Influence of Land Use Change on Grant River Hydrology, Grant County, Wisconsin

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Abstract

Over the past two centuries, widespread agriculture has been significantly altering the landscape. It is known that agriculture can significantly alter hydrologic processes and increase soil erosion. While corn is the most common crop in the United States, soybean agriculture increased rapidly in the late 20th century. However, in Grant County, WI the increase began in the 1990s (USDA). Soybeans are associated with soil degradation, resulting in increased surface runoff and soil erosion. Even though soybean cropping is becoming increasingly more popular, a paucity of research has been conducted to identify the potential significance that increased surface runoff and soil erosion will have on hydrologic processes. This thesis examines potential impacts of shifts to increased soybean planting in the SW Wisconsin's Grant River watershed where instrument records for water and sediment yields span pre- and post-1990 years of cropping practices. Overall, it was found that soybean agriculture has yet to have noticeable effects on the Grant River hydrology. This is most likely because of land use management practices that were introduced around the same time as soybean agriculture became popular in the Grant River watershed. Included in these new conservation practices are various tillage techniques and USDA programs such as the Conservation Reserve Program (CRP), Grassland Reserve Program (GRP), and Conservation Reserve Enhancement Program (CREP). Additionally, cattle grazing intensity in the watershed has been reduced. In order to fully conclude the impacts of soybean agriculture on the landscape, agricultural plots should be studied as well as hydrological changes in a smaller watershed than the Grant River.

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1.0 Introduction

Human land use has effected runoff and soil erosion since about 9000-8500 B.C. in many semi-arid regions and agriculturally-related clearing of forests began by around 5000 B.C. (Starkel 1987). The Upper Mississippi Valley (UMV), however, has experienced geomorphically significant human influences on the landscape only since the early 19th century with the inception of Euro-American agriculture (Knox 2001). Both Doolittle (1992) and Knox (2001) agree, based on field work and literary reviews, that the Native American influences on erosion and sedimentation in the UMV before Euro-American agriculture began was insignificant compared to the effects of Euro-American agriculture. Euro-American agriculture in the UMV caused a drastic increase in the rate of soil erosion and caused geomorphic changes in the Mississippi River system

In most regions in the world, it is often difficult to separate the effects of human land use on the landscape from natural landscape processes since agriculture and deforestation have been present for thousands of years in these regions. In the UMV, however, large-scale agriculture has only been present for about 200 years, making it significantly easier to distinguish between human and natural influences on fluvial processes (Knox 2001). This makes agricultural regions along the UMV useful and important in studying the effects of different agricultural crops and cropping systems on watersheds.

When Euro-American agriculture reached the UMV, the dominant crops in southwest Wisconsin were corn and wheat (Blanchard 1924). In Wisconsin, wheat was the chief crop during the 1800s because it was easy to grow and an important food product for early miners during Wisconsin's cold winters (Schafer 1932; figure 1). As the mining boom ended, and agriculture became increasingly important in Wisconsin's economy, corn and oat cropping replaced wheat (Schafer 1932; figure 1). Corn agriculture slowly increased until 1971 when the number of acres of corn planted greatly accelerated. This expansion of corn agriculture lasted until 1985 in Grant County and 1981 in the state of Wisconsin (figure 1 and 2). The initial push for an increase in corn agriculture came from the Secretary of Agriculture, Earl Butz, who served from 1971-1976. Earl Butz viewed unused land as "wasteful," and made policies that encouraged farmers to plant fence row to fence row to increase productivity (Knox, verbal communication 2007). For the few years after Earl Butz left office, the succeeding Secretaries, John A. Knebel and Robert Bergland, continued the Butz policy of increased corn production. After 1985 in Grant County and 1981 in Wisconsin, corn agriculture decreased by about 25% in Grant County and 15% in the state and has stayed around the same productivity level since (figure 1 and 2).

In the mid-1980s, as corn agriculture began to decrease, soybean farming became increasingly popular in Wisconsin, especially the southwest (view figure 2). This recent rise in soybean cropping is attributed to increased popularity of soybeans commercial food producers and consumers (Soper et al. 2003). Additionally, the negative environmental effect of monoculture agriculture has been greatly realized, influencing farmers to switch to a rotational system in which soybeans are a commonly included.

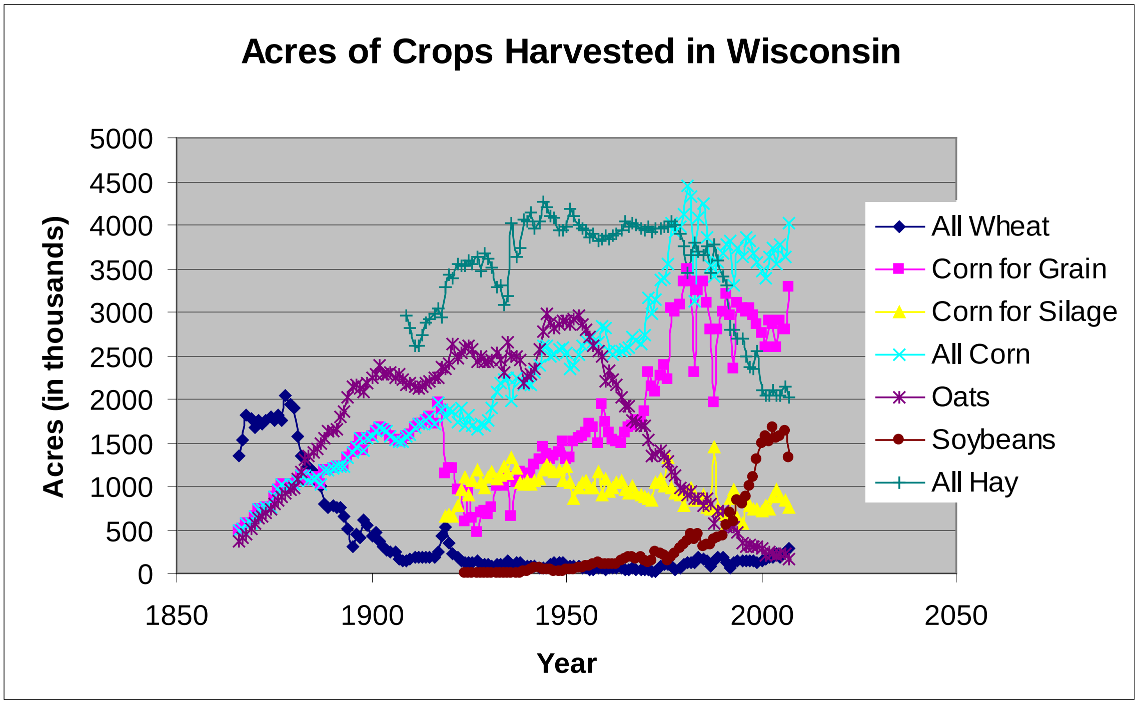

Figure 1 Acres of Crops Harvested in Wisconsin, 1866-2007 (USDA).

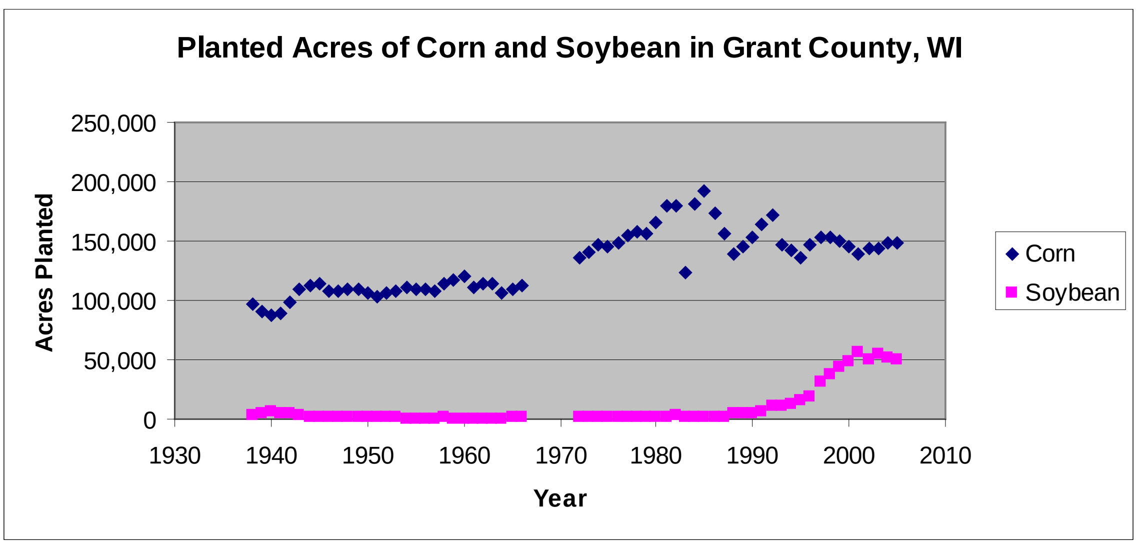

Figure 2 Acres of corn and soybean planted in Grant County, Wisconsin, 1938-2006 (USDA). Corn increases during the mid-1980s and then decreases. Soybeans stay constant until the late nineties and then increase until 2002 when it levels off.

Although the acres of planted soybean fields in southwest Wisconsin have increased sharply since the mid-1980s, little research has been done to assess the impacts of soybean cropping on hydrologic processes. This type of research is especially important in southwest Wisconsin, in comparison to other regions within the corn/soybean belt, due to the highly sensitive landscape associated with the region's steep slopes and deeply carved river valleys. The goal of this thesis is to identify the influences of soybean cropland on erosion and sedimentation in a highly dissected landscape by studying the responses of discharge and sedimentation to changing soybean acreage in the Grant River watershed, a tributary of the Mississippi River in the southwest Wisconsin Driftless Area (figure 3).

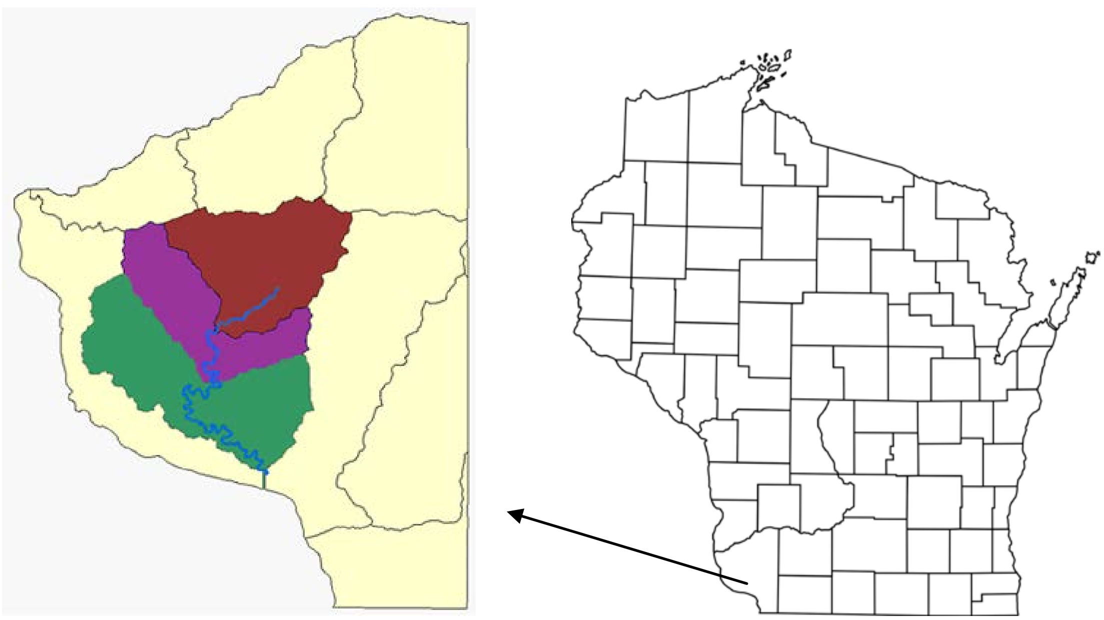

Figure 3 The Grant River watershed in Grant County, Wisconsin. Watershed separated into upper, middle and lower subwatersheds.

