2017 Wisconsin Act 10: Central Sands Lakes Study

Scope of Work

Long Lake, WI
Photo Credit: DNR Water Use Section

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This document was developed by the Wisconsin Department of Natural Resources (the department, or DNR) in conjunction with the Wisconsin Geological and Natural History Survey (WGNHS), the United States Geological Survey (USGS), and partners from the University of Wisconsin System. The document represents the current proposed approach to be used to implement the designated study area requirements specified in 2017 Wisconsin Act 10 and is subject to change. Questions regarding this document or the Central Sands Lakes Study should be directed to DNRDGCentralSands@wisconsin.gov.

Definitions (Acronyms, Abbreviations)

Term	**Definition**
CSLS/Study	Central Sands Lakes Study
DATCP	Wisconsin Department of Agriculture and Consumer Protection
DEM	digital elevation model
Department/DNR	Wisconsin Department of Natural Resources
DG	DNR Bureau of Drinking Water and Groundwater
DOA	Wisconsin Department of Administration
EM	DNR Environmental Management Division
EMOR	Electronic Monthly Operating Report
ET	Evapotranspiration
FTP	File Transfer Protocol
GIS	Geographic Information System
GMAO	Global Modeling and Assimilation Office
GPR	ground penetrating radar
GPS	Global Positioning System
GRN	Groundwater Retrieval Network
IMPLAN	Impact Analysis for Planning
LiDAR	Light Detection and Ranging
LPR	Little Plover River
MODFLOW	USGS Modular Three-Dimensional Finite-Difference Groundwater Flow Model
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NCDC	National Climate Data Centers
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWIS	National Water information System
NWS	National Weather Service
PEST	Parameter Estimation module
PWS	Public Water System
REMI	Regional Economic Models Inc.
RIMS II	Regional Input-Output Modeling System
RTK GPS	Real Time Kinematic GPS
SDE	Spatial Database Engine
SFR2	MODFLOW Streamflow Routing package
SWB	Soil Water Balance
SWIMS	Surface Water Information Management System
USDA	United States Department of Agriculture

USGS	United States Geological Survey
UWS	University of Wisconsin System
UWSP	University of Wisconsin-Stevens Point
UZF	Unsaturated Zone Flow (MODFLOW package)
WCS	Web Coverage Services
WFS	Web Feature Services
WGNHS	Wisconsin Geological and Natural History Survey
WISA	Wisconsin Institute for Sustainable Agriculture
WU	DNR Water Use Section

Glossary

Anisotropic – Having different values when measured in different directions (e.g., vertical vs. horizontal).

Aquifer – A water-bearing unit of permeable rock, sand, or gravel.

Aquitard – a geological formation that impedes vertical groundwater flow.

Bathymetry – Measurement of the water depth of a lake bed or ocean floor. Bathymetry is the underwater equivalent of topography.

Conductance – A term describing the permeability of a stream bed or lake bottom, or how easily water is able to move through a defined thickness of the bed material.

Confining Unit (or confining bed) – A low permeability layer directly above or below a water-bearing layer.

Discharge – Water released from the saturated zone to the surface. The term may refer to natural groundwater seepage to lakes, streams and springs, or to groundwater extracted through a well system.

Drainage Lake – A lake with an inlet and an outlet.

Evapotranspiration – The loss of water from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

Groundwater flow model – A numeric groundwater flow model is a computer program used to simulate and predict aquifer conditions and groundwater flow under various input conditions.

Groundwater Flux – The rate of groundwater flow per unit area through porous or fractured media, as measured perpendicular to the direction of flow. Groundwater flux is synonymous with specific discharge.

High Capacity Well – A well that, together with other wells on the same property, is capable of pumping 100,000 gallons per day or more. This excludes wells whose primary use is residential or for fire protection.

Hydraulic Conductivity – A physical property that describes the ease with which a fluid (usually water) can move through pore spaces or fractures of a medium.

Hydraulic Head – A combined measure of the elevation and the water pressure at a point in an aquifer or on a water body. Head represents the total energy of the water and is measured as the static elevation of water in a well or the elevation of water in a lake. Water flows from areas of higher head to areas of lower head.

Hydrostratigraphy – The identification and differentiation of geologic units based on their hydraulic properties (aquifers/aquitards).

Interception – Precipitation that does not reach the soil but is intercepted by the leaves and branches of plants or the forest floor

Median – The middle value of a data set, such that half of the values in the set are greater than the median and half are less than the median.

Piezometer – An observation well designed to measure the elevation of the water table or hydraulic head of groundwater at a particular level below the ground surface. The well normally has a small diameter and allows groundwater to enter only at a particular depth, rather than throughout its entire length.

Quartile – A value that divides a set of data into four equal parts. A dataset has three quartiles: the lower quartile, the median of the data set, and the upper quartile.

Recharge – The volumetric rate of water entering the groundwater flow system over an area.

Runoff – Water, from rain, snowmelt, or other sources, that flows over the land surface.

Seepage Lake – A lake without an inlet or outlet.

Specific Yield – Aquifer storage properties such as specific yield and storativity describe the capacity of an aquifer to release groundwater per unit surface area of aquifer per unit decline of hydraulic head. Specific yield describes an unconfined aquifer's ability to release water through gravity drainage.

Soil Water Storage – The volume of water held within the unsaturated zone at any particular time

Transmissivity – A measure of the capacity of a saturated aquifer to transmit water horizontally.

Unconfined Aquifer – An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table forms the upper surface of an unconfined aquifer.

Water Budget – An accounting of the inflows, outflows, and storage changes of water in a hydrologic unit or system.

Table of Contents

1.0 Study Overview

This document outlines the Scope of Work for the Central Sands Lakes Study (CSLS). The study is being completed by the department to fulfill requirements enacted in 2017 Wisconsin Act 10 ("Act 10"), specifically those in s. 281.34 (7m), Wis. Stats.

The study will investigate the potential for groundwater withdrawal-related impacts to Pleasant, Plainfield and Long lakes. The lakes are located primarily in Waushara County in Wisconsin's Central Sands region. The study will include data collection and analysis, hydrologic modeling, a field study, and a significant impact determination for each of the three lakes. If significant impacts from groundwater withdrawals are identified, the department will evaluate special measures to address predicted impacts, complete an economic impact analysis, compile a decision document for public hearing and comment, and create final reports and recommendations for submission to the Wisconsin Legislature.

The purpose of this document is to share the department's approach to this study with its partners and the public. This Scope of Work is intended to assist with work planning, define roles and responsibilities for the department and its partners, help establish cost estimates, and ensure a defensible approach to answer mandated questions. It may also serve as a basis for future management efforts.

1.1 Statutory Requirements

Act 10, s. 281.34(7m)(b-f), Wis. Stats, requires that the department conduct a study to model and evaluate three lakes (Plainfield, Pleasant, and Long). Required components of this study may include:

- Evaluate and model the hydrology of Pleasant Lake, Plainfield Lake, and Long Lake in order to:
  - Determine whether existing and potential groundwater withdrawals are individually or cumulatively causing or are likely to cause significant reduction in any of the three lakes below its average seasonal water levels.
  - Establish whether there is a connection and/or causal relationship between groundwater withdrawals and an existing or potential significant reduction below the water bodies' average seasonal water level.
- Through field study, verify any connection and/or causal relationship between groundwater withdrawals and existing or potential significant reduction below the water bodies' average seasonal water level.
- If a significant reduction in one of the three lake's water level caused by groundwater withdrawals is identified, propose special measures relating to existing and potential groundwater withdrawal in all or part of the study area to prevent or remedy the reductions.
- If special measures are recommended:
  - Conduct an analysis of the economic effect of the recommended special measures on specific businesses, business sectors, public utility ratepayers, local government units, and the state's economy as a whole.
  - Prepare required reports, as described in Section 1.3.

Under Act 10 the department may seek to evaluate other navigable water bodies within a designated study area including the Fourteenmile Creek Watershed, the Ten Mile Creek Watershed, and the Lone Rock-Fourteenmile Creek Watershed, located in Adams, Portage, Waushara, and Wood counties. The department anticipates completing the study of the three lakes as required by Act 10, prior to expanding the study area. It is important to note, however, that the information gained through the study of the three lakes will provide the foundational information necessary to conduct any expanded study in the future.

1.2 Department Tasks

To meet the above requirements, the department must perform the following tasks:

- Frame the requirements of Act 10 in terms meaningful to groundwater model construction and scenario development.
  - Define appropriate model parameters and transient model calibration period(s).
  - Realistically represent existing groundwater withdrawals and land use.
  - Develop a method to predict and model potential future groundwater withdrawals.
  - Create model scenarios to meet the study objectives.
- Define "significant reduction" and "average seasonal water level" for each of the three lakes under consideration.
- Design and implement a field study to investigate the degree of connectivity between Central Sands lakes and groundwater withdrawals.
- Identify and model special measures that are feasible and effective in mitigating any identified significant reductions due to groundwater withdrawals.
  - Identify the navigable water or part of the navigable water that is or may be affected.
  - Identify the specific area to which the special measures should apply.
- Collect and evaluate sufficient data to analyze the potential economic impacts of any recommended management options (special measures) on a broad array of constituents, including local and statewide impacts.

1.3 Study Deliverables

If study results indicate that special measures relating to groundwater withdrawals are necessary to prevent or remedy significant reductions to any of the three lakes' water levels, Act 10 [s. 281.34 (7m)(c), 281.34 (7m)(e), and 281.34 (7m)(f) Wis. Stats.] requires the department to produce several documents related to study findings and recommendations. The first document the department must issue is a decision document including a description of study findings, recommendations for special measures designed to mitigate impacts, and an analysis of the economic impact of the proposed special measures. The decision document will cover all aspects described in s. 281.34(7m)(c), Wis. Stats. Following release of the decision and several months prior to the end of the study period, the department will hold a public hearing and comment period on the decision document. Notice of the hearing will be given to the public and to each land and well owner affected by the proposed special measures. Public input will be used to inform a set of two reports to the Legislature: a report including the same types of information included in the decision document and a detailed description of special measures that the department recommends the Legislature adopt by statute. These final reports are to be submitted to the joint committee on finance and to the chief clerk of each house of the Legislature prior to June 3, 2021.

