Appendix F –Central Sands Lakes Study Technical Memorandum: Land Use in the Central Sands

Part 1 - Land Use History in the Central Sands: Implications for defining the “natural” state of water bodies

Introduction

It is easy to assume that records prior to the beginning of widespread groundwater pumping for irrigation in the 1960s represent a natural, unimpacted hydrologic regime for water bodies in the Central Sands. However, a brief look at the history of land use in the region shows that human activities were changing the movement of water long before the advent of irrigated agriculture (Figure 1). Since the arrival of European settlers in the 1800s, landscape changes in various parts of the Central Sands Region have included land clearing for dry-land farming or lumber, widespread planting of trees, wetland conversion, dairy and crop farming, and the growth of grasslands or scrub. Each of these changes affects the amounts of water evaporated and transpired at different times of the year and subsequently impacts the amount of water that recharges the water table. This in turn changes groundwater flow patterns to and from water bodies. In addition to transforming land cover over the entire region, people actively manipulated groundwater levels with extensive ditching and damming in Adams, Portage and Wood counties for half a century before the advent of irrigated agriculture.

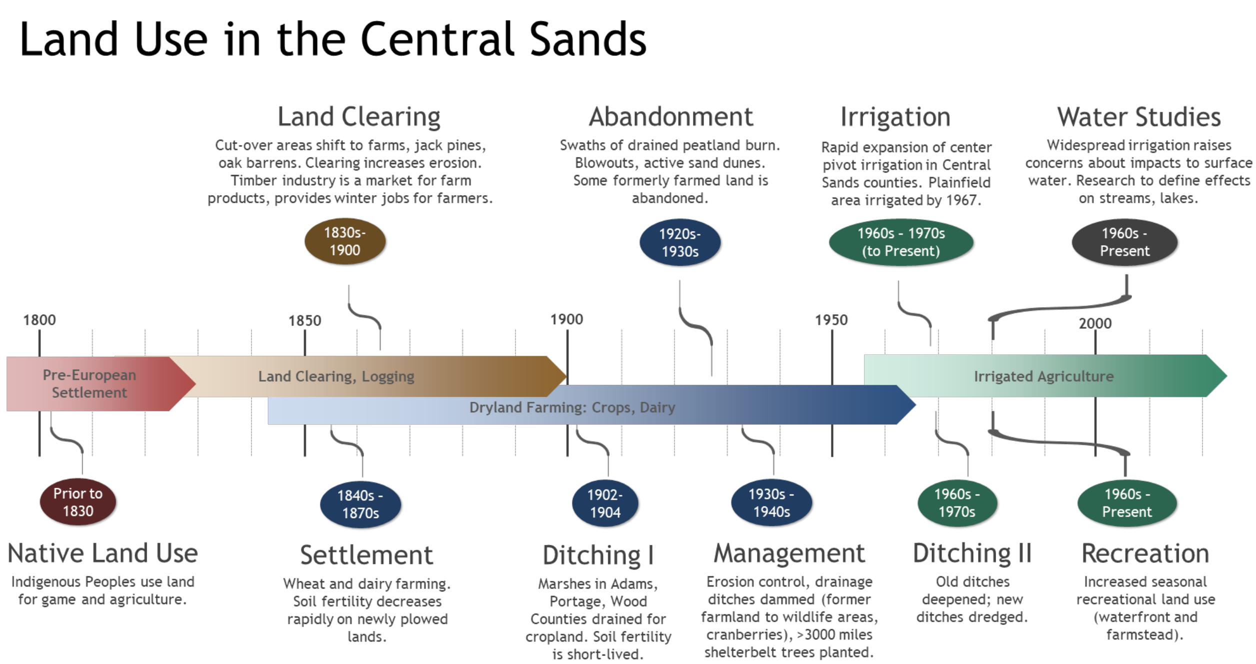

Figure 1. Central Sands land use timeline

History of Pre-Irrigation Land Use in the Central Sands

Humans began making small-scale changes to the natural landscape of the Central Sands Region hundreds of years before European settlement. The region was a cultural cross-roads as well as an ecological transition zone and was used by different groups of indigenous people at different points in history for agriculture and hunting. During some periods, land use by indigenous peoples included the practice of “firing” the forests to produce conditions more favorable for game hunting or agriculture. (Butler, 1978; Steinhacker and Flader, 1973). Both human-caused and natural fires were instrumental in shaping Central Wisconsin's ecological landscape (Rhemtulla et al., 2009). Land cover disturbance associated with the activities of native peoples were important in shaping the pre-settlement landscape but small relative to the changes that began with the arrival of large numbers of Europeans in the early nineteenth century.

In the 1830s and 1840s, land clearing began to drastically change the Central Wisconsin landscape. Many parts of the Central Sands were cleared to make way for farming (Rhemtulla et al., 2009). The lumber industry continued to dominate the region's economy through the end of the nineteenth century, to some extent through logging in parts of the region, but mainly due to the numerous sawmills along the central reach of the Wisconsin River (Butler, 1978; Goc, 1990; Holt, 1965). At this time, a few early European settlers and speculators came into the region and took over the best farmland. However, the sands, with their inability to hold water, were poor for farming and were one of the last parts of the state to be homesteaded. Blowouts and shifting sand dunes increased during this time due to land clearing. In some parts of the region, flash fires killed new seedlings and encourage the growth of jack pine and scrub oak barrens on cut over land.

The late 1840s to 1870s saw an influx of settlers who raised wheat or established dairy farms on successively sandier, less fertile land. Agriculture was briefly successful on newly-turned soils, but soil fertility declined rapidly and dramatically. (On John Muir's boyhood homestead, productivity decreased from 25 bushels of wheat per acre to 5 bushels per acre in only five years.) The decrease in productivity lead to clearing of additional land. Despite the poor productivity of much of the land, the farm economy "worked" as long as the lumber industry provided a nearby market for produce and winter jobs to supplement income. (Steinhacker and Flader, 1973)

Prior to European settlement, about one third of Adams County and large swaths of Portage and Wood counties were covered with wetlands. Early settlers did not plant crops in the vast marshlands but often cleared tamarack and cut the wetlands for "wild hay". The first widespread incursion into the wetlands took place during a dry period in the early 1890s, when the associated low water table encouraged farmers to begin to plow up marshes for cropland (Steinhacker and Flader, 1973). Initial yields of newly farmed lands were high, and black peat soil looked fertile to the eyes of immigrant farmers, but productivity rapidly declined.