Geomorphology of the Grant River Watershed

The Grant River watershed is a small watershed that drains about 269 square miles in the Driftless Area of southwest Wisconsin (figure 3). The Driftless Area gets its name because it was not glaciated during the Quaternary period. As a result, the landscape was not flattened due to glacial erosion and deposition. Instead, the Driftless Area has a characteristically rugged topography due to a long history of rivers and streams cutting into the landscape, forming deep, river-cut valleys and steep, sensitive slopes. The Grant River basin lies in the southwest portion of the Driftless Area and is topographically characteristic of the Driftless Area. To the north, the watershed is bounded by a cuesta landform known as Military Ridge. Military Ridge is a high drainage divide south of the Wisconsin River. The cuesta runs east-west and is capped by erosion-resistant Galena dolomite. The southern and western border of the Grant River watershed is the Mississippi River. The eastern border is marked by the Platte River watershed in Grant County.

The surficial bedrock geology of the Grant River watershed is dominated by nearly flat-lying and stream dissected Ordovician and Silurian carbonates and sandstones (Heyl et al. 1959 from Knox 2006). The rock structure dips gently southwestward from military ridge, with Galena and Platteville carbonates on top, underlain by St. Peter sandstone and Prairie du Chein dolomite. The carbonate units were deposited 400 million years ago in the middle Ordovician when Wisconsin was under a tropical, shallow ocean. Over the past 400 million years, streams have incised this dolomite down to the St. Peter sandstone and Prairie du Chein dolomite in certain locations in the watershed.

Although the stream-cut valleys and high ridges were unaffected by flowing ice during the last glacial period, they still show evidence of influences from the climate of the Wisconsin glacial period. Across southwest Wisconsin, a blanket of loess was deposited by westerly winds blowing silt off the Mississippi floodplain during

Pleistocene glacial advances into the Mississippi headwaters. During the Late Wisconsin glacial period, the Driftless Area was also eroded by severe mass wasting under tundra climate conditions and catastrophic floods that occurred when Glacial Lake Wisconsin drained (Mason and Knox 1997; Knox 2006). This mass wasting resulted in the removal of upland and hill slope loess-derived silt and clay. Small headwater tributaries of the Mississippi River, like the Grant River, became aggraded by as much as 10 meters of colluvial and alluvial sediment composed of the loess-derived silt and clay, mixed with cobbles and boulders (Knox 2006). Sediment underlying the floodplain of the Grant River has mostly been winnowed of silt and clay, leaving large accumulations of gravely alluvial fill with the abundant cobbles and boulders concentrated near the top (Knox 2006). The cobbles and boulders subsequently form an erosion-resistant "armored surface" that provides a stable base for the Grant River and other Holocene and historical streams (Knox 2006).

These streams rarely incise their "armored surface," but their deep, high energy flows promote bank erosion and lateral channel migration which often results in the formation of a historical meander belt. The meander belt's alluvial surface constitutes a new historical floodplain inset against the earlier historical floodplain (Knox 2006). In the Galena River and Platte River systems, southeast of the Grant River, meander belts were well developed in headwater reaches by the 1920s, suggesting the Grant River meander belt developed around the same time (Knox 1987; Woltemade 1994).

A historical meander belt in conjunction with the new historical floodplain efficiently transports downstream water and sediment associated with moderate and large magnitude floods and reduces overbank valley floor sedimentation. The meander belt also contributes to flood-peak attenuation (Woltemade 1994; Lecce 1997; Knox 1987, 2006). Woltemade (1994) showed that the Grant River meander belt is capable of containing floods in excess of the 10-year event in some areas while other areas could contain flood waters in excess of the 25-year event. The lower main trunk valleys of the Grant River and similar tributaries do not develop a historical meander belt because they have a relatively low floodplain gradient and stream power, resulting in insufficient shear stress to cause rapid meandering (Woltemade 1994; Lecce 1997; Lecce 2001; Knox 1987, 2006). Therefore, the lower valley experiences anomalously high rates of vertical accretion, especially when considering the improvements in land cover and land conservation since 1950 (Knox 2006).

Soil erosion in Grant County increased considerably since Euro-American arrival. The combination of intense land use through mining and agriculture and a landscape susceptible to erosion have created high rates of soil loss off hill slopes and farm fields.

Soils of the Grant River Watershed

The predominant soil types of Grant County are mostly silt loams. Within Grant County there are six soil associations representing broad areas of similar soil properties and settings. While each association consists of a few dominant soils, there are also small areas of other soil types that will not be discussed because their contributions to the overall landscape is minimal

The Tama, Downes, and Muscatine soil association is made up of deep silty soils formed on upland prairies and savannas. This association can be found on broad ridge tops throughout the county, with exception to the northern part. These three soils are formed primarily in loess that overlies reddish clay at depths below three and a half to four feet. The reddish clay is derived from weathered older loess and from weathered limestone. The soils of the Tama, Downes, and Muscatine association are easy to manage and are among the best soils for agriculture in the county (Natural Resource Conservation Service, NRCS 2007).

The Tama, Downes and Muscatine soil association covers about 7% of Grant County (figure 5). The most common series within this association, the Tama series, are deep, silty, and well-drained soils. They are found primarily on upland ridges and have slopes ranging from zero to 15 percent. These soils formed under prairie in a thick silt blanket deposited by wind from the Mississippi floodplain during the last glaciation (NRCS 2007). The natural fertility of these soils is high, with a high moisture supplying capacity and a moderate permeability (NRCS 2007). The Tama series soils are among the most desirable for agriculture in the country, along with Downes and Muscatine which cover 0.7% and 0.3% of Grant County, respectively (figure 5). Because Tama soils have been heavily farmed for the past 150 years, they have experienced high levels of erosion, with 85% of the soils eroded (figure 4). Specifically, 45% of the soils are moderately eroded while 40% are severely eroded (figure 4).

The Fayette, Seaton, and Stronhurst series comprises a second association and represents deep silty soils formed on uplands under trees. Association two is most commonly found on upland ridges in the southern and western parts of the county that border the Mississippi River. The soils of this association are formed in materials similar to that of Tama, Downes, and Muscatine. However, because they formed beneath forest cover, they have a lighter color surface layer. Association two soils are well-suited to agriculture, but they require more careful use and management than soils in association one (NRCS 2007).

The most common soil series of the Fayette, Seaton, and Stronhurst association is the Fayette series. The Fayette series covers nearly 20% of Grant County (figure 5). The series is made up of deep, silty soils that are well drained and on sloping to steep topography. The soils have formed under hardwoods on rolling upland ridges and on valley slopes, ranging from two percent to 30% (NRCS 2007). The silt is 42 inches or more thick and was probably blown onto the uplands during the time of the last glaciation by winds eroding the Mississippi River floodplain. The silt cover overlies limestone and sandstone bedrock and is coarser closer to the Mississippi River.

Fayette soils are mostly in the western and southern parts of the county, where the silt cover is thickest. They are generally moderately high in natural fertility and their capacity to supply moisture and their permeability is moderate. The soils are eroded easily, particularly by water and if the slopes are steep and long. Fayette soils are commonly used for farming because of their high natural fertility and moderate ability t o supply moisture, but farmers must manage their lands carefully to reduce erosion. According to the Natural Resource Conservation Service (NRCS) soil survey, 55% of Fayette soils in Grant County are moderately eroded and 37% are severely eroded (figure 4).

Dubuque, Dodgeville, and Hixton series comprise a third association which is characterized by moderately deep to deep, silty or loamy soils. This association is made up largely of Dubuque, Dodgeville, and Hixton soils, but also includes some amounts of

Gale and Hesch soils. Most of association three can be found in northern and central sections of the county.

Dubuque and Dodgeville soils occur on sloping upland ridges and formed in silt that overlies reddish clay. The clay, similar to that of association one, was derived from weathered limestone and older weathered loesses. Dubuque soils formed under forest cover while the Dodgeville soils formed under prairie.

The Dubuque series, a silt loam, makes up about 27% of Grant County (figure 5). Dubuque soils are well-drained. Their silt depth in the soil profile varies based on geographic location. Dubuque soils in the southwest portion of the county tend to have deeper silt depths while the depth thins to the northeast. Dubuque soils are found on rolling upland ridges with slopes ranging from 2% to more than 45% (NRCS 2007). Natural fertility of the soils in the series can be anywhere from moderately low to moderately high (NRCS 2007). The permeability is moderate and the moisture supplying capacity ranges from low to high (NRCS 2007).

Dubuque soils are commonly used for farming in Grant County, especially in the southwest portion where the Grant River watershed lies and the soils are deeper and on shallower slopes to reduce erosion. The NRCS soil survey reports that 53% of Dubuque soils are moderately eroded while another 27% are severely eroded (figure 4).

The Gale, Hixton, and Hesch soils of association three are on valley slopes below the ridgetops. The Gale series formed in silt that is underlain by weathered sandstone at depths of less than three feet. The Hixton and Hesch series have formed mainly from sandstone, but they also contain some finer material. Hixton and Hesch soils are loam or fine, sandy loam composition. The Hesch soils formed under a mixed cover of prairie and forest, thereby having a darker colored surface soil and browner subsoil than the Hixton soils.

The soils of association three are easily eroded, making their use for agriculture limited. However, these soils can be productive, especially the Dubuque series, if well managed.

A fourth soil association is represented by the Dubuque and Sogn series, and these soils occur on steep, rocky slopes adjacent to major streams and between the lower, gentle valley slopes and upland ridges. Outcrops of rock also occur in many places.

The Dubuque and Sogn soils have formed in silt derived from similar materials described above for other soil series. Within this association, Dubuque soils formed under forest cover while Sogn soils formed under prairie vegetation. Stony rock land soils also occur within this association in areas of steep slopes adjacent to sandstone and limestone outcrops. Stony rock land is made up of various kinds of shallow soils with many rock outcrops and large boulders. This land type is found on steep breaks below the upland ridges with slopes ranging from 20-60% (NRCS 2007). The soil materials between rock outcrops range from sand to silt in texture and have formed in thin deposits of loess or in materials weathered from sandstone and limestone. Runoff in rock land is rapid, making the land extremely susceptible to erosion. The soil's susceptibility to erosion coupled with shallow soils results in Stony rock land being difficult to farm. It is wiser to keep Stony rock land in permanent vegetation, such as grasses or trees.

In general, this association is ill-suited for cultivated crops, and more productive for pasture or trees. On the other hand, Dubuque and Sogn soils can support cultivated crops (NRCS 2007).

The Sparta, Meridian, and Dakota series comprise soil association five. These soils are deep, sandy or loamy soils on terraces and are underlain by sandy outwash from the receding glaciers to the east. The association occurs on stream terraces of major streams in the county, mostly along the Wisconsin and Mississippi Rivers. Sparta and Dakota soils do not appear in the Grant River watershed and Meridian soils occur rarely, making it unnecessary to further discuss this association.