In addition to the study reports, the CSLS will generate a calibrated groundwater flow model of the three study lakes. The groundwater model files and associated technical report will be made publicly available. In support of the model and for other purposes, up-to-date databases of geographic, hydrologic, geologic and water resource information of relevant features in the designated study area will also be made available.

1.4 Study Setting and Geographical Extent

The three lakes named in Act 10 are located in the Wisconsin Central Sands, an area characterized by a highly productive glacial aquifer composed of sandy or gravelly stream or lake sediment and glacial till. The department has defined the Central Sands aquifer as the contiguous area east of the Wisconsin River with sand and gravel surficial deposits greater than 50 feet deep. The sand and gravel deposits are underlain by sandstone bedrock throughout most of the region and by crystalline rock near the Wisconsin River. The western portion of the Central Sands has flat topography of lake plain or glacial outwash sediments except for occasional pinnacles and hills of sandstone. This area has a high density of irrigated agriculture. North-south trending glacial moraines form narrow ridges rising as much as 120 feet above the sand plains. Topography east of the moraine ridges is hummocky; this terrain formed as the result of the collapse of sediments deposited on glacial ice.

The three study lakes are seepage lakes located high in the landscape on the glacial moraines. The lakes have no surface water outlet or inlet, and lake water levels are controlled to a large degree by the elevation of the water table. Plainfield and Long lakes are part of a chain of lakes formed in a former glacial tunnel channel produced by meltwater running beneath the glacier.

1.5 Project Budget and Funding

Wisconsin's 2017-2019 state budget, passed in September 2017, provides $400,000 to the department to cover costs for the first two years of the CSLS.

1.6 Study Partners

The CSLS will be led by the department's Water Use (WU) Section. However, meeting the requirements of the Act will require extensive support from our partners at organizations including the Wisconsin Geological and Natural History Survey (WGNHS), the United States Geological Survey (USGS), and the University of Wisconsin System (UWS). This section identifies the general roles the various organizations are expected to play.

Overall project management, led by the department, will be coordinated by a team consisting of a point of contact from each major partner: the department, WGNHS, and USGS. Communications between these partners will be frequent and facilitated by project team leaders. Communications with stakeholders will include assistance from WGNHS and UWS.

Data storage and access will be coordinated with WGNHS, USGS, and UW-Stevens Point (UWSP). Some data collection activities will be completed by the department, while others will be contracted with WGNHS, USGS, and UWSP.

Resource evaluation will receive support from the department's Water Quality program, UWS, and other experts who are still being identified. The field study to evaluate connectivity between groundwater withdrawals and lake levels will be led by the department's Water Use program with support from WGNHS, USGS and UWS.

Constructing and calibrating hydrologic models is critical to effectively meeting the requirements of the Act. This will include a groundwater flow model and any other hydrologic models necessary. The department will contract with USGS to conduct the modeling and write the modeling report. The department will play a lead role in developing scenarios to evaluate any special measures. WGNHS and UWSP will work closely with USGS to incorporate data and modeling components from previous models.

Special measures to address significant lake level reductions, if found, will be developed and evaluated in cooperation with USGS. An economic impact analysis of special measures will be led by the department's Water Use Program with input from UW-Madison's Dept. of Agricultural and Applied Economics.

1.7 Timeline

As outlined in s. 281.34 (7m), the department must begin the CSLS evaluation and modeling by June 3, 2018 and has three years to complete the study. Time management will be critical in this study to ensure study outcomes are accomplished.

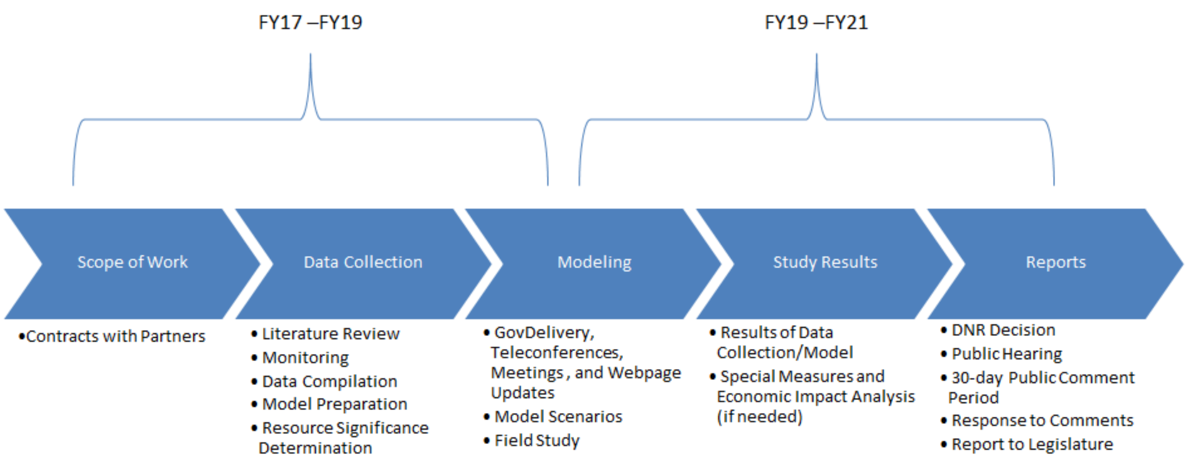

Figure 1. Proposed Timeline for the Central Sands Lakes Study

1.8 Communication

Stakeholder input will be important during the evaluation and modeling portion of the CSLS and post-study.

The department will maintain a CSLS webpage: http://dnr.wi.gov/topic/Wells/HighCap/CSLStudy.html or www.dnr.wi.gov search "Central Sands" which will include content such as the timeline, scope of work, key technical roles, study partners, and additional information as needed. Interested parties may visit the website and subscribe to the department's GovDelivery *Central Sands Lakes Study Topic* by clicking on the red envelope icon. Additional questions or comments can be emailed to DNRDGCentralSands@wi.gov. Other department social media accounts, including Twitter and Facebook, may also be utilized to share information during the study.

Technical memoranda may be periodically released related to the implementation of specific components of the CSLS (modeling, data collection, field study). The release of any memoranda will be posted on the department's Central Sands Lakes Study webpage.

Upon the release of a Draft CSLS Report including the department's decision (under s. 281.34 (7m)(c)), a public hearing will be held along with a 30-day public comment period. Notification will be provided to land owners potentially impacted by any proposed special measures and all well owners in that area that have notified the department of their well location. Comments received may inform the report that is due to the Legislature due prior to June 3, 2021. [Note: The final reports will be submitted only if the department recommends that the Legislature adopt special measures.]

2.0 Data Collection

Sound data support is needed to establish an appropriate conceptual model that can successfully represent the hydrology of Pleasant Lake, Plainfield Lake and Long Lake and allow the department to evaluate the existing and potential impacts of groundwater withdrawals on these water resources, as required by Act 10 (s. 281.34(7m)(2)b), Wis. Stats). Existing information about lakes and streams, hydrogeology and water budget components will be compiled from previous modeling efforts and studies in the Central Sands (UW-Stevens Point Central Sands Model (Mechenich et al. 2009, Kraft et al. 2010, Kraft et al. 2012), Little Plover River Model (Bradbury et al. 2017)), published materials, and other sources. Where existing data are not sufficient to meet study needs, additional field work will be conducted to fill in knowledge blanks.

2.1. Water Resources

2.1.1 Groundwater Levels

Groundwater elevation data will be used to establish site specific head targets, regional groundwater flow and the spatiotemporal variation of the water table. In areas surrounding the study lakes, groundwater levels will be used to define groundwater flow patterns in greater detail.

Potential sources of existing groundwater elevation data include wells in the USGS statewide groundwater monitoring network, monitoring wells operated by the Wisconsin Institute for Sustainable Agriculture (WISA), water elevation data collected from privately owned high capacity wells, static water levels reported by municipalities, and measurements of static water levels in miscellaneous production wells (Figure 2). Some of these water level observations have been used as head targets for previous modeling efforts. Several existing monitoring wells have also been identified adjacent to Long Lake and other lakes in the model domain. Water level data sources will be assessed for relative data quality and weighted accordingly in the groundwater model.

In addition to data from specific monitoring points, generalized water table elevation maps are available for the counties in the study area (Lippelt and Hennings, 1981). These maps may be used as a comparison to simulated water table contours.

Existing water elevation data will be compiled and assessed by WGNHS and the department to determine if additional data points are required to meet the needs of the study. Water level data needs will depend on model design features such as grid spacing and layering. The department anticipates that additional monitoring wells and piezometers will be needed adjacent to the three study lakes to determine groundwater flow directions, vertical gradients, and areas of groundwater inflow/outflow to the lakes. The department will work with partners at WGNHS and USGS to install and monitor additional water level monitoring points.

