying it across America. In concord, in my own rural Town of Dunn we created the thousand-acre Waubesa Wetlands Scientific Reserve to save wetland and upland habitats vital to Sandhill Cranes and to seventy other species of nesting birds, and also to preserve the remarkable system of layered peats—down to depths of 95 feet—that underlie the waving fabric of vibrant life that make up its vital green and black "skin." Our townspeople chose the Sandhill Crane as the avian symbol of the Town of Dunn to accompany our development of a land ethic for our town and codified this ethic into laws and ordinances. It was a work of love for the environment and its creatures that effectively gave cranes and the other abundant life status as valued "citizens" across our 34square mile landscape.

Our cranes increased and multiplied from a single pair in 1972 to currently 10 pairs, fulfilling Waubesa Marsh with fruitful abundance. So much was the scope of the "completion" of this wetland system and our home within it, that in 2010 a pair emerged one day in late summer to introduce their nearly full-grown chick to our natural lawn, and then returned day after day to feast on its rich bounty. Wonderful turf comprising some 70 species as it grades into the surround marshland furnishes supports their and other species' abundant life. Fulfilled are my marsh and I—fulfilled by their fruitful presence!

The Endangered Species Act, passed by all of us to assure an abundant and fruitful life for us and the other creatures came under serious threat in the mid-1990s. The "playing field" of American decision-making and law-making began to change dramatically, increasingly threatening the life of creatures we were protecting as part and parcel of our own lives and landscapes. Certain special interests—interests that became relentless in furthering themselves even at the loss of plant and animal lineages—exerted a concerted effort to divide the "playing field" of Congress (as they called it) and the state legislatures also, polarizing our legislatures into "two sides"—much like in the competitive team sports of football and baseball. These special interests were even successful in producing an annual book for college and university students entitled, *Taking Sides*, that furthered this polarization on environmental issues where accord, rather than discord was vital to life. I, and many other Americans, were surprised by this dramatic change of the "playing field." And we soon learned that as regards our national natural legacy, we were now supposed to be "for" or "against" saving species—even those whose long-standing lineages were heading toward termination. Some of these interests even proposed that people were the most endangered species, telling us that we should be "against" the Endangered Species Act.

For me, as for a predecessor mine at Wisconsin, Aldo Leopold, the biblical book of Ezekiel spoke some powerful and ageless wisdom to this situation. For Aldo, a key passage was Ezekiel 34:18: "Is it not enough for you to drink the clear water, do you have to muddy the rest with your feet?" And for me, was Ezekiel 33:1: a call to those who watch from the towers on the city wall to sound the alarm when trouble is coming.

In the midst of all this, on January 30, 1996, I was quoted by *The New York Times,* as proclaiming,

> "The Endangered Species Act is OUR Noah's Ark;
> Congress and special interests are trying to sink it!"

This report on page 13 of *The New York Times*, served as a prelude to my appearance on Fox Morning News in D.C. with a live cougar—borrowed from the Columbus, Ohio Zoo—to enable me to make a dramatic debut in the national media. I sounded the alarm—modeling my approach after the biblical prophet Ezekiel! And while a crane would perhaps have been a better companion, that was out of the question. However, the Columbus Zoo had a cougar—a cougar that could travel! And so it was that a cougar represented the endangered Florida Panther, and by extension all the other endangered species of the nation.

On a pleasant winter morning in 1996 I stood with a Fox Morning News coffee cup in my hand, with the cougar and its two trainers nearby, looking through a window into the news studio. When the cougar and I were called in, the anchorman allowed us—the cougar and I—to open hearts and homes across Washington, D.C. to the plight of endangered species and the Endangered Species Act. Within an hour or so following, the cougar and I were rising by elevator from an underground government garage into the office of U.S. Interior Secretary Bruce Babbitt who was in the midst of a news conference on the Endangered Species Act. As I entered his office, he turned the conference over to me and the cougar, and asked me to repeat the story for the media. Not much more that an hour later, I and my feline companion arrived at another news conference of even grander scale, and—speaking to an array of about 16 microphones, scores of cameras, and batteries of TV videographers at a large hotel near the White House—I told the story of Noah and the Ark, emphasizing the tremendous cost in time, resources, and reputation by faithful Noah. I estimate that the result was that my NYT message got out, powerfully, to between 30 and 40 million people.

"Maverick" as the cougar was named, cooperated famously—awing the Fox anchor who was left nearly speechless "by all those muscles beneath its fur"; impressing reporters with its predatory rise from the Secretary's commode to bat at a cloud of fur-enclosed microphones stretched above the cougar on telescoping poles; posing marvelously for that AP wire service photo; and turning its open mouth to my hand as I placed it on his head, licking it affectionately as I concluded with:

"The Endangered Species Act is saving remarkable creatures like these!"

A short few hours later, congressmen Young and Pombo fired off a news release, charging that I had unfairly "changed the playing field." And my phone rang nearly non-stop at my university office for the next three months. No matter what a caller's religion, non-religion, or belief about Noah, they all knew the story of faithful Noah was true; "Even if it never happened, it still is a true story" said one caller. And the prophet Ezekiel was right too!

Ye, I had changed the playing field, as charged by Young and Pombo. Thanks to the good people that had orchestrated all of this, I *was* changing the playing field—from *competitive* play to *cooperative* play, from *political* play to *ethical* play. A Mennonite couple studying at the university taught us something of these two different kinds of play, when following the annual community Thanksgiving dinner we host at our home, suggested that we play the game of *Monopoly*. But it was *Monopoly* with a twist. We would play the game *cooperatively*! They explained how we could play so that all players would win. While competitive play might be best—as for example in collegiate football—cooperative play might also be best—as for the "Endangered Species Game." Both types of play have their place no doubt. But cooperative play applied to the "economy of cranes" is redeeming, wholesome, and worthy. It helps us understand something of the meaning of life!

The Economy of Cranes

A new chapter opening recently on the great marsh when five Whooping Cranes—not Sandhills but Whoopers!—stopped nearby on their springtime journey north—to my greatest-ever surprise and delight! Over a span of four days, here was another of the world's total of 15 species of crane in my own rural town! The Sandhill, the most common of all. The Whooper, the rarest of all! Three miles south of Waubesa Wetlands they foraged in and around a small marsh, refueling before completing their trip to Necedah National Wildlife Refuge a short distance north. Unknown to them, they were benefitted locally from our Dunn Land Ethic and from the Town of Dunn Land Stewardship Plan; and they were benefitted nationally from the remarkable Endangered Species Act adopted some 35 years earlier in our nation's environmental decade. The Sandhills did not like the incursion of Whoopers as they returned to lands and marshes they once shared. I and my fellow citizens of the Town of Dunn, however, were thrilled! Like many people across the country and around the world, I have been watching—both anxiously and joyously—the tremendous efforts are being made to re-establish the Whooping Crane in North America. Wonderfully, for me personally, two Whooping Cranes hatched and fledged in the wild in 2010 in northern Wisconsin. Flying with their parents, Whooper chick W1-10 was observed at Necedah and W3-10 in Wood County. They were two of seven hatched in the wild that year, the largest number in recent history in my home state. These fledgling flights are fruitful outcomes that represent the immense efforts, commitment, passion, and compassion of determined and dedicated people working across the continent and through the decades. Of these, Ron Sauey and George Archibald first come to my mind, who as students at Cornell University, decided to pursue a life of meaning and dedicated service. They created the International Crane Foundation (ICF) in 1972, beginning in the buildings of a horse farm owned by Ron's parents. Rented for a dollar a year, this farm near Baraboo, Wisconsin anchored their dream of rescuing the whole family of cranes—the Gruidae—with its 15 species around the world.

I met with Ron and George at a Baraboo coffee shop in those early years of the horse farm, to hear of their vocational vision and passion, even as I helped develop the field of wetland ecology by initiating an on-going course in Field Investigations in Wetland Ecology taught for 12 to 15 University of Wisconsin graduate students. Taught by the marsh and me from my home on Waubesa Marsh every autmumn, scores of these students went on to become wetland scientists. Among these were several from Southeast Asia who would become crane and wetland conservationists for their home countries and the wider world. Early on, however, tragedy struck, as Ron suffered a fatal cerebral hemorrhage. But his and George's dream did not die. A new place was developed as a permanent home for ICF. The original farm now has a wonderfully rich restored prairie named after Ron. Says George, "It's a living reminder of a wonderful friend, the dream we shared, and of the fragile and glorious Earth that gives life and responds so beautifully to restoration." And a dream it was! A dream come true! This focus of Ron's short life and George's long career has really effected a positive and inspiring change in the world of conservation!

Endangered species work, of course, is not only about individual species, but also about their habitats. The 15 species of crane and the rest of the millions of species on earth do not exist or flourish by themselves. And this is where my graduate wetlands research class and my training wetlands research and conservation scientists come in. Cranes are wholly dependent upon available habitat—not only diverse wetland ecosystems and associated uplands, but also migration paths that cross many landscapes, land uses, and international political boundaries. They depend upon the land ethics and land use policies of the places they inhabit and navigate.

And they are supported by conservationists and scientists who work to interweave cranes, wetlands, ethics, and policy into integrative education and understanding they convey to the wider populace.

An important realization from such integrative understanding is that every species—every endangered species—depends upon myriad connections they must make and maintain with the rest of the world, with the biosphere. Cranes, as for all other species, live within "the economy of the biosphere." The "economy of cranes" necessarily is a "subsidiary" of the biospheric economy. Although little recognized, the "economy of people"—the human economy—necessarily is also a "subsidiary" of the biospheric economy. We all share and contribute to the same economy.

North America's Whooping Crane is still "at the brink" of extinction, even as it has been recovering. Thanks to the diligence and dedication of thousands of conservationists and American and Canadian citizens, including their support of local and national legislation to conserve cranes and their habitats, there is good reason to be hopeful about the Whoopers' future. Their population in the wild increased from 15 known birds in 1940-1941 to about 400 in 2010. In addition 175 are kept in captivity to augment natural breeding with captive breeding. Their status has improved greatly, even as it remains precarious. The lessons learned from its being pushed to the edge by unregulated hunting, loss of wetlands, inattention, and neglect are important ones that need to be etched in our memories and policies and practices in our stewardship of land and life. The lessons learned from wetland ecosystems are also to be so remembered and etched, even as these increase as we come to understand the immensely-important hydrologic and biotic functions of wetland systems and landscapes. While Whoopers still are easy targets for the shotgun and rifle, we have come finally to recognize them not as targets but as living jewels in the landscape, deserving of every effort by human beings to be faithful stewards of this remarkable living gift of creation.

What is a crane? What is a crane, in its 15 remarkable specific representations? A crane is a symbol of fulfillment and "completion" of their wetland habitats. Most importantly, it is a symbol of fulfillment and "completion" of an economy in which people who share and adjoin their habitats and flight-ways, whose cultures are enriched and inspired by their stately beauty, and who are deeply committed to living rightly on earth. Fulfilled are we by the fruitful presence of cranes in our lives and landscapes.

This is an invited chapter for an upcoming book on wildlife conservation with publication planned for 2016.

HYDROLOGY AND CHRONOLOGY OF A PEAT MOUND IN DANE COUNTY, SOUTHERN WISCONSIN

T. K. KRATZ, M. J. WINKLER, AND C. B. DEWITT
Institute for Environmental Studies
University of Wisconsin-Madison

Abstract

This study describes the hydrologic conditions that have caused the formation of a three hectare peat mound. This wetland is elevated two meters above the adjacent 100 hectare Waubesa Wetlands and has developed at the transition area between upland and lowland.

Results from 37 hydrologic stations located on the mound indicate the existence of an artesian source of water beneath the peat. Because of the ability of clay layers to confine an aquifer more than silt and sand layers, the stratigraphy of the mineral soil beneath the peat may dictate the amount of vertical flow of water and thus the height to which the peat can accumulate. The rate of groundwater flow and the topography of the artesian site determine whether peat will accumulate. The beginning of peat formation at the mound is dated at 7500 ±80 years before present (WIS-1265).

INTRODUCTION

The purpose of this study is to describe the hydrologic conditions that have caused the development of a peat mound, an elevated wetland which has formed at the transition between upland and lowland. The study site is a three hectare portion of the 100 hectare Waubesa Wetlands located in Dane County, southern Wisconsin (Figure 1). In southern Wisconsin peatlands are typically located in local depressions of the landscape where water levels are relatively high throughout the year (Bedford, *et al.* 1974). They often form in a manner similar to the way the majority of Waubesa Wetlands formed, by the accumulation of organic matter in a shallow lake bay or lake (Friedman, *et al.* 1979). The peat mound examined in this study is different from the more typical basin-filled peatlands of the region in several respects.

First, its surface is elevated two meters above the adjacent basin-filled wetland. This is remarkable because for peat to accumulate the water level must be at or near the surface of the peat throughout the year. The high water levels retard the rate of decomposition, so that rate of productivity of organic matter exceeds the rate of decomposition. The difference in elevation between the mound and the basin-filled wetland implies a dramatic change in the elevation of the water table over a relatively short distance in the peatland. The water table, and hence the surface elevation of the peat, drops nearly two meters in less than 40 meters of horizontal distance (Figure 2). This is an exceedingly steep slope for peatlands in this region. Only blanket bogs in Great Britain and Ireland exhibit steeper slopes (Moore and Bellamy 1974).

Secondly, the three-dimensional shape of the peatland is convex, not flat or concave like a typical basin-filled wetland. In this respect the mound is more similar to raised *Sphagnum* bogs that occur 800 km to the north (Heinselman 1970).

Finally, although lake sediments (gyttja) underlie the basin-filled portion of Waubesa Wetlands, no lake sediments underlie the

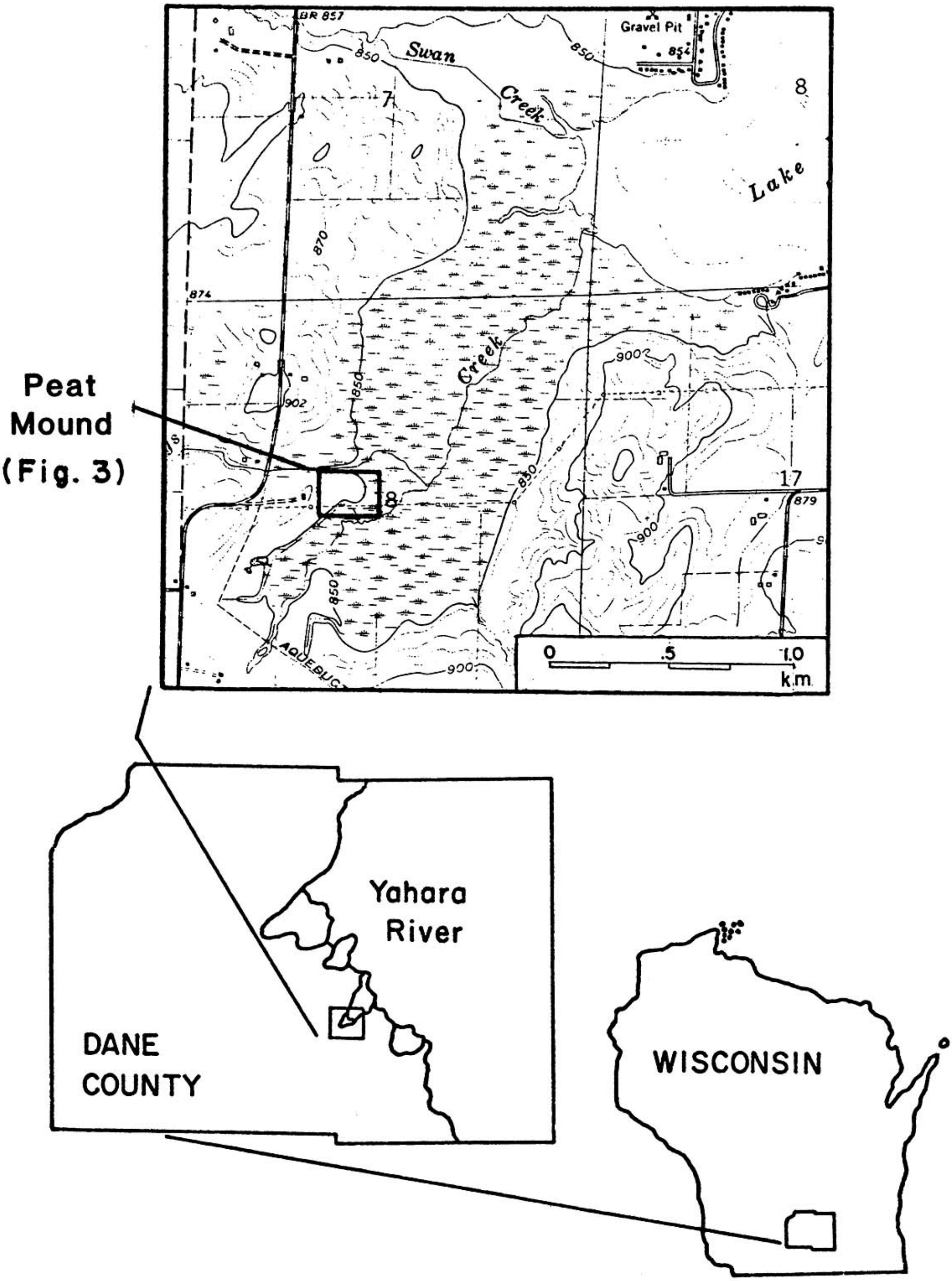

Fig. 1. Map of Waubesa Wetlands and its location in Wisconsin. The peat mound is shown in more detail in Figure 3.

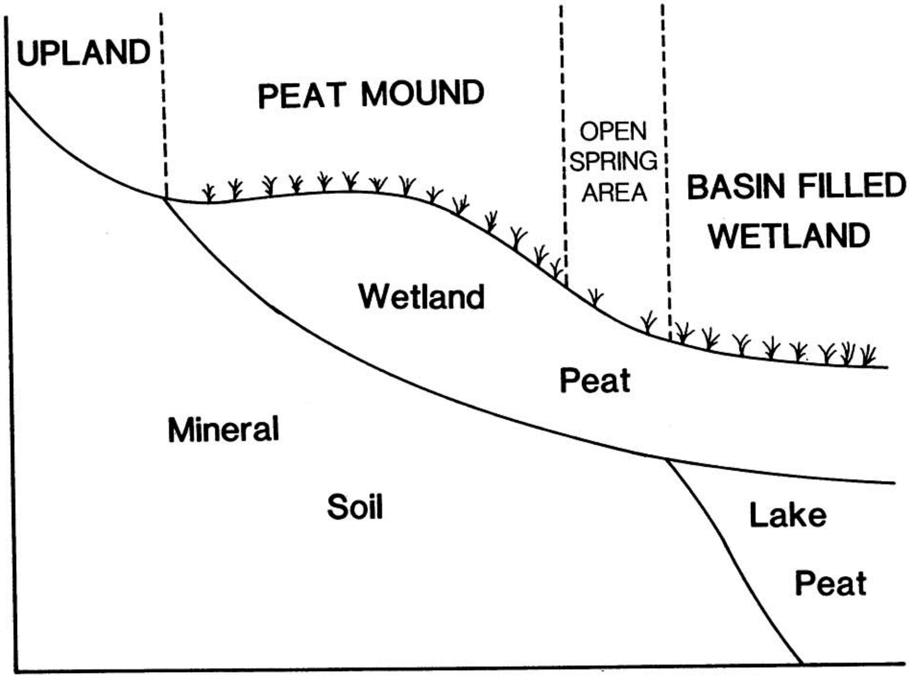

Fig. 2. Schematic diagram showing the relative positions of the peat mound and open spring area in relation to the upland and basin-filled wetland.

one to two meters of peat of the mound. The lack of underlying lake sediments implies that the peat did not form through a basin-filling process typical of many peatlands in the region.

