Draft Study

On the Question of Agricultural Water Use in Central Wisconsin

Paul Fowler, Wisconsin Institute for Sustainable Technology, University of Wisconsin-Stevens Point

Corresponding author: paul.fowler@uwsp.edu

Wisconsin Institute for Sustainable Technology (WIST), College of Natural Resources, University of Wisconsin, Stevens Point, WI 54481, USA

Abstract
Water use by agriculture has become an issue in many areas where groundwater levels have dropped. Because the impact of agricultural water use is a driver of water use policy it is important to understand other factors that may also be impacting groundwater. This paper reports an examination of scientific literature on water use by trees compared to water use by vegetable crops. Evapotranspiration by trees results in significant water loss and interception of precipitation by forest canopy also impacts groundwater recharge. Studies in different geographical areas, including the U.K. and Northern Wisconsin, have shown water use by trees on an annual basis that exceeds the amount used to grow potatoes. Studies in China, the U.K and South Africa predicted that reforestation and afforestation would reduce water available for surface flow or aquifer recharge by as much as 56%. The analysis focuses particularly on Wisconsin, where a six-county area ranks as one of the top vegetable-growing regions of the U.S. and where groundwater levels have become an issue. Reforestation has increased significantly in this area. The researcher concludes that while agricultural water use has undoubtedly increased in Wisconsin over the past 50 years, it may not be either the sole or major source of groundwater depletion and reduced stream flow.

Keywords:
Agricultural water use
Evapotranspiration
Groundwater impacts
Reforestation
Water use policy

1. Introduction
Much has been made in both the scientific literature (Kraft et al., 2012; Weeks and Stangland, 1971) and the media (FOX11 NEWS, 2014; Prengaman, 2013) of the impact of agriculture on groundwater levels in Wisconsin's Central Sands, so named for the defining geomorphological feature of the region, a broad plain that is a remnant of the last glaciation. Much of the area is underlain by the Central Wisconsin Sand and Gravel Aquifer (CWSGA), a contiguous area east of the Wisconsin River where groundwater is stored in sand and gravel deposits more

than 50 feet deep. The aquifer covers approximately 1.5 million acres in parts of Adams, Marquette, Portage, Waupaca, Waushara and Wood counties.

Models arising from the scientific work are being used to drive Wisconsin water-use policy and regulation (Wisconsin Department of Natural Resources [WDNR], 2014). The basis for arguing the negative impact of agriculture on groundwater are relationships established and data measured over the past 50 years between the number of high capacity wells in use in the state and a lowering of groundwater levels.

Whilst this argument is persuasive, it is almost certain that other factors are at play. This paper presents an analysis of Forest Inventory Assessment data to demonstrate that the same period also coincides with some dramatic changes in growing stock volume of major tree species and postulates that groundwater levels are impacted by forest population.

2. Materials and methods

Forest area and forest type group was acquired in acres from the Forest Inventory and Analysis databases using the Forest Inventory Data Online portal for the survey years 1996, 2013 and 2014. Data for the following forest type groups: white/red/jack pine, spruce/fir and exotic softwoods were aggregated as 'softwood'. Oak/hickory, elm/ash/cottonwood, maple/beech/birch, aspen/birch were aggregated as 'hardwood'. Data for the entire state of Wisconsin was accessed 19 March 2015. Data for the six counties of Adams, Marquette, Portage, Waupaca, Waushara and Wood was accessed April 28, 2015.

3. Results

The area of forested land in Wisconsin has been steadily increasing in recent decades and currently stands at approximately 17.1 million acres (Table 1), representing over 50 percent of the State's total land area.

Table 1

Area in acres of forest land in Wisconsin by stand age in 1996 and 2013.

	Stand age		
Year	0–59 years	60–200+ years	Total acres
1996	9,804,288	6,158,659	15,962,947
2013	8,236,679	8,864,485	17,101,164

Wisconsin now has more forested land than at any time since the first Forest Service forest inventory in 1936. The greatest volume gains in the last 14 years have been the softwood species, eastern white pine (+67%) and red pine (+60%) (WDNR, 2012). The period also coincides with a sharp increase in the area of stands that are over 60 years old (44%).

The data for the entire state is largely reflected in the six county area comprising Wood, Portage, Waupaca, Adams, Waushara and Marquette counties (Table 2) which approximately coincide with the area designated as Wisconsin's Central Sands and underlain by the Central Wisconsin Sand and Gravel Aquifer. Thus, analysis of this six county area shows a 15% increase in forestland from 1,047,018 acres in 1996 to 1,207,770 in 2014. In that same period the softwood acreage increased by 50% - from 224,880 acres in 1996 to 337,785 acres in 2014. That softwood acreage became more mature too in the period with 27% of the acreage comprising trees aged between 40 and 99 years in 1996 compared with 58% in 2014.

Table 2. Area in acres by forest type by county in the Central Sands region in 1996 and 2014.