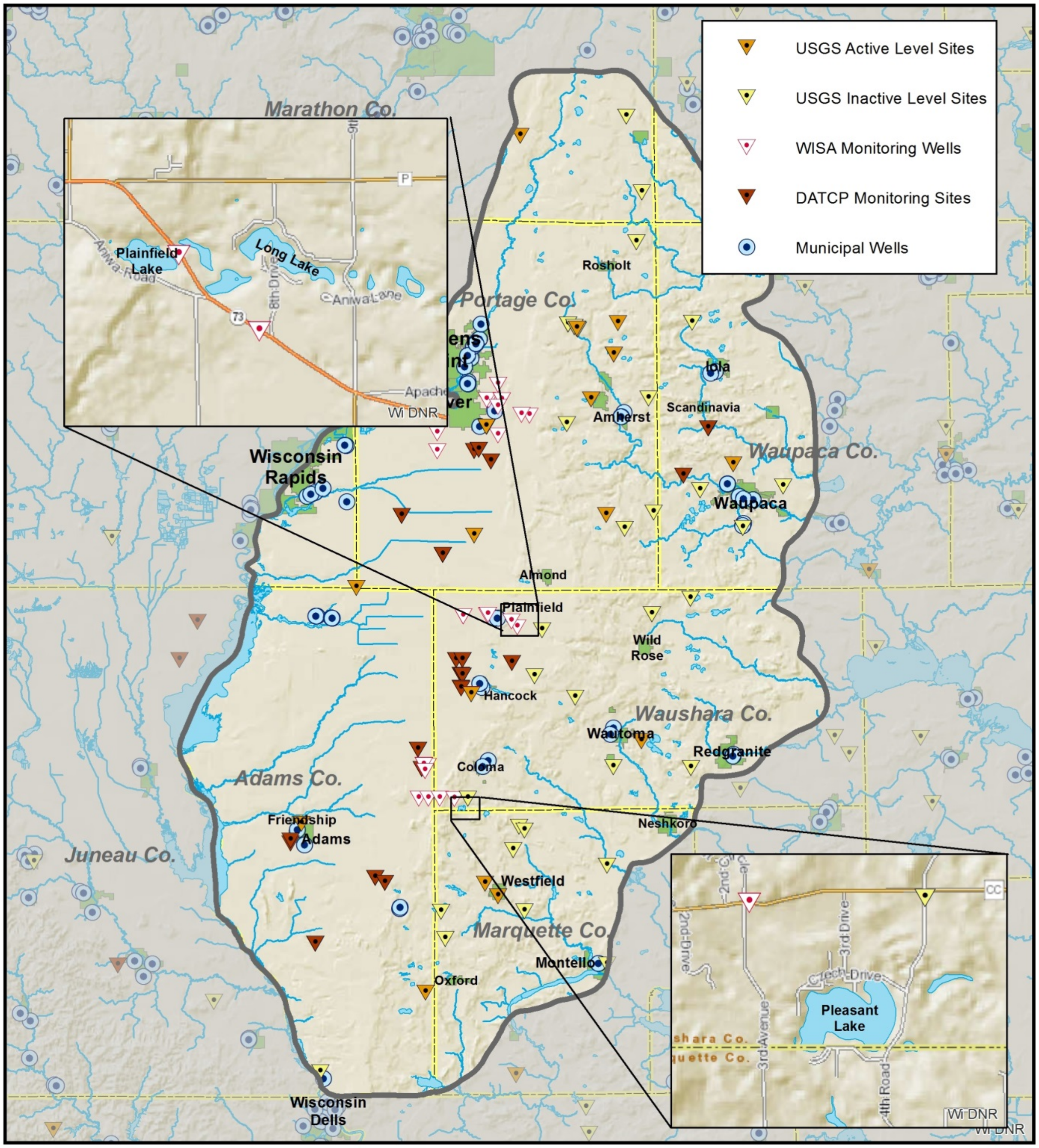

Figure 2. Map of Groundwater Level Monitoring Locations within the Central Sands Region.

2.1.2 Lake Levels

Lake elevation data for Pleasant Lake, Plainfield Lake, and Long Lake and for other lakes within the study area will be used as head targets to support hydrologic model calibration. In addition, lake level measurements of the three lakes will be used to determine average seasonal water levels. In most cases, lake elevations represent the elevation of the water table. Available elevation data for lakes within the study area (model domain) will be considered for use as head targets in the groundwater model. Existing lake level data for Wisconsin seepage lakes have been compiled as part of a multiagency research project headed by managed by the UW Center for Limnology. Data from lakes with historical or ongoing lake level monitoring will be assembled from DNR's SWIMS database, county conservation departments and the USGS monitoring network. Available lake elevation data points are shown in Figure 3. While lake elevation point measurements are available for many of the lakes in the Central Sands, data availability and quality are highly variable. Lakes such as Huron Lake in the Plainfield chain of lakes have a significant history of water level monitoring while others have few or no lake level measurements available. Additional lakes in the study area will be instrumented as needed to obtain data points for model calibration.

Long-term lake level data are needed to estimate seasonal water level variability and average seasonal water levels for the three study lakes. Where long-term records are not available, data from hydrologically similar lakes and from USGS monitoring wells with long-term records within the study area will be assessed for statistical correlation to the study lakes and may be used in the assessment of average seasonal water levels. The department's monitoring section will assist in calculating water level statistics with support from study partners as needed.

Historic lake level data are often sporadic and are typically recorded annually or less frequently. These types of data may not by themselves be sufficient to determine average seasonal water levels. The department anticipates contracting with the USGS to install bubble gages on the three study lakes. Bubble gages will provide information about daily water level fluctuations and aid in the evaluation of seasonal variability and average water levels. To establish an appropriate dataset for model calibration, the department will work with county conservation offices and UWSP to instrument other lakes within the study area with either a stilling well or staff gage to evaluate lake levels on a daily to weekly scale.

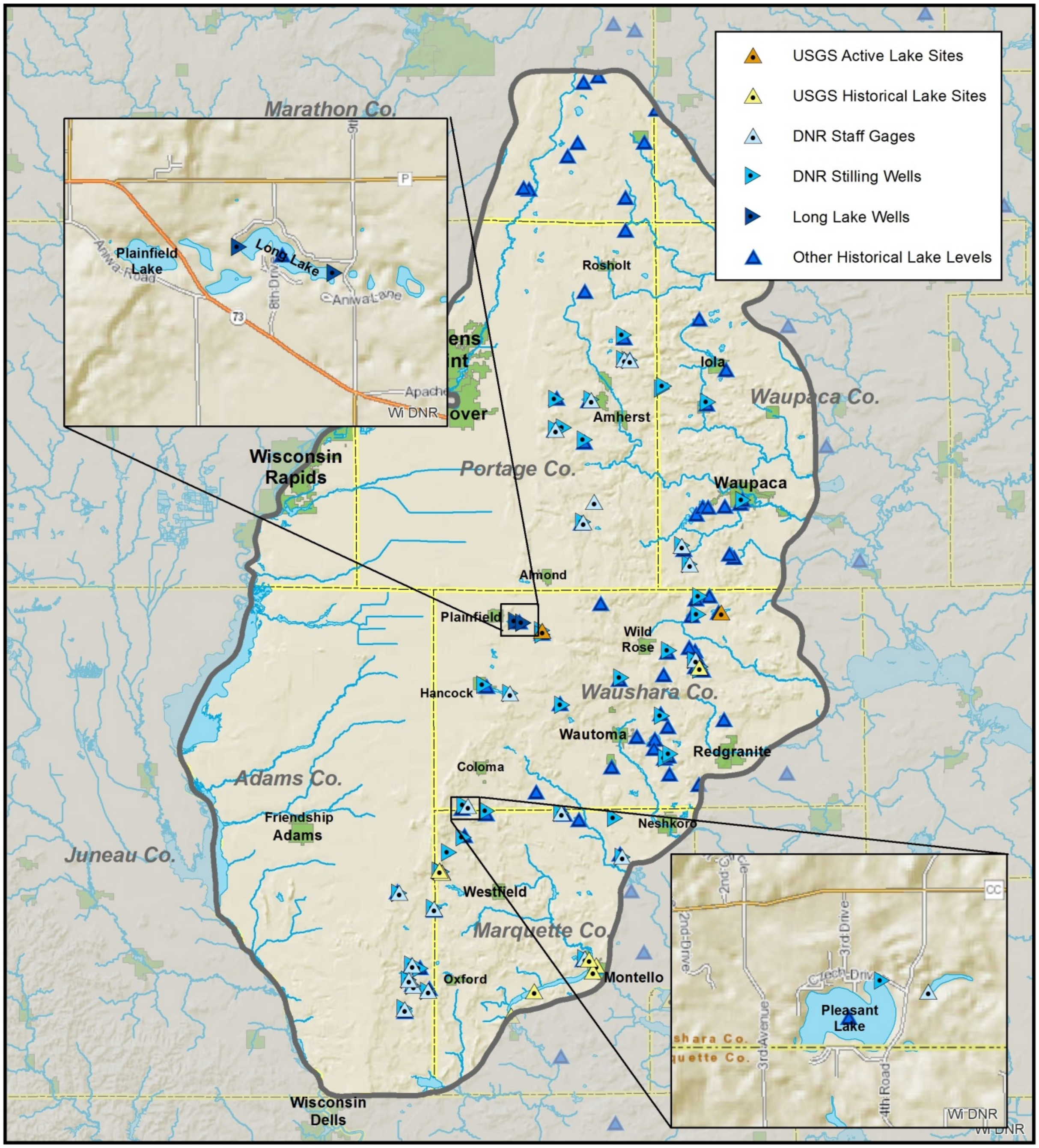

Figure 3. Map of Lake Level data points within the Central Sands Region.

2.1.3 Streamflow

Streamflow measurements, particularly baseflow data, are needed to provide flux targets in the groundwater model. Comparison of model results to streamflow measurements is necessary to confirm that the model correctly represents the hydrologic system. Because the study lakes are located in headwater areas near the groundwater divide, a good understanding of flow in headwater streams near the lakes is critical to ensure the water budgets within the three lakes are correctly modeled.

Various existing sources provide streamflow data for the Central Sands region. The USGS currently has continuous monitoring at several stream gages in the Central Sands, for the most part on larger streams and rivers. Historical streamflow data are also available for USGS gages that operated in the past (mainly in the 1960s and 1970s); these sites include both downstream reaches and some headwater streams.

In addition to data from the gage sites, point measurements are available for many Central Sands streams. Researchers at the University of Wisconsin-Stevens Point Center for Watershed Science and Education (UWSP) have been collecting baseflow data on a monthly basis since 2005. The UWSP dataset includes 142 sites with 2 or more data points and an additional 248 sites with a single measurement. The distribution of UWSP flow monitoring sites will be evaluated in light of the current modeling effort, and streamflow measurement locations may be adjusted to meet data gaps identified for this project.

Individual flow measurements collected for various department projects, by county staff, and by volunteer monitors available in the department's SWIMS database and from counties will also be assessed for use in this study.

The department and USGS are supplementing the existing streamflow data by installing three new stream gages on Chaffee Creek, Big Roche a Cri Creek, and the South Branch of Tenmile Creek. These gages will provide continuous monitoring points in headwater areas of streams near the study lakes. Streamflow monitoring sites, including current and historical USGS gage sites, current UWSP baseflow sites, and other point measurements are shown in Figure 4.

The department and USGS will compile streamflow data and evaluate for flux target use.