In the late 1890s, increased rains raised water levels, flooding the marshland fields. This coincided with the introduction of new dredging technology, and in 1902-1904, drainage ditches were dug throughout the Central Sands marshlands. Ditches were often installed with a 1-mile spacing, draining around one hundred thousand acres in the Central Sands counties of Adams, Portage and Wood. The Leola Drainage District, one of the smaller drainage districts, excavated 40 miles of ditches and drained 15,000 acres. Land speculators bought up the newly drained land, but projects failed due to rapidly decreasing soil fertility. By 1907, the Leola Drainage district was "practically broke" due to unpaid assessments. Other drainage districts suffered a similar fate (Goc, Leola Ditch).

In the 1920s, drying peat in former marshlands promoted "virtually inextinguishable fires" that sometimes burned through the winter (Goc, 1990). In 1930, fire consumed 300,000 acres of peat in central Wisconsin, both east and west of the Wisconsin River (Steinhacker and Flader, 1973). In places, peatlands burned away completely to expose the bare sand underneath. Throughout this period, many previously farmed lands were abandoned. Land covers on formerly cultivated lands included weeds, brush, jack pine, scrub oak, and bare peat sprouting dense aspen thickets.

Beginning in the 1910s and continuing through the first part of the twentieth century, making a living on low-productivity land became untenable for some farmers, and the amount of active agricultural land in the Central Sands declined. While many farms, especially dairy farms, continued as economically sustainable enterprises throughout this period, many previously farmed lands were abandoned. According to Goc (1990), in 1918, "surveyors in Portage County found that 'abandoned farms are not unusual, especially in the valley of the Wisconsin River (specifically in the towns of Grand and Plover);" and that "by 1923, 15% of the 1,557 farms in Adams County stood vacant." Dust bowl conditions and blowouts increased during the drought years of the mid-30s. Sand dunes become active on cleared land. Formerly drained and farmed acreage was "unoccupied and unused", and "the region was dotted with abandoned farmhouses." (Ely and Wehrwein, 1964, quoted in Butler, 1978). New Deal programs actively moved some farmers off poorer land to better land. Large areas of land reverted back to the public domain. A land economic inventory in 1938-1939 (the Bordner Survey) identified 69,000 acres of land in the Central Sands, including some land in the Plainfield area, as "Poor land previously Cropped." The majority of that land remains unfarmed today (65% of it is forested, 4% is grassland). Figure 2 maps the shifts in agricultural and non-agricultural land use between 1930 and modern day.

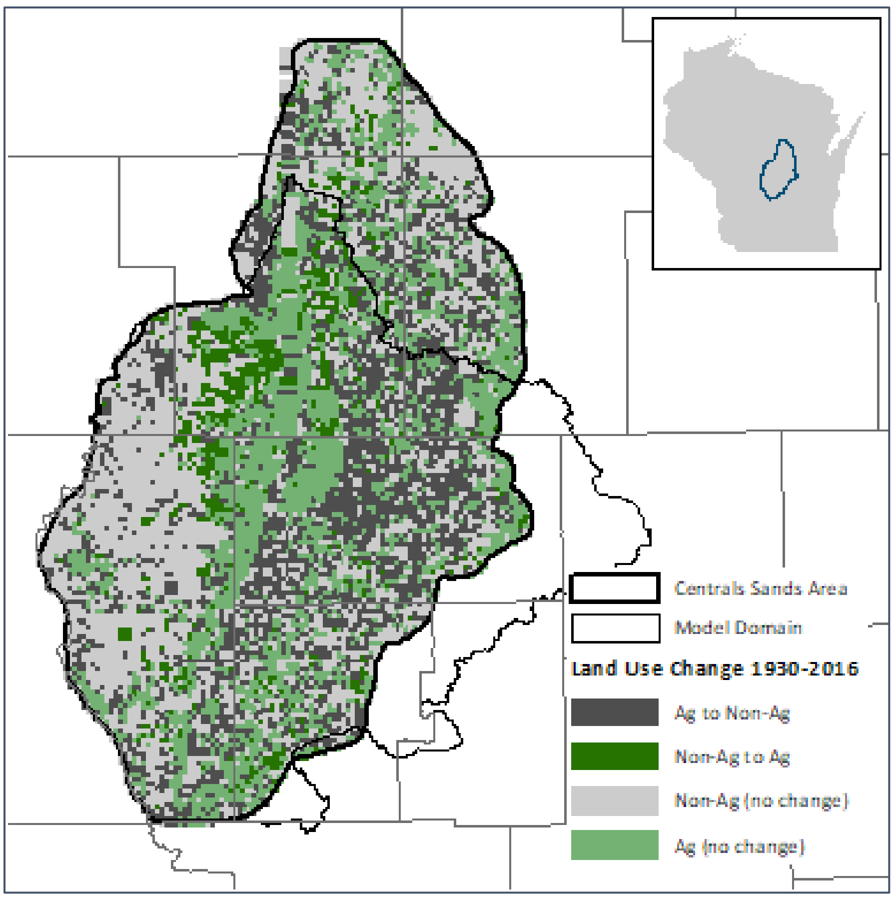

Figure 2. Land use changes in the Central Sands between 1930 and 2016. Dark gray areas were agricultural in 1930 but currently have a non-agricultural land use, dark green areas were not agricultural in 1930 but have since changed to agricultural land use, light green areas were agricultural in both 1930 and 2016, and light gray areas were non-agricultural in both 1930 and 2016. (Here, non-pasture grassland is included in the non-agricultural land use category.) Land use is mapped on a quarter-section (2,640 ft x 2,640 ft) grid. Land use in a cell is mapped as "changed" if greater than 50% of the landcover in the cell is in a different category in 2016 than in 1930.