The sixth soil association in the Grant River watershed includes soils of floodplains that are subject to overflow. Soils of this association include the Arenzville and Orion series and alluvial land. In this association the land is nearly level and the water table is generally high. Arenzville and Orion drain relatively well while alluvial land occurs in close proximity to stream and river channels and is poorly drained and subject to frequent overflow in comparison. Except for alluvial land, this association is well-suited to agriculture (NRCS 2007). Agriculture would be difficult to manage on the alluvial land due to the frequent flooding.

While the soil associations give a good picture of how groups of soils are dispersed throughout Grant County, they do not show the frequency with which each soil is encountered in Grant County nor to what level each soil is eroded in the county. The dominant soil types in Grant County and the Grant River watershed are generally well-suited for agriculture. For this reason, much of the land in Grant County and the Grant River watershed have been converted to agricultural fields. This conversion has resulted in increased erosion from farm fields and increased sedimentation in river systems. Additionally, the wide scale conversion to agricultural lands has altered natural vegetation cover, impacting both soil erosion and watershed dynamics (Knox 2001, 2002).

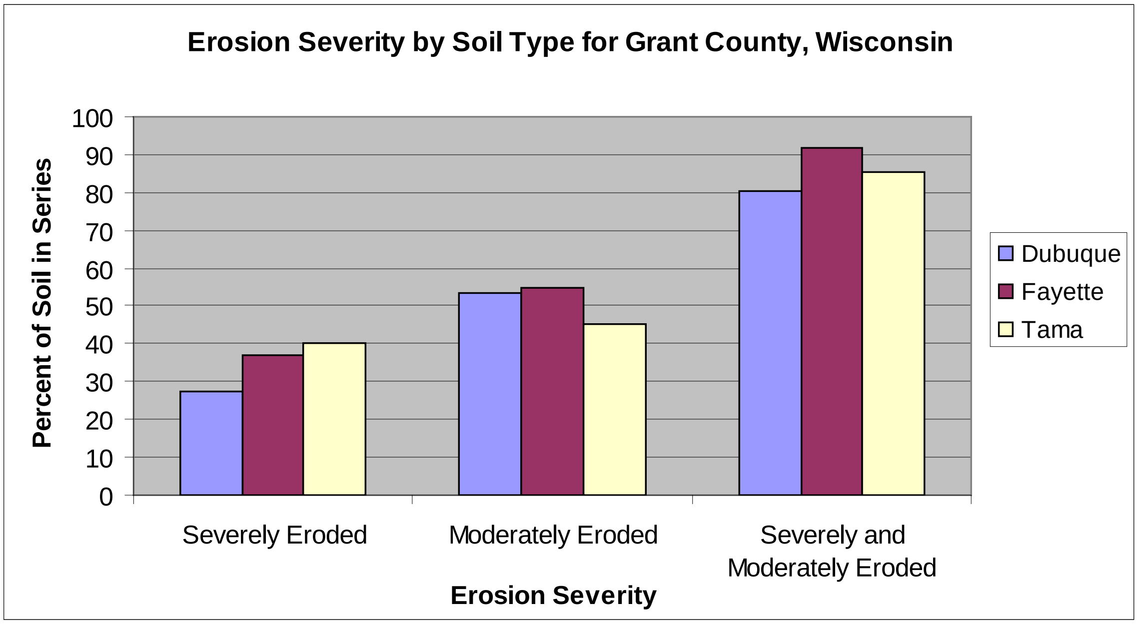

Figure 4 Erosion severity by soil type for Grant County, Wisconsin (NRCS 2007)

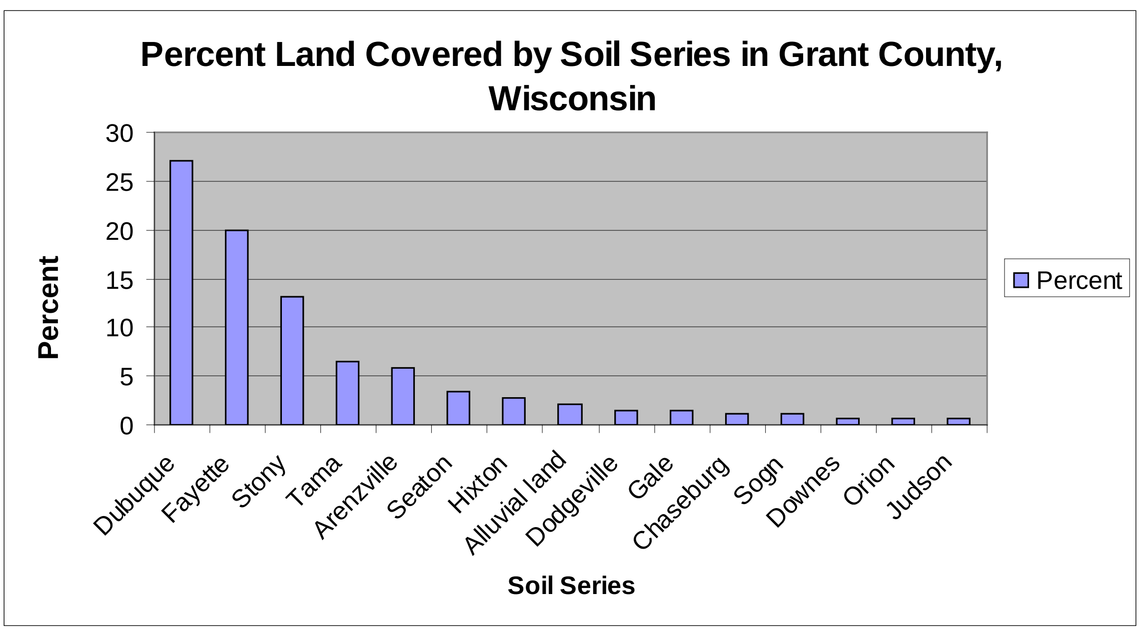

Figure 5 Percent of land covered by soil series in Grant County, Wisconsin (NRCS 2007).

Soil-Vegetation Relationship in the Grant River Watershed

Soils of upland drainage divides in the Grant River watershed are represented mostly by Mollisols. Mollisols are notable for their thick organic layer that developed in association with annual prairie plants and grasses. The rich layer of loess that was derived from the Mississippi River floodplain during the last glacial period allowed for grasses and plants to establish when springs and summers became humid from the wet Pacific and tropical air masses that began reaching Wisconsin towards the end of the glacial period.

At the end of each growing season, the annual plants and grasses die but decompose extremely slowly due to the cool, dry winters. This creates a rich humus layer that forms a soil chemistry which prevents hard clay formation, leaving the soil soft and arable. Burrowing organisms, such as worms, enters the humus layer to speed decomposition and help mix the organic humus layer with the inorganic loess. It is this mixing that has allowed the formation of a thick topsoil, creating the fertile mollisols throughout the Driftless Area.

Since Euro-American arrival to the region, the mollisols have been greatly modified by agricultural clearing and plowing. The removal of prairie vegetation and growth of agricultural crops has reduced the amount of humus material available. The agricultural clearing and plowing has also increased soil erosion and soil compaction, reducing the vertical differentiation of the soil layers (Knox 2001). This has reduced both the fertility and arability of the mollisols in southwest Wisconsin.

Vegetation distribution throughout southwest Wisconsin has undergone shifts throughout the Holocene period (around 12,000 year ago to present). Alluvial records and fossil pollen data shows that a prairie-forest ecotone extended from the northwest to the southeast across the UMV throughout the Holocene. During the Holocene the ecotone migrated slightly farther east and then retreated west based on climatic shifts (Baker et al. 2002; Knox 2007). Up until the inception of Euro-American agriculture in the Driftless Area, the upland divides of the region were covered by prairie grasslands while hardwood forests and brush prevailed on many hill slopes (Trewartha 1940; Knox 2007, Knox 2001).

The upland prairies were maintained through frequent low-intensity fires set both by lightening and Native Americans (Ostergren et al. 1997). These fires could spread easily along the undissected ridge tops given they were uninterrupted by bodies of water and topographic barriers. The prairie vegetation that accumulated after every growing season provides an abundance of dead, dry plant material for fuel. Fires sped up the decomposition process, returning nutrients back to the soil. In between fires, pioneer tree species, such as bur oak, occasionally became established, but frequent fires that swept the prairies normally removed the majority of sprouting trees (Ostergren et al. 1997, Public Land Surveys 1832-1833). The sporadic burning commonly resulted in development of oak openings within the prairie and thinly dispersed oaks throughout the prairie uplands, forming oak savannas.

Steep eastward- and northward-facing hill slopes were less susceptible to fire and promoted growth of hardwood forests (Ostergren et al. 1997). The hardwood forests protected the sensitive, rugged landscape of the Driftless Area. Dense, hardwood forests protected the ground from raindrop impact and the erosional stresses of surface runoff.

From Public Land Surveys completed by Lucius Lyons and others from 1832-1833, the pre-settlement vegetation of southwest Wisconsin, including the Grant River watershed, can be reconstructed. The early land surveys describe the prairie landscape as ranging from gently rolling to very hilly. Other than grasses, the prairies were characterized by thinly dispersed bur, black, and white oak. The same trees also characterized steep hill slopes where forest vegetation was more prevalent. A larger variety of deciduous trees were common along streams and floodplains, such as sugar maples, elm, ash, and aspens. The larger diversity along streams reflects wetter conditions and lack of fire there.

Settlement Patterns of Southwest Wisconsin

Early 19th century Euro-American settlement in southwestern Wisconsin emphasized both mining and agriculture, but it was rich deposits of lead that accelerated settlement of the region (Schafer 1932). As a result, the region is referred to as the Wisconsin Lead Region, bordered by the Wisconsin River to the north, the Mississippi River to the west, the state of Illinois to the south, and Green and Dane County to the east. Settlers who came to the Lead Region for mining rarely supported themselves solely through mining. Most needed to supplement their income as well as grow much of their own food by farming. Therefore, most immigrants who settled southwestern Wisconsin during the early 1800s were farming and mining.

By the time Euro-American settlers reached Wisconsin's lead mines, the landscape was already perforated with earlier, shallow diggings by the French and Indians (Schafer 1932). During early European settlement of the UMV, the French and

Indians often traded with one another for a variety of goods. It is thought that the French settlers taught Indians the art of lead mining so that they could pay the Indians to mine lead for the French to then sell to other interested parties (Schafer 1932). When other Euro-Americans arrived to the lead mines, they not only found these ancient diggings, but they also encountered Indians still engaged in extracting lead ore from the shallow diggings using stone picks, bone spades, wooden shovels, gun barrels for crowbars, and occasionally Euro-American mining implements (Schafer 1932).

By 1816, American mining in the lead district had begun, but leasing of land for mining did not start until 1822 (Schafer 1932). In 1822, lead mining became more profitable due to tariff increase and global price increase resulting from increased global demand (Schafer 1932). This produced a rush of immigrants to Wisconsin's lead region and the government's decision to lease the land for mining. By 1827, the upper Mississippi mines were out-producing all other lead mining regions in the United States. By 1840, Wisconsin's lead region produced 15,130,000 pounds of lead out of the nations 31,240,000 pounds total output, equaling nearly 50% of the total production (Schafer 1932). Lead mining continued to increase steadily through 1847, and then gradually declined (Schafer 1932). The decline in lead mining occurred because most of the shallow lead mines had been exploited and the remaining lead was deep below the ground surface. Additionally, the California Gold Rush of 1849 resulted in additional lead mining declines as the miners left Wisconsin to exploit the gold in California.