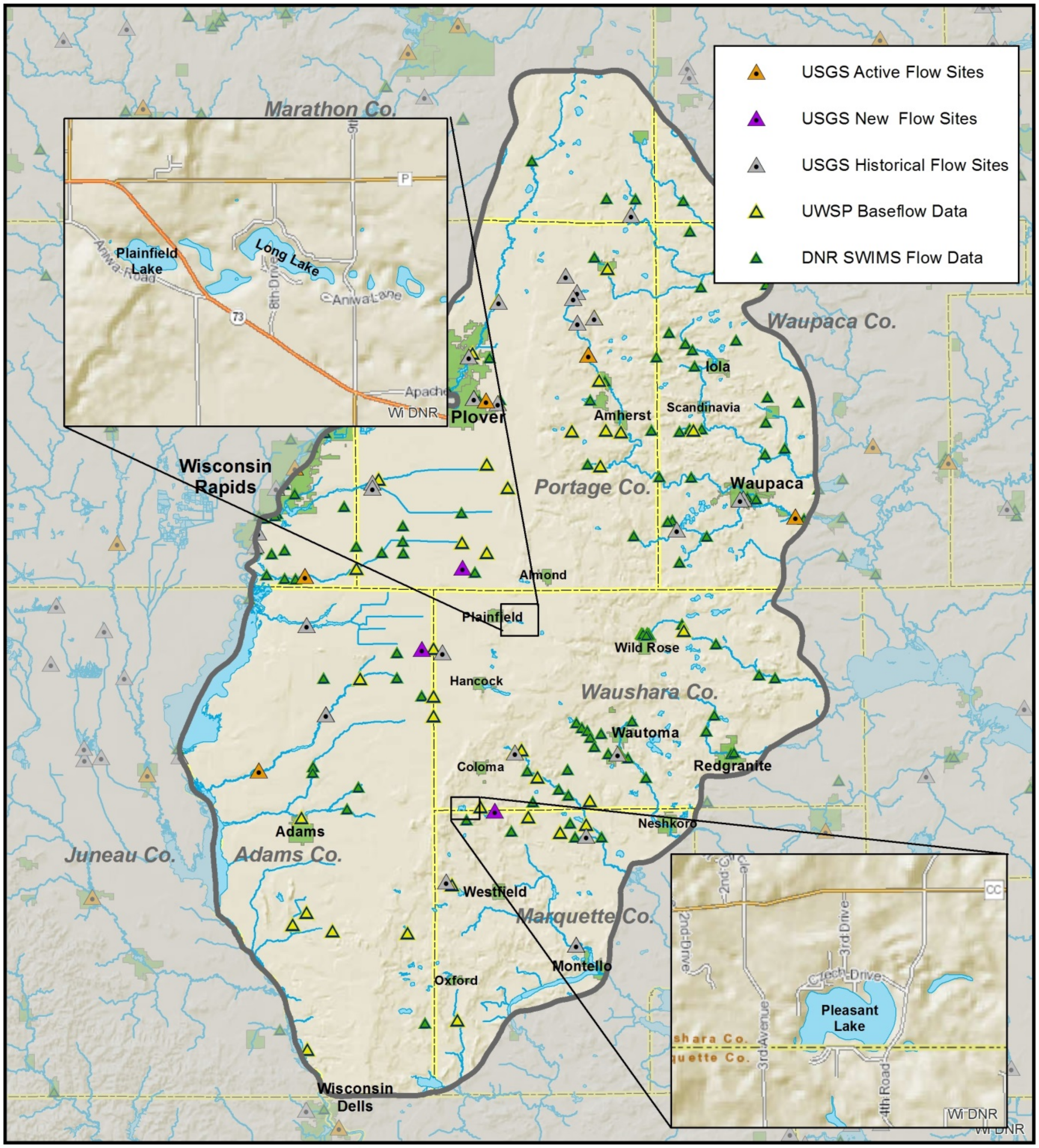

Figure 4. Map of Streamflow Measurements within the Central Sands Region.

2.2 Stratigraphy

2.2.1 Geologic interpretation (bedrock elevation, local/regional aquitards)

The configuration of different geologic units and their hydrologic properties determines how groundwater moves through the subsurface. The stratigraphy of the study area must be conceptualized in sufficient detail to accurately model groundwater-surface water interactions, and the immediate vicinity of the study lakes will require a detailed stratigraphic analysis. Important features that need to be identified include depth to bedrock and geologic features that could significantly impede the flow of groundwater (aquitards). Geologic data will be used to determine the hydrostratigraphy of the study area.

Information on geology in the Central Sands region is available from geologic borings, well driller logs reviewed by WGNHS, geologic formations reported by well drillers, geophysical logs, and preexisting groundwater models of the region (UWSP Central Sands model, LPR model). Data from individual wells and borings are available and will be compiled digitally. It is expected that over much of the study area, the density of wells is high enough that the geology of the upper aquifer can be well understood. However, some data gaps requiring additional field work (geologic borings) are anticipated.

Existing data on bedrock rock topography and aquifer thickness will be utilized (Weeks, 1971). Geologic log data will be assessed to determine areas where depth to bedrock is not well constrained. If these areas are near the three study lakes, additional borings or geophysical work (e.g. passive and active seismic, electrical resistivity) may be needed to determine bedrock depths. A depth to bedrock map will be developed from these data.

Surficial geologic maps (including GIS files) and cross sections are available on a county scale for Adams County (Clayton, 1987), Portage County (Clayton, 1986), Waupaca County (Mode, 2015), and Wood County (Clayton, 1991). Bedrock maps are available for Portage County (Greenberg, 1986) and Wood County (Brown and Greenberg, 1986). No published county-wide geologic maps are available for Marquette or Waushara Counties. Eastern Waushara County Quaternary geology is mapped at the 1:100,00 scale (Hooyer, 2004). Surficial geologic mapping in western Waushara County is ongoing at WGNHS, and mapping data in this area are likely to be available for use in model development.

Geologic data from existing data sources will be assessed to determine appropriate model layering. One step in this process is likely to be a determination of the areal extent, thickness, depth, and continuity of the New Rome Member, a regional layer of fine-grained sediments that may serve as a local aquitard (Brownell, 1986; Attig et al., 1988). Previous work conducted by WGNHS (Hart, 2015) and the department will be incorporated into the present modeling effort as needed.

Relatively detailed knowledge of the stratigraphy adjacent to Pleasant, Long, and Plainfield Lakes will be required to understand and model the degree of connection and groundwater movements between the lakes and groundwater. Some of this type of work has been completed adjacent to Long Lake (Kniffin, unpublished, 2014, Krueger and Martens, 1980); data from these previous investigations will be compiled and incorporated into this study. Additional data collection could include the completion of geologic borings and/or geophysical surveys (Resistivity, Active and Passive Seismic, Ground Penetrating Radar (GPR)) conducted by WGNHS.

2.2.2. Cross Sections

Following the compilation of geologic data, cross sections will be prepared to aid in the conceptualization of stratigraphy and the groundwater flow system. Regional-scale north-south and east-west cross sections will be created, along with north-south and east-west transects through the area near the three study lakes. The visualization of stratigraphy is also expected to include the creation of fence diagrams. This work is expected to be completed by WGNHS and DNR.

2.3 Elevations

Accurate elevations for lakes, stream beds and land surfaces are necessary for creating a well-calibrated groundwater model. The land surface and waterbody bed elevation data, in conjunction with groundwater level elevations, allow the model to simulate interaction between groundwater and surface water. There are several types of elevation data that may be utilized for the study.

USGS 10-meter digital elevation models (DEMs) are available for the entire model domain but do not provide the accuracy required for water body elevations, particularly in the low-relief areas west of the terminal moraine.

LiDAR (Light Detection and Ranging) provides elevation data with a resolution of 5 feet or better, an appropriate level of detail for most land surface within the model domain; LiDAR data are currently available for Adams, Portage, Waupaca, and Wood Counties. Complete LiDAR data are not available for Marquette County or Waushara County.

More detailed elevation data will be collected to support model development in some areas where LiDAR is not available and where additional accuracy is needed, particularly water bodies near the study lakes and low-relief areas. Elevations for water bodies in the model domain near the study lakes, including other lakes and headwater streams, will be determined using real time kinematic (RTK) GPS, which has elevation accuracy on the order of centimeters.

2.4 Aquifer Parameters

Aquifer characteristics (hydraulic conductivity, aquifer storage and lake bed/stream bed properties) are key components in successful groundwater model development. Existing data, representative values from past studies and new field data will be collected to ensure that realistic values are used for these parameters.

2.4.1 Hydraulic Conductivity

Hydraulic conductivity is a measure of the water-transmitting capability of subsurface materials. Hydraulic conductivity values may be derived from aquifer pumping tests, slug tests, or specific capacity tests. For the purposes of constructing a groundwater model, results from aquifer pumping tests, which represent the average hydraulic conductivity of a large volume of the aquifer, are particularly valuable. Depending on the test design, pump tests may also provide information about aquifer storage parameters. WGNHS, with technical support from the department, will conduct a literature review to compile data from pump tests and slug tests in the region, including pumping tests conducted on municipal wells. WGNHS will also compile specific capacity data for high capacity wells and calculate hydraulic conductivity values. There are a large number of specific capacity tests available in the study area because of the high density of high capacity wells in the region. Some aquifer test data have been previously compiled as part of the Little Plover River Model and other Central Sands groundwater flow models – this work will be considered for incorporation into the present modeling effort.

The department anticipates that the majority of hydraulic conductivity data will represent conditions in the sand and gravel aquifer. Depending on the distribution of data and availability of representative literature values, additional field testing may be conducted to define aquifer parameters for the sandstone aquifer.

A potential aquitard that has previously been identified in the Central Sands is a fine-grained (clay/silt) layer known as the New Rome. A literature review will be conducted to determine an appropriate extent and hydraulic conductivity for this layer. Past work by Weeks (1969), Brownell (1986), Hart (2015), and previous evaluations conducted by the department will be incorporated into the Central Sands Lakes Study as necessary. Additional field work, such as geologic borings or aquifer testing may be conducted if preliminary findings indicate that model results are sensitive to the hydraulic properties of this unit or if the spatial extent of the New Rome needs to be refined.