As land unsuitable for farming was abandoned, many drainage ditches were dammed either by individuals or as WPA projects to restore wetlands and reduce soil erosion. Cranberry growers began to take over some formerly drained areas that were returned to wet conditions (Goc, 1990). Some of the abandoned land in places like Leola Marsh and the Buena Vista area, became part of wildlife areas in the mid-1900s.

At the same time, reforestation of some Central Sands areas occurred under the influence of conservationists like Aldo Leopold. For example, UW-Extension foresters and County Conservationists promoted tree-planting to reduce the dust-bowl conditions seen in the early 1930s. From 1935-1942, farmers in seven Central Sands counties planted over 3,000 linear miles of shelterbelt trees, including 1,200 miles in Waushara County alone. These erosion-control barriers were almost exclusively pine, typically planted along the edges of 40-acres fields. It would be 20 years (1950s-60s) before shelterbelt trees were mature enough to provide appreciable erosion protection (Goc, 1990).

Expansion of Irrigated Agriculture

In the last half of the 20th century, irrigated agriculture turned crop farming in the Central Sands into a more productive enterprise. Farmed land area had continued to decrease through the 1950s in parts of the Central Sands such as Waushara and Waupaca Counties. Irrigation, from a mix of surface water and groundwater sources, was practiced on a small scale from the late-1930s through the mid-1950s (Summers, 1965; Berkstresser, 1964). The first center-pivot irrigation system was patented in 1952, and the technology was rapidly put into use. Irrigated acreage in Portage County increased from 6,900 acres in 1959 to 25,100 acres in 1969 to 55,000 acres in 1977 (Butler 1978, Table 8). During the same period, the number of irrigation wells in the Central Sands west of the glacial moraines increased from 50 in 1958 to about 325 in 1967 (Butler 1978). The Plainfield area was one of the first developed for irrigated agriculture. By 1967, Devaul and Green (1971) identify parts of Portage, western Waushara (including the Plainfield area), and eastern Adams counties as zones irrigated by ground water for growing vegetable crops. As agriculture expanded in the 1960s and 70s, many old ditches were deepened, and new ditches were dredged in the Buena Vista and Leola Marshes. As of 1967, 1,200 acres of the Leola Marsh and 400 acres of the Buena Vista Marsh had been converted to irrigated farmland (Weeks and Stangland, 1971).

At the same time that irrigated agriculture was expanding, the Central Sands counties experienced an influx of seasonal recreational landowners on both waterfront and farmstead properties (Butler, 1978). The influx of new landowners raised land values, adding to the economic pressures on famers to increase productivity on existing agricultural land (Summers, 1965). Recreational landowners are also one of the groups most likely to be adversely affected if increased pumping from irrigation causes declines in water bodies they use for recreational purposes. By the late 1960s, rapid expansion of irrigated agriculture caused concerns regarding the potential effects that groundwater withdrawals could have on water levels and flows in surface water bodies. Irrigated agriculture in the Central Sands has continued to expand into the 21st century, currently covering over 200,000 acres in the Central Sands region (Figure 3). The expansion of Central Sands irrigation and its potential impacts on surface waters are discussed at length elsewhere (Bradbury et al. (2017a), Kraft and Mechenich (2010), Kniffin et al. (2014)). Weeks and Stangland (1971), Kraft et al. (2012), Bradbury et al. (2017a), and many others, including this study, investigate the effects of irrigation pumping on surface waters.

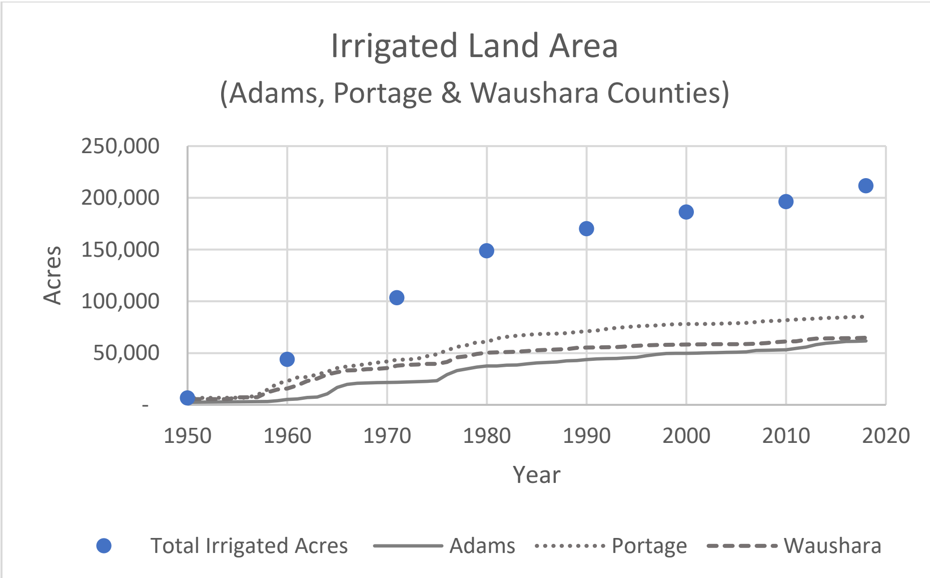

Figure 3. Expansion of irrigated land area in three Central Sands counties

Land Use History: Implication for Lake Levels

Some lake level records are available for the period after European settlement but prior to widespread conversion to irrigated agriculture (Voter et al., 2021). Dramatic water level changes were a part of this regime. Holt (1965) records that kettle lakes in the Central Sands region declined by as much as 2-6 feet during droughts in the 1940s-1960s. The hydrologic regimes of lakes during this period are very likely to have been altered by the numerous human changes to the natural landscape over the preceding century. An initial investigation used a steady-state groundwater flow model (Sellwood, 2015) to demonstrate that the creation of the ditch network could potentially cause small water level reductions at lakes several kilometers away from the ditches. However, the details of how the hydrologic regime would have responded to the shifting land uses and hydrologic alteration are not known, and data on pre-settlement water levels are not available. Because of this, it is not possible to derive a truly “natural” or “unimpacted” hydrologic regime for these lakes using available data from either the pre-1960s or post-1960s time period. Therefore, the strategy chosen for conducting lake impact analysis is to define a base hydrologic regime using a groundwater model calibrated to available data and to identify stresses that would cause an ecologically significant deviation from that regime.