This preliminary study provides a description of the physical conditions that have caused the development of the mound. Because the source, distribution, fluctuation and flow of water are central to the development of peatlands, we have taken a hydrological approach.

The Study Area

The site is near a terminal moraine that marks the extent of Wisconsin glaciation 13,000-17,000 years ago (Mickelson and McCartney 1979). A drumlin is located immediately next to the peat mound. Beneath the glacial till are layers of sandstone (Cline 1965). Artesian springs are common in the region, and occur at the base of the mound.

The vegetation was disturbed by plowing and the planting of reed canary grass, *Phalaris arundinacea,* about 50 years ago. The reed canary grass still dominates the site, and therefore the peatland is classified as a degraded fen (Curtis 1959). *Gentianopsis procera* occurs in comparative abundance in patches on the top of the peat mound (Burr 1980), and the groundwater is mineral rich. Other plants at the site which are characteristic of sedge meadows or wet prairies but are also found in fens are *Carex stricta, Andropogon gerardii,* and *Spartina pectinata* (Bedford, *et al.* 1974). *Cornus stolonifera* occurs in patches at both the top of the mound and in the basin-filled portion of the wetland, but not on the slopes, where *Phalaris* dominates.

One to two meters of fibrous sedge peat has accumulated in the study area. The top 50 cm is more decomposed than the deeper peat.

The site is owned by The Nature Conservancy.

Methods

Surveying. We established a 50 × 50 meter grid system on the mound using wooden stakes to mark the intersection of the grid. From this grid we defined a coordinate system to allow horizontal control at the site. All positions on the mound can be located by two coordinates.

To determine relative elevations of the surface of the mound, we leveled approximately 200 points using a Leitz automatic level. We produced a contour map with 40 cm contour intervals using computer assisted two-dimensional interpolation and smoothing routines (Figure 3). Back-checking with actual data showed the interpolation and smoothing routines did not distort the data. Smoothing was necessary because of the high degree of microrelief on the mound, caused by sedge tussocks and ant hills.

Hydrology. Thirty-seven hydrologic stations were established on the peat mound. Thirty are located on a 25 meter grid system (Figure 3). The other seven are located 10 meters apart on a transect from the top of the mound down to the basin-filled wetland. Each station has a shallow open well (about 50 cm deep) and a piezometer. Each piezometer is a 1.1 cm diameter titanium pipe open at both ends. To prevent the pipe from clogging while it was being pushed through the peat, we placed a loosely fitting bolt into the lower end of the piezometer so that the head of the bolt completely covered the lower opening. After driving the piezometer to the proper depth we lifted the pipe 2 cm, opening the lower end. The bottom

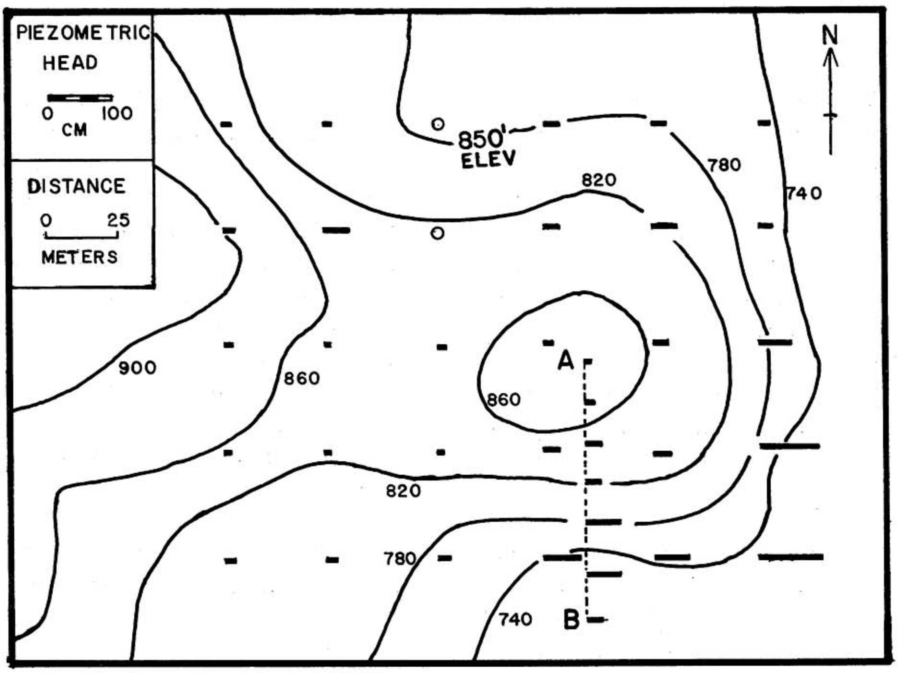

Fig. 3. Contour map of the peat mound showing the location of the piezometric head at the 37 hydrologic stations. Contour interval is 40 cm (relative to arbitrary base station); the 780 cm contour line coincides with the 850 ft. U.S.G.S. contour line (see Fig. 1). A-B marks the transect shown in Figure 4. Hollow circles indicate negative piezometric head (see text).

openings of the piezometers are in mineral soil three to four meters beneath the surface of the mound.

The level of the water in the piezometer measures the hydraulic head of the stratum at the bottom of the pipe. This was compared with the water level in the well. We call the difference between the two levels, the piezometric head. If the water level in the piezometer is higher than the water level in the open well, we arbitrarily called this a positive piezometric head. Water will tend to move upward. The surface elevation at each station is known and elevations are marked on each piezometer.

We measured the elevation of water in each well and piezometer using a wooden dipstick in a four hour period on 13 November 1979, and again on 25 October 1980. There were no substantial differences between the results. Our figures are based on the 13 November 1979 data. Dipstick displacement was calculated and accounted for in the results.

Stratigraphy. We determined the stratigraphy of the underlying sediments at several stations along the transect using Livingstone, Hiller, or Davis peat corers, as well as a standard soil auger.

Laboratory analysis. Pollen and charcoal analysis was done at the Center for Climatic Research. Pollen was scarce but at least 100 grains were counted at each level. Standard pollen analytical techniques were used (Faegri and Iverson 1964).

Results and Discussion

The contour map of surface elevations of the mound shows the existence of a raised dome of peat (indicated by A in Figure 3)

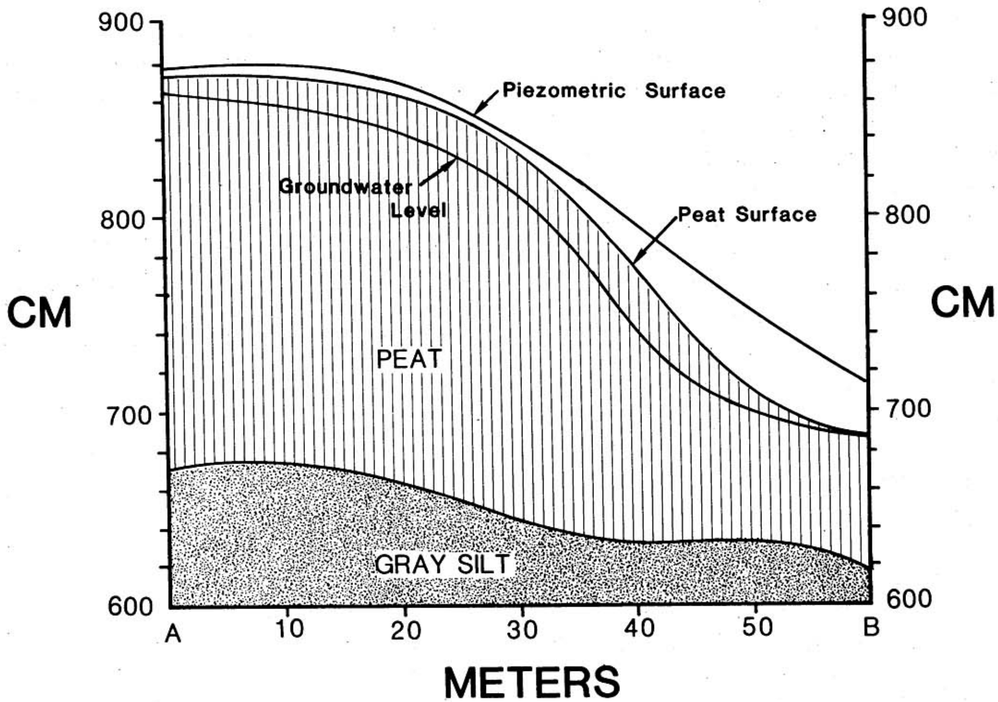

Fig. 4. Cross section of the peat mound, showing the relationship among the piezometric surface, peat surface, groundwater level, and mineral soil (gray silt). The location of the transect is shown in A-B in Figure 3.

nearly two meters above the surface of the basin-filled peatland. The water table closely follows the surface elevations, usually being within 30 cm of the surface. To determine the source of the water in the peat mound, we measured the piezometric head at 37 locations. Figure 3 shows that 35 of the 37 stations have a positive piezometric head, indicating an artesian source of water. We cannot fully explain the anomalous readings at the other two stations, although there may be a very localized perched water table near the two stations. In contrast to the positive piezometric head in the mound, a hydrologic station in the basin-filled portion of the wetland showed no difference in water levels between a piezometer and an open, shallow well. This indicates that the hydrology of the peat mound is qualitatively different than the hydrology of the basin-filled wetland.

The artesian source of water has allowed the peat to accumulate to an elevation nearly two meters above the surrounding basin-filled wetland. To investigate the reasons for the existence and location of the relatively steep slopes emanating in three directions from the raised dome of peat, we placed hydrologic stations ten meters apart along a transect from the top of the mound down to the basin-filled wetland (Figure 3). Figure 4 shows that although there is a good correlation among the piezometric surface, the surface of the peat, and the water table, the piezometric head is greater midway down the slope than on the top of the mound.

It might be expected that a region with a greater piezometric head would be able to supply water to a higher elevation, allowing the peat to accumulate to a greater height, than a region with a lesser piezometric head. The data refute this. Although the top of the mound has a high piezometric head, the slopes have higher heads. The highest piezometric heads are found at the base of the slopes near the open springs (Figure 3).

There are at least two reasons why the elevation of the peat is not positively correlated with the piezometric head. Under very high heads the vertical flow of water may be great enough to prevent any accumulation of peat. This would be the case if there were little resistance to flow in the substrate. Any excess organic matter is dislodged and washed away by the water. This is the most likely explanation of why the open spring area at the base of the mound (Figure 2) still exists after thousands of years of peat accumulation elsewhere in Waubesa Wetlands.

Secondly, if there is substantial resistance to vertical flow through the substrate, a high piezometric head need not be associated with an elevated water table and subsequent peat accumulation. To test this idea, we conducted a preliminary experiment to see if there is greater resistance on the top of the raised sedge meadow. Detailed stratigraphies were determined at both locations. In addition, at the midslope point seven piezometers were placed at various depths in various substrates according to the predetermined

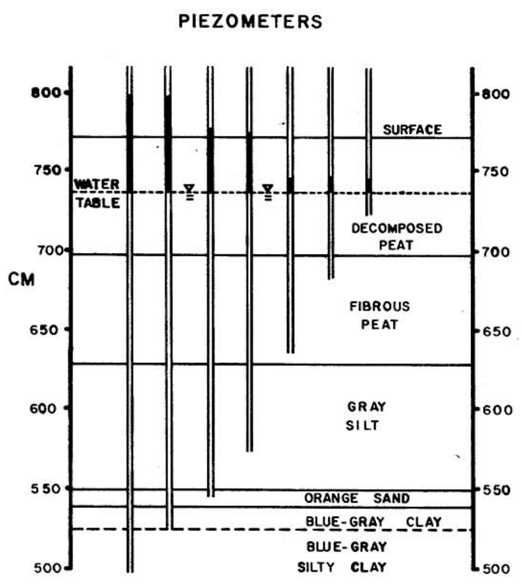

Fig. 5. Piezometric heads (dark lines) at seven levels in the stratigraphy at a midslope point. Note the three distinct levels of the piezometric heads.

stratigraphy. The results are shown in Figure 5.

Although the piezometers were placed at seven depths, there are only three distinct values of piezometric head. Two barriers to vertical flow are suggested by this result. The first is at the boundary between the blue-gray clay layer and the orange sand and the second is at the interface between the gray silt and the fibrous peat. The stratigraphy at the top of the mound differs from the stratigraphy midslope. At the top of the slope there is no blue-gray clay layer beneath the orange sand. Although we have not yet done the piezometric test, the lack of the clay layer probably affords greater vertical flow rates, allowing a higher water table and greater peat accumulation on the top of the mound. In addition, the sand lens may allow significant rates of horizontal flow from the mound to the basin-filled wetland, so that not only does vertical flow meet a greater resistance midslope, but horizontal flow is enhanced. The vertical extent of the water table is thus limited in the midslope region.

Chronology of the Peat Mound Development

The ages of the mineral soil strata and the peat underlying the top of the mound were estimated by correlating pollen spectra taken from various levels with published, radiocarbon-dated pollen diagrams (Friedman *et al.* 1979). The deposition of the mineral soil probably occurred rapidly after deglaciation. Although pollen grains are sparse, half of the grains counted from levels in the mineral soil are spruce. This suggests an age of about 12,500 years before present (L. Maher, Personal communication).

Peat sampled just above the mineral soil-peat interface from a core taken at the top of the mound has been radiocarbon dated at the University of Wisconsin-Madison (WIS-1265) by Dr. Margaret Bender. The date for the beginning of peat formation is 7500 ±80 years before present. This date indicates the beginning of the postglacial warm period in southcentral Wisconsin and the extension of the prairie into this area. It is a minimum date because of the charcoal layer at the transition between inorganic and organic sediment indicating a possibility of burned peat and therefore a hiatus in the core.

A decrease in groundwater supplies caused by a decrease in precipitation and an increase in temperature during this time might have decreased the piezometric head enough to allow peat to be produced and to begin to accumulate. A higher piezometric head would wash sediment away and a smaller head would be too intermittent to give a favorable production/decomposition ratio for build-up of peat. Once the peat begins to build up it acts like a sponge—raising the water table, and the peat acts also as a cap—slowing down the flow of water. The peat, then, accentuates the peat forming conditions and accelerates the accumulation of peat.

Other charcoal layers are common in the peat, suggesting that fires have swept over the landscape and have maintained oak-deciduous forest and prairie vegetation in the region to the present day. The peat mound itself may have also burned during dry periods in the past.

The Significance of Peat Mounds

Because of the importance of artesian sources of water to the hydrology and development of peat mounds, the ecological properties of the mound may differ substantially from other types of peatlands. For example, nutrient cycling, vegetation dynamics, and water relations in a wetland are all dependent to some degree on the hydrological properties of the wetland. Yet very little is known about the ecosystem dynamics of spring-dependent peatlands.

The occurrence of spring induced peat mounds in Jefferson County, southern Wisconsin has been reported by Milfred and Hole (1970) and Ciolkosz (1965). Van der Valk (1975) and Holte (1966, cited in Van der Valk) describe similar systems in northwestern Iowa. Although the vegetation of the

Iowan fens is different from that of Waubesa, the hydrologic setting is similar.

In Europe several authors discuss springs and their effects on peatland development (Hafsten and Salem 1976; Holdgate 1955a, b; Kirchner 1975; Lahermo *et al.* 1977; Moore and Bellamy, 1974; Wickman 1951). But because of differences in water flow, topography, climate, and water chemistry, the peatlands described in these studies are similar to our site only because springs are important in their development.

There is little knowledge of the regional distribution and abundance of peat mounds, but the geologic condition giving rise to these peatlands may not be rare (Ciolkosz 1965; G. B. Lee and J. H. Zimmerman, personal communications). Because these peatlands may often occupy the transition area between upland and more extensive wetlands, they are more subject to agricultural disturbances such as runoff, drainage, and tillage. The vegetation differences between the Iowa fens and the mound at Waubesa Wetlands may be a function of the land use history of each area as well as the climatic and geochemical differences of the area. The Excelsior fen complex in Iowa which has more than eleven peat mounds and associated spring terraces is badly degraded by cattle pasturing although the wetter areas still have *Lobelia kalmii, Eupatorium perfoliatum,* and *Parnassia glauca; Gentianopsis procera* was found at the nearby Silver Lake fen which is an Iowa Natural Area Conservation site (M. Winkler, personal observation).

Ecological processes taking place in this intermediate position in the landscape are important in the coupling of land and water systems (Hasler 1975).

Conclusions

An artesian source of water has allowed vertical accumulation of peat and development of a peat mound. Stratigraphy of mineral soil beneath the peat influences the amount of vertical flow of water and ultimate height of the peat. The mound may be approaching (or may already be at) an equilibrium height.

The peat mound, because of its location between the upland and basin-filled wetland, may act as an important buffer, intercepting runoff of nutrients from the upland. Also, because of their location at the upland-wetland interface, many peat mounds have probably been eliminated or degraded in some way. Because the ecological processes occurring in this kind of peatland are not well known, more detailed research needs to be done before the complexities of this hydrologically interesting ecosystem are understood.

Acknowledgments

We would like to thank Cornelia Burr, Jim Bruskewitz, Fran Heliotis, John Meland, Bruce Porter, and Steve Ugoretz for their discussion of this project during class meetings of IES 900 in the fall semester 1979. David and Daniel Winkler helped with part of the field work. Stefan Winkler translated the Kirchner article. Dorothy Ingle and Melanie Woodworth typed the manuscript. Portions of the work were supported by NSF grants #DEB 77-14501 to C. B. DeWitt and ATM 79-26039 to J. E. Kutzbach.

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Estimation and Extrapolation of Climate Normals and Climatic Trends

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(Manuscript received 11 December 2006, in final form 6 July 2007)

ABSTRACT

WMO-recommended 30-yr normals are no longer generally useful for the design, planning, and decision-making purposes for which they were intended. They not only have little relevance to the future climate, but are often unrepresentative of the current climate. The reason for this is rapid global climate change over the last 30 yr that is likely to continue into the future. It is demonstrated that simple empirical alternatives already are available that not only produce reasonably accurate normals for the current climate but also often justify their extrapolation to several years into the future. This result is tied to the condition that recent trends in the climate are approximately linear or have a substantial linear component. This condition is generally satisfied for the U.S. climate-division data. One alternative [the optimal climate normal (OCN)] is multiyear averages that are not fixed at 30 yr like WMO normals are but rather are adapted climate record by climate record based on easily estimated characteristics of the records. The OCN works well except with very strong trends or longer extrapolations with more moderate trends. In these cases least squares linear trend fits to the period since the mid-1970s are viable alternatives. An even better alternative is the use of "hinge fit" normals, based on modeling the time dependence of large-scale climate change. Here, longer records can be exploited to stabilize estimates of modern trends. Related issues are the need to avoid arbitrary trend fitting and to account for trends in studies of ENSO impacts. Given these results, the authors recommend that (a) the WMO and national climate services address new policies for changing climate normals using the results here as a starting point and (b) NOAA initiate a program for improved estimates and forecasts of official U.S. normals, including operational implementation of a simple hybrid system that combines the advantages of both the OCN and the hinge fit.