Hydraulic conductivity values will be set to a reasonable value and allowed to vary during the calibration process. Calibration and sensitivity analysis results may indicate areas where more data is needed, in which case additional field work may be done.

2.4.2 Aquifer Storage

Aquifer storage parameters describe the volume of water released from an aquifer for a given decline in hydraulic head. Aquifer storage properties are important for defining an aquifer's response to pumping over time in transient model simulations. Pumping test data, existing flow models and existing literature on the Central Sands will be reviewed to determine appropriate aquifer storage properties.

2.4.3 Conductance

Conductance is a parameter that describes the ability of a lake or streambed to transmit water. It is defined as *KA/L*, where *K* is the vertical hydraulic conductivity of the bed material, *A* is the area of the model cell and *L* is the bed thickness. Determining accurate values for lakebed conductance is likely to be important in accomplishing the goals of this study. Field testing, such as soil borings, seepage meters, and/or geophysics will be used to determine bed thickness and hydraulic conductivity of the three study lakes in order to calculate this parameter (see Section 2.2). Field work details will be informed by the findings of an ongoing tunnel channel study being conducted by Kniffin (unpublished, 2014). Lakebed conductance values for other lakes in the groundwater model will be determined using CSLS study fieldwork and literature values.

Typically, groundwater model results are not very sensitive to changes in streambed conductance. However, recent work in the Central Sands area (Bradbury, 2017) indicated that modeled stream depletion results were sensitive to streambed conductance. This sensitivity may be due to parameter compensation rather than an actual physical property (Fienen pers. comm.) and will be addressed in the CSLS model calibration process. Streams will be broken up into smaller zones and conductance will be more closely tied to physical characteristics to gain a better understanding of the importance of conductance. Field work may be undertaken by WGNHS to better define streambed conductance. The nature of that work will be guided by findings in upcoming WGNHS stream survey(s).

2.5 Lake Properties

2.5.1 Bathymetry

Lake bathymetry is required as an input to the MODFLOW lake package, and as an aid to understand the lakes' water budgets. Bathymetry maps created in the 1940s-1960s are available for the three study lakes and other lakes in the study area. More recent bathymetry surveys have also been completed for Long Lake (Krueger and Martens, 1980) and Pleasant Lake (Onterra, 2014). No field work is anticipated to collect additional lake bathymetry data.

2.5.2 Lake Water Budget

The lake water budget is an equation describing inputs and outputs of water in a lake. Inputs to the lake system include precipitation, surface runoff, flow in inlet streams, and groundwater flow into the lake. Outputs from the lake are evaporation from the lake's surface, flow through surface water outlets, and groundwater flow out of the lake bed.

Lake Evaporation and Precipitation

Evaporation and precipitation at the surface of a lake are significant components of its water budget. Evaporation from a lake is controlled by factors such as lake area, albedo, and air and water temperature. Climatic data required to calculate evaporation are available from the National Oceanic and Atmospheric Administration (NOAA). Typical evaporation rates for Wisconsin are available in Farnsworth et al., 1982 and a statewide lake evaporation dataset from Read et al., 2014. If needed, site specific evaporation rates will be estimated for the lakes.

Precipitation directly on lakes will be determined either by installing rain gages at the three study lakes or by interpolating precipitation data from nearby weather stations. A combination of these two methods may be used for present day and historic/future scenarios.

Surface water inflow and outflow

None of the three study lakes has a surface water inlet or outlet. Surface runoff into the lakes is expected to be a minor component of the lakes' water budgets and will be estimated based on daily precipitation data and the lake's drainage basin characteristics (area, soil types, land cover). GIS data coverages to determine these basin characteristics are readily available from the Natural Resources Conservation Service (NRCS), the United States Department of Agriculture (USDA), etc).

For other lakes within the model domain having surface water inlets or outlets, flow data will be compiled from existing measurements or collected as needed for model construction.

Groundwater inflow and outflow

Properly quantifying groundwater inflow and outflow is key to understanding the hydrology of seepage lakes. Some field work has been completed to characterize groundwater flow at Long Lake (Krueger and Martens, 1980, Kniffin, unpublished, 2014). Past groundwater modeling exercises have also identified general groundwater flow patterns around the three lakes (UWSP Central Sands model). Additional field work is anticipated to characterize groundwater flow patterns into and out of the lakes, potentially including the installation of piezometer nests, seepage meters and lake chemistry.

2.6 Water Budget (Groundwater Model)

The water budget of the groundwater model describes the movement of water into and out of the groundwater system. Inputs to the system include groundwater recharge (Recharge = precipitation + applied irrigation water – evapotranspiration – interception – overland runoff + Δ soil water storage) and groundwater flow entering from outside the modeled area. Gebert et al. (2011) estimated recharge on a statewide basis using stream baseflow measurements. More recently, Hart and Schoephoester (2013) estimated recharge for a four-county area including Waushara County using the GIS-based Soil Water Balance (SWB) model. Results of these studies will be used as a point of comparison for recharge results in the current study. Outflow from the groundwater system includes well withdrawals, water leaving the groundwater system through streamflow, evaporation directly from lakes, and groundwater flow leaving the model domain.

2.6.1 Precipitation

Precipitation is the main source of water entering the surface water/groundwater system. Daily precipitation data are available from NOAA weather stations throughout the Central Sands region (Wisconsin Rapids, Stevens Point, Hancock, Friendship, Wautoma, Oxford, and Waupaca). Precipitation data will be used to determine model inputs for steady state and transient scenarios. Historical precipitation data will also be important in determining average seasonal water levels for Long Lake, Plainfield Lake, and Pleasant Lake (see Section 2.2).

2.6.2 Pumping/Applied Water

A primary goal of the Central Sands Lakes Study is to assess the current and potential impacts of groundwater withdrawals on the study lakes. Thousands of high capacity wells currently operate within the Central Sands. An accurate representation of these withdrawals is critically important for meeting the study objectives. Beginning in 2007, high capacity well users were required to report monthly water withdrawals to the department, but response rates were initially poor. In 2011, programmatic changes led to improved water use reporting rates. In 2011, more than 85% of registered water users reported withdrawal volumes to the Department. In recent years (2012-2016) water withdrawal reporting rates have exceeded 95% and efforts have been made to improve each well's geolocation. High capacity withdrawal data from 2011 to present will be used to determine groundwater withdrawal rates in the model at present-day levels and to predict future pumping in areas with potential for future development into irrigated agriculture. The department will provide pumping data for past years and estimate location, pumping and applied water for future withdrawals.

2.6.3 Evapotranspiration

The evapotranspiration (ET) rate describes the amount of water that is transpired by plants or evaporated directly into the atmosphere without infiltrating to the water table. ET is an important component of the overall water budget. The department anticipates that ET will be estimated by the USGS using a combined approach employing the SWB and the Moderate Resolution Imaging Spectroradiometer Model (MODIS).

The SWB model is based on computer code developed by the USGS to calculate the spatial and temporal variations in groundwater recharge. The SWB model calculates recharge on a daily time step by use of commonly available data layers in combination with tabular climatological data. The department anticipates using adjusted SWB code that relies on empirically based ET estimates from MODIS16. MODIS16 is a product developed by NASA based on satellite-derived data that provides estimates of ET representing all transpiration by vegetation and evaporation from canopy and soil surfaces. ET is computed globally every day at a spatial resolution of 1km^2 (0.39 mile^2) using MODIS landcover and leaf area index data, and global surface meteorology from the GMAO (Global Modeling and Assimilation Office – NASA).

2.6.4 Runoff

Drainage and overland runoff are important considerations although not dominant components of the water balance in the study area due to slope and soil textures that facilitate infiltration. At a minimum, a 10-meter DEM in conjunction with the curve number runoff estimate approach will be used within SWB to calculate flow direction and quantify runoff for the study area. Low topographic features and portions of the study area that drain into closed depressions will be defined using a DEM sink analysis. The closed depressions likely facilitate recharge by capturing precipitation for subsequent percolation before it can run off into local surface drainage networks.

2.7 Field Study Data

Act 10 requires a description of the degree to which the department verified the connection between groundwater and navigable waters and the causal relationship between groundwater withdrawal and reductions in flow or water level to navigable waters by the use of field work or field study (s.281.34(7m)(2)(c)(2), Wis. Stats.).

The department is not aware of historical examples of our own staff conducting field work of this nature. As such, the department is conducting a literature review to identify examples of similar work in academic settings or by government agencies in other states.

Following the literature review and consultation with partners at WGNHS, UW and USGS, the department will establish a methodology to evaluate the potential connection between changes in groundwater flow to a lake and groundwater pumping. The department is considering several different study designs. Generally, the study would involve observing any changes in groundwater flow in the lake bed and changes to lake levels associated with test pumping a well near a lake in the study area, or observing groundwater fluxes associated with pumping directly from a lake. Chemical signatures may be used to demonstrate whether or not there is a connection between groundwater and lakes in the designated study areas.

One or more lakes will be chosen for field study based on having characteristics conducive to establishing the extent of hydrologic connection between groundwater and surface water, if such a connection exists. These characteristics include, but are not limited to: a relatively small surface area, steep-sided bathymetry and sand and gravel geology typical of the area. These characteristics would allow the selected lake or lakes to be instrumented to measure potential drawdown from the test pumping in a practical manner. A simplistic groundwater flow model may be constructed to help the department determine whether a field study is feasible for a particular lake, what kind of lag time to expect between pumping and drawdown, and what pumping rate may be required to induce observable changes in groundwater fluxes and water levels. Whether groundwater fluxes are induced by pumping from the lake itself or from a nearby well, the department anticipates installing nests of mini-piezometers to measure relative change in groundwater flux to the lake.

One additional challenge to the field study design is the need to discharge pumped water at a location that will not influence the results of the test. The discharge may need to be located a substantial distance from the pumping site due to the flat topography and transmissive aquifer typical of the study area. Another possibility would be to discharge the water by evaporation and transpiration processes.

Field study results, in addition to establishing the degree of connection between surface water and groundwater are expected to allow investigators to refine parameters such as lake-bed conductance in the modeling component of the overall study.

The department will work with WGNHS and other partners to implement the field study.