When Euro-Americans settled in Wisconsin's Lead Region, they set up diggings any where there was a sign of lead. This included prairies, gentle hill slopes, and steep hill sides (Schafer 1932). In addition, timber was a necessary product in the diggings, and even more necessary if the miner wanted to smelt his own ore. In response, the government leased timber tracts to the miners, which resulted in rapid deforestation of the region (Schafer 1932). Neither the land used for mining nor timber was chosen based on environmental and economic sustainability. Mining and deforestation occurred on portions of the landscape that was extremely susceptible to erosion, such as the steep hill sides. Farm land was also chosen without considering sustainability. Farmers would buy land based on soil quality rather than topography and erosion susceptibility (Schafer 1932). Additionally, establishing a farm required timber harvesting to build fences, barns, and other structures. The combination of lead mining and agriculture in the 19^{th} century led to rapid rates of soil erosion (Knox 2001, 2006; Lecce 2001). However, it is important to point out that the impacts of mining on erosion are modest in comparison to the impacts of Euro-American agriculture throughout the 19^{th} and early 20^{th} centuries. Mining had minimal influences on flooding and overbank floodplain sedimentation, but did significantly influence sedimentation on channel beds and point bars in channel reaches near large mining operations (Adams 1940; Adams 1942). The presence of trace lead and zinc minerals in the eroded soils have proved to be useful tools estimating ages of historical sedimentation and flooding (Knox 2006).

Farming in southwest Wisconsin initially included large numbers of hogs, especially of the “prairie racer” variety, and cattle for dairy (Schafer 1932). To feed the hogs and cattle, and for their own sustainability, farmers grew corn and wheat. Winter breakfasts commonly involved buckwheat as an ingredient (Schafer 1932).

By 1860, Grant County led in agricultural land in the lead region (Schafer 1932). People immigrated to Grant County in large numbers from 1840-1870 to enter agriculture (figure 6). Agricultural development boomed in the years around the Civil War, partly due to technological innovations and partly due to increases in farm product prices (Schafer 1932). There were 2,286 farms in Grant County in 1860 as compared with 1,863 farms in Iowa County and 1,534 farms in Lafayette County (Schafer 1932). However, Grant County is much larger than both Iowa and Lafayette counties. As a result, Iowa and Lafayette Counties have less agricultural land, but agriculture is more concentrated in Iowa and Lafayette Counties than in Grant County (figure 7). In 1860, Iowa County had about 2.42 farms per square mile and Lafayette County had 2.22 farms per square mile. During the same year, Grant County had only 1.94 farms per square mile. From 1850 to 1870, the concentration of farms in the three counties experiences a steep increase. This rapid increase in farm concentration represents the quick transition from mining to agriculture in the region.

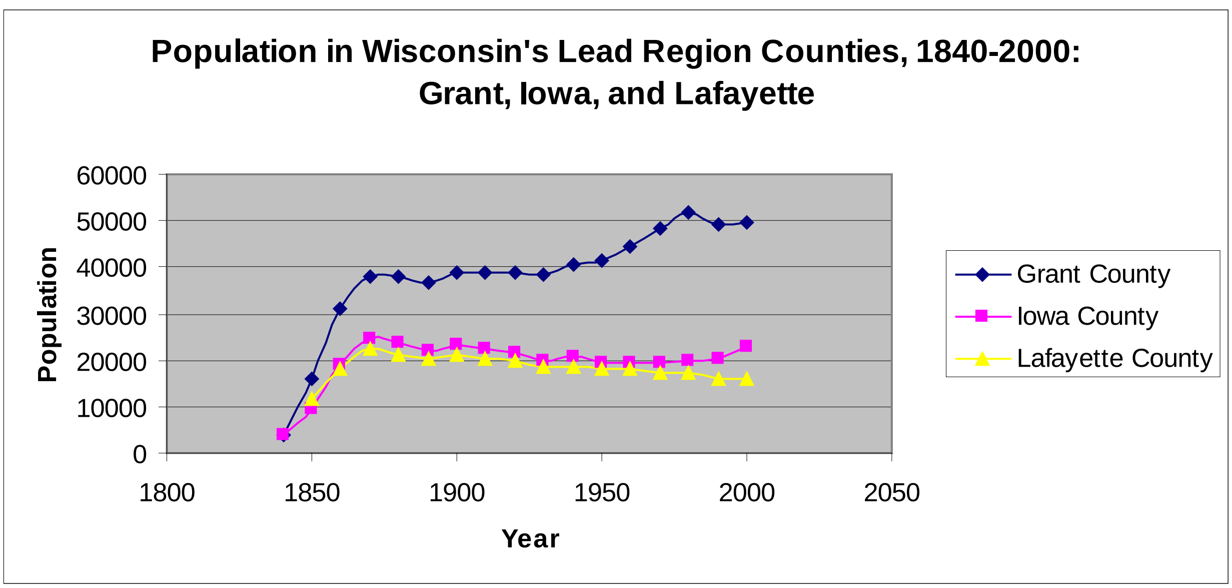

Figure 6 Population in Wisconsin's Lead Region Counties, 1840-2000: Grant, Iowa, and Lafayette. Data from: Historical Census Browser, University of Virginia Geospatial and Statistical Data Center. 2004. <http://fisher.lib.virginia.edu/collections/>.

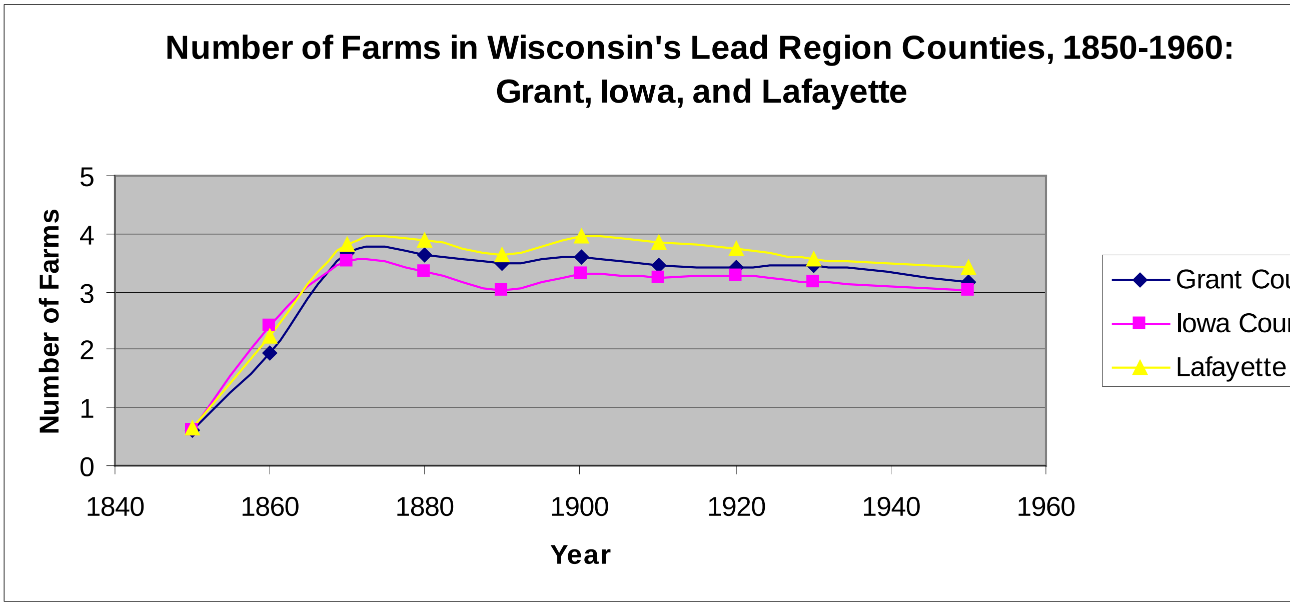

Figure 7 Concentration of farms per square mile in Wisconsin's Lead Region Counties, 1850-1960: Grant, Iowa, and Lafayette. Data from: Historical Census Browser, University of Virginia Geospatial and Statistical Data Center. 2004. <http://fisher.lib.virginia.edu/collections/>.

Settlement and Post-Settlement Landscape

The landscape of the Grant River watershed has a local relief that averages between 50 and 120 m km^{-2}, making the landscape extremely susceptible to erosion (Knox 1987, 2001). The slopes under cultivation in the Grant River watershed are overlain by about 50 cm or more of silt-dominated loess and clayey residuum. This sediment became especially vulnerable to erosion after the protective natural vegetation was replaced by agricultural cropland (Knox 2001).

Euro-Americans began removing the natural vegetation and cultivating the land in Grant County beginning in the 1830s (Blanchard 1924; Shafer 1932). By the mid-19th century, Grant County settlement was mostly complete, with agriculture widespread throughout the watershed (Shafer 1932; Holford 1900). When the leading industry became agriculture, the best farm land was taken first. The first farmers in the region converted most of the upland prairies and gently sloping lowlands to agriculture, leaving the steep hill slopes for those farmers who arrived later (Schafer 1932). Not considering the extreme susceptibility of the steep slopes to erosion, many of the slopes were converted to agricultural lands. Quickly recognizing that the fertile soil was taken away by water and wind, the farmers abandoned their fields that were on the steep slopes (Schafer 1932). After many years of fire suppression, the steeper hills are now reforested chiefly by oak, hickory, and other deciduous trees.

It is easy to see effects of Euro-American agriculture in floodplain alluvial deposits because floodplains in the Driftless Area tend to be dramatically aggraded and retain much of their overbank, flood-related sedimentation (Beach 1994). Comparison of the Grant River alluvial activities before and after agricultural settlement shows a large magnification in landscape sensitivity (Knox 2001).

The types of crops, their locations on the landscape, and seasonal planting and cultivation schedules all have strong influences on landscape sensitivity to erosion (Boardman 1993; Knox 2001). By replacing the natural vegetative cover with crops, like soybeans and corn, more of the landscape's surface is exposed to shear stress from raindrop impact and surface runoff.

Raindrops fall at a velocity of around 9 m s^{-1}, which breaks up natural soil aggregates (Storey 1964). The destruction of soil aggregates reduces soil infiltration capacity because the broken particles clog the natural soil pathways that allow the water to move through the soil profile (Knox 2001). Bare soil also offers minimal hydraulic friction to overland flow in comparison to vegetation- or litter-covered surfaces. When water moves fast over the surface it decreases infiltration into the soil because there is less time for the water to percolate through the soil profile. As a result, the soil is more susceptible to erosion by water entraining loose soil particles on the ground surface.

Soybeans, in comparison to corn, make the soil more susceptible to erosion by surface runoff (figure 8). The soybean plant's morphology is much smaller than corn, leaving a greater proportion of soil bare, thereby exposing the soil to erosive forces. A corn plant is much larger, resulting in more interception of raindrops before they hit the soil. Therefore, a shift to soybean cropland favors increased erosion, which is often reflected by increased suspended sediment in river flow or increased sedimentation on floodplains in the watershed.

Figure 8 Soybean field half of a mile northwest of Belmont, Wisconsin. Photo courtesy of James C. Knox. This picture represents the ease with which surface runoff can carry soil from soybean fields to a river. Note the rill erosion across the field. This rill erosion could be reduced if there was a grassway where the rill erosion is present.

During cultivation and grazing, soil is compacted by heavy machinery or animals, which also destroy natural soil structure, reducing infiltration capacity. Cultivation and grazing deplete soil organic matter (SOM) which influences soil physical, biological and chemical properties that control soil productivity and quality (Doran and Parkin 1996). Soils with decreased SOM experience decreased porosity and permeability, which increases water runoff and soil erosion rates (Knox 2001).