1. Introduction

Climate services of different countries provide customers with statistical information about climatic variables (mainly at the surface) that is based on long-term observations at meteorological stations. This statistical information mainly consists of parameters of the statistical distribution of climatic variables. The most important of these parameters are climatic normals, which are considered to be official estimates of the expected values of climatic variables. The importance of normals derives from their use as a major input for an enormous number of critical societal design and planning purposes.

Because of the widespread need for representative

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DOI: 10.1175/2007JAMC1666.1

normals along with other climate statistics, it is crucial that climate services deliver the best estimates possible. This is universally not the case, however; currently there are either no or suboptimal published estimates of the *current* climate, that is, the expected values of climatic variables today, at time and space scales relevant to the myriad applications for which they are needed. The reason for this is threefold:

1) The contemporary climate is changing at a pace rapid enough to already have important impacts. Climate statistics, including normals, are nonstationary. In the case of U.S. climate divisions, there are many instances in which linear trend estimates (discussed later) yield changes in seasonal temperature and precipitation normals over the last 30 yr that are between 1 and 3 standard deviations of the residual variability. Examples are presented in Fig. 1—note in particular the January–March (JFM) temperature trends in the western United States and October–December precipitation trends in the south central United States. The existence of these trends is one of two sources [the other is El Niño–Southern Oscillation (ENSO) variability] of virtually all of the skill inherent in official U.S. seasonal forecasts, because these forecasts are referenced to the official 1971–2000 U.S. normals (Livezey and Timofeyeva 2007, manuscript submitted to *Bull. Amer. Meteor. Soc.*). In fact, it is impossible to exploit optimally the ENSO signal in empirical seasonal prediction without properly accounting for the time dependence of normals (Higgins et al. 2004).
2) Current physical climate models cannot credibly replicate the statistics of today's climate at scales needed for practical applications, because they cannot credibly replicate recent past climates at these resolutions. These models seem to reproduce the time evolution of the global mean annual temperature well but often fall far short for seasonal mean temperatures at subcontinental and smaller spatial scales at which the information can be practically applied (Knutson et al. 2006). The situation is worse for replication of the evolving statistics of the precipitation climate. We consequently are not in a position to develop accurate estimates of current normals and other statistics through generation of multiple modeled realizations of the climate. However, dynamical climate models may facilitate the development and testing of competing empirical approaches (see section 4).
3) Since the early 1990s, little research and development attention has been devoted to finding improved alternatives to existing (and often misapplied) empirical approaches for estimation and extrapolation of normals, which include linear trend fitting and the so-called optimal climate normal (OCN; Huang et al. 1996; Van den Dool 2006) used in seasonal prediction by the U.S. National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA).

The consensus expectation of the climate community is that the global climate will continue to change, and therefore the fundamental problem emphasized here will not disappear. In the meantime a great deal of research attention and resources are being devoted worldwide to improvement of global climate models, but it will take many years before these models can be leveraged directly for monitoring current climate at time and space scales practical for applications. In contrast, viable alternatives to current empirical techniques do exist for estimation and extrapolation of time-dependent normals and other climate statistics. Therefore, they should be explored and adopted, including for official use to supplant current practices.

The intent of this paper is to highlight the problem of empirical estimation and extrapolation of time-dependent climate statistics, with a particular emphasis on normals, to raise the problem's profile and encourage increased attention to it in the applied climate community, and to effect changes in official practices. To meet these goals, we will analyze and compare the expected error of four current approaches (one introduced here for the first time) for estimation and extrapolation, through the use of a statistical time series model appropriate for many meteorological time series.

The three current methods are 30-yr normals that are officially recomputed every 10 yr (e.g., for 1961–90, 1971–2000) in the United States by the NOAA National Climatic Data Center (NCDC) and are traditionally available 2–3 yr later (historically in 1963, 1973, . . . , 2003), the above-mentioned OCN, and least squares linear trend fitting. The fourth approach is a modification of least squares linear fitting to model more closely the observed characteristics of the likely underlying cause of rapidly changing normals—namely, global climate change. In the first two of the four techniques, extrapolations are made by assigning the latest computed value to future normals, but in the latter two they are made by extending the linear trend into the future.

In the presence of strong, dominantly linear trends largely attributable to global climate change (like those characterizing North America in the winter and spring), it is intuitive that each successive approach of the four listed above (if appropriately applied) should outper-

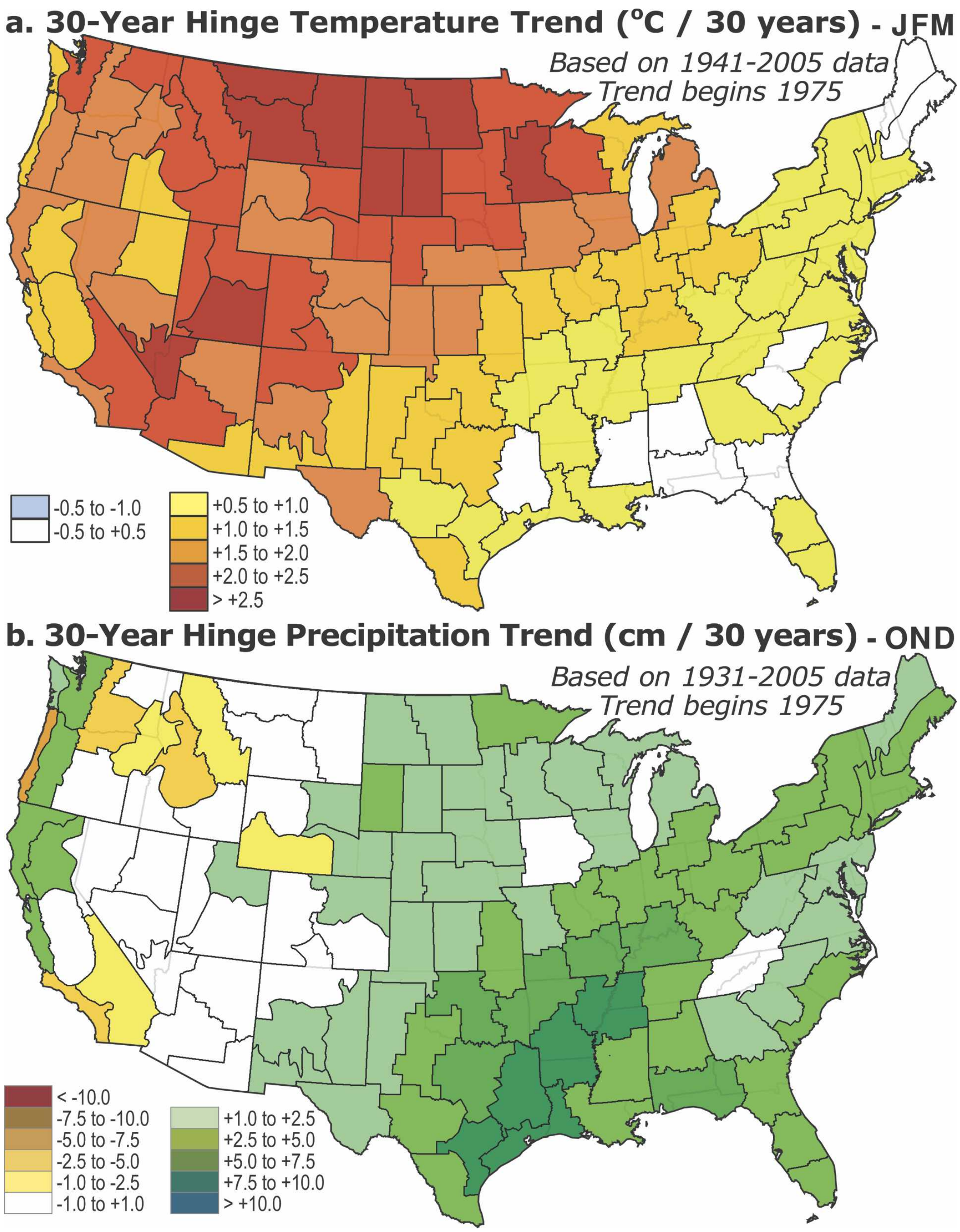

FIG. 1. Trends in (a) January–March mean surface air temperature and (b) October–December mean precipitation normals for 102 U.S. climate divisions. Trends are for the 30 yr ending in 2005 and are estimated using a technique described in section 3b.

form those preceding it. The analysis here will provide an objective, quantitative basis for this intuition. Problems associated with least squares linear trend fitting and its misapplication will also be discussed. The results here and a few other basic precepts can constitute a starting point for best practices for normals and trends for working climatologists.

Following the comparative analysis, the paper contains a brief discussion of nonlinear and adaptive trend estimation methods. An overview of recent advances in the treatment of two other important nonstationary components in climate statistics, the diurnal and annual cycles, is included in an appendix. The paper concludes with summary remarks and recommendations.

2. Trend-related errors in estimates of climatic normals

Let us consider a time series of annual (or monthly for specific month, etc.) values of a meteorological variable $y(t)$ that consists of two independent components:

$$y(t) = Y(t) + y'(t). \quad (1)$$

Time t in this case is in years, $Y(t)$ is the time-dependent expected value of $y(t)$ (e.g., climatic trend), and $y'(t)$ is climatic noise described by a zero-mean stationary red-noise random process with variance σ^2 and 1-yr autocorrelation g. Let us assume that the actual trend in expected value $Y(t)$ is linear with known constant a and b in the expression

$$Y(t) = a + bt. \quad (2)$$

The trend parameter b can be expressed in relative units of sigma per year as $\beta = b/\sigma$. Instead of the actual $Y(t)$ we always use its estimate $\tilde{Y}(t)$ derived from observed data. The accuracy of $\tilde{Y}(t)$ depends on the method by which it is estimated. Let $\delta^2(t)$ be the mean-square error of estimated expected value $\tilde{Y}(t)$ and $\eta(t)$ be the mean (expected) square relative (to the climatic noise; i.e., scaled by σ) error:

$$\delta^2(t) = \overline{[Y(t) - \tilde{Y}(t)]^2} \quad \text{and} \quad \eta(t) = \delta^2(t)/\sigma^2. \quad (3)$$

In the remainder of the article, $\eta(t)$ will be referred to as the "error" for simplicity.

a. Thirty-year normals

The traditional approach to climate normals will be evaluated first. A comprehensive historical analysis of the evolution of the definition of climatic normals can be found in Guttman (1989). The normals, recommended by the World Meteorological Organization (WMO), are 3-decade averages recomputed each 30 yr (for surface variables only). However, NCDC and many other climatic centers voluntarily recompute them each decade. If this practice survives during the next few years, the current 1971–2000 normals will be replaced by 1981–2010 normals as soon as they are computed and released, likely by 2013.

A 30-yr average was long considered an acceptable trade-off between excessive sampling errors from climatic noise for shorter averages and unacceptably large changes in the climatic normal $Y(t)$ over the averaging period for longer averages. A time average will generally approximate a monotonically changing normal that is best near the midpoint of the averaging interval, with error increasing toward the beginning and end of the interval. However, if the change is slow then it will still constitute a good estimate over the entire span, in this case 30 yr. Here we will quantify the way faster-changing climatic normals compromise the acceptability of the 30-yr average trade-off. In section 2b, the same problem will be addressed for other averaging periods updated annually, that is, moving averages, and the results will be applied to assess the OCN method.

There are two major categories of users of the WMO normals. The first category of these users is forecasters, who predict (in some fashion) climate anomalies in the future for time intervals from a few weeks to 1 yr. The predicted climate anomalies must be expressed as anomalies from the official (i.e., past) normals. Because the climate is nonstationary, however, a prediction of the normal is necessary as well and becomes a key part of the forecast and a source of much of its skill (or lack thereof). The other user category needs climatic normals for more distant periods of time (on the order of 10 yr) for planning and design purposes. Consider the case in which all of these consumers use the official normals for the next decade, until new normals can be computed and released.

Here an N-yr average of the observed $y(t)$ is the estimate of its climate normal. Let $\tau = t - t_0$, where t_0 is the last year of the averaging period. Using (2) and (3), it is straightforward to obtain

$$\eta(N, g, \beta, \tau) = \eta_a(N, g) + \eta_b(N, \beta, \tau), \quad (4)$$

where $\eta_a(N, g)$, the contribution to the error η from the sampling error of averaging red-noise residuals $y'(t)$ over N yr, is

$$\eta_a(N, g) = (1 + g)/[1 + g + (N - 1)(1 - g)], \quad (5)$$

and $\eta_b(N, \beta, \tau)$, the contribution to η related to the known trend $\beta = b/\sigma$, is

$$\eta_b(N, \beta, \tau) = \{\beta[(N - 1)/2 + \tau]\}^2. \quad (6)$$

The expression for the sampling error (5) is from Polyak (1996). The expression for trend-related error (6) follows from the derivation and represents systematic, not random, error. It is equal to zero at the mid-interval time $t^* = t_0 - (N - 1)/2$ and increases in both directions from this point proportionally to the squares of trend b and time increment $t - t^*$.

The error $\eta(N, \tau)$ of WMO normals ($N = 30$ yr), computed from (4)–(6) for different β and g, is given in Table 1 for $\tau = 0$ and $\tau = 10$ yr. As noted in the introduction, the range of β in Table 1 has been observed for U.S. climate-division seasonal mean tem-

TABLE 1. Theoretical estimates of $\eta(N, g, \beta, \tau)$, the expected mean-square relative [i.e., $\delta^2(t)/\sigma^2$] error of WMO normals at the end of an $N = 30$ yr period of averaging ($\tau = 0$) and 10 yr later ($\tau = 10$ yr) for different linear trends $\beta = b/\sigma$ and lag-1 correlations g in climatic records. Values equal to or greater than 0.25 are shown in boldface.

	$g = 0$		$g = 0.1$		$g = 0.2$		$g = 0.3$		$g = 0.5$	
	$\tau = 0$	$\tau = 10$	$\tau = 0$	$\tau = 10$	$\tau = 0$	$\tau = 10$	$\tau = 0$	$\tau = 10$	$\tau = 0$	$\tau = 10$
$\beta = 0$	0.03	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.09	0.09
$\beta = 0.01$	0.05	0.09	0.06	0.10	0.07	0.11	0.08	0.12	0.11	0.15
$\beta = 0.02$	0.12	**0.27**	0.12	**0.28**	0.13	**0.29**	0.14	**0.30**	0.18	**0.33**
$\beta = 0.03$	0.22	**0.57**	0.23	**0.58**	0.24	**0.59**	**0.25**	**0.60**	**0.28**	**0.63**
$\beta = 0.05$	**0.56**	**1.53**	**0.57**	**1.54**	**0.57**	**1.55**	**0.59**	**1.56**	**0.62**	**1.59**
$\beta = 0.10$	**2.14**	**6.04**	**2.14**	**6.04**	**2.15**	**6.05**	**2.16**	**6.06**	**2.20**	**6.10**

perature and precipitation. Calculations of g for residuals from these estimated trends range from near 0 to greater than 0.5; therefore Table 1 spans real-world scenarios.

Different applications require different accuracy in the trend estimates. In the absence of an econometric approach in which a cost function limits our natural desire to improve the accuracy of information any further, however, we can adopt the minimal requirement that the error should not exceed a traditionally acceptable value that corresponds to standard error $\delta \leq 0.5\sigma$. This formal criterion is often used in statistical meteorology (Vinnikov 1970). It corresponds to $\eta \leq 0.25$, which will be referenced throughout subsequent discussions.

Note first in Table 1 that the errors $\eta(g, \beta, \tau)$ are not noticeably dependent on g, the measure of redness in the residual time series, but rather on trend β and on τ, where τ is the amount of time after the last year of observations used to compute normals. The error in "persisting" WMO normals exceeds the acceptable limit for $b \geq 0.3\sigma$ (10 yr)$^{-1}$ for almost all τ [and for $\tau =$ 10 yr and $b \geq 0.2\sigma$ (10 yr)$^{-1}$]. As soon as $b \geq 0.2\sigma$ (10 yr)$^{-1}$ and τ is close to 10 yr, the WMO normals should not be used for computing climatic anomalies. Except for weak underlying trends, the error is already unacceptable when the 30-yr normal is released (between $\tau = 2$ and 3 yr).

An attempt to solve this problem motivated scientists at NWS's Climate Prediction Center (CPC) to further develop and implement the OCN. OCN, introduced pragmatically and empirically, has never been explained in sufficiently simple terms but has not been used much outside of CPC. The error associated with OCN estimation and extrapolation will be evaluated next.

b. Optimal climate normals

The first empirical attempts to find the optimal length of the averaging period for hydrological and meteorological data were by Beaumont (1957) and Enger (1959). As a criterion, they used the variance of the difference between N-yr averages and values of climatic variables 1 yr ahead. Later, Lamb and Changnon (1981) estimated the "best" temperature normals for Illinois observed temperature and precipitation using as a criterion the mean absolute value of the same differences. The CPC criterion (applied to 3-month average surface temperatures and precipitation) is based on the maximum of a correlation-like measure between N-yr averages and values 1 yr ahead over the verification period (Huang et al. 1996). The CPC group showed that their criterion produced practically the same results as those used by Beaumont (1957) and Enger (1959). Simple analysis shows that all of these criteria are based on similar definitions of a measure of error in climatic normals when compared with the time-dependent expected value. In fact, the theory of OCNs can be derived from the same simple model (3)–(5) for the error in climate normals.

Expression (4) for the error in the expected value estimate obtained by averaging observed $y(t)$ for N consecutive years $\eta(N, g, \beta, \tau)$ is a sum of two components. The first one, $\eta_a(N, g)$, decreases monotonically with increase in N. This is the expected sampling error from the climatic noise—its decrease with increasing N is what is expected intuitively. The second component, $\eta_b(N, \beta, \tau)$, increases as N increases if the trend $\beta \neq 0$. It is the expected deviation of the N-yr average from the trend line at the end of the averaging interval and beyond, which must increase with N because the number of years from the midpoint of the interval increases. As a result, the error $\eta(N, \tau)$ has a minimum $\eta_{\text{optimal}}(N, g, \beta, \tau)$ at $N_{\text{optimal}}(g, \beta, \tau)$.

Our ability to correctly estimate the climatic anomaly $y'(t_0)$ at the end of the averaging period ($\tau = 0$) and to extrapolate it into the future time, $\tau > 0$, depends on the error in expected value $Y(\tau)$. Optimal climate normals can be defined as the average of the climatic variable for the time interval N_{optimal} that minimizes the

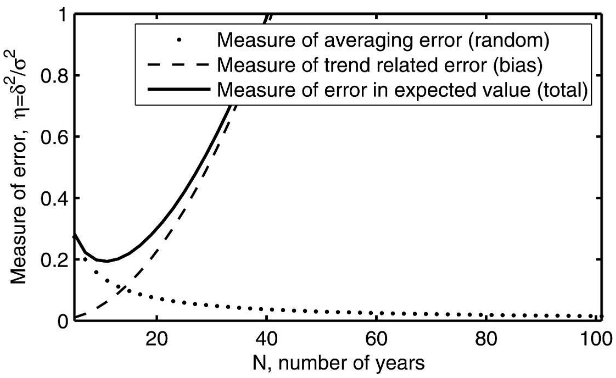

FIG. 2. Optimal climate normals: $\eta(N, g = 0.2, \beta = 0.05, \tau = 0)$—the error of expected value $Y(\tau = 0)$ at the very end of an averaging time interval of N yr for a specified linear trend $\beta = 0.05$ and lag-1 autocorrelation $g = 0.2$ (solid line). Dotted and dashed lines show separately the averaging $\eta_a(N, g = 0.2)$ and the trend-related $\eta_b(N, \beta = 0.05, \tau = 0)$ components of the error.

error $\eta(N, g, \beta, \tau)$ in estimates of expected value $Y(\tau)$. Estimates of N_{optimal} for given g, τ, $\beta \neq 0$ can be obtained from the condition

$$\eta(N, g, \beta, \tau) = \text{minimum}, \tag{7}$$

and then substituted into (4)–(6) to compute η_{optimal}.