Part 2 - Defining Land Use for Model Scenario Development

Introduction

Land use affects the timing and amount of groundwater recharge due to variations in factors like vegetation and soil permeability. Certain land uses, such as agriculture, can also be associated with groundwater withdrawals that directly influence the movement of water. We also focus attention on land use because it is a part of the water budget where we have some level of control (as opposed to precipitation, for example). To complete the Central Sands Lakes Study goal of identifying current and potential impacts of groundwater-withdrawal-related reductions on Central Sands lakes, we developed three different land use scenarios and then modeled lake level regimes under each. The land use scenarios are (1) a representation of current land use, (2) a simulated, realistic land use pattern that does not include irrigated agriculture and (3) a land use distribution where non-agricultural lands identified as potentially irrigable are converted to irrigated agriculture. This memo describes Central Sands land use distribution and the development of the three land use scenarios.

Current Land Use in the Central Sands

The distribution of land use types is based on USDA's Cropland Data Layer (CDL) and DNR's Wiscland 2.0.

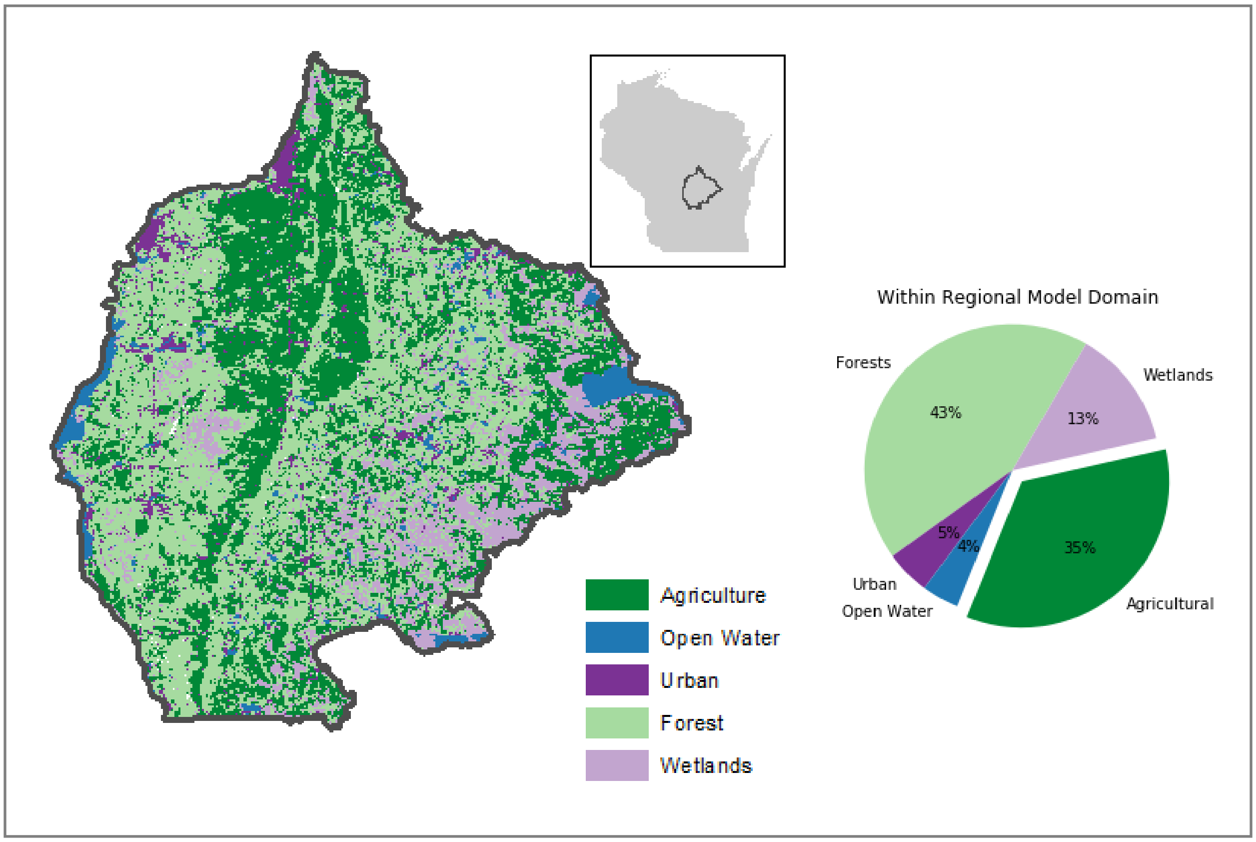

Figure 4. Regional distribution of land use types in 2018 (USDA CDL)

Regional Land Use Overview

The area of the Central Sands Lakes Study model domain is around 2,500 square miles, or 1.6 million acres. At a regional level, the most extensive land cover type is forest (700,000 acres), followed by agricultural land (570,000 acres) (Figure 4). Here, the agricultural land use category includes irrigated and unirrigated crops, as well as grassland. Together, forested and agricultural land uses cover 78% of the Central Sands. The remaining 22% of land area is made up of wetlands, urban areas, and open water. As shown in Figure 4, agricultural areas are concentrated in the central part of the model domain, including the areas near the study lakes, while wetlands and urban areas are more common nearer the model boundaries. Forest land is found throughout much of the region. Near the study lakes, forested lands are often associated with areas with greater topographic relief, such as glacial moraines. Regionally, 85% of forested land is deciduous, 14% is evergreen, and 1% is mixed.

Agricultural Land Uses

Agricultural land makes up 35% of the Central Sands (570,000 acres). In our modeling scenarios, this land was subdivided by crop type. As shown in Figure 5, the most common crop in 2018 was corn (41% of all agricultural land). Other crops like soybeans, alfalfa, potatoes, and dry beans together make up 48% of agricultural land, which each crop type making up 14% or less of the total. Grassland or pasture is 10% of all agricultural land; grassland is concentrated in the northwestern part of the region, west of the glacial moraines.