In the Grant River watershed, the most common crops are corn and soybeans, with lesser acreages of oats, wheat, and hay (U.S.D.A.). It has been well documented that cropping systems that include soybeans in the rotation decrease soil quality by decreasing soil organic carbon as reflected by decreased soil aggregate stability (SOC; Leibig et al. 2002; Studdert and Echeverria 2000; Varvel 1994; Karlen et al. 1994; Havlin et al. 1990). Soybeans may cause the soil to possess a higher proportion of microaggregates (<0.25 mm; Fahad et al. 1982; Martens 2000), causing a decrease in interaggregate porosity and a proportional increase in soil bulk density (Leibig et al. 2002). As a result, agricultural fields that are currently under soybean cultivation may experience increased surface runoff.

While soybeans may deplete the physical properties that influence the erosiveness of a soil, rotations that include legumes, such as soybeans, improve soil fertility through the additional of ammonia. Legumes have a mutual relationship with a common soil bacterium, Rhizobium, which allows the plant to fix nitrogen so that it can be used by other plants. Rhizobium live in legume root nodules and intake inert nitrogen (N_2) and biologically fixes it, releasing ammonia to the soil. Ammonia is the only form of nitrogen that most plants, including all crop types, absorb and process. Nitrogen is a necessary element in manufacturing chemical compounds that are necessary to carry out life processes; some examples include nucleic acid, amino acid, and proteins. Nitrogen deficiency is a common problem in agricultural soils. Therefore, growing soybeans adds necessary nutrients to improve soil fertility and feed subsequent crops, such as corn or forage.

Rotations that include forage crops also improve soil quality and ground cover, thereby decreasing erosion. Forage crops put less stress on soil nutrients since forage usually requires less nitrogen and phosphorous than larger crops like corn (Karlen 2006). Most forage crops have large root systems beneath ground, with a higher biomass below ground than above. As a result, the majority of the biomass is left in the soil after harvest. This biomass is easily decomposed, improving SOM input and soil fertility.

Soybean Agriculture: Impacts on Grant River Discharge and Sedimentation Rates

There has been a large increase in acres of planted soybean crops since the mid-1980s (figure 9). This is widely due to the introduction of a two-year corn and soybean rotation to the Western Corn Belt during the later half of the 20th century (Leibig et al. 2002). This occurred for several reasons, but primarily as a method to potentially decrease degradation of soil from monoculture agriculture. Additionally, soybeans use similar equipment to corn and are simple to grow, which has become increasingly important as farm size has increased over the past 100 years (Karlen 2006). As of late, there has been a rise in commodity programs that emphasize the short-term profit that corn-soybean rotations make available, as well as increased food and industrial uses for both corn and soybean oils and various by-products (Karlen 2006; Karlen 2004; Soper et al. 2003).

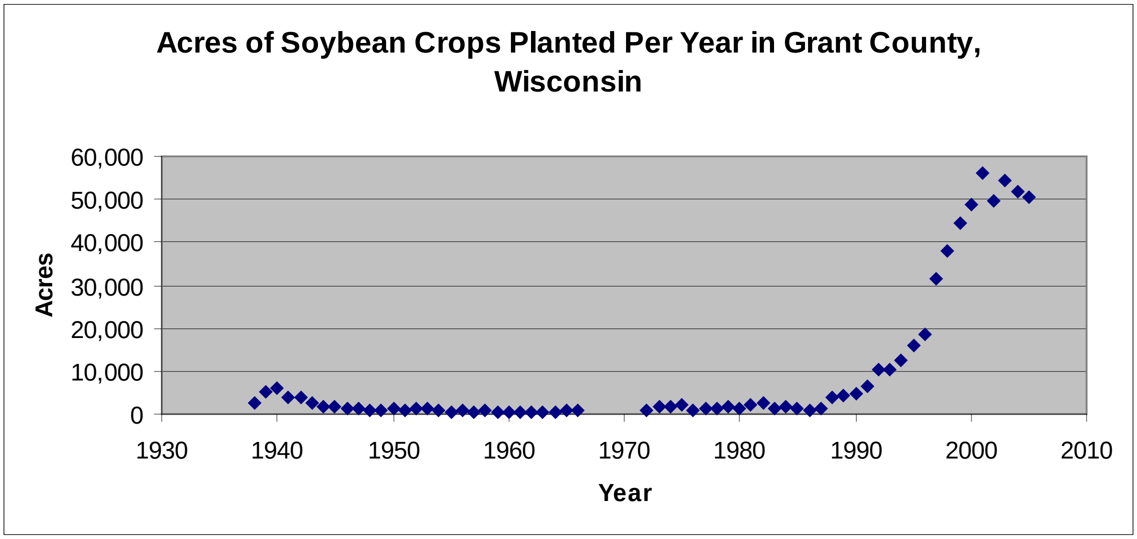

Figure 9 Acres of soybean crops planted per year in Grant County, Wisconsin, 1938-2007 (USDA). Soybean agriculture accelerates from the mid-1980s through the early 1990s.

Soybeans are growing in popularity by consumers and farmers, and it has been well documented that soybeans degrade the physical properties of soil (Leibig et al. 2002; Studdert and Echeverria 2000; Varvel 1994; Karlen et al. 2006, 1994; Havlin et al. 1990). Therefore, it is useful to assess the possible impacts of the sudden increase in acres of planted soybean crops has had on soil erosion and the subsequent fluvial sedimentation.

The Grant River watershed is selected for this study because this watershed is predominantly agricultural with a high quantity of land devoted to corn-soybean cropping, while urban areas cover less than one percent of the watershed (Woltemade 1994). Currently, around a quarter of the watershed is more than 75% cultivated land, with another quarter between 51-75% cultivated. The remaining land is either less than 15% cultivated, used as pasture, or left as grassland (figure 10).

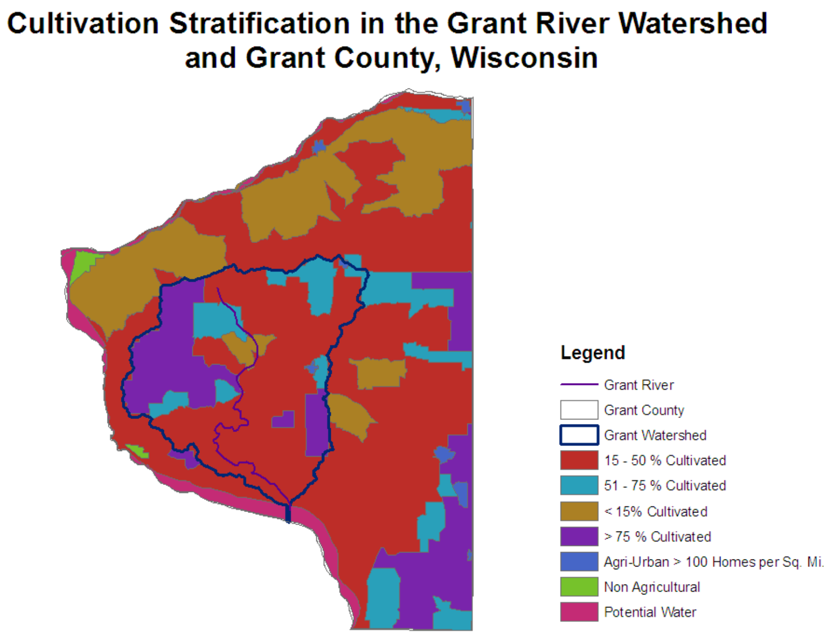

Figure 10 Cultivation data from USDA, watershed data from USGS.

Starting in 1999, the Grant County NRCS field office in Lancaster, Grant County conducted cropland surveys that documented crop types and erosion for watershed units. Tillage practices were summarized at the county level. These transect surveys began as a method to track soil erosion from cropland fields.

In 1982, the Wisconsin legislature passed a new land conservation law that established a statewide goal of reducing erosion from all cropland fields to tolerable levels by the year 2000. One method that the NRCS used to track the progress in reducing erosion was conducting a survey called the National Resources Inventory (NRI; Wisconsin Department of Agriculture 1998, WDOA). An NRI was conducted every five years and gave information about Wisconsin's average sheet and rill erosion for the state, but these data are only statistically significant at the state level (WDOA 1998). County databases from these NRI inventories gave a little information as to the soil erosion rates at a county level. Only 38% of the cropland in Wisconsin had soil erosion rates entered into a county database as of 1996 (WDOA 1998). Additionally, only seven counties have greater than 90% of their cropland acreage entered into their database.

In order to assess erosion at the county level, the State of Wisconsin requires that transect surveys be completed on a yearly basis for each county with 100,000 acres or more of planted crop land (NRCS 2002). Transect surveys were originally developed by Purdue University in 1994 for the Conservation Technology Information Center so that county-wide conservation tillage surveys could be conducted (WDOA 1998). Illinois modified the survey to include soil loss information (WDOA 1998). The survey method has shown to be a statistically reliable roadside survey method with data collected every half-mile from points located on each side of the roadway. Approximately 500 sample points are inventoried in an established route that traverses the county six to eight times (WDOA 1998; figure 11).

MAP OF COUNTY TRANSECT SURVEY ROUTE

Figure 11 NRCS 2004.

The Grant County surveys use a two person team and the entire field process takes about three days to complete (WDOA 1998). The transect data are collected in mid-May to early June, immediately following spring planting, but before the first row cultivation takes place or the crop canopy closes (WDOA1998). Information recorded for each point includes crop information, tillage system, crop residue levels, and other factors which are used as input to estimate erosion with the universal soil loss equation. Watershed codes area also entered to further identify the soil erosion status or trends of specific watersheds.

The data collected from transect surveys are used to document progress in reducing soil erosion at the county and watershed scale, verify additional funding needs to help reduce erosion, and to provide counties and the public with statistically reliable data which can be used to update land water resource management plans (WDOA 1998).

The transect surveys conducted by the Lancaster NRCS field office splits the Grant River Watershed into three watersheds, including the Upper Grant, Middle Grant, and Lower Grant (figure 12). Therefore, data from these surveys show trends within the specific regions of the watershed. In order to assess the status of the watershed as one unit, the data from the three sub-watersheds were combined.

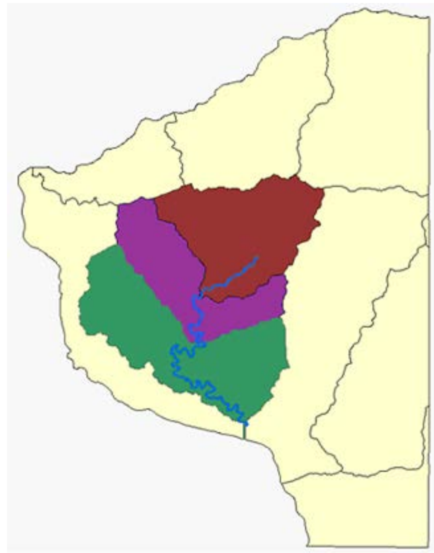

Figure 12 The Grant River watershed. The red is the upper subbasin, the purple is the middle subbasin, and the green is the lower subbasin.

Based on data from these transect surveys, corn and soybeans make up the majority of all crops grown in the Grant River watershed, representing nearly 58% of planted acres in 2006 (figure 13). Since 1988 the amount of acres of soybeans planted in Grant County has increased significantly, while corn has been experiencing a slow decrease in acres planted since 1986 (figure 2). However, due to the advertisement of growing corn for ethanol in 2006, the year of 2007 experienced a huge growth in acres planted with corn. In Grant County, corn increased 6.7% since 2005 while increasing 19% since 2005 in the Grant River watershed (figure 2, 14). Additionally, starting in 2000, acres of planted soybeans stop increasing and leveled off in Grant County, while this trend began in 1998 in the Grant River watershed (USDA, figure 9 and 15).