For illustration, consider a process with lag-1 correlation $g = 0.2$ and trend b $= 0.05\sigma$ yr^{-1}. These parameters could belong to time series of wintertime seasonal mean surface air temperatures for a number of western U.S. climate divisions. Figure 2 shows the dependence on N, the number of years of observations averaged to obtain the estimate of $Y(t_0)$, of $\eta(N, g, \beta, \tau)$ and its components $\eta_a(N, g)$ and $\eta_b(N, \beta, \tau)$ for $\tau = 0$. The two components respectively are the sampling error from the climatic noise (decreasing with N) and the error from the diverging trend (increasing with N). In this example, the function has a minimum at $N = N_{\text{optimal}} \approx$ 11 yr.

Forecasts at CPC and other climate prediction centers do not, in general, exceed 1-yr lead ($0 \leq \tau \leq 1$ yr). Estimates of $N_{\text{optimal}}(g, \beta, \tau)$ and $\eta_{\text{optimal}}(g, \beta, \tau)$ for $\tau =$ 0 and 10 yr and for realistic ranges of g and β, $\beta \neq 0$, are given in Table 2. The estimates for $\tau = 1$, not shown here, are very close to those for $\tau = 0$. Note the following from Table 2:

1) The optimal period of averaging N_{optimal} and its associated error η_{optimal} depend more on β than on g except for large g; that is, it is dominated by trend rather than weak red noise. Thus, if the climatic trend has a seasonal cycle and geographical pattern, so will the optimal period of averaging.
2) For trends as large as $b = 0.1\sigma$ yr^{-1} the optimal period of averaging N_{optimal} is very short (from 6–7 yr for $\tau = 0$ to 3 yr for $\tau = 10$ yr) and the error η_{optimal} of OCN exceeds the acceptable limit of 0.25 for almost all τ shown. For $b = 0.05\sigma$ yr^{-1}, $\tau > 0$, and $g > 0.2$, the error also exceeds 0.25.
3) The errors related to the climatic trend in the OCN estimates of $Y(t_0)$ are systematic, not random. Such errors should be treated differently than random errors.
4) The WMO-recommended 30-yr averaging (Table 1) is close to the OCN for very weak climatic trends ($b = 0.01\sigma$ yr^{-1}), and the error is identical within the precision of both tables. Because OCN is updated annually, however, it is the preferred choice even with very weak underlying trend, but not as practiced at CPC (see the paragraph after next). As a consequence, OCN has two advantages over conventional practice: N_{optimal} adjusted to the situation and immediate updates through the last year.

Thus the WMO technique is a good treatment for very weak climatic trends, and the OCN technique is good for modest to medium trends with the lead τ relatively small, but neither has acceptable error for strong trends and longer leads.

TABLE 2. Optimal climate normals technique: analytical theoretical estimates of N_{opt} (yr) and η_{opt} (where opt denotes optimal) for $\tau = 0$ and 10 yr and different lag-1 correlation coefficients g and trends β in climatic records. Values equal to or greater than 0.25 are shown in boldface.

		$g = 0$		$g = 0.1$		$g = 0.2$		$g = 0.3$		$g = 0.5$	
$\beta = b/\sigma$	Year	N_{opt}	η_{opt}	N_{opt}	η_{opt}	N_{opt}	η_{opt}	N_{opt}	η_{opt}	N_{opt}	η_{opt}
$\beta = 0.01$	$\tau = 0$	27.5	0.05	29.2	0.06	31.1	0.07	33.1	0.08	38.2	0.11
	$\tau = 10$	22.1	0.09	23.7	0.10	25.5	0.11	27.4	0.12	32.2	0.15
$\beta = 0.02$	$\tau = 0$	17.4	0.08	18.5	0.10	19.6	0.11	20.8	0.13	23.7	0.17
	$\tau = 10$	12.6	0.18	13.5	0.19	14.5	0.21	15.5	0.23	18.1	**0.29**
$\beta = 0.03$	$\tau = 0$	13.4	0.11	14.1	0.12	15.0	0.14	15.8	0.16	17.9	0.22
	$\tau = 10$	8.9	**0.29**	9.5	**0.31**	10.2	**0.33**	10.9	**0.36**	12.5	**0.43**
$\beta = 0.05$	$\tau = 0$	9.6	0.15	10.1	0.17	10.7	0.19	11.2	0.22	12.5	**0.29**
	$\tau = 10$	5.7	**0.56**	6.0	**0.59**	6.4	**0.62**	6.7	**0.66**	7.5	**0.88**
$\beta = 0.10$	$\tau = 0$	6.2	0.23	6.5	**0.26**	6.7	**0.29**	7.0	**0.33**	7.6	**0.42**
	$\tau = 10$	3.0	**1.54**	3.1	**1.59**	3.2	**1.64**	3.2	**1.69**	3.2	**1.81**

As mentioned earlier, OCN is currently used at CPC for short-term climate prediction, $\tau \leq 1$ yr, using empirically, not theoretically, estimated optimal averaging time intervals (for $\tau = 1$ yr) fixed at 15 yr for monthly precipitation and 10 yr for monthly temperatures (Huang et al. 1996; Van den Dool 2006). From Table 2 these averaging periods correspond approximately to those for short-lead cases with $b = 0.03\sigma$ yr^{-1} and $b = 0.05\sigma$ yr^{-1}, respectively. As a consequence, the entries in Table 2 are underestimates of the errors of CPC/OCN when underlying trends in precipitation and temperature differ much from these values. More specific, for $\tau = 0$, CPC/OCN will have larger errors than those in Table 2 for all cases except $b = 0.05\sigma$ yr^{-1} and $g = 0.1$ for temperature and $b = 0.03\sigma$ yr^{-1} and $g = 0.2$ for precipitation. Fixed N is more convenient but is inadvisable unless N_{optimal} varies little across a user's applications.

The OCN technique is an attempt to account for the effects of a climatic trend without defining and estimating the trend itself. Consideration will be given next to the use of observed data to estimate climatic trends and to utilize the estimated dependence of expected value on time. Such an approach should work better than the OCN for very strong trends.

3. Time-dependent climatic normals

a. Least squares linear trend

Consider again the same (as above) climatic process $y(t)$ whose random red-noise component has standard deviation σ and lag-1 autocorrelation g. Suppose there is confidence from independent sources that this record has a linear trend in expected value $Y(t) = a + bt$. Using a least squares technique, the unknown parameters a and b and the statistics of their errors can be estimated through use of an analytical solution obtained by Polyak (1979). A summary of the same equations is reproduced in Table 2.1 of the English edition (Polyak 1996). Now the estimates of the expected normal at the end of the interval and beyond are based on the fitted trend line. We can use the same (1)–(3) and (5) equations and definitions as above, but with N now the length of the time interval used to estimate a and b in (2), and with a new expression, different from (6), for trend-related error $\eta_b(N, g, \tau)$, to write

$$\eta(N, g, \tau) = \eta_a(N, g) + \eta_b(N, g, \tau), \quad (8)$$

$$\eta_b(N, g, \tau) = [\sigma_\beta(r + \tau)]^2, \; r = (N - 1)/2, \quad \text{and} \quad (9)$$

$$\sigma_\beta^2 = (1 + g)/\langle r\{2[r + g/(1 - g)] + (1 - g)(r - 1)(2r - 1)/3\}\rangle. \quad (10)$$

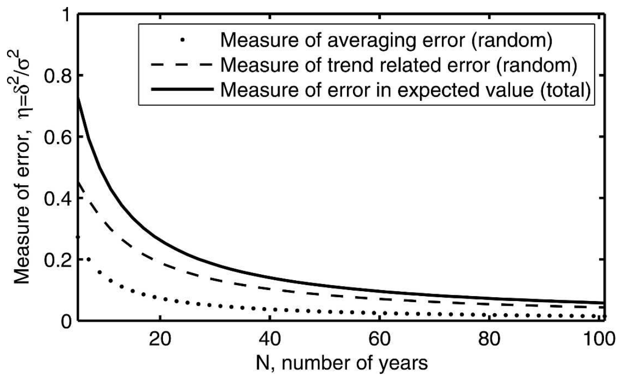

FIG. 3. Estimates of $\eta(N, g = 0.2, \tau = 0)$, the error in expected value $Y(t_0)$ at the end of time interval N yr utilized to estimate parameters of linear trend (black line). Dotted and dashed lines show separately the averaging and the trend-related components of error variance.

As before the first term represents sampling error associated with estimating the stationary part of the normal. However, now the second term represents the error at the endpoint of the estimation interval and beyond associated with the slope estimation, not the error associated with not accounting for the slope at all.

The values of $\eta(N, g = 0.2, \tau = 0)$, the error in expected value $Y(t_0)$ at the end of time interval N yr [used to estimate the trend in $Y(t)$], are displayed in Fig. 3 (the solid line). Dotted and dashed lines show separately the averaging and the trend-related components of error variance. The first of them (dotted line) is the same as in Fig. 2. It decreases with an increase of N. However, the trend-related error (dashed line) also decreases with an increase of N, because the error in estimating the slope must decrease as the length of the fitted series with the underlying trend increases. Furthermore, unlike before, the trend-related error does not depend on the trend, and as a consequence the total error η is random with no systematic component. We can conclude that the empirically estimated climatic trend $Y(t) = a + bt$ provides sufficiently accurate unbiased estimates of expected value of $Y(t_0)$ for records as short as ~30 yr in the case of $g = 0.2$.

Climatic normals, estimated from observations over a limited time interval, should be useful for predictions beyond the boundaries of this time interval. Given estimated parameters of a linear trend in expected value $Y(t) = a + bt$, we can use the same a and b to find $Y(t_0 + \tau)$, where t_0 is the end of the fitting period N and $t = t_0 + \tau$ is some time in the future. Errors in extrapolated $Y(t_0 + \tau)$ increase with increasing τ. Theoretical estimates of the error $\eta(N, \tau)$ for different N, τ, and g are shown in Fig. 4.

For all cases in Fig. 4 with $g < 0.5$, extrapolation of

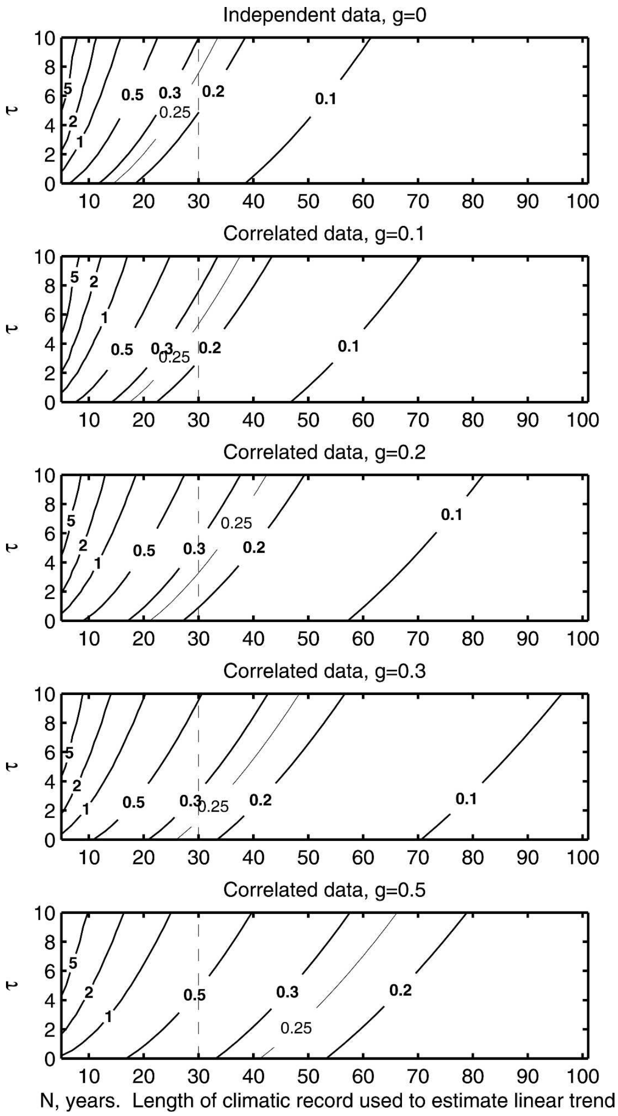

FIG. 4. Estimates of $\eta(N, g, \tau)$, the error for extrapolated expected value $Y(t_0 + \tau)$ beyond the end of time interval of N yr utilized to estimate parameters of linear trend; τ is in years.

the linear trend 1 yr into the future estimated from $N \geq 30$ has expected error less than the acceptable value of 0.25. For users of climatic information a decade in the future ($\tau \approx 10$ yr), trends must be estimated from significantly longer ($N \approx 40$–50 yr) climatic records for acceptable precision. In actuality, it is highly questionable that these longer trend fits are viable in practice because of the nature of actual trends discussed next.

As a practical matter, virtually all of the current important temperature trends over the United States (many exceed $b = 0.05\sigma$ yr^{-1}) have occurred over the last 30 yr. As a consequence, the only relevant (to current climate change) parts of Fig. 4 are those with $N \leq 30$ yr. Because of the strong dependence on the redness (g) of the residual variability, the results in Fig. 4 preclude accurate multiyear extrapolation except when the 1-yr lag correlation is zero or very small, because N should be constrained to be less than or equal to 30 yr.

TABLE 3. The maximum lead (yr) τ_{max} with acceptable error $\eta \leq 0.25$ for different 1-yr lag autocorrelation g and different projections of an underlying linear-trending normal estimated from climate time series models. Results for the hinge fit (trend period is 30 yr, the same as for the linear fit) are for generalized least squares, which yields small gains over the ordinary least squares results from the Monte Carlo experiment.

	τ_{max}			
g	Hinge fit (N = 65 yr)	Linear fit (N = 30 yr)	OCN (β = 0.03)	OCN (β = 0.05)
0.0	14	7	8	3
0.1	10	5	7	2
0.2	7	3	6	2
0.3	4	1	5	1
0.5	—	—	2	—

It is crucial to account for these considerations in studies focused on the current climate and on modern and future climate changes. In these instances, least squares linear trend fits to the last (prior to 2006) 40–100 or more years of data will generally underestimate recent changes and can distort and misrepresent the pattern of these changes. These problems can be avoided by following some sound practices for linear trend estimation: 1) Linear trends should never be fit to a whole time series or a segment arbitrarily, 2) at a minimum, a plot of the times series should be examined to confirm that the trend is *not* obviously nonlinear, and 3) to the extent possible, the functional form of the trend should be based on additional considerations.

In this context, note that very large scale trends associated with global climate change are approximately linear over the last 30 yr or so but decidedly not over the last 40–70 or more. This fact is the basis for the modified approach to linear least squares that will be examined next. First, however, the relative performance in estimation and extrapolation of normals between the OCN and linear least squares (given an underlying linear trend) will be summarized.

Table 3 shows error thresholds (as a function of redness) expressed as the maximum lead τ (in years) with acceptable error, for 30-yr linear trend fits and the OCN with $b = 0.05\sigma$ yr^{-1} and $b = 0.03\sigma$ yr^{-1}. The table reflects a main conclusion of the last section: that the OCN has acceptable error for modest to moderate underlying linear trends at medium to short leads, respectively. However, it is also clear from Table 3 that 30-yr least squares linear fits (hinge fits are discussed in the next section) substantially outperform the OCN with

$b = 0.05\sigma\ \text{yr}^{-1}$ and are competitive (as long as the autocorrelation in the climate noise is very small) at $b = 0.03\sigma\ \text{yr}^{-1}$. The OCN's advantage with $b = 0.03\sigma\ \text{yr}^{-1}$ (as reflected in Table 3) in operational CPC practice should be less for every g because of the use of fixed (and suboptimal) averaging periods. Except for very small g, this overestimation of operational OCN $\tau_{\max}$ will be greater for temperature series than for precipitation because the latter's averaging period (15 yr) is generally closer to the optimal period (Table 2).

The calculations here suggest that 30-yr linear trends are at least as good for operational purposes for all but very modest trends ($b < 0.03\sigma\ \text{yr}^{-1}$), at least for temperature normals (for precipitation normals, OCN's advantage is lost for only slightly stronger trends). As shown in the next section, a modification to the linear trend fits (based on global climate change considerations) that reduces the trend-related error extends the useable extrapolation range even further.

b. The least squares "hinge"

Very large scale trends (in global, hemispheric, land, ocean, etc., seasonal and mean annual temperatures) associated with global warming are approximately linear since the mid-1970s but decidedly not when viewed over longer periods. In particular, smoothed versions of these series dominantly suggest little change in their normals from around 1940 up to about the mid-1970s (e.g., Solomon et al. 2007).

With the reasonable assumption that the strong trends over North America (and probably elsewhere as well) in the last 30 yr or so are related to global warming, an appropriate trend model to fit to a particular monthly or seasonal mean time series to represent its time-dependent normal is a hingelike shape. This least squares hinge fit is a piecewise continuous function that is flat (i.e., constant) from 1940 through 1975 but slopes upward (or downward as dictated by the data) thereafter: $Y(t) = a$ for $1940 \le t \le 1975$ and $Y(t) = a + b(t - 1975)$ for $t \ge 1975$. The choice of 1975 as the hinge point is based on numerous empirical studies and model simulations that all suggest the latest period of modern global warming began in the mid-1970s. The slope b is insensitive to small changes in this choice.

The hinge shape is clearly the behavior of the JFM mean temperature series for the climate division representing western Colorado (Fig. 5), where the observed series and the ordinary least squares hinge fit are both shown. Western Colorado temperature was selected as an example for Fig. 5 because it has little or no ENSO signal, but to first order the hinge dominantly characterizes the behavior of U.S. climate-division monthly and seasonal mean time series with moderate to strong trends, especially for surface temperatures.

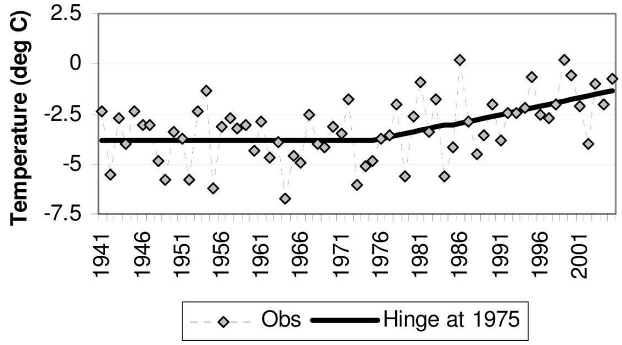

Fig. 5. January–March mean temperatures for western Colorado, and the ordinary least squares hinge fit to the data.