2.8 Lake Evaluation Data

In order to meet the goal of establishing a threshold for significant impact (i.e. significant reduction in average seasonal water level), the department will need to identify criteria to quantify lake ecosystem health as it relates to water levels. This will likely involve an inventory of all historical data collected at the study lakes, determining trends over time and comparing historical data to those data that will be collected as part of the CSLS. Data that may be used to determine the threshold for significant impact include: temperature and dissolved oxygen, water chemistry, lake mixing regime, presence of endangered species, habitat, near shore and wetland connectivity, plant community surveys, fish surveys, frequency of fish kills, biological surveys including wildlife, and access to and usability of swimming beaches, boat launches, piers, and boating activities in general. Data may be collected by a variety of partners including department water quality program staff, USGS, UW partners, County Conservation Department staff, WISA staff and possibly citizen volunteers. Data will be compiled, managed and evaluated by department staff for feasibility in making a determination of significant impact.

3.0 Resource Significance Determination

Act 10 directs the department to determine whether existing and potential groundwater withdrawals are causing or are likely to cause significant reduction of average seasonal water levels of Pleasant Lake, Plainfield Lake and Long Lake (s. 281.34(7m)(2)(b), Wis. Stats). Neither "average seasonal water level" nor "significant reduction" is defined in the Act. Therefore, the department must define these terms.

Water use staff will collaborate with department staff from the Water Quality program and with UW partners to determine the average seasonal water level of the three lakes identified in Act 10. The long-term record of water levels in the lakes will be analyzed to determine statistical distributions of water levels over time. Median and quartile values are expected to provide the best description of average seasonal water levels, as well as water level range and variability. The median provides a good measure of central tendencies of a data set and is less susceptible being disproportionately influenced by outliers such as very low or high water levels than other averaging methods.

Due to decadal scale oscillations (Watras et al., 2014), it is necessary to evaluate average seasonal water levels over a time scale that exceeds 30 years. In some cases it may be necessary to infer historic lake levels in the three lakes using known water levels in the designated study area and historic precipitation data. Once a long-term record of water levels is established, then median and quartile values can be calculated. In order to address the requirement to assess seasonal water levels, lake level measurements and calculated median and quartile values will be divided into seasonal categories to define the average seasonal water levels.

In addition to determining the average seasonal water levels for the three lakes, the department must also determine what constitutes a significant reduction in water levels. It is important for significant reduction criteria to have a scientific basis, as well as account for human use and values. The department will conduct a literature review to assess ecological and other markers used by other jurisdictions in their determination of significant impact to lakes. The department will also establish designated use categories similar to those defined in the Clean Water Act. These four categories may include: 1) fish and aquatic life (such as presence or absence of endangered species), 2) navigation (such as watercraft launching), 3) water quality (such as nutrient loading), and 4) wildlife (such as habitat for waterfowl). More specific components of each category will be established, and these criteria will be used to determine what is considered to be a significant reduction in water level for each of the three lakes.

Once average seasonal water levels and significant lake level reductions have been established, they will be used as criteria to inform the groundwater flow modeling effort. Average seasonal water levels will be used as targets for model development. If model results indicate that groundwater withdrawals cause lake levels to fall below the defined significant impact levels, model scenarios will be developed to simulate different water management strategies to avoid or minimize impacts. Modeling efforts would focus on determining changes in withdrawal amounts or land management that would prevent groundwater withdrawal-related lake level reductions from exceeding established thresholds. These model results may be used in conjunction with the economic impact analysis to develop recommendations for special measures to prevent or remedy significant reductions, as prescribed in Act 10.

4.0 Data Management and Accessibility

Staff from the DNR, WGNHS, USGS and at least two UW campuses will be contributing or using data in the CSLS. This data management plan is designed to maintain consistency in data sources, maximize availability to multiple users and applications, minimize the need for multiple versions and ensure public transparency through the process.

4.1 Baseline Data

Baseline data will mostly include geographical information about the CSLS area that will be used as core model inputs. The data may be refined or updated throughout the study as field data is obtained, but will be treated as the best available information regarding the CSLS area. This data is integral to CSLS and it is expected that all collaborators in the project will be referencing the same baseline data. The department will be responsible for maintaining, hosting and serving base maps used in the CSLS. To minimize processing time, all baseline data will be trimmed to far field extent of the modeling domain. These maps will include:

1. 24K hydro (DNR)
2. Waterbodies (DNR)
3. Wetlands (DNR)
4. Digital Elevation Models (DEM)
    a. LIDAR DEMs for Portage and Adams county
    b. USGS 10m DEMs for the remaining extent
5. Wisconsin Land Cover (Wiscland 2.0)
6. High capacity well locations
7. Wisconsin tax parcels (DOA Wisconsin Parcels 3.0)
8. Wisconsin Soils (DNR)
9. USDA cropland data layers (multiple years)

All baseline data will be maintained by the department and hosted via Web Feature Services (WFS) for feature class and tabular data and Web Coverage Services (WCS) for gridded data. Duplicate versions of each dataset will be hosted in parallel on a dedicated DNR File Transfer Protocol (FTP) website. The department will also maintain metadata for each dataset explicitly including version tracking and updates.

4.2 Water Level and Flow Data

A large number of groundwater level, lake level and streamflow observations will be used in the CSLS. Department staff will create a single dataset referencing all known observations that could be potentially useful in this study. Data in this dataset will be attributed with reference to original sources, periods of record, summary statistics and locations. Since many of the observations were not taken or recorded in commensurate time steps or units, department staff will develop basic scripts to summarize and display these data in interfaces useful for data exploration. All observations for each point will be compiled and made available as a monitoring point in the DNR SWIMS database, USGS National Water information System (NWIS) or as a static Oracle table created. Static data tables will be maintained on the DNR Spatial Database Engine (SDE) and made available via WFS and FTP.

Resource	**Source**	**Data Location**
Groundwater	DNR PWS (EMOR)	DNR GRN
Groundwater	USGS	USGS NWIS
Groundwater	DATCP Water Levels	DNR SDE
Groundwater	DNR Well Construction	DNR GRN
Groundwater	DNR Groundwater Quality	DNR GRN
Groundwater	County Staff/Local Groups	DNR SDE
Groundwater	USGS/WGNHS observations from past models	DNR SDE
Groundwater	WGNHS Well Construction	WGNHS
Lakes	USGS Lake Gages	USGS NWIS
Lakes	Volunteer Monitoring Coordinators	DNR SWIMS
Lakes	County observations	DNR SWIMS
Lakes	Historical Lake Levels	DNR SWIMS
Streams/Rivers	USGS Gages	USGS NWIS
Streams/Rivers	UWSP Baseflow Monitoring	DNR SWIMS
Streams/Rivers	DNR Biologists	DNR SWIMS
Streams/Rivers	USGS/WGNHS observations from past models	DNR SDE

Table 1. Table of Resource Data, Source of Data and Storage Location

4.3 Weather Data

Weather data are high volume and widely available from a number of providers including the National Weather Service (NWS), NOAA, NASA as well as a number of universities. Once datasets are identified that best meet the model needs, data will be either be compiled and hosted by the department or referenced to the source (NOAA, NWS, NASA, etc.) through programmed scripts.

4.4 Model Input Data

DNR, WGNHS and USGS will collaborate to interpret baseline data and create model inputs. This will include data such as the aquifer properties (hydraulic conductivity storage, thickness, etc.), recharge, boundary conditions, withdrawals, stream/lake conductance, and flux/flow targets. These datasets will be uploaded and shared via the DNR SDE and FTP sites. Through the process of model calibration and validation, it is likely that the model input data will be corrected or refined. Throughout the study, the corrected/refined input data will be uploaded and previous versions will be archived. Metadata and versioning of all changes will be done by department staff and made available along with each data set. Archive dataset will also be stored and maintained by the department.

4.5 Model Output Data

While the models are in process of development, calibration, parameter estimation, etc., draft processing scripts will be shared between collaborators. Once these scripts are finalized and vetted through the peer review process, they will be made available on the department website or other script sharing services.

5.0 Model Design, Calibration, and Scenarios

The evaluation and modeling phase is the largest and most complex component of the Central Sands Lakes Study. Modeling will be completed using an established groundwater flow model framework (MODFLOW) and a modeling approach similar to that used for the Little Plover River (LPR) model (Bradbury, 2017). The CSLS model will quantify existing and potential impacts of groundwater withdrawals to the three lakes. In addition any documents required by Act 10, a modeling report will be produced to reflect the construction of the model and its use.

Surface water flows and groundwater levels within the CSLS region are controlled by factors including precipitation, soil type, aquifer characteristics, land surface elevation, land cover, and land management. The use of a groundwater flow model is necessary to simulate the system and the variables that control it. The CSLS will rely on best practices in the field of hydrology, to evaluate the three lakes' deviation from their average seasonal water levels in relation to climate, groundwater withdrawals and other factors. Simulation of current conditions and evaluation of "what-if" scenarios will allow for decision making by resource managers, land owners, and others.

The following section describes groundwater flow model software and groundwater model set-up, inputs, calibration, optimization, and scenarios. The department intends to partner with the USGS Wisconsin Water Science Center to complete all components of the model design, calibration, optimization, and scenarios.

5.1 Hydrogeologic Setting and Conceptual Model

Anderson et al. (2015) defines a conceptual model as “a qualitative representation of a groundwater system that conforms to our understanding of the hydrogeological principles and is based on geological, geophysical, hydrological, hydrogeochemical, and other ancillary information.” In other words, a conceptual model is a simplification of the real world. Establishing a conceptual model is an important step in model development because it informs the creation of model inputs and how the model functions. The conceptual model includes data sources such as soils, geology, geophysics, landcover, land management, climate, and hydrology. The completion of the desktop data review and the in-field data collection and field study described in Section 2.1 and 2.2 will facilitate a conceptual model of the groundwater system within the CSLS study area.

5.2 Hydrologic Model Design

The components of the conceptual model, including flow, recharge, discharge, boundary conditions, pumping, and changes in storage, are reflected as standard groundwater flow equations that are solved numerically, and the resulting model solution includes hydraulic heads and flow rates. The CSLS groundwater flow model will use the USGS MODFLOW finite-difference code (Harbaugh, 2005; Hunt and Feinstein, 2012). Finite-difference models simulate groundwater flow by dividing the model domain into a geometric grid of rows, columns, and layers. As a result, the model domain is made up of numerous grid cells, each of which takes on hydraulic or boundary properties appropriate to its position in the groundwater system.