Between 1999 and 2007, the percent of corn, soybean, forage, and idle lands in the Grant River watershed has remained relatively steady, with exception for the year 2007 where corn increased and was mirrored by a decrease in soybeans and forage (figure 13). The percent of the Grant River watershed planted with small grains varies greatly by year, increasing from 1999 to 2001, then decreasing through 2005, and increasing significantly in 2007 (figure 13).

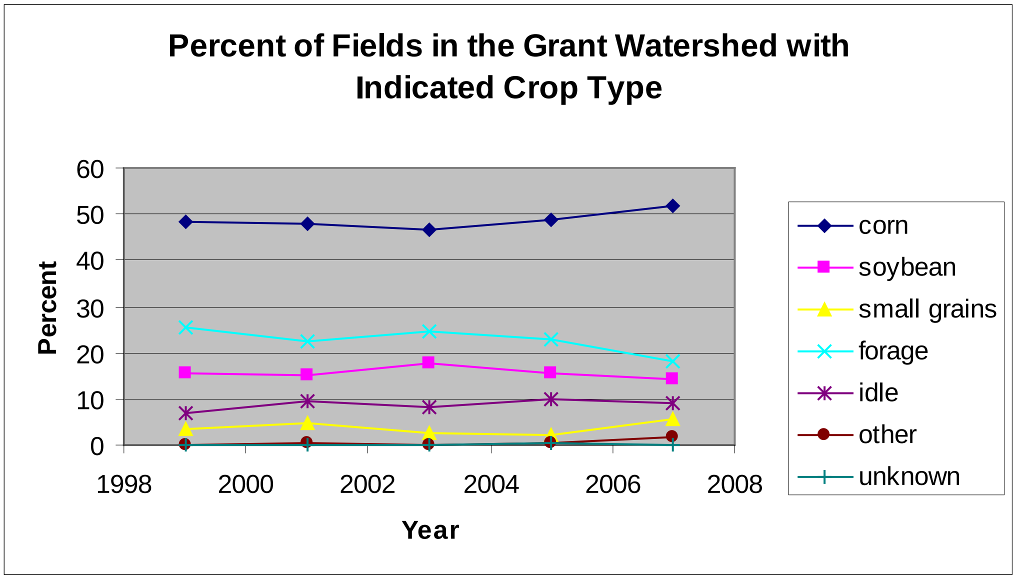

Figure 13 USDA 2008.

The majority of corn is grown in the Middle Grant River watershed, however, the difference between acres planted in the middle and lower sections are minimal, differing at most by 10,000 acres, or 33%, and being identical during 2005 (figure 14). Soybeans are chiefly grown in the Middle Grant River watershed as well, with 50% more soybeans grown in the middle than the lower watershed prior to 2007 (figure 15). During 2007, the number of soybeans grown in the lower and middle sections of the watershed is identical (figure 15).

Acres of small grains planted in the three sections of the watershed vary greatly based on year (figure 16). During some years the middle watershed experiences highest acreage of small grains while other years the lower watershed experiences highest acreage. The number of acres devoted to small grains in the upper watershed varies year to year, but always remains relatively low.

The majority of forage crops are consistently planted in the middle Grant River watershed from 1999 through 2007 (figure 17). The middle section experiences around 35% more acres of forage than the lower for the years of the transect surveys, 1999 through 2007. Additionally, the acres of forage planted in the middle watershed stays relatively stable from 1999 to 2005 (figure 17). Then, in 2005, acres of forage increased nearly 12% from 2003 and then decreased drastically by 23%. However, in the lower and upper watershed, forage slightly decreased in acreage from 2003 to 2005 and then again from 2005 to 2007 (figure 17). As a result, total forage for the watershed stays relatively the same from 1999 through 2005, with a drastic decrease of almost 20% from 2005 to 2007.

The middle watershed dominates in acres of idle cropland, containing between 81% and 88% of the idle cropland for the watershed (figure18). The upper and lower reaches of the watershed have relatively low idle cropland, with their total acres about equal to each other for the years of the survey (figure 18). Additionally, the total acreage in the upper and lower reaches of the watershed is less than 2000 acres each. From the years of the transect survey, 1999 through 2007, the trend for idle crop land in the watershed shows that total idle cropland has been increasing. From 1999 to 2007, the acres of total cropland in the watershed increased 35%.

For each crop type, the upper section of the watershed experiences the lowest acreage, with two exceptions. The first exception is in 2001 where acreages of small grains planted in the upper and lower watershed are equal. The second exception is with idle cropland. Although the lower and upper sections of the watershed have relatively equal acres of idle cropland, the upper section often has slightly more. The upper section of the watershed experiences less agriculture because it is highly dissected in comparison to the middle and lower sections. The lower reach of the watershed experiences higher rates of flooding and sedimentation from floods, and is therefore, less attractive farmland than the middle reach of the Grant River watershed.

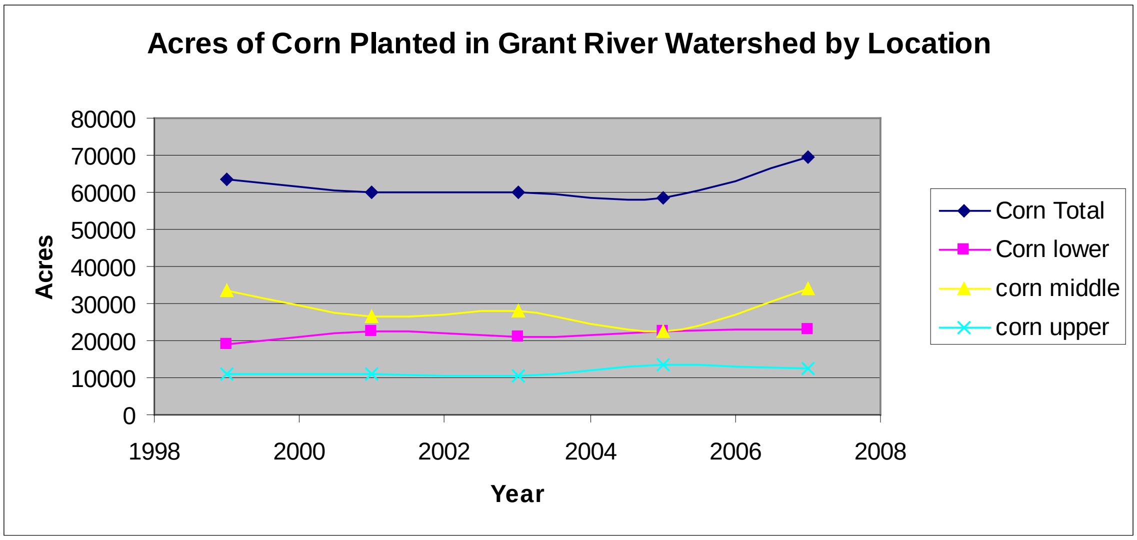

Figure 14 NRCS Transect Survey data. Obtained in 2008.

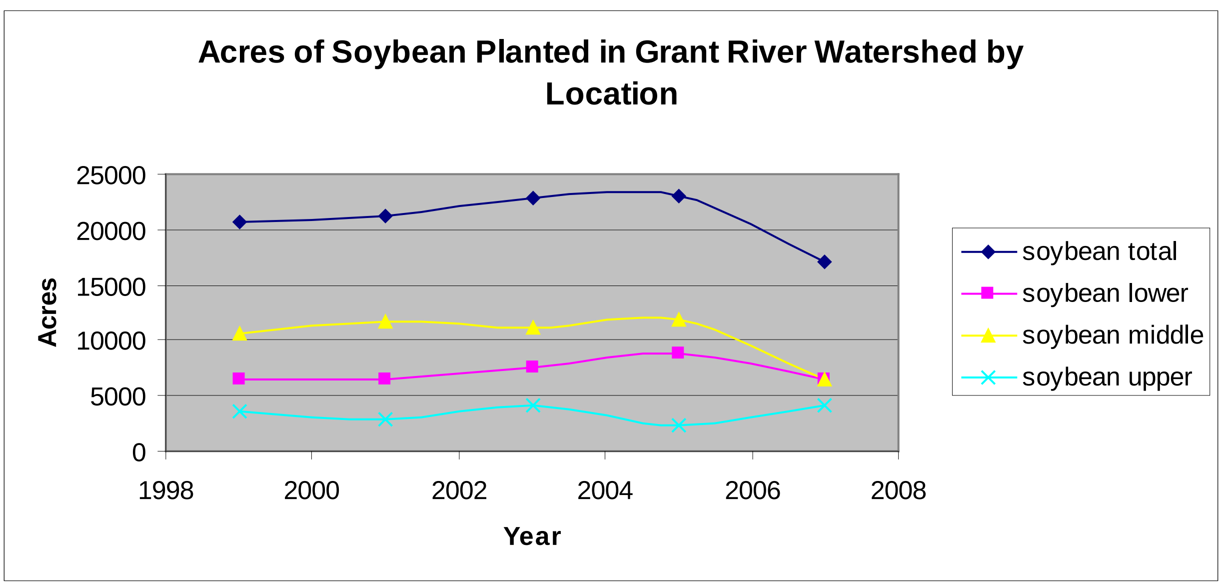

Figure 15 NRCS Transect Survey data. Obtained in 2008.

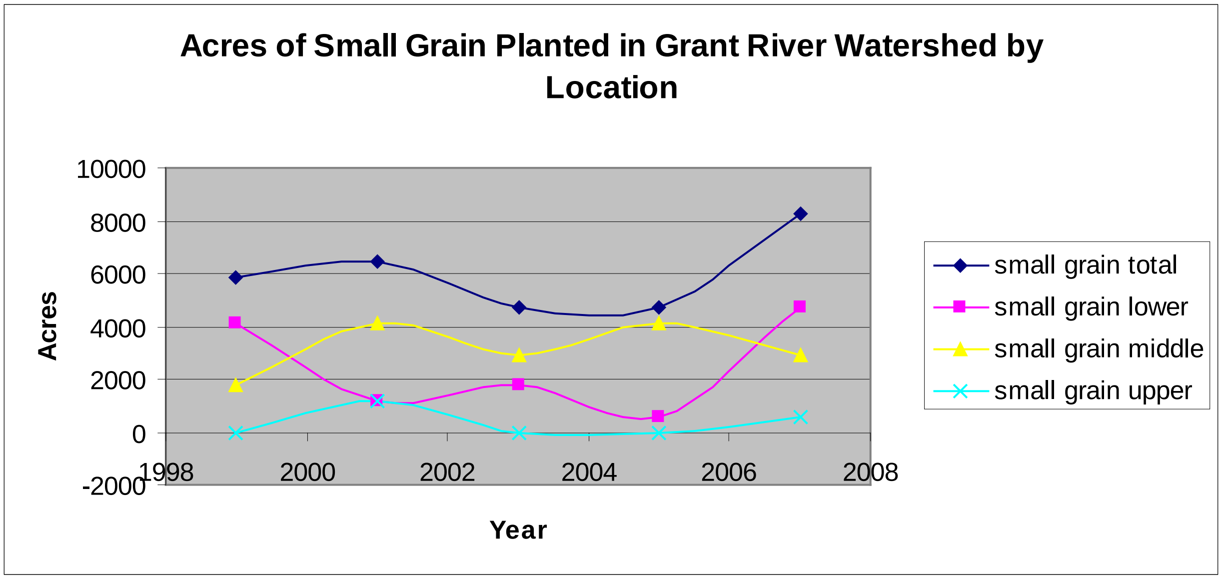

Figure 16 NRCS Transect Survey data. Obtained in 2008.