The hinge technique was first (and exclusively) used in 1998 and 1999 by CPC to help to estimate and extrapolate normals for the cold-season forecasts for 1998/99 and 1999/2000, respectively—both winters with a strong La Niña. After the winter of 1997/98, the great El Niño winter, it was determined at CPC that the cold bias in the winter forecast for the western United States was entirely a consequence of failing to account for a warming climate. Based on the work of Livezey and Smith (1999a,b), the warming was associated with global climate change.

The hinge fit was subsequently devised not only to estimate and extrapolate the trends, but to assess more accurately the historical impacts of moderate to strong ENSO events on the United States. This signal separation required the reasonable assumption that ENSO and global change were independent to first order. With this assumption, conventional approaches for estimating event frequencies conditioned on the occurrence of El Niño or La Niña (e.g., Montroy et al. 1998; Barnston et al. 1999) were modified to account for the changing climate as well.

The effectiveness of the hinge-fit method for the JFM 2000 U.S. mean temperature forecast is shown in Fig. 6. The three panels in the figure are conditional mean temperature probabilities using a version of conventional methods (often referred to as composites; Barnston et al. 1999; Fig. 6a); conditional probabilities using the hinge for trend fitting and signal separation (Fig. 6b); and the verifying observations (Fig. 6c). The first steps to construct (Fig. 6b) consisted of hinge fits to the JFM time series through 1999, calculation of JFM residuals from the hinge fits for past La Niñas, 1-yr extrapolations of the fitted slopes, and addition of the La Niña residuals to the 1-yr extrapolations to obtain conditional frequency distributions. After some spatial

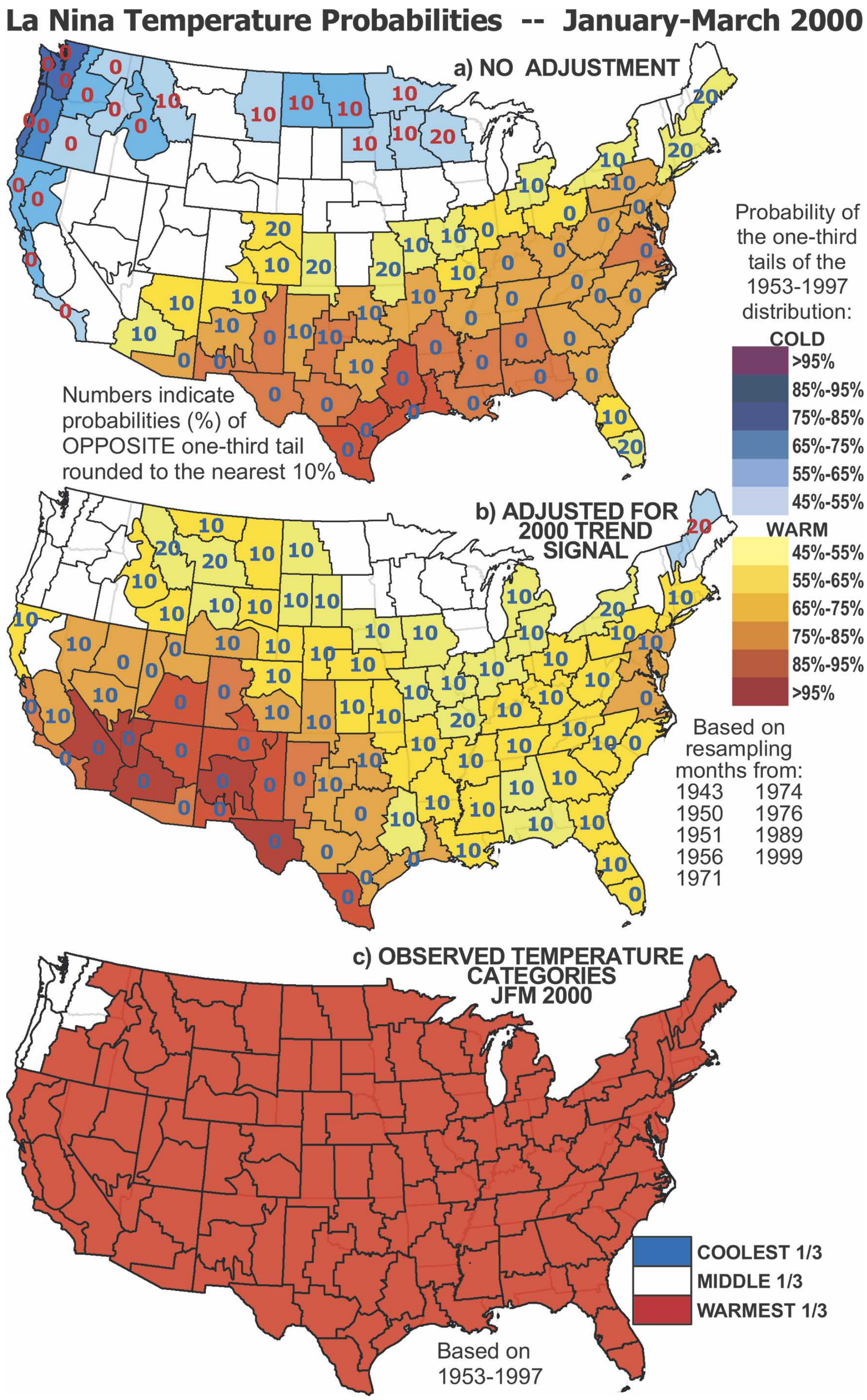

FIG. 6. Probabilities, (a) without and (b) with separate treatment of trend and La Niña, for three temperature categories (above-, near-, and below-normal equally probable for 1953–97 data) of January–March 2000 mean surface air temperatures for 102 U.S. climate divisions, and (c) the corresponding observations.

smoothing, these values were then referenced to three equally probable categories based on 1953–97.

Note the large differences between Figs. 6a and 6b and their implications for JFM and the extraordinary similarity between Figs. 6b and 6c, the forecast and observed conditions. The year 1966 was used as the hinge point in these 1999 calculations; use of a more appropriate mid-1970s point would have produced a forecast with even wider coverage of enhanced probabilities of a relatively warm JFM.

It is clear from CPC's and subsequent experience that composite studies of ENSO impacts that do not attempt to account for important trends are deficient from the outset. There fortunately are seasons/areas of the United States for which recent trends are still weak but the ENSO signature is strong, for example much of the Southeast in the winter (Fig. 1). In these instances the climate analyst can ignore trend to diagnose ENSO-related effects; otherwise trend consideration is a critical first step for useful results, regardless of the methods employed.

Here, to explore hinge-fit expected errors, Monte Carlo simulations are used to assess the reduction in error by using a hinge instead of a straight-line least squares fit. Our expectation is that hinge fits will have smaller overall error, simply because the use of 35 additional years (1940–74) of observations to estimate climate normals in the mid-1970s will constrain the starting value at the beginning of the trend period.

In effect, the hinge approach reduces the usual oversensitivity of least squares linear trend fits to one of the endpoints of the time series. A particularly important example of this problem is the pattern of U.S. winter temperature trends computed from the mid-1970s. The winters of 1976/77 and 1977/78 were unusually warm in the west with record cold in the east. Least squares linear trend fits starting from 1976 or 1977 consequently tend to overestimate warming in the east and underestimate it in the west, leading to maps with far more uniform warming than the pattern in Fig. 1.

Simulated time series 75 yr in length (to represent 1940–2014) were generated by adding random, stationary red noise with standard deviation of 1 and lag-1 autocorrelation g to a constant zero over the first 36 yr (to 1975) and to an upward linear trend with constant slope thereafter. Monte Carlo experiments, each consisting of 2500 simulations, were conducted for $\beta = 0.03$ and g ranging from 0.0 to 0.5. Straight lines and hinges were fit with ordinary least squares to each time series with data spanning 1975–2004 and 1940–2004, respectively. Each fit was then extrapolated linearly to 2014, and its difference from the specified value of the underlying hinge was computed. The results should not depend on slope, and this was confirmed by other calculations.

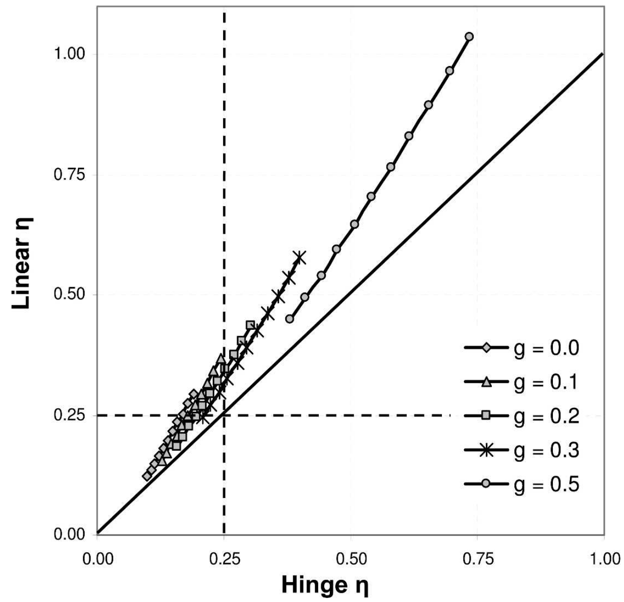

FIG. 7. Error η of climate normal estimates (with $\beta = 0.03$) at leads from zero to 10 yr for ordinary least squares straight-line and hinge fits to modeled climate time series.

Results in the form of error η for both fits at leads $\tau = 0, \ldots, 10$ are displayed in Fig. 7. The error η for the hinge is less than that for the straight-line fit for every point plotted, and its advantage increases with lead and (mostly) the autocorrelation in the residual noise.

Use of generalized least squares for hinge fits should reduce expected errors even further; therefore, these errors were also computed. The gains over the ordinary least squares results in Fig. 7 are small but meaningful, and therefore the generalized least squares results are shown in Table 3. Note that use of the hinge essentially eliminates OCN's advantage for all but $g = 0.5$ (rarely observed in U.S. climate-division data for $\beta \geq 0.03$), and even more so when OCN is implemented in a suboptimal fashion with fixed averaging periods. The results here suggest that a preferred approach would consist of the OCN (with variable averaging period) for cases with weak trends and the hinge for cases with moderate to strong trends. Such a strategy would require hinge fits everywhere first for a preliminary diagnosis of the strength of the trend and the redness of the residual climate noise, to guide the choice of final fits and for case-by-case specification of OCN averaging in weak trend situations, respectively.

As a service to the applied climatology community, maps of hinge-based trends for 3-month mean U.S. climate-division surface temperature and precipitation for 3 nonoverlapping periods, which, along with Fig. 1, span the year, are included in appendix A (a more complete set was available at the time of writing online at http://www.cpc.ncep.noaa.gov/trndtext.shtml). The data used in all of the maps and time series shown here and the reasons for their use are also described in appendix A.

c. Other shapes

Error estimates made in the previous four sections are directly applicable in practice only when it is reasonable to assume that changes in normals over the last 30 yr are dominantly linear. The possibility that the shape may be otherwise or unstable is likely the source of some reluctance to adopt a new, albeit simple, approach like the hinge fit to replace the OCN. In fact, a comparison of performances in Table 3 (that are overstated for CPC/OCN) for the stronger trends ($\beta > 0.03$) observed commonly for U.S. surface temperatures and precipitation over the last 30 yr suggest that the hinge will produce substantial gains even for trends linear to just first order.

Examples of two U.S. climate divisions (and there are many) for which β well exceeds 0.03 for JFM mean temperature but the climate normal since 1975 is not clearly tracking in a straight line are shown in Fig. 8. In both cases the mean temperatures seem to have leveled off (at much higher levels than pre-1980) over the last 20 yr so that the CPC/OCN gives lower estimates of the 2005 normals than does the hinge. For desert California and the Sierra Nevada (Fig. 8a; $\beta = 0.06$) the transition appears gradual from the mid-1970s, but for north central Montana (Fig. 8b; $\beta = 0.04$) it looks like it occurred more abruptly in the late 1970s.

The differences in the character of these time series and that for western Colorado (Fig. 5; $\beta = 0.06$) may be partially or mostly a consequence of climate noise. Western Colorado does not have much of a winter ENSO signal, but the other two locations do and the respective ENSO impacts are nonlinear (Livezey et al. 1997; Montroy et al. 1998). The possibility that the differences are also the result of real differences in local (or regional) processes also governing recent climate change cannot be discounted, however. In any case, climate models universally predict warming to continue.

Perhaps a better model for time-dependent U.S. seasonal temperature normals is a parabolic hinge, in which the data can dictate a flatter (semicubical parabola) or steeper (cubical parabola) growth after the mid-1970s. Such a model has all the advantages of the hinge—smooth piecewise continuous fits to a stationary climate followed by a changing one, utilizing all the data and allowing straightforward extrapolation—but with the flexibility to accommodate departures from linear growth. On the other hand, it is unclear whether there is a physical basis for this choice. Nevertheless, this and other techniques, including adaptive techniques that can accommodate changes in slopes, need to be explored more thoroughly.

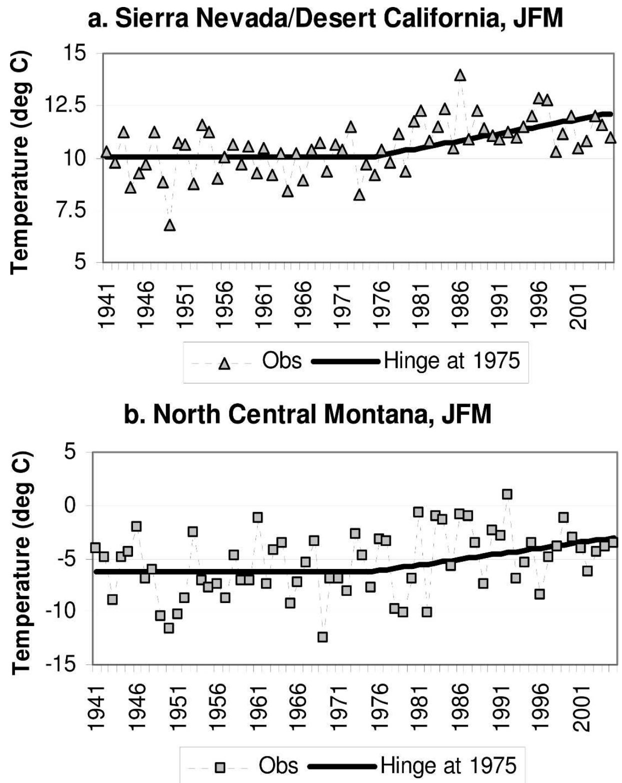

FIG. 8. January–March mean temperatures for (a) the Sierra Nevada and desert California and (b) north-central Montana, and the ordinary least squares hinge fits to the two time series.

More sophisticated low-pass filters than moving averages (i.e., OCN) are frequently used to smooth climate time series. These approaches are purely statistical and do not explicitly address normals as time-dependent expected values, either through use of collateral observational and dynamic model information or time series models to represent the physical processes. A good discussion of these methods that emphasizes the problem of fitting a climate time series near its current endpoint is by Mann (2004). In that paper, the best representations of the recent behavior of the Northern Hemisphere annual mean temperature are produced with use of different versions of the so-called minimum-roughness boundary constraint.

From the perspective of the discussions here and in section 3b, the resulting trends in Mann (2004) are likely modest overestimates of the rate of recent increases in temperature normals. This is a consequence of cooling trends between approximately 1950 and the mid-1970s in the low-pass filtered series that are dominantly a consequence of the exceptionally cold 1970s in North America (cf. Solomon et al. 2007), which in turn is dominantly a result of an exceptionally cold eastern United States (mentioned earlier). There is little evidence that these downturns in the filtered time series are a consequence of other than "climate" noise. In this context it is also difficult to justify the use of these smoothed series for separating ENSO impacts from those of a changing climate, which is another reason (in addition to overestimation of recent trends) to prefer hinge fits.

To round out a comprehensive overview of estimation and extrapolation of climate normals, the progress in developing techniques for the analytical approximation of seasonal and diurnal dependencies of $Y(t)$ from available observations is summarized in appendix B.

4. Concluding remarks

It is clear from the analysis here that WMO-recommended 30-yr normals, even updated every 10 yr, are no longer generally useful for the design, planning, and decision-making purposes for which they were intended. They not only have little relevance to the future climate, but are more and more often unrepresentative of the current climate. This is a direct result of rapid changes in the global climate over approximately the last 30 yr that most climate scientists agree will continue well into the future. As a consequence, it is crucial that climate services enterprises move quickly to explore and implement new approaches and strategies for estimating and disseminating normals and other climate statistics.

We have demonstrated that simple empirical alternatives already exist that, with one simple condition, can not only consistently produce normals that are reasonably accurate representations of the current climate but also often justify extrapolation of the normals several years into the future. The condition is that recent underlying trends in the climate are approximately linear, or at least have a substantial linear component. We are confident that this condition is generally satisfied for the United States and Canada and for much of the rest of the world but acknowledge that there will be situations for which it is not. In this context, two approaches need to be highlighted:

1) Optimal climate normals are multiyear averages not fixed at 30 yr like WMO convention but adapted climate record by climate record based on easily estimated characteristics (linear trend and 1-yr residual autocorrelation) of the climate records. The OCN method implemented with flexible averaging periods only begins to fail for very strong underlying trends (between 0.5 and 1 standard deviation of the residual noise per decade) or for longer extrapolations with more moderate background trend (see Tables 2 and 3). Least squares linear trend fits to the period since the mid-1970s are viable alternatives to OCN when it is expected to fail (Fig. 4 and Table 3), but there is an even better alternative.
2) Hinge-fit normals are based on modeling their time dependence on the known temporal evolution of the large-scale climate and are implemented with generalized least squares. They exploit longer records to stabilize estimates of modern trends in local and regional climates; therefore, they not only outperform straight-line fits (Fig. 7) but even OCN for underlying trends as small as 0.3 standard deviation of the climate noise per decade (Table 3).

Given these results, we make three recommendations:

1) The WMO and national climate services should formally address a new policy for changing climate normals and other climate statistics, using the results here as a starting point.
2) NOAA's Climate Office, NCDC, and CPC should cooperatively initiate an ongoing program to develop and implement improved estimates and forecasts of official U.S. normals.
3) As a first step, NCDC and CPC should work together to exploit quickly the potential improvements to their respective products demonstrated here. To be specific, the simple hybrid system described in section 3b that combines the advantages of both the OCN and the hinge fit should be implemented in regular operations as soon as possible to produce new experimental products.

As new work on climate normals and their use for forecasts of climate variability and change moves forward, climate analysts need to be cognizant of two points emphasized in sections 3a and 3b:

1) Linear or other trends should never be fit to a whole time series or a segment arbitrarily; the functional form of the trend should be based on examination of the time series and, to the extent possible, additional considerations.
2) Any assessment of the historical impacts of ENSO and their use in risk analysis or prediction *must* take into account climate change and, to the extent possible, separate its effects.