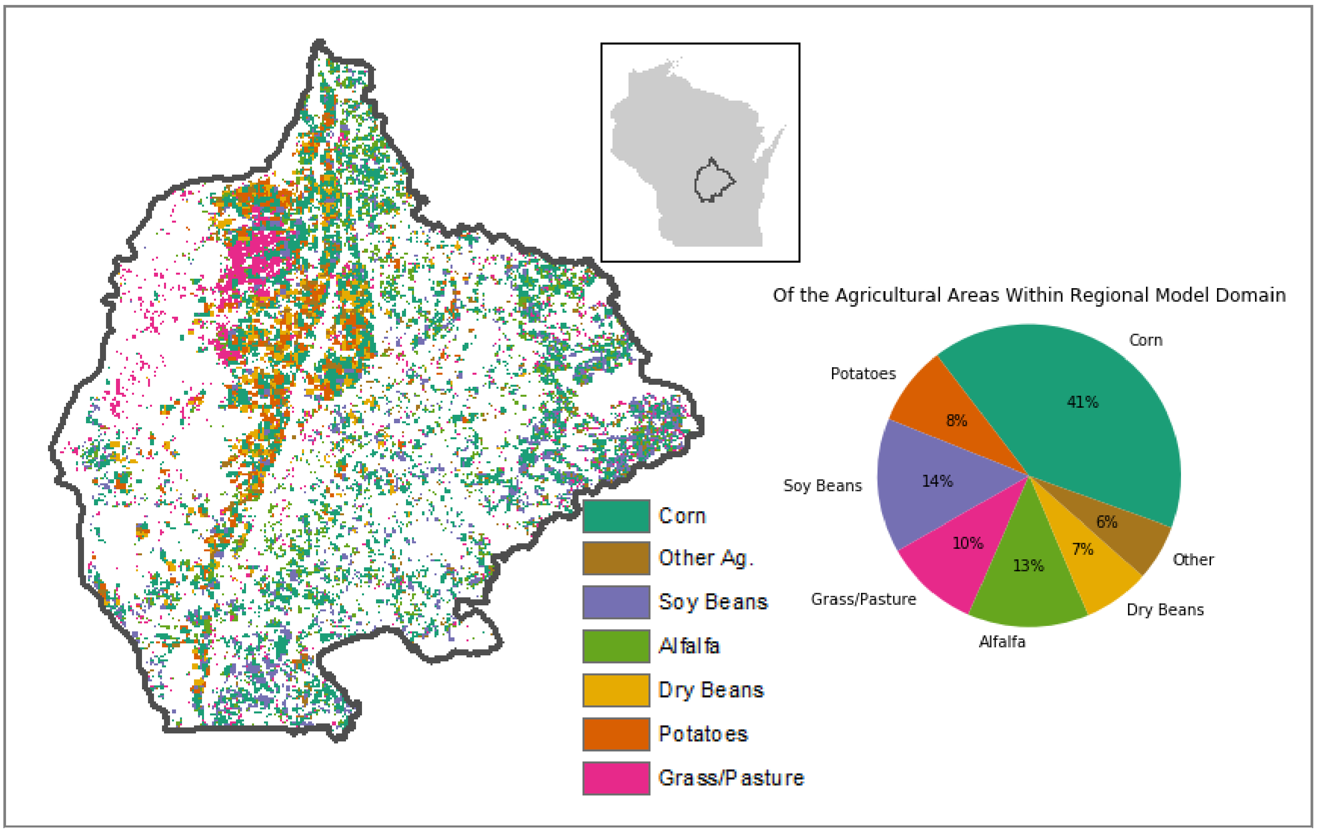

Figure 5. Regional distribution of crop types for all agricultural land (USDA CDL)

Irrigated Agricultural Land Uses

Irrigated agriculture makes up 240,000 acres, or 42% of all the agricultural land in the model domain. Figure 6 shows the proportions of different irrigated crop types and their spatial distribution. Irrigated agriculture is concentrated in the central part of the model domain, including near the Plainfield lakes and to the west of Pleasant Lake. Similar to all agricultural land, corn is the dominant crop type on irrigated land. Potatoes and dry beans make up a larger proportion of irrigated agricultural land (17%

and 14% of irrigated lands, respectively) than they do for all agricultural land. Alfalfa and grassland make up a relatively smaller proportion of irrigated land than they do all agricultural land.