The CSLS model domain will cover a portion of the Central Sands sand and gravel aquifer. It is necessary for the model domain to extend beyond the three lakes to constrain the regional hydrology that ultimately influences the local hydrology of the three lakes region.

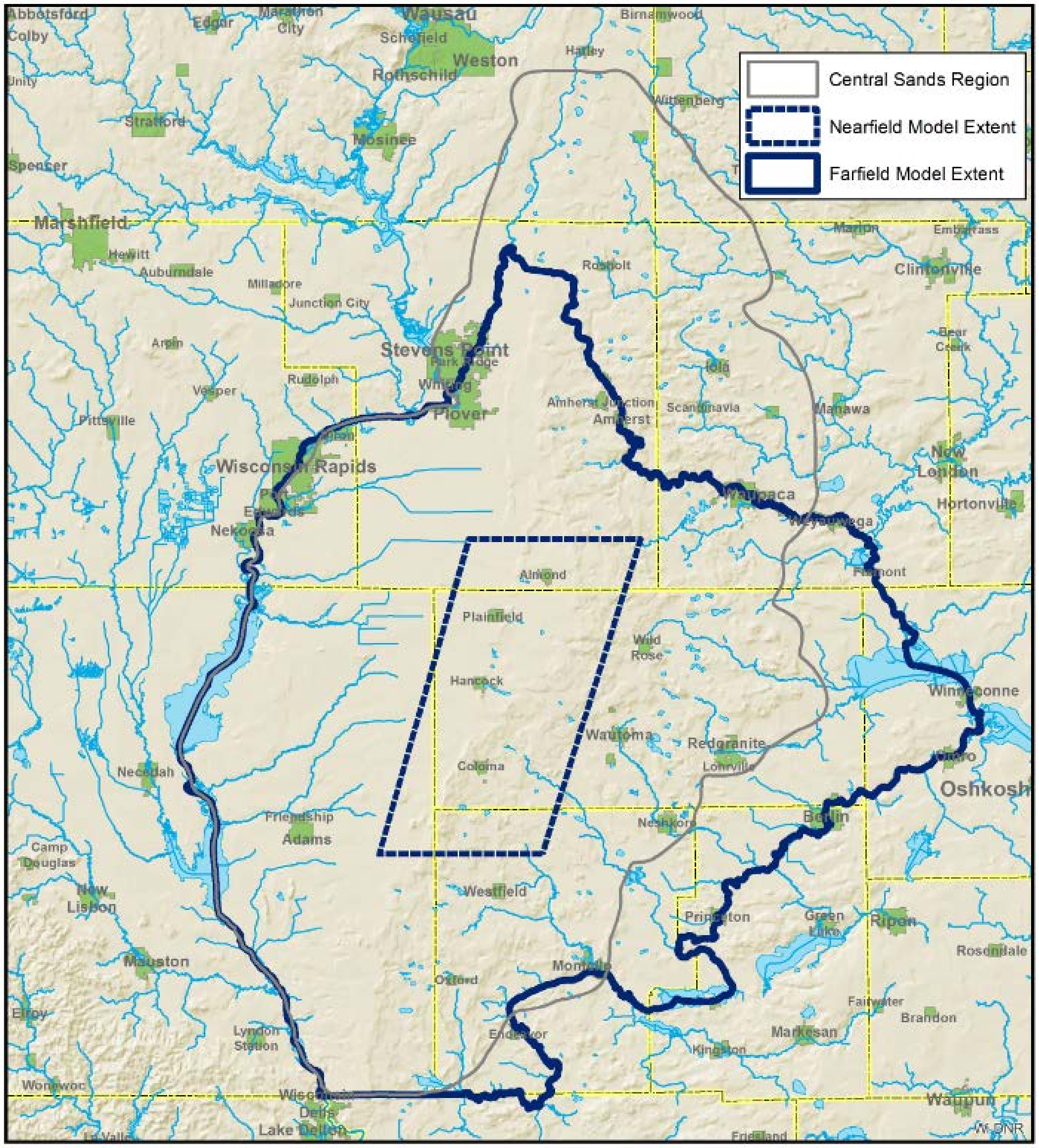

Figure 5. Map of the Proposed Model Domain. Initial estimate of the near-field area (the dotted parallelogram) containing the three study lakes; the estimated far-field area is defined by the dark blue boundary.

There are several possible approaches to defining the model grid. One approach would be to use a single cell size e.g. 300-foot x 300-foot across the model domain. An alternative approach would be to refine the grid in the region near the three lakes by using a smaller cell size compared to a larger cell size in the remainder of the model domain, referred to as the far-field. The incorporation of a near- and far-field model grid would ensure that the region's hydrologic boundaries are adequately simulated, as described in Section 5.3, while allowing for site-specific analysis in the region of the three lakes as required by Act 10. The near-field will extend beyond the hydrologic bounds of the three named lakes for the sole purpose of properly calibrating the water budget of the three study lakes. Gridding options will be explored in the model development process which may also result in a refinement of the boundary between near- and-far field model grids.

The model will contain layering to represent the hydrostratigraphy identified during development of the conceptual model. The number of vertical model layers will be determined once this geologic data analysis has been conducted. Model layering may be similar to the LPR model, which had three layers: layers 1 and 2 representing the sand and gravel aquifer, and layer 3 represented the underlying sandstone.

The MODFLOW groundwater flow model is a numerical finite-difference model that is capable of simulating both steady state and transient three-dimensional groundwater flow. Similar to the LPR model, the CSLS model will use climate, streamflow, and other data from a single year, possibly 2018, to represent steady state conditions in recent time. The steady state model represents average conditions and serves as a starting condition for the transient model. The transient model will simulate conditions representative of monthly stress periods, likely during 2019 and 2020 as well as one year of above-average precipitation and one year of below-average precipitation. If an appropriate dataset exists, an effort will be made to either calibrate or validate the model with conditions between 2012 and 2017.

5.3 Model Boundary Conditions

Boundary conditions are a key component of the conceptualization of a ground-water system; they serve as both mathematical constraints and a representation of the sources and sinks of water within the system. Within the CSLS model domain, distinct boundary types will be used to simulate recharge, discharge, and the spatial extent of the ground-water system controlling Plainfield, Long, and Pleasant Lakes. The boundary types include constant head, drains, lakes, streams, recharge, and wells.

Constant-head boundaries fix the water level in a model cell, and flows to or from adjacent cells are computed on the basis of that water level. With the exception of the southern boundary, constant head boundaries corresponding with the Plover River, Tomorrow River, Embarrass River, Wolf River, Fox River, Neenah Creek, and the Wisconsin River would be used constrain the model. Each of these rivers has constant flow and represents a regional discharge location for groundwater. A small section of the southern edge of the model does not have a corresponding hydrologic boundary and therefore either a specified head or specified flux boundary may be used.

A drain boundary is able to export water from the model domain but cannot contribute water to the model. As the water table level increases above the drain elevation (i.e. land surface), the discharge out of the model from the drain increases. Wetland complexes and springs, specifically Mecan Springs, will be simulated using drain boundary conditions.

The lakes within the CSLS model domain include both seepage and drainage lakes; all three of the study lakes are seepage lakes. Flow rates between the lakes and the aquifer are a function of the lake bottom elevation relative to the groundwater level. The LAK package (Merritt and Konikow, 2000) calculates lake stage automatically based on the water budget, which is a function of groundwater inflow and outflow, surface water inflow and outflow, direct precipitation on the lake, evaporation, and anthropogenic inflow and discharge. The lake boundary is simulated through the MODFLOW lake package and can be used for both steady state and transient simulations. Pleasant, Long and Plainfield lakes will be simulated using lake boundary condition. Other lakes in the near-field model domain may also be simulated as lake boundaries to facilitate near-field model calibration. Lakes in the far-field may be represented in MODFLOW as cells with higher hydraulic conductivity rather than the MODFLOW lakes package.

Streams and drainage ditches can represent both groundwater sources and sinks. Near-field streams, including Tagatz, Chaffee, Fordham, Little Roche A Cri, Big Roche A Cri, the Mecan River, Schmudlack Creek, Carter Creek and the South Branch of Tenmile Creek, will be represented in the model as head-dependent flow boundary conditions with the Streamflow Routing (SFR2) package. This type of boundary condition allows water to be added to or removed from the groundwater system, depending on head levels in adjacent model cells. Far-field streams that have substantial flow information may also be head-dependent flow boundaries with their flow to be used as calibration targets. Far field streams not used as flux targets will be represented as specified-head boundaries, with their primary function being to constrain groundwater levels.

Recharge is an important model input that represents direct infiltration of water from the land surface to the unconfined water table and is a function of the interaction of precipitation, runoff, land cover, land management and evapotranspiration. For transient simulations recharge is applied to the landscape as a spatiotemporal variable (varying in space and time) input. Monthly recharge rates will be estimated using a modified version of the Soil Water Balance model that includes satellite-based estimates of evapotranspiration.

In transient modeling it is important to determine the lag time between a precipitation event and the time that water reaches the water table. A correct lag time is needed to assign precipitation events to the correct stress period when simulating surface water responses. It is also important to ensure that the model is run for a long enough duration for stresses to be exhibited at the water bodies of interest. MODFLOW's Unsaturated Zone Flow (UZF) package may be used to address this.

Pumping wells will be used to simulate groundwater withdrawal from all high capacity wells. Each well's location, construction, and average reported monthly water withdrawal will be included within the model. Any surface water withdrawals within the model domain will also be simulated.

5.4 Model Parameterization

The CSLS groundwater flow model will require that each model cell be assigned specific information including cell thickness, model layer, horizontal and vertical hydraulic conductivity, specific yield, and, where appropriate, streambed and lake properties. Initial modeling will be based on field data. The initial parameter values will be subject to modification in the parameter estimation process to achieve calibration (Section 5.5).

Model parameters are described briefly below. Many of the initial values will be dependent on WGNHS work to characterize the stratigraphy and aquifer characteristics as described in Section 2.