The additional considerations mentioned in the first point immediately above can include results or insight from state-of-the-art climate models. Until now a discussion of the role such models can play in the work and programs we are recommending above has been deferred. There are two potential uses for models that best track the large-scale climate and can replicate at least to first order the variability associated with ENSO and other important modes of interannual variability (i.e., the climate noise). Both uses depend on the fact that the time dependence of climate normals is "known" reasonably well (at least for some parameters, places, and seasons) if the ensemble of model runs is large enough and the runs do not span time scales on which long-term drift associated with, for example, the thermohaline circulation becomes important. In these instances a qualifying model can be used 1) to gain insight about the functional form of regional and subregional trends and 2) as a tool to test competing empirical methods for estimating and projecting these trends. Of course, efforts continue to improve the ability of climate models to replicate the climate comprehensively at smaller spatial and shorter temporal scales. We look forward to when these models can do this credibly and be directly exploited for computing climate normals and other climate statistics.

Acknowledgments. KYV acknowledges support by NOAA through a Climate Program Office grant to CICS.

APPENDIX A

U.S. Megadivision 3-Month Mean Temperature and Precipitation Trends

Maps of hinge-based trends (section 3b) of 3-month mean temperature and precipitation for 102 U.S. climate megadivisions (formed from the original 344) are shown in Figs. A1 and A2.

Climate-division data are often used at CPC (Barnston et al. 2000; Schneider et al. 2005) instead of station data because of the noise reduction inherent in aggregating nearby stations that strongly covary on intraseasonal to interannual time scales. The original 344 divisions are aggregated to 102 megadivisions mostly through combination of small adjacent divisions in the eastern half of the United States. Western divisions are essentially identical in both datasets. The reduction to 102 was originally done to approximate an equal-area representation for the United States, which is especially desirable for principal component–based studies; however, the additional aggregation provides further noise reduction for the adjacent, strongly covarying eastern divisions. Numerous studies reaffirm that the 102-division setup is more than sufficient to capture the spatial degrees of freedom in the coherent variability of U.S. seasonal mean temperature and precipitation. Megadivision normals are simple arithmetic averages of those for the divisions that compose them.

Data spanning from 1941 (1931) to 2005 with the hinge at 1975 are used to fit the temperature (precipitation) data at each division for each 3-month period. Combined with Fig. 1, Figs. A1 and A2 span the whole year. Based on arguments presented in sections 3a and 3b, we believe the trends displayed here more accurately represent modern U.S. climate change than any previously published.

On each temperature trend map the first color generally does not represent an important trend. The same is true for precipitation except for season/locations that are arid/semiarid. The overall bias for all maps is dominantly warming and significantly toward increasing precipitation. Note for temperature trends (Figs. 1a and A1) that 1) the Southwest has warming trends in every season; 2) west of the high plains the country has significant and consistent warming trends winter through summer (Figs. 1a and A1a,b), 3) trends are dominantly weak and inconsistent east of the high plains in summer (Fig. A1b) and autumn (Fig. A1c), and the Southeast has mostly a weak cooling trend in the spring (Fig. A1a); and 4) the wintertime trend map (Fig. 1a) is remarkable, reflecting almost-continent-wide warming (the exception is Maritime Canada, not shown).

For precipitation trends (Figs. 1b and A2), only the Northwest (autumn/winter; Figs. 1b and A2a,c) and Texas (spring/summer; Figs. A2b,c) have large areas of negative precipitation trends in more than one season and these are mostly small. Note that much of the crop-producing United States outside Texas and some of its surroundings has positive precipitation trends in the growing season (Figs. A2b,c). There is no indication in these results of a trend toward more drought nationwide. Among several area/seasons where trends are upward, the south-central region in the autumn (Fig. 1b) stands out as the most notable.

APPENDIX B

Annual and Diurnal Cycles in Climatic Trends

The annual cycle in seasonal mean normals is often much larger than typical day-to-day weather-related fluctuations. In addition to season-to-season variations in multiyear averages, climatic trends also display seasonality. The general approach to approximation of seasonal cycles in climatic trends has been formulated

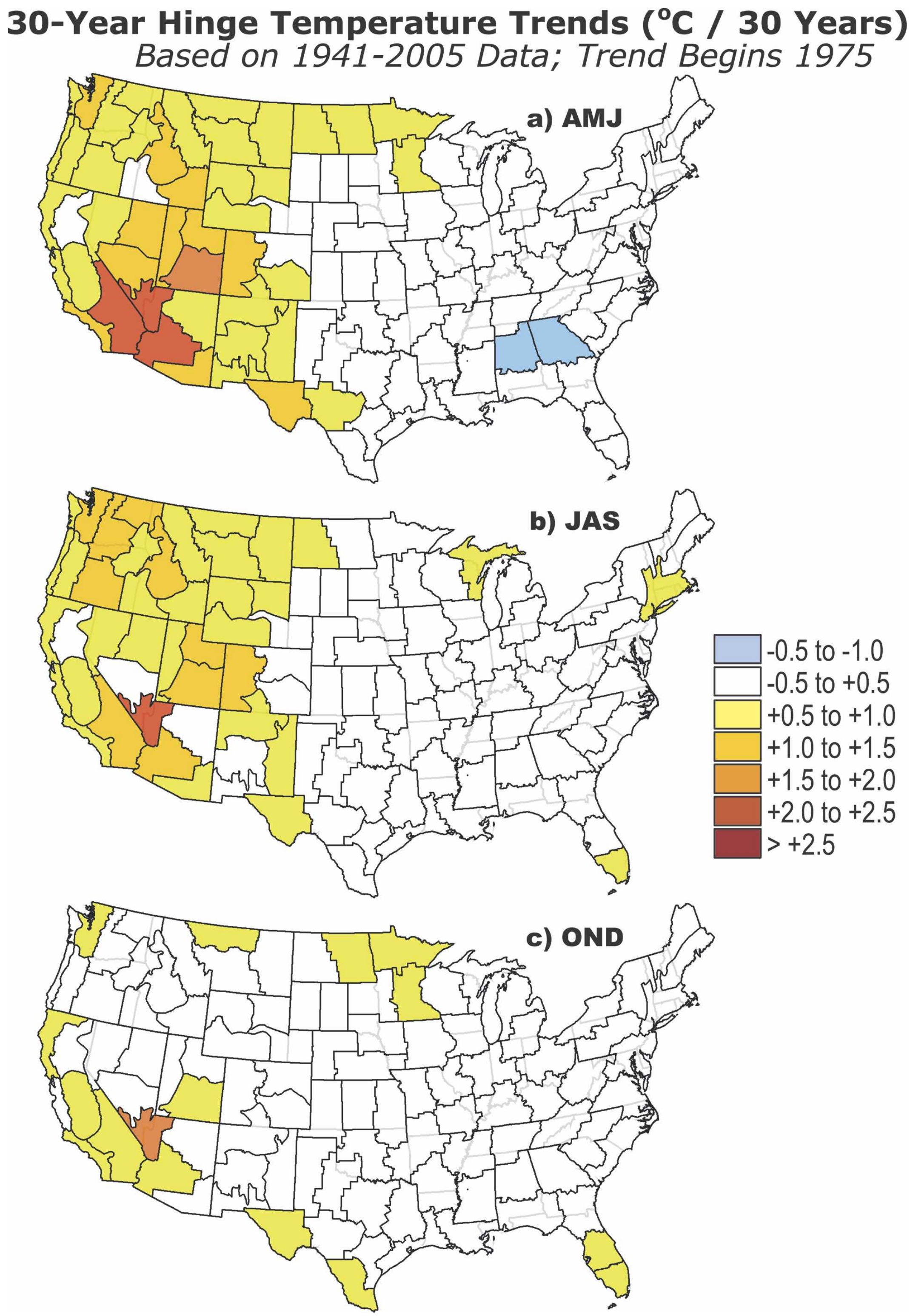

FIG. A1. As in Fig. 1, but for 3-month mean temperature for (a) April–June, (b) July–September, and (c) October–November.

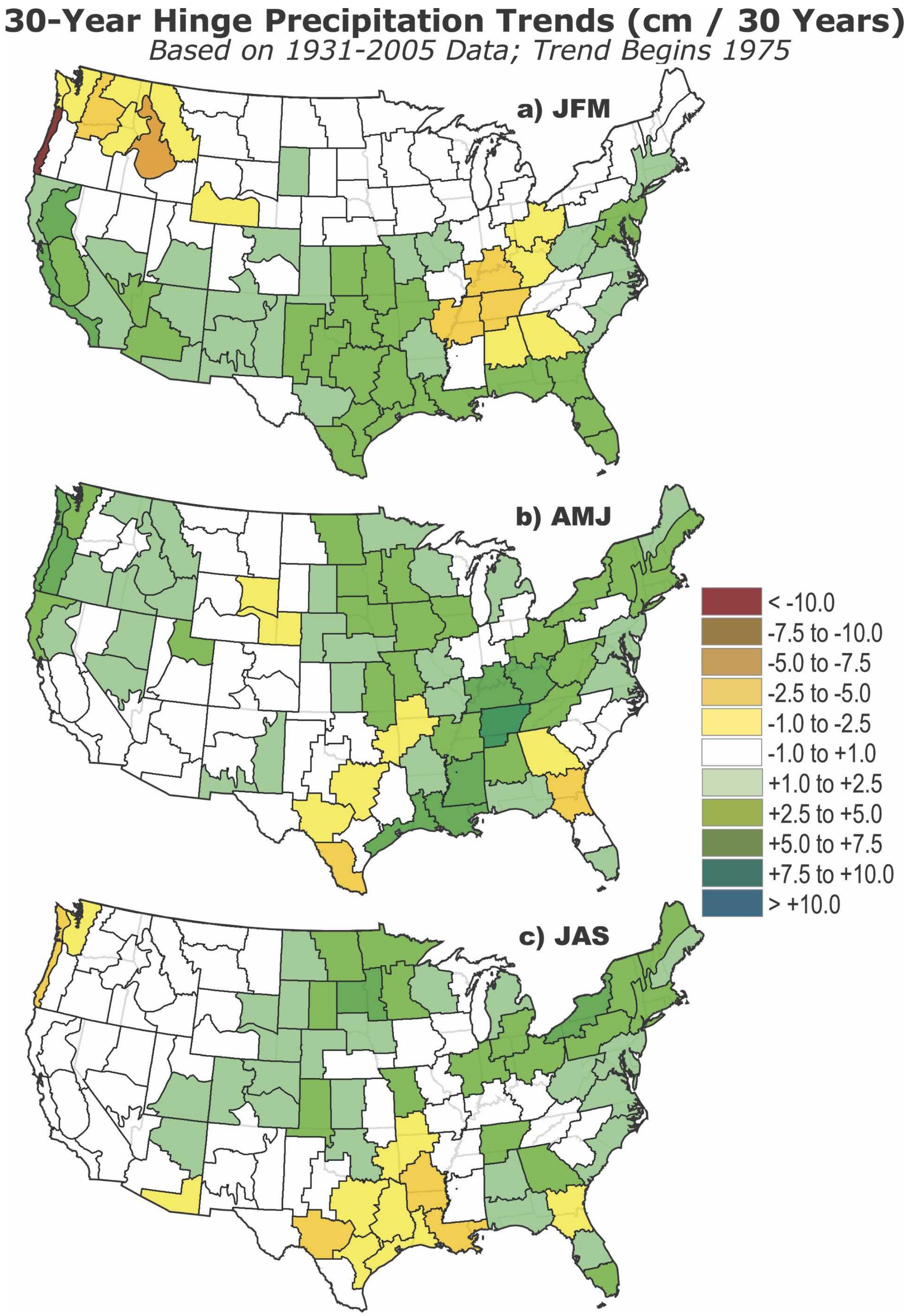

FIG. A2. As in Fig. 1, but for 3-month mean precipitation for (a) January–March, (b) April–June, and (c) July–September.

by Vinnikov et al. (2002b). The main idea is that instead of $Y(t) = a + bt + ct^2 + \cdots$ with constants a, b, c, and so on, the polynomial approximation of the expected value $Y(t)$ is written

$$Y(t) = A(t) + B(t)t + C(t)t^2 + \cdot \cdot \cdot, \qquad \text{(B1)}$$

where $A(t) = A(t + T)$, $B(t) = B(t + T)$, $C(t) = C(t + T)$, and so on, are unknown periodic functions with period $T = 1$ yr. Vinnikov et al. (2002a,b) and Cavalieri et al. (2003) used a linear trend assumption and a limited number of Fourier harmonics of the annual period to approximate $A(t)$ and $B(t)$ for daily observed hemispheric sea ice extents and surface air temperatures.

Different techniques need to be used for variables with seasonal cycles that cannot be approximated properly with a small number of harmonics of the annual cycle. Such techniques can be based, for example, on piecewise least squares approximation of periodic functions $A(t)$, $B(t)$, and so on, by algebraic polynomials in the vicinity of each specific phase of a seasonal cycle.

In addition to the seasonal cycle there is a diurnal cycle in most climatic records, and there can be diurnal cycles in trends as well. In such a case, the generalized coefficient functions $A(t)$, $B(t)$, and so on, in (B1) consist of short-time diurnal variations with a fundamental period of 1 day superimposed on the longer-period annual cycle (Vinnikov and Grody 2003; Vinnikov et al. 2004, 2006). Such processes are well known as amplitude-modulated signals in radio physics.

This approach has been tested using multidecadal time series of hourly observations of surface air temperature at selected meteorological stations (Vinnikov et al. 2004). In addition, application of this new technique to satellite microwave monitoring of mean tropospheric temperatures made it possible to resolve a contradiction between satellite and surface observations of contemporary global warming trends (Vinnikov and Grody 2003; Vinnikov et al. 2006).

A limited number of Fourier harmonics is often also not sufficient to obtain an accurate approximation of the shape of diurnal cycles. As before, other classes of periodic functions can be found or constructed to improve approximations of $Y(t)$. In this instance, estimation of $Y(t)$ can be based on patchwise least squares approximation of periodic functions $A(t)$, $B(t)$, and so on, by two-dimensional algebraic polynomials in the vicinity of each specific phase of seasonal and diurnal cycles.

These techniques can be used also for approximation and evaluation of climatic trends and cycles in variance, lag, and cross correlation and in higher moments of the statistical distribution of climatic variables, in the same way that the least squares technique is used for approximation of trends in expected value. Estimates of $Y(t)$ can be utilized to compute residuals $y'(t)$ for each t. Then, using the same technique for the variables $y'(t)^2$, $y'(t)^3$, $y'(t)^4$, $y'(t)y'(t \text{ lag})$, $x'(t)y'(t)$, and so on, we can evaluate trends in variance and other moments of the statistical distribution of the variables $y(t)$ and any other variable $x(t)$. This idea has been recently formulated and applied to study trends in variability of selected climatic variables (Vinnikov and Robock 2002; Vinnikov et al. 2002a). However, no statistically significant trends were found in twentieth-century variability of the large-scale climatic indices that were analyzed.

Studying seasonal (and diurnal) cycles in variances and lag correlations is necessary if we want to use the generalized least squares technique instead of the ordinary one to estimate unknown parameters in (B1). Taking into account the covariance matrix of observed data, the generalized least squares technique provides a more accurate estimate of $Y(t)$ and a much better estimate of its accuracy (Vinnikov et al. 2006).

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Present in Waubesa Wetlands, in the Great Fen:

Sticky False-asphodel (*Triantha glutinosa*)

Photo © E. McCarthy

Life history | State status | Habitats and landscapes | Species guidance | Other resources | Photos

Species overview

Sticky False-asphodel (*Triantha glutinosa*), a State Threatened plant, is found on MARLY shorelines, cold calcareous seeps, and fens. Blooming occurs late June through early August; fruiting occurs early July through late October. The optimal identification period for this species is early July through late August.

Synonyms: Narthecium glutinosum, Tofieldia glutinosa ssp. glutinos, Tofieldia racemosa var. glutinosa, Triantha glutinosa

Identification

- **Distinguishing characteristics**: Fruit twice as long as the perianth; scape sticky-hairy.
- **Flower characteristics**: Raceme 2 to 5 cm, flowers white, 2 to 3 together at each node, on sticky-hairy pedicels 3 to 6 mm.
- **Fruit characteristics**: Ovoid, thin-walled, 5 to 6 mm; seeds fusiform, 1 to 1.3 mm.
- **Leaf characteristics**: Basal leaves several leaves, 8 to 20 cm long, to 8 mm wide; cauline leaf single and usually near the middle of the stem or absent.

Phenology

- **Blooming phenology**: late June through early August
- **Fruiting phenology**: early July through late October
- **Optimum time to identify**: early July through late August

Other

- **Growth form**: Forb-erect
- **Vegetative reproduction**:
- **Life cycle**: Perennial
- **Comments**: Associated Species: Cladium mariscoides, Hypericum kalmianum, Iris virginica, Parnassia glauca, Solidago ohioensis, Euthamia graminifolia, Thelypteris palustris, Eleocharis elliptica.

Source: Wisconsin Department of Natural Resources, with citation of its presence in Waubesa Wetlands by Quentin Carpenter 1995. Toward a New Definition of Calcareous Fen in Wisconsin (USA). Ph.D. Dissertation, University of Wisconsin-Madison.

WAUBESA WETLANDS: A CASE STUDY OF WETLANDS PRESERVATION

Calvin B. DeWitt[1]

ABSTRACT

General strategies and tools for preservation have been applied to Waubesa Wetlands, 4 miles south of Madison, Wisconsin. Strategies include: individual and organized private ownership; land-use inventories, plans and ordinances; and acquisition by purchase, gift and easement. Tools include: quid pro quo and management agreements; first rights of refusal; "crazy-quilt" ownership patterns; and reverter clauses. Local wetland preservation has positive Impacts upon wetland preservation generally and should be widely used.

INTRODUCTION

This paper presents a case study of local wetland preservation and derives from it a set of practical strategies and tools of general use. The case study is for Waubesa Wetlands, 4 miles south of Madison, the state capitol of Wisconsin. These wetlands border the southwest end of Lake Waubesa, one of four major lakes of the Yahara River chain in Dane County. They are in the Town of Dunn, a rapidly growing township community of 5000 people distributed across 34.5 square miles on farms, in scattered subdivisions, and in linear lakeshore developments.

Waubesa Wetlands extends 1.2 miles from the lake-edge and covers several hundred acres. It includes sedge meadows, shrub carrs, emergents, a fen of some 30 acres, an alkaline floating mat of 30—40 acres, an elevated peat mound, and numerous large springs. It supports an extensive and diverse animal population including a breeding pair of Sandhill Cranes, a symbol of the Town of Dunn. The marsh has been under study by numerous University of Wisconsin classes since 1972 and its postglacial formation from a bay in Lake Waubesa has been the subject of a detailed study (Friedman, DeWitt, and Kratz, 1979).

HISTORY OF PRESERVATION

Interest in Waubesa Wetlands extends backwards several thousand years, if the concentration of native American artifacts, campsites and effigy mounds in this and similar areas around Lake Waubesa (McLachlin) are any evidence. From the earliest verifiable accounts we

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Reprinted from: Calvin B. DeWitt, 1981. Waubesa Wetlands: a case study of local wetlands preservation. *In*: Richardson, Brandt, ed. *Selected Proceedings of the Midwest Conference on Wetland Values and Management*. St. Paul, MN: Minnesota Water Planning Board, University of Minnesota Water Resources Research Center, Upper Mississippi River Basin Commission and Great Lakes Basin Commission, pp. 491-501.

know that the mother of two present retired residents on the marsh, Dr. Alice Watts and Mrs. Mary Sondern, was responsible for conveying to her daughters a high degree of respect for the Waubesa Wetlands as well as an interest in protecting them in their natural state (Dr. Alice Watts, 1981, personal communication). Past responsible private use and ownership has been part of the history of this marsh and accounts in part for its good state of preservation.