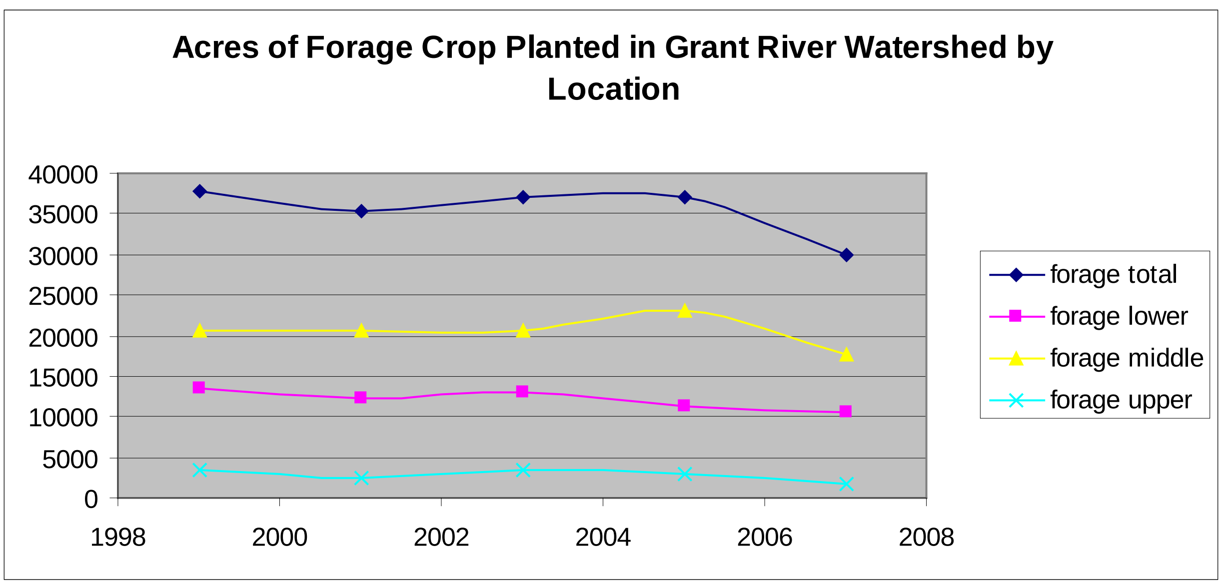

Figure 17 NRCS Transect Survey data. Obtained in 2008.

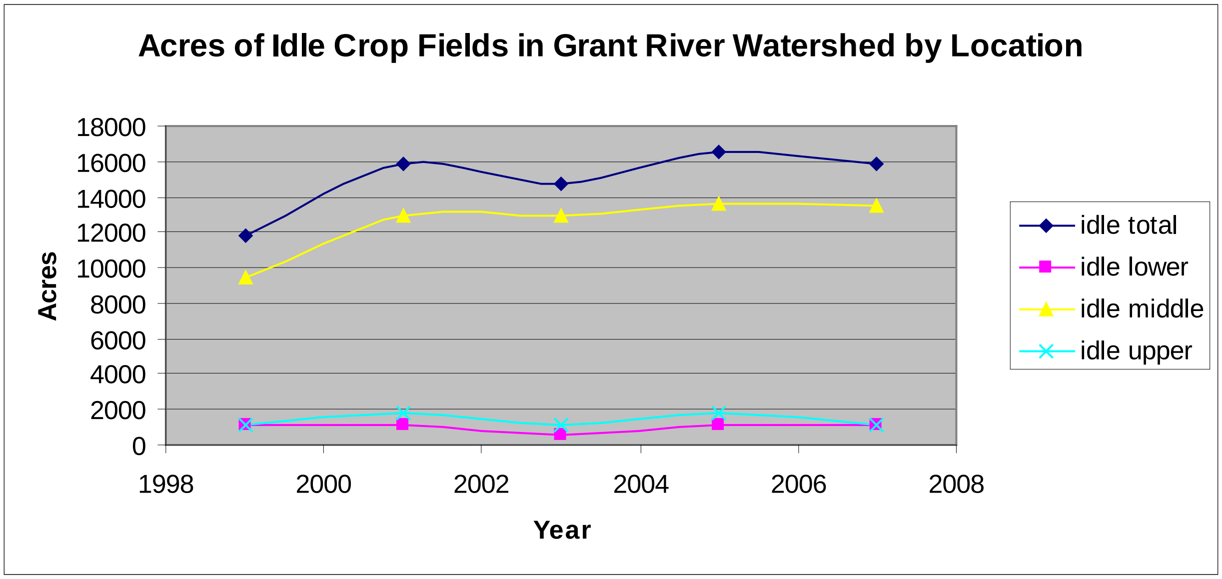

Figure 18 NRCS Transect Survey data. Obtained in 2008.

The transect surveys show that corn is the most commonly planted crop in the Grant River watershed (figure 19). While planted corn acreage varies between 58,000 and 70,000, it always covers around 50% more acres than the second most common crop type, which is forage. In fact, the acres of corn planted in the middle reach of the Grant River watershed surpasses the total acres of crop planted for each of the other crop types, with exception to forage (figure 20). Additionally, the amount of forage crops planted in the middle reach of the watershed is about equal to the total amount of soybean crop planted in the entire watershed and around twice the amount of acres of soybeans planted in the middle reach of the watershed (figure 20).

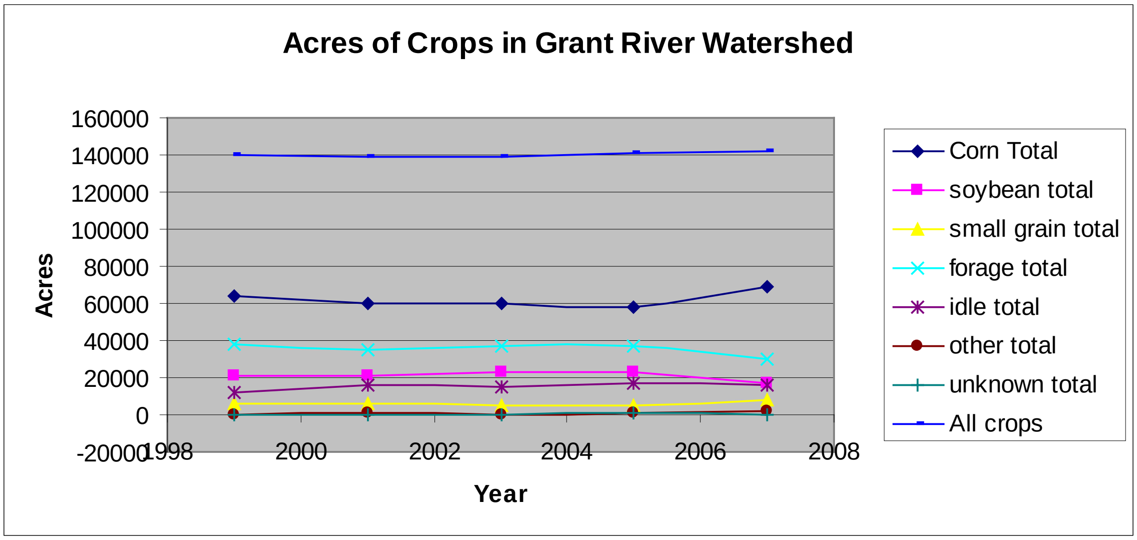

Figure 19 NRCS Transect Survey data. Obtained in 2008.

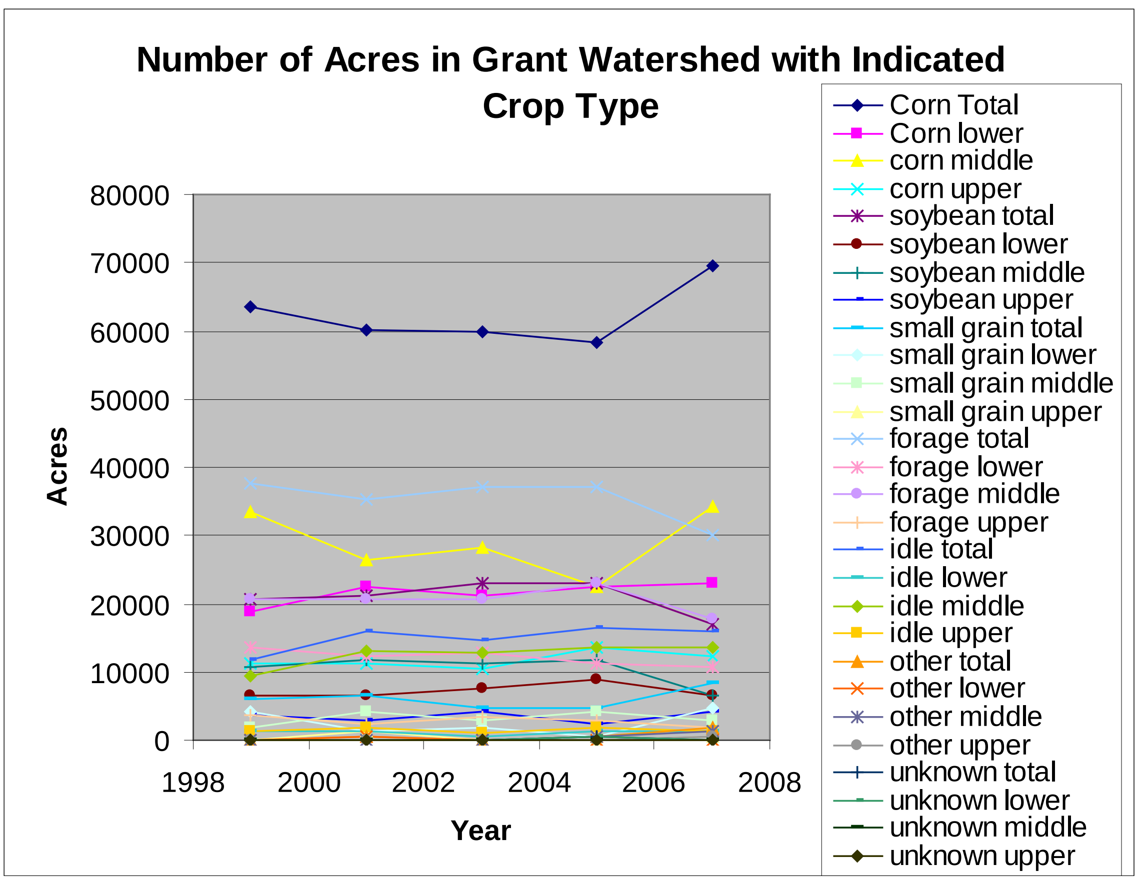

Figure 20 NRCS Transect Survey data. Obtained in 2008.

The total amount of acres planted in the Grant River watershed has stayed relatively the same from 1999 through 2003 (figure 21). From 2005 through 2007, the total acres planted in the watershed experiences a small increase of about 3%. This increase is most likely a result of farmers using more land for corn agricultural in order to meet the demand for corn-derived ethanol.