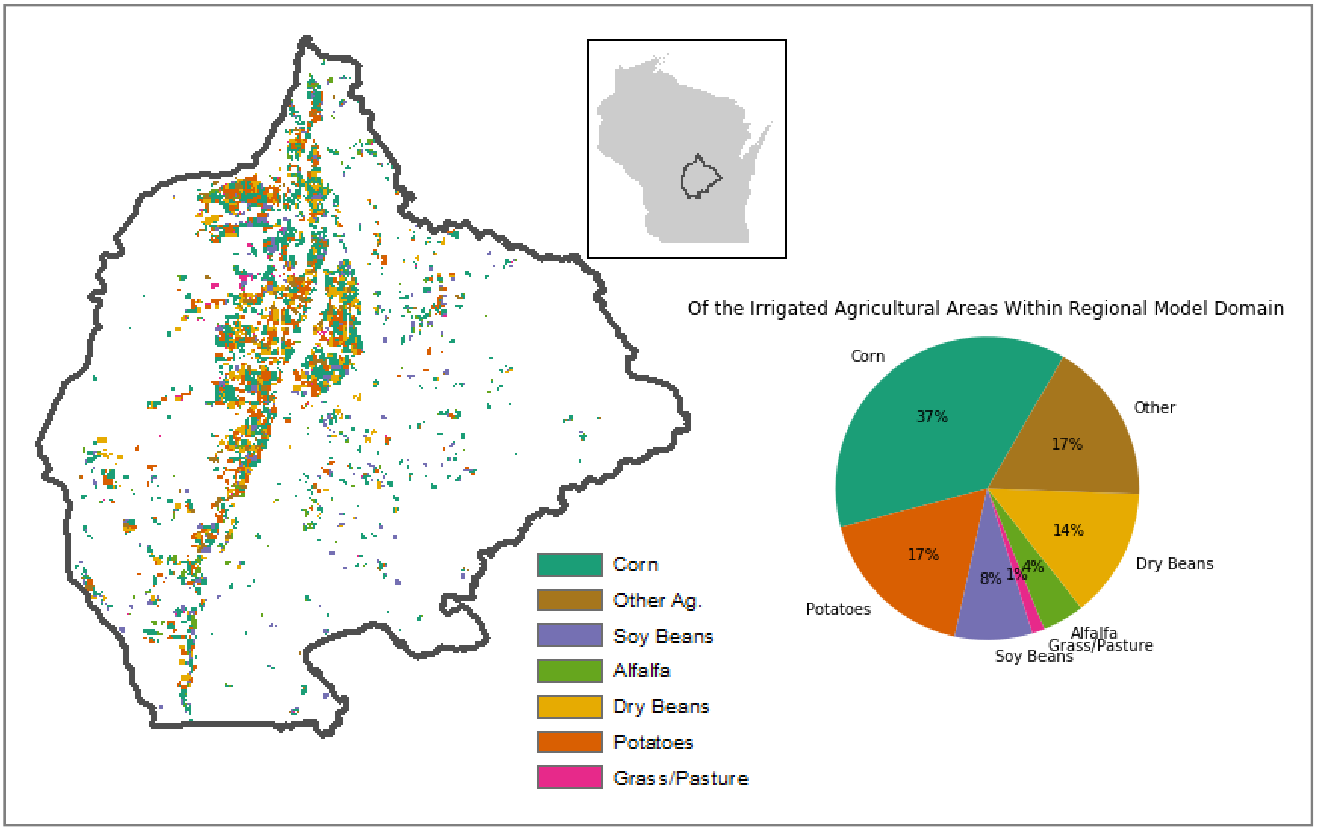

Figure 6. Regional distribution of crop types for irrigated land. (USDA CDL)

Crop Rotations

The Cropland Data Layer land use information described above provides a snapshot of land use for the year 2018, but for the purposes of better simulating land use during long-term modeling, we assigned agricultural lands to various crop rotations. These rotations were identified from the Wiscland 2.0 land use dataset. We used four different rotations that are common in the Central Sands: Cash Grain, Dairy, Grass/Pasture and Potato/Vegetable. The most common crop rotations in the region are Dairy and Potato/Vegetable, which each make up about a third of total agricultural lands (Figure 7). The frequencies of crop types in each rotation are shown in Table 1. The Dairy rotation is composed of primarily corn, alfalfa, and grass (hay), while the Potato/Vegetable rotation is mostly corn, potatoes, and beans. Note that corn is the most common crop in all but the Grass/Pasture rotation, matching our observation that corn is the most common crop on agricultural lands. As mapped in Figure 7, Potato/Vegetable is by far the most dominant crop rotation near the study lakes. In the groundwater model, the crop assigned to a field in any given model year is based on its rotation category and the probabilities shown in Table 1. The exception to this frequency-based crop assignment is that in the potato/vegetable rotation, potatoes are only grown every four years, with one-quarter of all potato/vegetable parcels growing potatoes in any given year, to reflect current farming practices in potato/vegetable rotations. For the other three years in the potato/vegetable rotation, crops were assigned based on the probabilities listed in Table 1.

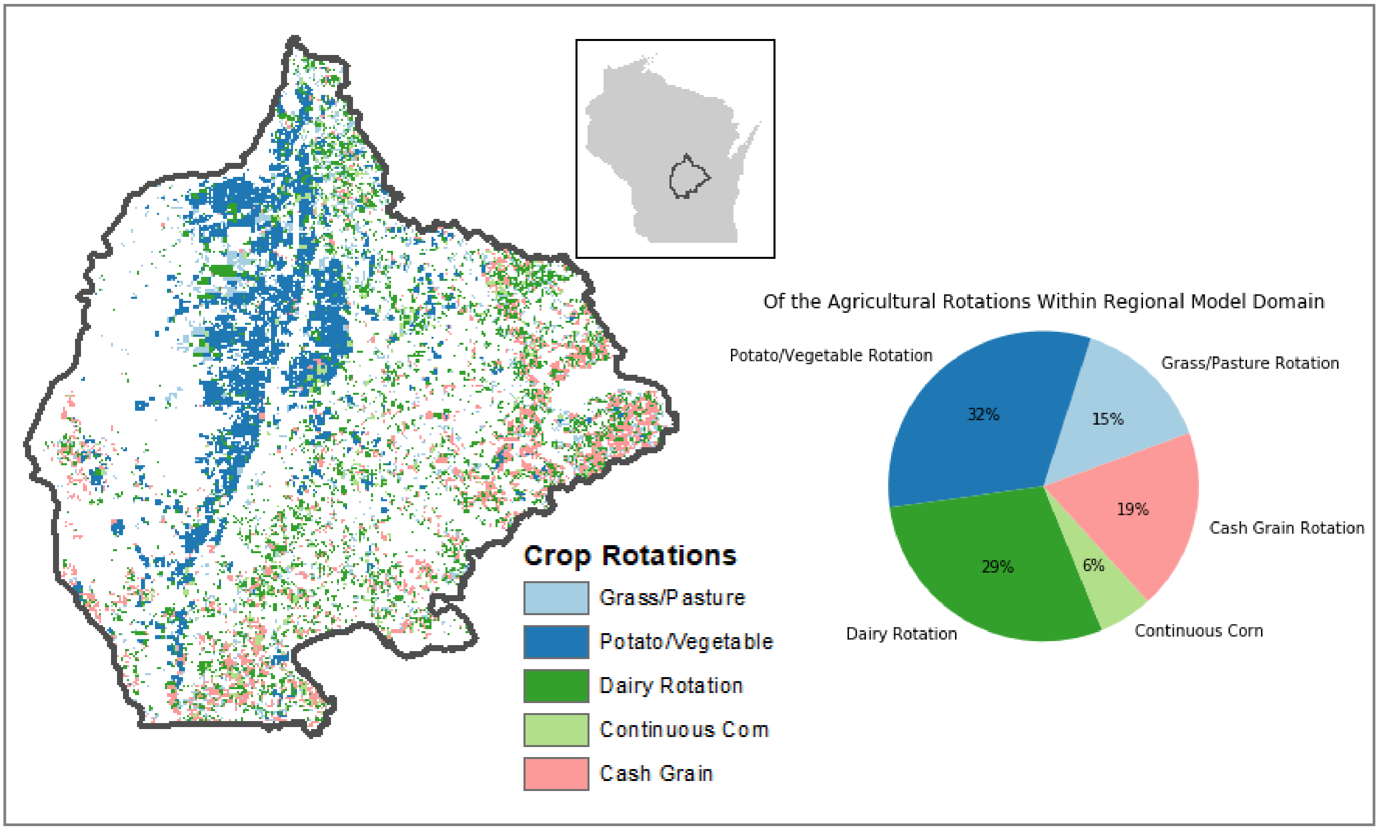

Figure 7. Crop rotations on agricultural land (Wiscland 2.0)