	Year					
	1996			2014		
County	Forest type			Forest type		
	Softwood	Hardwood	Total	Softwood	Hardwood	Total
Adams	78,414	174,959	253,373	76,220	178,477	254,697
Marquette	13,465	82,319	95,784	37,148	96,830	133,978
Portage	34,360	137,229	171,589	55,417	127,212	182,629
Waupaca	31,934	151,345	183,279	55,654	163,069	218,723
Waushara	33,323	94,330	127,653	61,507	123,363	184,870
Wood	33,384	181,956	215,340	51,839	181,034	232,873
Total	224,880	822,138	1,047,018	337,785	869,985	1,207,770

4. Discussion

4.1. Impact of forest type, age and area

The results tabulated above are significant for the following reasons:

(1) softwood species maintain high levels of interception (in which rainfall reaches surfaces of branches, leaves, and trunks but then evaporates rather than reaching ground) over all four seasons whereas hardwood species that shed their leaves intercept less during the winter months.

(2) mature tree stands have well-developed canopies that intercept very significant amounts of rainfall, in some cases up to 45%, meaning that only 55% may be available for aquifer re-charge, *before* any account is made for transpiration; forest age has been demonstrated to be a significant factor in determining streamflow response (Webb and Kathuria, 2010).

(3) greater reforestation and afforestation will increase rainfall interception at the expense of groundwater recharge.

(4) evapotranspiration by trees is shown in a number of studies to be greater than that of grass, crops or vegetables (Hall et al., 1996; Huang and

Gallichand, 2006; Jimenez-Martinez et al., 2010; O'Brien et al., 2004; Tanner, 1981).

4.2. Water use of tree versus vegetables

Evapotranspiration is a widely used measure to quantify the use of water by plants and that use is reported in millimeters over a period of time. The bigger the number, the greater the water use and the less water available for groundwater recharge. Herbaceous plants including vegetables generally transpire less than woody plants including trees because they usually have less extensive foliage and additionally losses by vegetables are limited by their short crop cycle. Furthermore, softwood forests tend to have higher rates of evapotranspiration than hardwood forests, particularly in the dormant and early spring seasons. This is primarily due to the enhanced amount of precipitation intercepted and evaporated by conifer foliage during these periods (Swank and Douglass, 1974).

Studies in the UK have shown that between 25 and 45% of annual rainfall is typically loss by interception from softwood stands compared with 10-25% for hardwoods (Calder et al., 2003). These percentages remain remarkably constant over a wide range of total rainfall. Taken together softwoods may be expected to use some 550–800 mm of water (Nisbet, 2005) compared with 370–430 for potatoes (Hall et al., 1996). Tanner (1981) reported potato evapotranspiration in Wisconsin was between 293 and 405 mm. In Wisconsin where annual rainfall varies from 719 to 923 mm (averages based on weather data collected from 1981 to 2010 for the NOAA National Climatic Data Center), red pine plantations can tap significant water stored in the subsurface soil and where roots are within a couple of meters of the water table may be net depleters of ground water.

Relevant research that has evaluated evapotranspiration from red pine plantations include Weeks and Stangland (1971), and Sun et al. (2008). Weeks and Stangland (1971) estimated average evapotranspiration from pine trees at 493 mm. The study by Sun et al. (2008) estimated annual evapotranspiration from red pine plantations on sandy soils in Northern Wisconsin in the range of 574 to 594 mm per year. More recently Mao and Cherkauer (2009) studied evapotranspiration in a range of vegetative land covers throughout the Great Lakes region. They concluded that average evaporation from softwood forest was about 569 mm.

4.3. Reforestation and Afforestation

While State of Wisconsin policy encourages reforestation and afforestation through its Department of Natural Resources Reforestation Program, other nations are being more circumspect. Indeed, the United Kingdom's Forestry Commission in 2002 commissioned work to investigate the impact of reforestation on ground water sources. The investigators noted that in softwood species recharge is predicted to be about one quarter that under grass and essentially non-existent in years with average or below average rainfall (Calder et al., 2002).

Similar concerns about groundwater quantity were investigated in Australia. A study carried out by Sinclair Knight Merz (2008) predicted that land use change from commercial agricultural to a high forestry scenario would reduce water available for surface flow or aquifer recharge by 56%. Further modeling indicated that no-flow months could increase in frequency from very much less than 1% of months to as much as 30% of months under a high forestry regime.

A study in China suggested that the average water yield reduction as a result of forestation may vary from about 50 mm per year (50%) in a semi-arid region in northern China to about 300 mm per year (30%) in the tropical southern region (Sun et al., 2006).

In South Africa, since 1999, forest plantations have been categorized as stream flow reduction activities and required to be licensed and to pay water charges (Department of Water Affairs and Forestry, 1999). The National Water Act is based on conclusive findings that forest plantations established in former natural forests, grasslands, or shrub land areas consume more water than the baseline vegetation, reducing water yield (stream flow) as a result (Albaugh et al., 2013, and references therein).

5. Conclusions

Whilst agricultural water use has undoubtedly increased in Wisconsin over the past 50 years, we suggest that it may not be either the sole or major source of groundwater depletion and reduced streamflow. Concerns in other nations regarding the impact of forested land on water availability coupled with the fact that Wisconsin currently has the largest forested land area with the most mature stands since pre-European settlement times leads us to contemplate that reforestation and afforestation may have as large a part to play as agriculture in the impact on groundwater inventory. We suggest that a program of research be undertaken to study these matters further.

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