The major stimulus for what was to become a major preservation project came in 1965 from the actions of Prof. Carl and Julia Bogholt, wetlands residents whose longtime dream was to purchase and preserve the entire wetland. When confronted with an apparently certain condemnation of their land to allow construction of a major power line alongside their home and across their marsh, they quickly arranged to deed the affected land to the DNR. Since the DNR agreed to respect the Bogholts* wishes, and since the power company is not empowered to condemn state land, they were forced to relocate the powerline crossing a quarter mile south. But shortly thereafter the DNR granted permission for a natural gas line along the donated land, an action which raised the ire of the Bogholts and guaranteed that they would not be the recipients of any additional Bogholt land. Nonetheless, 100 acres donated in 1965 was now in DNR ownership to form the nucleus for further wetland preservation.

Table 1 summarizes the subsequent acquisitions by the DNR and The Nature Conservancy (TNC) which followed the Bogholt gift. Additional summaries of the history of Waubesa Wetlands preservation are given by Voigt (1975) and Sauey and Harris (1980).

Table 1. Waubesa Wetlands Land Acquisition by State of Wisconsin Department of Natural Resources (DNR) and The Nature Conservancy (TNC)

		Acres	Year
1.	Bogholt Gift to DNR Fisheries	100	1965
2.	Berkan Gift to DNR Fisheries	27	1972
3.	DNR Transfer of Above 127 Acres from Fisheries to Scientific Areas		1974
4.	Bogholt Gift to TNC	40	1974
5.	TNC Purchase of Clemans Tract	41	1975
6.	DNR Scientific Areas Purchase	51	1981
	DNR Scientific Areas Easement	13	1981
	Total to Date	272	

The gift of Dorothy and Ted Berkan, Sr. of 27 acres which followed in 1972 was motivated by a love for the marsh and particularly for its nesting pair of Sandhill Cranes which upon return from their annual migration are fed corn by the Berkans in the adjoining pasture and even in the Berkans* barn (Dorothy Berkan, personal communications, 1973-1981; also see Gould, 1972). In 1974 the security of the then 127 acre preserve was increased by its official designation as State Scientific Area No. 114 by the Scientific Areas Preservation Council of the State DNR, thereby making It part of the Wisconsin system of Scientific Areas (See Tans, 1974 for a description of this Agency and its program).

But the fen and a large and beautiful spring owned by the Bogholts remained outside the preserve. Since the spring produces a creek some 50 feet wide and provides the only water access from the Bogholt farm to Lake Waubesa, it remained vulnerable to development should the farm fall into unfriendly hands. Prof. Bogholt had been approached on several occasions about the. addition of his 30—acre fen and large spring to the preserve. But his distrust of and anger toward the DNR did not make them a candidate for such a gift. An attempt to involve the Head Foundation, stewards of the Aldo Leopold Memorial Preserve, also failed. Failure this time was eventually found to be rooted in strongly differing state and national political allegiances. At the recommendation of Reed Coleman of the Head Foundation, Paul Olson of the Wisconsin Nature Conservancy was introduced to the Bogholts, in whom they rapidly developed confidence.

The unexpected posting of a for-sale sign by neighboring fanner Russell Clemans provided the needed impetus for action. Prof. Bogholt agreed to give 40acres including his fen and spring to The Nature Conservancy on the condition that this organization also purchase the Clemans* 41 acres. And now, with a suitable recipient of the gift, and agreement by TNC to purchase the Clemans* tract, an additional 81 acres was added to the preserve for a new total of 208 acres.

The most recent addition, consisting of a sale of 51 acres and easement of 13 acres to the DNR came in response to a proposal for a small housing development. A new owner of the land between the Bogholts and Berkans proposed to build a bridge across Swan Creek to allow construction of homes on uplands bordering the marsh. Individuals and the Town of Dunn worked to prevent this move using the Town Land Use Plan, testimony to Dane County, and a court challenge to the County on an action that would have allowed the bridge to be built. During this tense period of dispute between the various parties, the DNR, now committed to protect and enhance the new State Scientific Area, entered negotiations with the owner and purchased the land. The 13-acre easement was donated by Robert and Beverly Aberg.

This concludes a summary of the preservation of Waubesa Wetlands to date. It suggests that a major impetus to the formation of the preserve was a. series of threats to the integrity of the wetlands. This is true enough, but is not sufficient to explain why it all happened as favorably as it did. These additional reasons are given in the following sections, and are listed in a way that allows ready generalization to other wetland preservation projects.

PRESERVATION STRATEGIES

The proximity of a major urban area and the emergence of new subdivisions here and there throughout the countryside clearly allow little time for preservation of Waubesa Wetlands. This and other such ecosystems face “the preservationist*s dilemma”: not threatened, there may be no need to save it; threatened, there may be no time to save it. Consequently, the following simultaneous strategies and tools were initiated as soon as possible, ready to serve any opportunity for preservation.

1. Responsible Private Ownership and Preservation

Often there are more wetlands or more acreage on a given wetland than are reasonable for preserve acquisition. For Waubesa Wetlands the goal of a 1000-acre preserve represents a land value in excess of $1,000,000. Private ownership thus is essential, especially in early stages of preserve establishment. And there are cases such as the Aldo Leopold Memorial Preserve in which responsible private ownership is the only approach needed. The strategy of responsible private ownership and preservation includes: identifying all owners of land within the area to be preserved; discussing with each owner their personal attitudes and plans; identifying those owners who are responsive to preservation objectives; establishing, improving, and maintaining communications with these responsive owners; assist1ng~ them in appropriate ways; and making them aware of means for secure transfer of land to other responsible owners when necessary.

For Waubesa Wetlands this approach has been both essential and successful. A number of responsible owners know much about the wetlands they own and the large wetlands of which theirs are a part. Some have sponsored field trips, meetings, and outings for community and friends to extend the wetlands knowledge base. Some have prepared wills which assure continued preservation of the portions they currently own. As pointed out by Laniti (1979): “Responsible private ownership should be considered the first line of defense in a local open space preservation strategy. The best way for a person to gain a solid understanding of and respect for the environment is to maintain a close, continuous relation with a part of it. If enough people have this opportunity, public environmental protection efforts will enjoy strong local support.”

2. Organized Private Ownership: the Leopold Memorial Preserve Model

Although there are some obvious advantages to private ownership, there clearly are limitations. Two major problems are lack of general agreement on what constitutes good stewardship, and, the possibility of unsupportive ownership following property transfer. These problems can largely be solved using the Aldo Leopold Memorial Preserve dual instruments of a Management Agreement and a First Right of Refusal, details of which are given in the next section. The unsuccessful attempt to use these tools on Waubesa Wetlands may be due to close proximity to Madison, resulting in owners* reluctance to enter an agreement which might restrict their options during an unsettling period of development—induced tax increases. The Leopold Preserve, however, is proof of the effectiveness of this approach.

3. Inventories, Planning Documents, and Ordinances at the Local, County, and State Levels

Inventories are the basis for plans which are the basis for ordinances and acquisitions. Thus it is important to check on the inclusion and accuracy of description for the wetland Identified for preservation, and to assure that this in turn is reflected in subsequent plans, ordinances, and acquisitions. Often, plans and inventories have not been made, in which case the advocates for preservation should encourage such to be done. If they haveS been done, they often must be done at low resolution, and may omit features which can be discovered only after careful and at least year—long observations have been made.

For Waubesa Wetlands, the timing was ideal for assuring that this wetland was adequately described by Dane County. First, the inventory was~ being conducted by Jim and Libbie Zimmerman and Barbara Bedford, which assured careful work from the start. Second, the survey was being conducted at the same time that extensive
·information being collected on Waubesa Wetlands by University classes was made available to the inventory team.

At the township level the Town of Dunn used the Dane County wetlands inventory (Bedford, Zimmerman, and Zimmerman, 1974) as a basis for the Town of Dunn Open Space Preservation Handbook (Lam, 1979) and Land Use Plan (Town of Dunn, 1979). It was an early version of this plan which in turn was the basis for adoption of Agricultural Conservancy Zoning by the Town of Dunn Board (1978). This zoning limited development to one house per 35 acres on nearly all lands bordering Town of Dunn wetlands. At the county level the Dane County Regional Planning Commission, sponsor of the inventory, used it in part to designate an open space corridor system in the Dane County Land Use Plan. And, following adoption of the Dunn Land Use Plan by the Town Board, the County Board adopted the Dunn Land Use Plan as an amendment to the County Plan.

At the State level, staff members of the Scientific Areas Preservation Council of the Wisconsin DNR were invited to visit Waubesa Wetlands to conduct an inventory and evaluation. Information derived from this inventory and evaluation were essential to the eventual designation of the portions of this wetland owned by the DNR as a State Scientific Area. Knowledge of the features of a given wetland and the careful documentation of that knowledge usually are fundamental to its preservation, And, the more broadly that knowledge is recognized and recorded, the more likely it is tote invoked when the time so requires.

4. Acquisition by Sale, Easement, and Gift

Although extensive purchase of land oftentimes is impossible, purchase often is the only effective course of action. In the case study, the sale of the Clemans farm was induced by the need for money, and although the seller was sympathetic to the idea of a preserve, a gift was out of the question. The prospect of the land coming into unsympathetic ownership had to be met by actual purchase. In a second instance, housing development appeared to be the alternative and apparently there was no recourse but to buy the land. Where this was not desired for a remaining 13 acres, an easement was negotiated which guarantees preservation in return for fencing and limited term firewood rights to adjacent wooded uplands.

Although it appears obvious, It must be said: For gifts of land to be made there must be both a willing donor, and a recipient acceptable to the donor. It was clear from the case of the Bogholts that there was a willing donor. But some obvious potential recipients were unacceptable. The DNR was highly suspect due to their permitting a natural gas line across wetlands previously given by the donor. Prof. Bogholt was also concerned that the University might put his lands to uses other than preservation if he should deed them over. And, he was hesitant about giving land to a foundation whose members had political views different from his own. These reservations about recipients emerged during numerous conversations with the Bogholts about the dream of a Waubesa Wetlands Preserve. Fortunately The Nature Conservancy was an acceptable recipient, was represented by a person with similar political views, and was willing to enter into a "quid pro quo" agreement with the Bogholts: "If I give 40, you buy the Clemans 40."

SPECIFIC TOOLS FOR SUPPORTING PRESERVATION STRATEGIES

In implementing the various strategies presented above the following useful tools were identified.

1. Scientific and Educational Use

To substantiate a case for wetland preservation information is needed on its size, biotic communities, presence of unusual species, processing of water and nutrients, and land ownership patterns. Although desirable to gather this information by interested citizens, it is useful to do so by encouraging wetland use in teaching and research by schools, colleges, universities and agencies. Both educators and researchers are pleased to find undisturbed natural areas available for their work.. Information gathered by such use can be used for inventories and informing interested parties. In the case study both educational and scientific use by university, schools, and naturalist*s organizations served to refine inventories and led to conversations, talks, lectures, papers, and newspaper articles which helped gain support of individuals, organizations and government for preservation of Waubesa Wetlands.

2. Feedback to Donors and Supportive Parties

Information about the wetland and progress being made on its preservation is owed to donors and is important in assuring other Individuals, the public and various agencies that the project remains an active one. For the Waubesa project, feedback to donors includes a spring binder notebook, nicely done, with scientific and esthetic descriptions of the donated land, maps and photos. Supportive parties are also visited periodically and are given published papers and articles resulting from work on the wetlands.

3. Selection and Support of Candidates for Local Public Office

What happens to a community*s wetlands is not independent of persons elected to public office. Candidates should be invited to attend "teas" at which their views on the preserve can be explored along wi-th other items. If not supportive, new candidates must be found who favor preservation of wetlands and know their values. Arrangements should be made so that the views of candidates can be widely heard throughout the community. In Dunn, preservation of prime agricultural lands and wetlands has been the major issue since 1972. Candidates were chosen based on their support for natural and agricultural systems preservation and these successfully ran for office. The town*s land use plan and agricultural conservancy zoning are a direct result. Newspaper articles describing this effort have been compiled by. the Environmental Awareness Center (1981).

4. Formation of Plan Commission and Keeping Wetlands on the Agenda

A local plan commission can be a very important asset for preservation of natural areas. Suggestions on its formation are given by Lamm (1980). The early work of a commission includes a careful inventory of natural areas, followed by the writing of a land use plan with areas to be preserved indicated. The plan is used as a basis for writing and adopting subdivision and zoning ordinances to make preservation of designated areas legally defensible. Finally, the Plan Commission enforces the ordinances tn the courts. In Dunn all of these steps have been taken since 1972, including a legal challenge to Dane County*s approval of a permit for bridge construction across Swan Creek.

5. Quid pro Quo Agreements

Sometimes a person hesitates giving land to a preserve because others might not do their part. Or a person might be concerned that a vulnerable parcel outside his personal control also be added to the preserve. In such cases a conditional gift is possible—a gift which is given only if another gift or purchase is certain. Such "quid pro quo" agreements offer the advantages of interesting a potential donor and providing a means for spurring others to act. This approach proved successful in arranging the gift of the remarkable "Bogholt Deep Spring Tract" to INC.

6. Management Agreements

A management agreement is a quasi-legal document which specifies policies for a jointly-owned preserve. It is drawn up interactively between supportive owners and signed by each. The result is mutual restriction of rights for the preserve*s benefit and for the security of knowing that adjoining property will not be abused. Although this tool has been unsuccessful for Waubesa, the Aldo Leopold Memorial Preserve uses this instrument along with the First Right as the primary means of preservation in the rural sand country.

7. First Rights of Refusal

A first Right of Refusal is a legal instrument used to protect a party*s interests in property not their own. For the exchange of a small fee, the holder of a First Right has 30 days to purchase property at the price offered by another party. During this period the holder of the right can investigate intentions of that party including willingness to sign a Management Agreement. If the party supports the preserve, the sale proceeds. If not, the holder of the First Right purchases the property. This tool was unsuccessfully tried on Waubesa Wetlands.

8. "Crazy-quilt" Ownership Patterns

As the Waubesa project progressed, it became apparent that land never is fully secure in a preserve no matter what the ownership. An agency might allow a transmission line or may "improve" a natural area for the benefit of a species. Such actions may discourage potential donors and researchers interested in long-term study. "Crazy-quilt" patterns of ownership can discourage actions by different adjoining owners since such actions mutually affect each other. And interspersing public and private lands can be done so that crossings by roads and transmission lines always involve public land, thus gaining protection from lands which cannot be condemned. Additional discouragement for such crossings can take the form of a pattern of ownership which, no matter what the route, clearly results in difficult legal problems. Although land in private ownership may pose few legal problems for the party building the road or line, land in a mix of public, corporate, and individual ownership presents a legal challenge best avoided. A pattern for maximizing discouragement for crossing of linear services is not in place at Waubesa, but is possible for a new project.

9. Reverter Clauses on Property Deeds

Reverter clauses are added to deeds and result in a, parcel reverting to the previous owner, typically TNC, if the purposes of the preserve are violated. Thus, if donors with parcels of the quality required of TNC wish to make gifts of land to universities, government agencies or conservation groups they might do so via TNC.

GENERALIZATIONS FOR WETLAND PRESERVATION

This case study of the preservation of Waubesa Wetlands identifies two aspects of wetlands protection at the local level: its site-specific peculiarities; and its broadly applicable generalities. By recognizing and appropriately responding to what is site-specific, and what is broadly applicable, this study advocates using local approaches as effective means for wetlands preservation.

Adaptation of Strategies and Tools to the Peculiarities of the Local Situation

Each local situation is unique. The wetland itself differs from all others, and so do the people. The values and perceptions of people differ widely, as applied not only toward the wetland itself, but also toward neighbors, government, and politics. For a preservation project to be successful, it is essential that the strategies and tools be carefully adapted to these values and perceptions. Difficulties, and what appear to be impossible situations often develop. These should be viewed as challenges to endurance and creativity. In the process of meeting these challenges, all done in the context of a wetland*s vibrant life and drama, one finds satisfaction. The work, once recorded as it is here, appears to be overwhelming. It is not. It is a means of personal fulfillment; it is an opportunity to learn about nature and human nature; it is a valuable public service.

General Strategies and Tools

Within the context of the individual peculiarities of a given time and place, the generalities remain conspicuous. These are listed as five strategies, and nine tools in the sections above. For a given project at its very beginning, a listing of these strategies and tools might be made, together with the names and telephone numbers of the persons to be contacted for each. A description following each of these might then be written and adapted to the local situation. And now the project has a “launching pad,” adaptive to situations as they arise, responsive to opportunities as they. emerge, instructive to new recruits as they enlist for the project~

The Importance of Wetlands Preservation at the Local Level

If the comprehensive systems approach to wetland preservation at the local level as advocated in this paper is adopted, its positive effects go well beyond the target wetland. The other major wetlands in Dunn—Mud Lake Marsh, Hook Lake Bog, Grass Lake, and Door Creek Marsh-—have also benefitted. Findings from Waubesa Wetlands have contributed to understanding the need for wetlands preservation at the county and state levels. Even at the national level, this local case has made some contribution to understanding of wetlands as three-dimensional “organisms” of which we only see the “skin” (Friedman and DeWitt, 1978).

A local approach to wetlands preservation is a good one because It provides a focus: an opportunity to explore an ecosystem in depth with all its ecological, political and human behavioral Interactions. But the fact is that It*s really not local after all. Its effect Is broad and wide, and its impact extends well beyond its boundaries to other towns, counties, and states. A local approach Is worthy of anyone interested in wetlands preservation. And the beauty of It all is that local projects are within the grasp of local citizens.

ACKNOWLEDGMENTS

Clearly this project involves a large number of people without whose cooperation and hard work the preserve never would have become reality. Some are acknowledged below, but all are deeply thanked. Of special note are: W. Thomas Lamm, Environmental Awareness Center, UW-Madison; James H. Zimmerman, UW-Madison; Barbara Bedford, Cornell University; Town of Dunn Board, Plan Commission, and Open Space Study Committee; Au Sable Institute of Environmental Studies, Mancelona, Michigan; Prof. Carl and Mrs. Bogholt; Dorothy and Ted Berkan; Dr. Alice Watts Garos and Halvor Garos; Mary and Clarence Sondern; Margaret Lalor; Russell Clemans; Violet Munchow; Billy Lalor; Ron and Patti Larson; Edmond Minihan; Wesley Licht; Rosalind Gausmann; Prof. Edna Thomas; Paul Olson; Emily Earley; Harriet Irwin; Reed Coleman; Ann Peckham; Robert M. Friedman; Timothy K. Kratz; Elm Quigley; Charles Andrews;

Marjorie Winkler; Francis Heliotis; Cornella Burr; Prof. Philip H. Lewis, Jr.; UW Emeritus President E. B. Fred; Kent Anderson; Clifford E. Germain; William E. Tans; Don Thompson; Bud Tabaka; Laverne Enger; and Harland Everson.