Table 1. Frequency of crop type in 2018 (USDA CDL) by crop rotation (Wiscland 2.0)

Crop	Rotation			
	Cash Grain	Dairy	Grass/Pasture	Potato/Vegetable
Alfalfa	1.5%	26.0%	20.6%	2.4%
Beans	0.3%	0.5%	0.8%	14.8%
Corn	60.0%	40.9%	5.1%	29.5%
Grain	4.2%	2.7%	1.4%	1.2%
Grass (Hay)	4.9%	19.6%	66.0%	7.4%
Misc. Veg.	0.2%	0.1%	0.2%	6.8%
Other	1.0%	1.4%	4.8%	6.7%
Potato	0.1%	0.1%	0.0%	17.0%
Soybeans	27.7%	8.7%	0.9%	5.7%
Sweet Corn	0.1%	0.1%	0.1%	8.4%

Development of “No Irrigated Agriculture” Land Use

The “No Irrigation” scenario was modeled to create a hypothetical land use in which non-irrigated lands remain in their present state, but currently-irrigated lands are replaced with reasonable non-irrigated land uses. This approach uses the distribution of land cover types on currently non-irrigated land to apportion non-irrigated land covers to currently-irrigated lands. Further, this approach simulates the heterogeneity in distribution of current land cover as it relates to underlying soil drainage and slope gradient. In simplest terms, this scenario attempts to make the currently irrigated lands look like the currently non-irrigated lands.

The first step in scenario development was to identify the various slope-soil types present in the currently-irrigated lands. Our analysis showed that grouping soils and drainage into three groups created the most different and distinct groups. We then used a statistical clustering method to divide currently-irrigated lands into the following three groups:

1. Coarse-grained/flat - Somewhat excessively to excessively drained soils with a slope gradient <=2.5% (n=3577)
2. Coarse-grained/hilly - Somewhat excessively to excessively drained soils with a slope gradient >2.5% (n=2156)
3. Finer-grained/flat - Moderately well drained to very poorly drained soils with a slope gradient <=2.5% (n=1013)

The second step was to assign one of the above clusters to each non-irrigated parcel based on that parcel’s mean gradient and soils drainage traits. Current landcover for each non-irrigated parcel was extracted from the Wiscland 2.0 level 2 dataset. Frequency distributions of land cover type were calculated for each cluster (see Table 2).

Table 2. Landcover frequency for non-irrigated land use types by soil texture/slope group. Cluster 1: Coarse-grained/flat. Cluster 2: Coarse-grained/hilly. Cluster 3: Finer-grained/flat

Land Use Category	Wiscland Description	Frequency in Cluster 1	Frequency in Cluster 2	Frequency in Cluster 3
Agriculture	Crop Rotation	14%	12%	21%
Grassland	Forage Grassland	4%	4%	5%
Grassland	Idle Grassland	4%	4%	8%
Forest	Coniferous Forest	54%	40%	18%
Forest	Broad-leaved Deciduous Forest	22%	38%	21%
Wetland	Emergent/Wet Meadow	2%	2%	12%
Wetland	Forested Wetland	0%	1%	15%

Finally, each currently-irrigated parcel was randomly assigned a non-irrigated landcover based on the frequency distribution for its cluster. For example, a flat parcel with coarse-grained soils that is currently irrigated would be in cluster 1 and would have a 54% chance of being assigned a non-irrigated land cover of “Coniferous Forest” or a 14% chance of becoming non-irrigated “Crop Rotation.” Comparatively, a hilly parcel with coarse-grained soils that is currently irrigated would be in cluster 2 and have a 40% chance of being assigned a non-irrigated land cover of “Coniferous Forest” or a 12% chance of becoming non-irrigated “Crop Rotation.” The distribution of land used in the no-irrigated-agriculture scenario is shown in Figure 8.

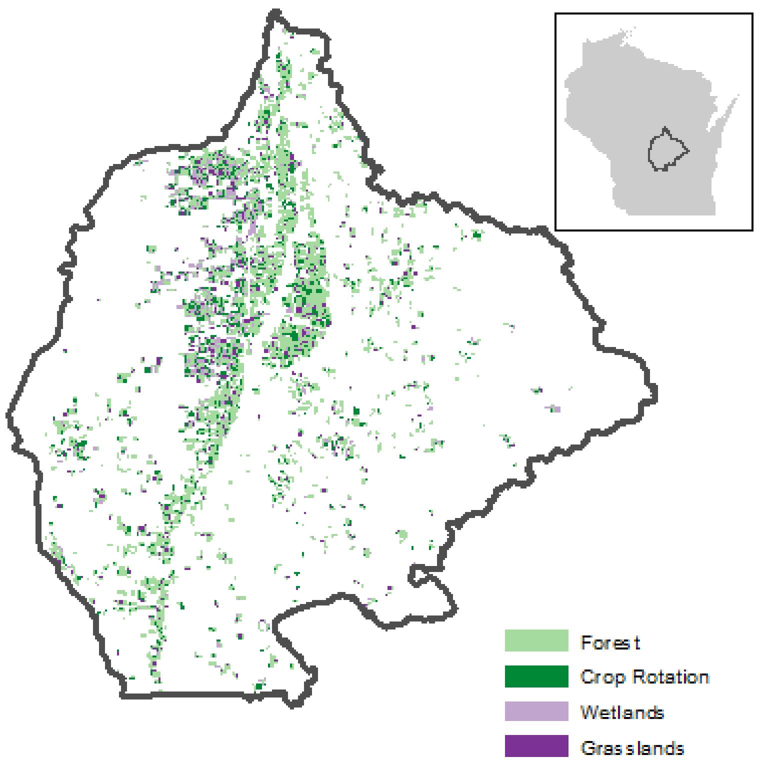

Figure 8. Alternate land use categories substituted for current-irrigated agriculture in the “no irrigation agriculture” land use scenario.