Cell thickness will dependent on a stratigraphic analysis conducted by the WGNHS. This analysis will determine the layering scheme used in the model. Previous models of the Central Sands have used a 3-layer scheme for the upper sand and gravel, lower sand and gravel, and sandstone units. The CSLS study may require a more detailed approach to incorporate a detailed representation of the lakes.

Aquifer properties including horizontal and vertical hydraulic conductivity, and specific yield will be estimated based on best available information and fieldwork conducted for this study. Elevations of the land surface and surface water bodies will be derived from survey-grade data collected at key locations by UWSP. Lake levels will be collected at multiple times.

In the CSLS setting, modeling results may be sensitive to streambed and lakebed conductance values. This was found to be the case in the Little Plover River modeling project (Bradbury, 2017). Assigning conductance values is usually done simplistically, but a new approach will be developed based on the Little Plover River modeling experience. Assigning conductance values will be done with consideration of specific lake and stream reach characteristics. Field data will be collected to support initial values which will then be refined in the parameter estimation process.

Data quality will be an important consideration in assigning initial parameter values. WGNHS and DNR will evaluate quality of all data used in the groundwater flow model.

5.5 Model Parameter Estimation

Both the steady state and transient models will be calibrated to appropriate datasets consisting of water levels in wells and lakes, and stream baseflow. The steady-state model will be tuned based on estimations of average conditions from data collected in one specific year (2018). Measured data will be assigned different weighting depending on the quality of the data and proximity to the 3 lakes. Model parameter adjustment to fit the model calibration targets (water level, stream flow) will be assisted by the use of the parameter estimation code PEST (Doherty and others, 2010). The impact of parameters on forecasts of interest will be documented and will guide further data collection in an iterative process known as stepwise modeling (Haitjema, 1995).

5.6 Optimization and Drawdown Potential

As specified in Act 10 (s. 281.34(7m)(c), Wis. Stats) if, at the conclusion of the CSLS, the department identifies a significant reduction in any or all of the three lakes' water levels related to groundwater withdrawals, the department may recommend special measures relating to existing and potential groundwater withdrawals that have been determined to be necessary to prevent or remedy a significant reduction in any or all of the three lakes' water levels. Any recommended special measures would be developed and evaluated using the groundwater model. To optimize these potential solutions and estimate the extent of each groundwater withdrawal's contribution to the total impact, the model outputs will be mapped to show the spatial variability of model-calculated potential impacts (drawdown in the 3 lakes) for both existing and potential future groundwater withdrawals.

The groundwater model will serve as a management tool to evaluate competing water uses including irrigated agriculture, industry, municipal supply, ecosystems, and others. By mapping potential drawdown spatially—showing the model-calculated potential impacts that wells have on water levels in the 3 lakes—multiple special measures can be developed. Special measures could potentially include systematic changes in well pumping based on drawdown potential. Constrained optimization may also be used to quantify the tradeoff between water use and lake levels and can consider variables such as the maximum amount of reduction allowed in each well and various groupings of wells as well as spatial proximity (Fienen, 2017).

5.7 Scenarios

Upon completion of a calibrated groundwater flow model representing current conditions, a number of "what-if" scenarios will be generated within the model to assist in answering the questions described in Section 1.2 It is important to define the scenarios prior to developing the model so that the model's input datasets can represent the requirements of each "what-if" scenario. The scenarios may include:

No-pumping scenario

To quantify the scale of withdrawal-induced impacts, a no-pumping scenario will simulate the condition of surface water and groundwater levels in the hypothetical case that all high capacity well groundwater and surface water withdrawals in the model domain were turned off and the land returned to native conditions. This scenario will not be considered a representation of pre-settlement conditions because post-settlement landscape changes (stream ditching, wetland drainage, etc.) will not be altered. This no-pumping scenario will involve modification to the recharge and well packages.

Transient lake drawdown scenario(s)

One or more model scenarios will be required to help design the field study to be conducted to investigate the causal relationship between groundwater withdrawals and a potential significant reduction of a lake's water level below its average seasonal level. These scenarios will help determine a suitable site, pumping rate, pumping duration, and discharge location for the study.

Long term climate variation scenario

An understanding of the impacts of climate variation is needed to distinguish water level changes resulting from groundwater withdrawals from those resulting from climate variability. This scenario is needed so that the range of variability in lake levels from the "no pumping scenario" can be compared to the range of variability from the "transient with pumping scenario" to determine the drawdown contribution from withdrawals.

Potential withdrawal scenario

The potential withdrawal scenario will provide an estimate of impact to the three lakes that may occur in the future as a result of an expansion in withdrawals. The analysis may include three types of groundwater withdrawals: 1) withdrawals from lands within the near field with the potential for conversion to irrigated agriculture; 2) withdrawals from high capacity wells approved during the CSLS period; and 3) pending high capacity well applications received by the Department but not approved as of the end of 2020. In addition to the incorporation of potential wells, these scenarios will incorporate changes in recharge resulting from changes in land use as well as pumping. This scenario will be run for a sufficient time to ensure that impacts can be realized at the lakes.

Special measures scenarios

If the department determines that special measures relating to existing and potential groundwater withdrawals are necessary in all or part of the study area, then those special measures will be developed through a thorough evaluation process using the calibrated model.

Parameters that may change in these scenarios include groundwater withdrawal pumping rates and recharge. Various combinations may be examined in these scenarios in order to maintain lake levels above the significant impact threshold. Pumping from wells near an impacted lake may be reduced more than those at a greater distance from the lake. Recharge may be affected by irrigation rates and land use types.

6.0 Special Measures

If significant water level reductions are identified in the evaluation above, modeling scenarios will be constructed to develop, evaluate and compare the efficacy of special measures designed to mitigate these reductions. These measures will be a key consideration in model design and data collection because the model must be capable of simulating and evaluating their effectiveness in addressing impacts. Optimization modeling would be used to explore the impacts of various combinations of management solutions to produce any special measures to be recommended to the Legislature. In optimization modeling, the desired attributes of the hydrologic and water-resource management systems (such as maximum allowed groundwater or lake level declines) are specified and the model determines, from a set of several possible strategies, a management strategy that best meets the desired outcomes (Barlow, 2005).

At the onset of the project, serious consideration will be given to anticipating which land use practices, economic incentives and regulatory measures may be most effective in minimizing impacts to the three lakes. Given that very few such strategies have been implemented in Wisconsin, research into existing literature on these practices will be required to identify effective and viable management solutions.

Additionally, the hydrologic, chemical, and ecological characteristics determined in the resource significance determination and field study phases of the study will inform any recommended special measures.

If recommended, special measures will be selected to maximize ecosystem and public benefits while minimizing negative economic outcomes. This will require an understanding of the existing and potential uses of the lakes being evaluated, as described in Section 3.0.

Although impacts on the lakes will be defined relative to average seasonal water levels, impacts to the lakes will need to be assessed under a range of potential conditions. Therefore the model will be constructed to simulate both existing and potential groundwater withdrawals, and a wide range of climatic and land use conditions. The groundwater model will be used to evaluate the effectiveness of any potential special measures.

The results of modeling any potential special measures scenarios, together with the evaluation, modeling, study results and conclusions and economic impact analysis, if needed, will be included in the department's decision document.

7.0 Economic Impact Analysis

According to Act 10 (s. 281.34 (7m) 5., Wis. Stats.) if the department recommends special measures relating to groundwater withdrawals, the decision shall contain "an economic impact analysis of the economic effect of the special measures… on specific businesses, business sectors, public utility ratepayers, local governmental units, and the state's economy as a whole." In conducting this analysis, department staff will estimate the direct and indirect costs of the measures as well as any potential economic benefits that may result from implementation of the special measures. Where possible, existing and established economic models and methodologies will be employed by the department to calculate discrete economic impacts and extrapolate these impacts to the broader state economy.

At the outset, it is not certain what, if any, special measures will be recommended. Therefore, this section describes the general components of economic impact analysis that could be necessary. Depending on the study outcomes, the scope of the economic impact analysis could change significantly from what is envisioned here.

Potential Economic Costs of Special Measures

Nearly all high capacity wells in the study area are associated with irrigation, potato wash/storage, and municipal water supply. If any proposed special measures affect timing or volume of groundwater withdrawals, the department will analyze costs to well owners such as, but not limited to the following costs:

For irrigation wells:

- Impacts on crop yields and quality.
- Costs to modify crop rotations.
- Potential changes to agricultural land values.
- Potential changes to agricultural land-leasing prices.

For municipal wells:

- Costs of conservation ordinances.
- Costs of demand management programs.
- Costs to ratepayers associated with withdrawal reductions.

For all groundwater withdrawals :

- Unrealized return on high capacity well construction.
- Unrealized return on facility (i.e. potato storage) construction.
- Potential changes to land values.
- Cost of meters and/or telemetry installation.

In addition to costs to well owners, department staff will estimate how land value changes will affect local property taxes. Further, the department will estimate the economic costs of regulation and oversight for any proposed special measure including costs of additional data collection as well as any costs of inspection and enforcement.

Potential Economic Benefits of Special Measures

If the Central Sands Lake Study identifies significant impacts to the lakes caused by groundwater withdrawals, it is possible that there may also be adverse economic impacts to lake owners. The department will investigate this and estimate the potential benefit to property values and local property taxes. The department will also identify any specific businesses that are directly affected by changes in water levels and estimate the economic benefit to them from implementation of special measures.

Regional and Statewide Economic Impacts

If an economic impact analysis is undertaken, the department will estimate the broader regional and statewide economic impact of any special measures. To do this, the department will employ a standard input-output economic model that uses multipliers to extrapolate individual costs to the regional economy. Examples of these models include RIMS II, IMPLAN, or REMI. Model selection and the scope of the regional economic analysis will depend on the nature of any special measures recommended and the scale of the costs.

Data Inputs

DNR will use existing data to the extent practicable if an economic impact analysis is undertaken. This will include data sources such as:

- DNR high capacity well locations
- DNR irrigated lands coverage
- County tax parcels
- County historical property tax information
- USDA agricultural statistics
- USDA cropland data layer
- DATCP agricultural statistics
- UW Extension Cost estimates

If additional data are needed, the department will either collect it directly or contract with other universities or agencies as deemed necessary.

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