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Searching for the Source: The Origin of Deep Spring in the Lower Lake Waubesa Wetlands

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Abstract: Nitrate and chloride concentrations from a variety of locations were analyzed to determine the source of a high-flow spring near Lake Waubesa in southern Wisconsin. Water samples were taken from the spring, another nearby hillside spring, Lake Waubesa, and two proximate wells. The lowest chloride and nitrate average concentrations of 0.00 and 1.56 ppm, respectively, were recorded from a municipal well with a depth range of 330 to 810 feet. The highest chloride average concentration of 59 ppm was recorded from the nearby hillside spring, while the highest nitrate average concentration of 8.95 ppm was recorded from Lake Waubesa, with the second highest of 7.51 ppm coming from the hillside spring. The spring's average concentrations were 32.13 for chloride and 3.99 for nitrate. These figures indicate chloride and nitrate concentrations decrease as depth below the ground surface increases and suggest the spring's source likely originates the upper bedrock aquifer.

Keywords: Springs, purple sulfur bacteria, source analysis, chloride and nitrate in natural waters

INTRODUCTION

Madison, Wisconsin, like urban areas around the globe, has experienced significant drops in its groundwater head levels over the past century, resulting in dramatic shifts in surface-groundwater interactions such as the reverse of Lake Mendota from a discharge to recharge zone (Hunt et al. 2001). These hydrological shifts are often visible in dry stream-beds and eutrophic lakes. Local approval of new real estate development requires study and documentation of potential environmental impacts, but groundwater effects are typically not evaluated. While serious threat to municipal water supply is likely decades away, diminishing aquifers have an immediate adverse effect on many natural environments, in particular those dependent on groundwater discharge.

The location, rate, and geochemical composition of groundwater discharge is determined by the underlying hydrogeologic units. Bradbury et al. (1999) have defined three primary aquifers which underlie the Madison area. Closest to the surface is the unlithified aquifer, which is composed of sandy till, outwash, and glaciolacustrine sediments. Below the unlithified aquifer lies the upper bedrock aquifer, a solid but permeable sandstone formation. The lower bedrock aquifer, separated from the upper bedrock aquifer by a narrow confining layer called the Eau Claire Aquitard, constitutes the deepest water-bearing layer above impermeable igneous and metamorphic formations (Clayton and Attig, 1997). Water travels through and between these layers according to the distribution of hydraulic head and hydraulic conductivity. Human-induced alterations from well pumping and decreased recharge area have the potential to reduce hydraulic head in these aquifers, thereby changing flow paths and potentially disrupting surface discharge to springs.

One such threatened natural area is the pristine expanse of wetland and aquatic habitat at the southwestern end of Lake Waubesa, a member of the Yahara chain of lakes. The unique hydrology of this area includes several small streams, a large and ecologically diverse calcareous fen, and, the main focus of this paper, Bogholt Deep Spring. Discharge from these sources converges in Lake Waubesa's shallow southern boot, where their colder temperatures and low nutrient loads could play an important role in inhibiting extensive algae blooms that plague similar hydraulically isolated areas like nearby Monona Bay.

Bogholt Deep Spring, tinted bluish-purple by its resident population of purple photosynthetic bacteria, is one of the most stunning natural features in the region. Under the right conditions, it appears as a blue spot from the air, standing out from the marsh like an enormous cornflower. It is also one of the largest springs in the area and creates a pool which provides a habitat for a number of waterfowl. In order to ensure that features like Deep Spring continue to accent the landscape for generations to come, it is necessary to determine their susceptibility to development pressures like groundwater withdrawal and loss of recharge zones. As mentioned above, this susceptibility is determined in large part by the path that spring water takes within the subsurface. By defining the hydrogeologic units through which the water flows, it is then easier to predict the impact of development on discharge at the spring. The goal of this paper is to determine the units which contribute significant amounts of water to Deep Spring and make suggestions on how to structure development so as to minimize disruption to the spring.

METHODS

Field Work

Deep Spring is located in a narrow slough connected to Lake Waubesa. Discharge occurs at the center of an inverted peat cone approximately 15 feet in diameter and 24 feet deep. The center of this cone was located using a combination of depth finder measurements and soundings with a Van Dorn sampler. Once this point was located, samples were collected at specific depths in the overlying water column using the Van Dorn sampler. Approximately 250 milliliters of water from each sample were coarsely filtered to remove organic debris and then placed inside a glass collection bottle. Dissolved oxygen measurements using a Yellow Springs model 51B oxygen probe were also measured up to 10 feet below the water surface in order to verify that oxygen levels decreased with depth.

Surface water comparison samples were collected from the shore of Lake Waubesa at Goodland Park and from both Swan and Murphy Creeks at their intersections with Lalor Road. Groundwater comparison samples were chosen based on their proximity to Deep Spring and also on the depth at which the groundwater originates. One small spring, hereafter referred to as

Drinking Water Spring, emerges from the uplands to the West of Deep Spring. Although the source of Drinking Water Spring is not known conclusively, its location on the hillside suggests that it is formed by the intersection of the dipping land surface with the water table. Samples were collected from Drinking Water Spring at both the discharge point on the hillside and also at several sand boils located within the spring pool. Samples were also collected from Wisconsin Department of Natural Resources well #8 at the Nevin State Fish Hatchery. The well is open at a depth of 180 feet below the ground surface and has an artesian discharge of 400 gallons per minute. The final groundwater samples were collected from Madison Water Utility well #30 which is open at a depth of 810 feet. Collection procedures at all sites were similar except for those samples from WDNR #8 and MWU #30. These samples were not filtered because of the assumed absence of organic matter. Figure 1 shows the aerial distribution of sampling points. Once out of the field, the samples were then frozen in order to prevent further microbial activity.

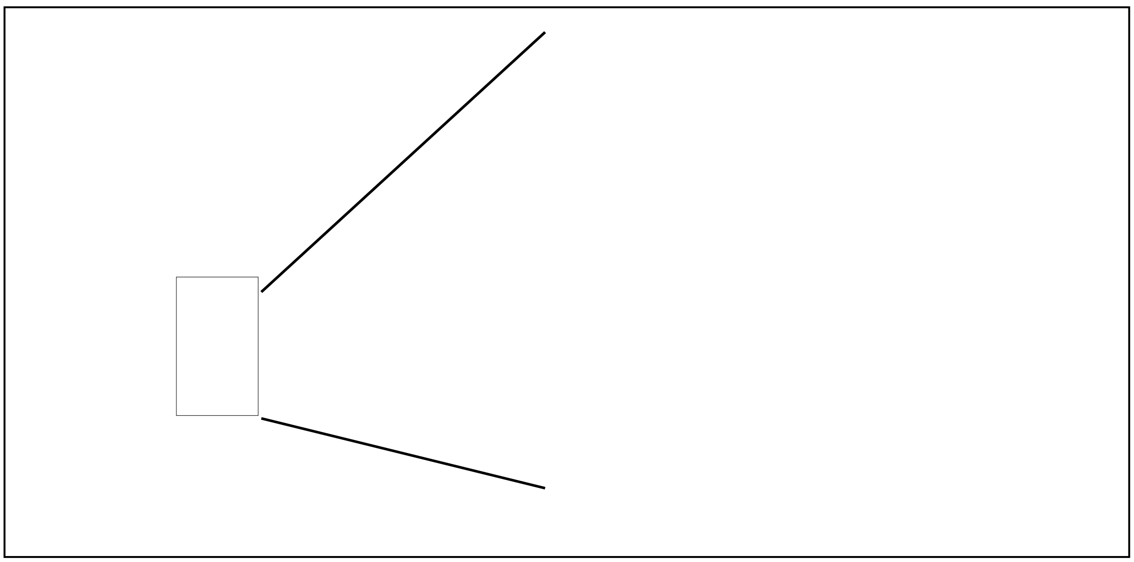

Figure 1. Arial Distribution of sampling points.

Laboratory Analyses

Samples from the bottom of Deep Spring, from the shore of Lake Waubesa, from the hillside at Drinking water spring and from MWU #30 were thawed in order to remove approximately 5 milliliters of water from each sample. These volumes were each acidified with 5 milliliters of a 1% nitric acid solution and sent to the University of Wisconsin Soil & Plant Analysis Lab to be tested for total dissolved cation concentrations.

The remaining samples were thawed shortly before analysis. Each sample was again filtered through a 0.1 micron filter to remove any iron colloids which may have precipitated during freezing. A 0.5 milliliter volume of each filtered sample was then removed for anion analyses.

Deep Spring Photographs

Upper:

Deep Spring is at the “toe” of the “stocking” that is joined by another large spring at the “heel” of the stocking. These, together with springs along “Deep Spring Whisker” which extends outward (south) of the “toe” joins with the other springs to produce Deep Spring Creek which flows as a stream of about 50-feet wide into Lake Waubesa.

Upper:

The Great Fen lies to the south of Deep Spring Creek and receives groundwater as a diffuse upward flow across its expanse toward Murphy Creek on the right and across the area to the south.

Upper:

Swan Creek is shown at the left with its wider upper branch originating upstream a few hundred feet, and its narrower lower branch being the main stream that originates in Fitchburg, enters the Town of Dunn and crosses Lalor Road on its way to Waubesa Wetlands. Its surface waters are continuous with the groundwater that underlies the wetland between Swan Creek and Deep Spring Creek. Not shown is Drinking Water Spring at the interface of the Waubesa Wetlands and the hillside west of Waubesa Wetlands whose flow enters the photograph at its right edge above the white triangle on the lower right. Its flowage begins as a surface water stream, but soon moves under the surface of the peat to flow beneath the surface toward Murphy Creek.

Lower:

Deep Spring is at the “toe” of the “stocking” and shows the presence of purple bacteria in the purple color here. The fen extends upward in the photo from shrub carr to highly stunted shrub carr whose diminutive botanical physiogomy is driven by cold uprising groundwater rich in calcium and magnesium.

Lower:

The “Heal Spring” at the “heel” of the stocking shows a ring of *Lemna* around the center of its upflow, and *Lemna* occupies other low-flow areas in this spring system. Bright green submerged vegetation, barely visible in this photo but periodically abundant, is *Spirogyra.*

Nitrate-N and chloride concentrations were chosen to differentiate between waters of different depths since they commonly originate from fertilizer and road salt application at the land surface. Since these anthropogenic inputs vary both temporally and geographically, their residues may be used to constrain both recharge areas and travel times (Swanson et al., 2001). These anions were measured using a Dionex ICS-1000 Ion Chromatography System. The samples were tested alongside standard solutions of known concentrations in parts per million (Table 1) and de-ionized water. Once the analyses were complete, the standard concentrations were compared to the ICS-1000 output in microsiemen minutes in order to produce standard curves which were then used to compute nitrate and chloride concentrations for the samples.

Table 1. Concentrations of chloride and nitrate-N in standards.

Standard #	*Nitrate-N Conc. (ppm)*	*Chloride Conc. (ppm)*
1	1.03	1.02
2	3.03	10.32
3	5.15	30.34
4	10.13	50
5	15.08	80.23

RESULTS

Table 2 shows the concentrations of nitrate and chloride measured in each sample, along with averages for each sampling location. Although care was taken to ensure repeatability, standard checks showed that machine drift occurred by as much as 25% of original concentrations. The results given by samples taken at Deep Spring show a small (CV=0.12) variation in nitrate concentrations but a larger (CV=0.37) variation in chloride concentrations. This variation in chloride samples is almost entirely due to the presence of one outlier, however, and may represent contamination by another source or analytic error. Samples taken from Lake Waubesa show large (8.95 ppm) average nitrate concentrations but small (3.48 ppm) average chloride concentrations. The small chloride concentrations are surprising given that published data on chloride concentrations in Lake Waubesa show values in excess of 40 ppm (Hausbeck et al., 2004). The values given in this study could represent temporal or physical heterogeneities in concentrations and should not be taken as representative of the lake as a whole.

The results also show differences among waters from the three groundwater sampling locations. Water emerging from well MWU #30 exhibits low average concentrations of nitrate (1.56 ppm) and chloride (0.00 ppm) compared to 5.55 ppm and 33.36 ppm at WDNR #8 and 7.51 ppm and 59.41 ppm at Drinking water spring. The coefficient of variation among samples collected at both locations at Drinking water spring was similar (CV=0.12) to that seen among the nitrate samples at Deep Spring, suggesting that the both the hillside and sand boil locations have a common source. The cation concentrations in the samples sent to the University of Wisconsin Soil & Plant Analysis Lab were unavailable due to a machine malfunction and will not be considered in the remainder of this study.

Table 2. Individual and averaged concentrations of chloride and nitrate at sampled locations.
† Refers to depth below the spring pool surface
‡ Refers to depth below ground surface

	Nitrate-N Conc. (ppm)	*Chloride Conc. (ppm)*
Deep Spring Surface (0'0" †)	3.29	21.62
Deep Spring Surface (0'0" †)	3.71	24.98
Deep Spring Middle (10'2" †)	4.11	28.43
Deep Spring Middle (12'6" †)	3.98	28.50
Deep Spring Middle (14'0" †)	4.50	32.69
Deep Spring Bottom (22'3" †)	4.10	57.95
Deep Spring Bottom (23'5" †)	4.21	30.77
Average	*3.99*	*32.13*
Coefficient of Variation	*0.10*	*0.37*
Lake Waubesa	8.65	2.94
Lake Waubesa	9.25	4.01
Average	*8.95*	*3.48*
Swan Creek	5.33	17.81
Murphy Creek	6.73	34.24
Drinking Water Spring (sand)	8.13	65.36
Drinking Water Spring (sand)	6.02	46.87
Drinking Water Spring (hillside)	8.25	61.17
Drinking Water Spring (hillside)	7.64	64.25
Average	*7.51*	*59.41*
Coefficient of Variation	*0.12*	*0.12*
WDNR #8 (180'‡)	4.88	28.50
WDNR #8 (180'‡)	6.21	38.21
Average	*5.55*	*33.36*
MWU #30 (810'‡)	1.56	0.00
MWU #30 (810'‡)	1.55	0.00
Average	*1.56*	*0.00*

DISCUSSION

The results show that the nitrate and chloride concentrations in groundwater samples correlate well with the depth at which the sample originated. The depths are, in turn, representative of the hydrogeologic unit through which the water flows and the residence time that the water spends within the ground. The water discharged from Drinking water spring most likely travels through the shallow unlithified surface aquifer and has a relatively short residence time on the order of 1 to 10 years (Swanson et al., 2001). Alternatively, the waters flowing upwards out of WDNR #8 originate at depths of 180 feet, and MWU #30 has an open depth range of 330-810 feet below the ground surface which places their sources within the upper bedrock aquifer and lower bedrock aquifer, respectively (Bradbury et al., 1999). Swanson et al. (2001) estimate that similar waters in the upper bedrock aquifer may have residence times from 10 to 15 years and speculate that water within the lower bedrock aquifer may have residence times as long as or greater than 50 years.

The longer residence times in the lower bedrock aquifer may constrain discharge from wells or springs to waters which recharged before road salt and fertilizer application became commonplace. The nitrate-N and chloride concentrations observed in samples from MWU #30 fit this model since they are much lower than those seen in other locations. Although Hausbeck et al. (1999) report chloride concentrations in excess of 100 ppm in one of the deep wells, this well is no longer in use and may have been contaminated. Waters originating in the unlithified and upper bedrock aquifers are generally more difficult to differentiate since both would have been exposed to road salt and fertilizers. Nitrate and chloride concentrations in both these waters would instead depend only on the land usage in the recharge area and in the case of nitrate, on the microbial activity occurring within the subsurface. Nevitzky (1978) saw the highest chloride concentrations entering the Nevin wetland in surface water input, but Swanson et al. (2001) saw similar concentrations in the unlithified and upper bedrock sources and suggest that nitrate and chloride concentrations from water in the unlithified aquifer may be more responsive to discrete application events. They could be expected, then, to show more seasonal variability than concentrations of these anions in water from the upper bedrock aquifer. The samples in this study, however, were all collected on the same or similar dates, preventing such a comparison.

The above relationships between hydrogeologic units and their waters are instrumental in determining the source for Deep Spring. The lower bedrock aquifer exhibits very low chloride concentrations which may mix with the >40 ppm concentrations in Lake Waubesa to produce the observed intermediate concentrations. Such a situation, however, might be expected to show chloride concentrations close to zero at the bottom of the spring pool and a gradual increase in concentration closer to the surface. The samples taken at Deep Spring show the opposite relationship, suggesting that water from the lower bedrock aquifer is not present in appreciable quantities.

The presence of purple sulfur bacteria, however, would indicate low oxygen levels that point to a source long-removed from exposure to atmospheric oxygen. Although dissolved oxygen levels were shown to diminish with depth, values at the deepest depth (10 feet) still showed significant oxygen and do not indicate completely anaerobic conditions. Burke et al.

(1973) observed that purple nonsulfur photosynthetic bacteria more oxidizing environments and are morphologically almost indistinguishable from purple sulfur bacteria. Although no Eh measurements were taken at Deep Spring, the presence of nitrate in the water samples and the absence of a distinct hydrogen sulfide odor, suggests that the spring pool habitat may favor purple nonsulfur bacteria over purple sulfur bacteria. If the colony in the spring pool is actually purple nonsulfur bacteria, then oxygenated water from a shallow source would be consistent with the bacterial presence.

The chloride concentrations from WDNR #8 match up the best with chloride concentrations observed in Deep Spring. Although average nitrate-N is about 30% lower in the spring water, the amount of organic matter contained in the peat may allow for a slight reduction of nitrate within or below the spring pool. Nitrate-N concentrations observed at Deep Spring show slightly higher concentrations at the bottom of the spring, implying that if higher nitrate levels were present at the source, they may be reduced as spring discharge flows past sediments in the peat cone.

As mentioned above, it is difficult to differentiate water from the unlithified aquifer and water from the upper bedrock aquifer since heterogeneity at recharge zones does not allow for common characteristics between all waters from one unit. Assuming, however, that the recharge areas are similar for both WDNR #8 and Deep Spring, the upper bedrock aquifer is a possible water source. Seepage from the unlithified aquifer is also possible, although given the low chloride concentrations in Deep Spring relative to Drinking water spring, it is difficult to imagine that these two springs share common recharge areas. Most likely, the spring discharge is a combination of waters from the upper bedrock aquifer and diffuse seepage from around the wetland area. This interpretation makes geologic sense as well. Given the presence of the wetland, it is reasonable to assume that the area functions as a regional surface water discharge point. At the same time, it has been shown that the upper bedrock aquifer contains layers of high hydraulic conductivity which transport water to points near the Yahara lakes where glacial valleys have cut into the bedrock sequence and allow discharge through the undifferentiated till (Swanson et al., 2006).

CONCLUSIONS

The results above suggest discharge to Deep Spring originates primarily as flow in the upper bedrock aquifer and possibly as diffuse seepage out of the unlithified aquifer. Given these two sources, it is important to recognize the development activities which may adversely affect spring flow. Since recharge to the upper bedrock aquifer may occur at points distant from discharge areas, simply creating a buffer immediately surrounding Deep Spring is not sufficient to protect it. Flow paths within the upper bedrock aquifer may be identified through computer models and used to predict the recharge areas to Deep Spring. These areas should then be developed in such a fashion as to maintain permeable surfaces and reduce runoff and evaporation. As the residence times along these flow paths can also be several years, the lag time necessary to see the effect of land use changes should also be taken into account (Hunt and Steuer, 2001).

ACKNOWLEDGEMENTS

The authors wish to thank: Laura Craig for her help in the Geology lab; the Bogholt's for their land donation; The Nature Conservancy and Wisconsin DNR for being responsible stewards; Nevin Fish Hatchery and Madison Water Utility for their water samples; Quentin Carpenter and Cal DeWitt for their mentoring; and Ruth DeWitt for her baked treats and hospitality.

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