Development of “Potential-Irrigated-Agriculture” Land Use

The statute tasked DNR with assessing the effects of “potential” groundwater withdrawals. To do this, a land use scenario was created that allows us to calculate an upper bound on the magnitude of impact that could potentially occur. The “potential-irrigated-agriculture” land use scenario was developed to model the effects of converting all non-agricultural potentially irrigable land to irrigated agriculture. This approach identifies parcels that are large enough to have irrigated agriculture, have similar soil and slope characteristics as parcels that are currently irrigated, and are not currently owned by any government entity. Based on these assumptions, the amount of irrigated agriculture in the Central Sands could theoretically double. This increase in amount of irrigated agriculture within the region is unlikely but this scenario illustrates the potential additional impacts that could occur as additional land gets converted to irrigated agriculture and places bounds on the magnitude of that impact.

The selection process for identifying potentially irrigable lands is as follows:

1) Select parcels that are not currently in agriculture, irrigated or not.
2) Select parcels that are not currently classified as urban or open water.
3) Select parcels with a slope of less than 8% and a soil drainage class of less than 6 (to match the approach for converting from irrigated agriculture to non-agriculture, as described above).
4) Select parcels greater than 30 acres. 76% of all existing irrigated ag is greater than 30 acres (with 46% of all existing irrigated ag parcels being 40 acres).
5) Select parcels that are not currently owned by any level of government, including:
    a. Village, town, township, or city owned
    b. County owned
    c. School owned
    d. University owned
    e. State owned, including DNR and DOT property
    f. Federally owned

These selection criteria identify about 232,000 acres of land that is not currently irrigated, but potentially could be (Figure 9). This would essentially double the amount of irrigated agriculture within the area, as there is currently about 240,000 acres of irrigated agriculture in the regional model domain. Most of the land near the study area that is potentially irrigable is already in irrigated agriculture, and most of the parcels selected to be converted into irrigated agriculture are farther out, particularly to the western half of the model area.

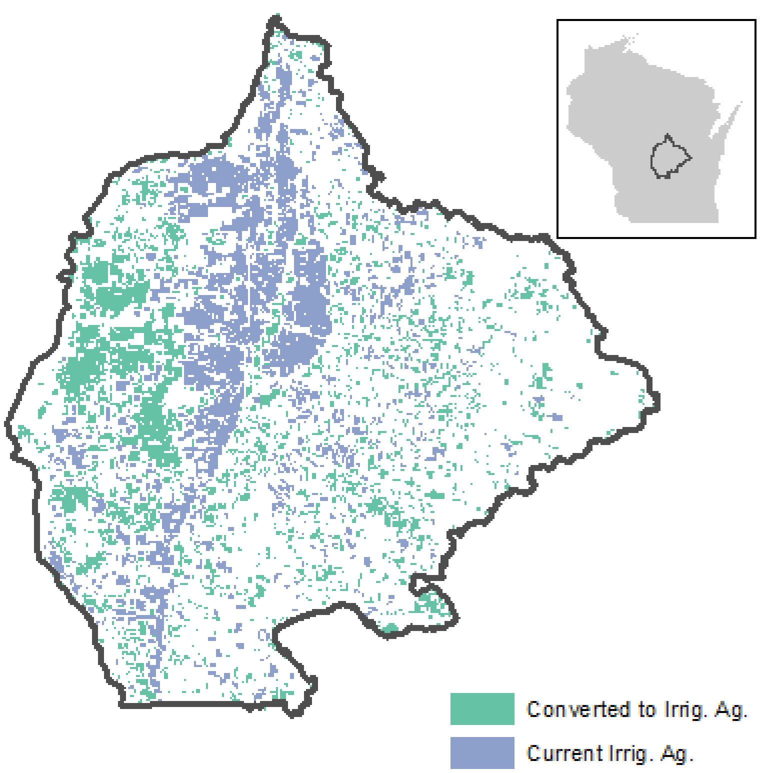

Figure 9. Irrigated lands in the "potential" land use scenario. This scenario modeled current irrigated lands (purple) and converted current potentially irrigable non-agricultural lands to irrigated agriculture (blue-green).

After identifying the parcels that could potentially be converted to irrigated agriculture, we identified crop rotations to assign to the newly converted parcels. Using a process similar to the "no irrigated agriculture" land use approach, we grouped parcels into the 3 clusters according to slope and soil type and identified the frequency of crop rotations associated with those clusters (Table 3).

Table 3. Landcover frequency for irrigated crop rotations by soil texture/slope group. Cluster 1: Coarse-grained/flat. Cluster 2: Coarse-grained/hilly. Cluster 3: Finer-grained/flat

Wiscland Description	Frequency in Cluster 1	Frequency in Cluster 2	Frequency in Cluster 3
Cash Grain	5%	13%	5%
Dairy Rotation	12%	33%	7%
Potato/Vegetable	80%	40%	82%
Grass/Pasture	4%	13%	6%

The parcels identified for conversion were assigned a crop rotation based on the frequency of occurrence in existing irrigated agriculture for the specific cluster. For instance, a flat parcel with coarse, well-drained soils (cluster 1) would have an 80% chance of being assigned to a Potato/Vegetable rotation and a 12% chance of being assigned to a Dairy rotation. Comparatively, a hilly parcel with coarse, well-drained soils (cluster 2) would have a 40% chance of being assigned a Potato/Vegetable rotation, a 33% chance of being assigned a Dairy rotation, and a 13% chance each for being assigned to a Cash Grain or Grass/Pasture rotation. The crops assigned to a given rotation in a given year were based on the probabilities provided in Table 1, as described in the crop rotation section, above. For more information on assignment of crops within a given rotation, see the discussion in Fienen et al. (2021).

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