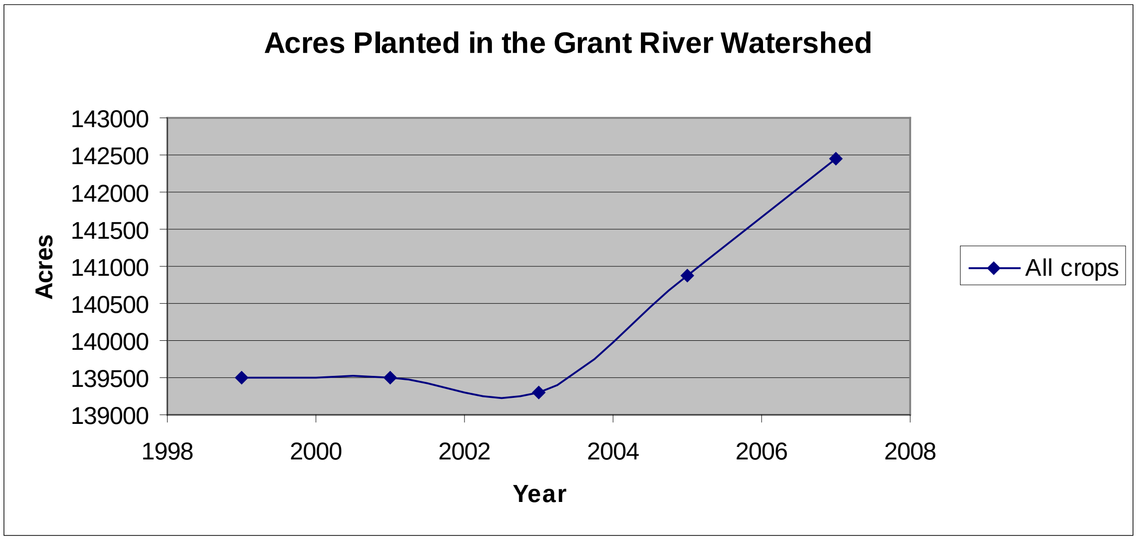

Figure 21 NRCS Transect Survey data. Obtained in 2008.

As stated earlier, the location of crops on a landscape greatly influences landscape sensitivity. Within the Grant Watershed, crop location characteristics include spatial relationship to the river, slope steepness, and soil type. Pasture dominates two mile strips that line the river's bank (figure 22). These strips are devoted to pasture probably because of the steep slopes along the deep valley of the Grant River. In the northwest and southeast sections of the watershed, on the uplands where slopes are less steep, corn and soybeans dominate (figure 22).

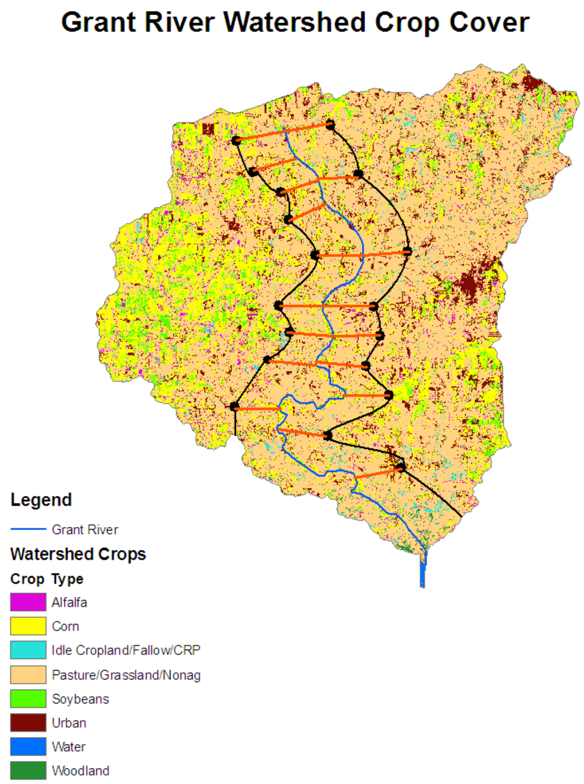

Figure 22 The red lines are 3200 meters measuring from the river to the black dot. The black lines roughly outline the 3200 meter strips along the river. The tan color represents pasture/grassland/nonagricultural cover. As this map shows, pasture dominates in the two mile strips surrounding the river. Corn and soybeans, yellow and neon green, respectively, dominates in the northwest and southeast corners of the watershed.

Farm fields in the Grant River watershed are located on slopes that vary from 0% to greater than 10%. For the years of the transect survey, the percent of fields grown on each slope type has stayed relatively the same, usually varying by less than one percent (figure 23). Around 38% of farm fields in the watershed can be found on slopes between five and seven percent. This correlates with the soil survey in that the best agricultural soils in the watershed, especially the middle reach, are Fayette and Tama silt loams on 6-10% slopes, followed by Tama silt loam on 2-5% slopes (figure 24).

About 20% of the fields in the Grant River watershed are found on slopes greater than 10% (figure 23). Therefore, while reforestation has occurred on many of the steep slopes, especially those with a slope of 15% or greater, areas highly susceptible to erosion are still under cultivation. To minimize erosion on these fields, management practices that increase soil conservation have been important in the ability to continue farming on these slopes.

The rest of the farm fields in the Grant River watershed are found on slopes between zero and ten percent (figure 23). Around 18% of fields are on slopes of eight to ten percent, 13% of fields are on slopes of three to seven percent, and 10% of fields are on slopes of zero to two percent. Most of the farm fields are found on steeper slopes because the Grant River watershed is highly dissected, and therefore, has little land with gentle slopes. For this reason, conservation practices in managing farm fields have become increasingly important and utilized by farmers in the past seventy years.

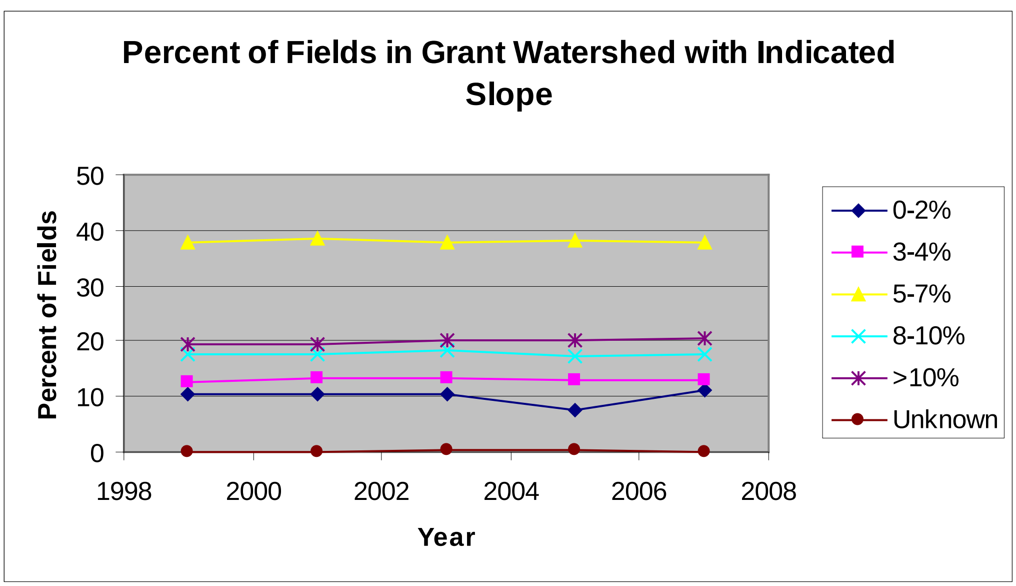

Figure 23 NRCS Transect Survey data. Obtained in 2008.

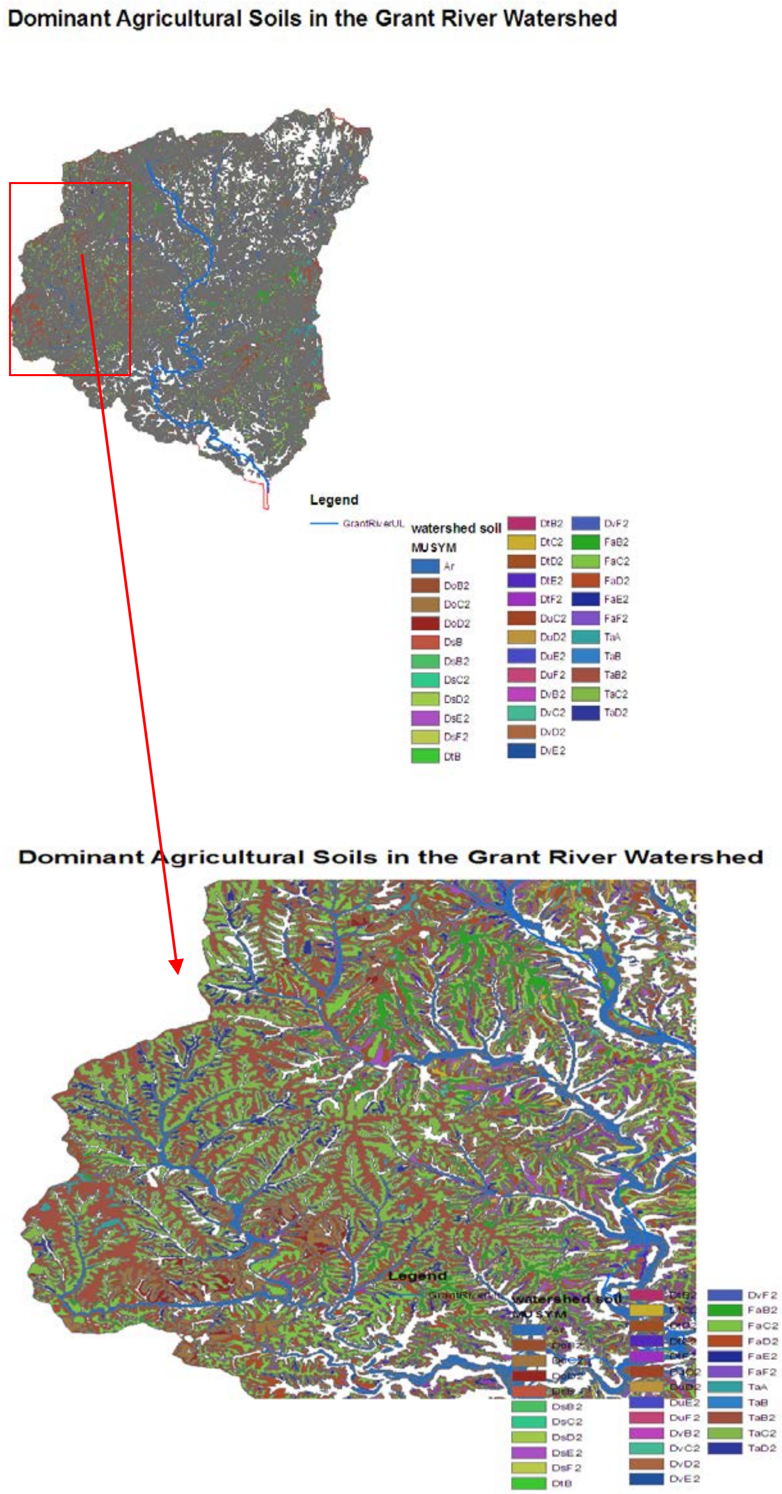

Figure 24 NRCS 2007. Northwest region of watershed enlarged to show the diverse soils within the watershed. View appendix A for the soil key.

Cattle grazing can also involve high rates of soil erosion if overgrazing occurs. While there is no data available at the watershed scale on cattle grazing, the USDA does have data at the county scale (figure 25). From the mid-1970s through the mid-1980s, the number of cattle in Grant County stayed relatively constant. However, since 1985 the number of cattle in Grant County has decreased by 22.5%.

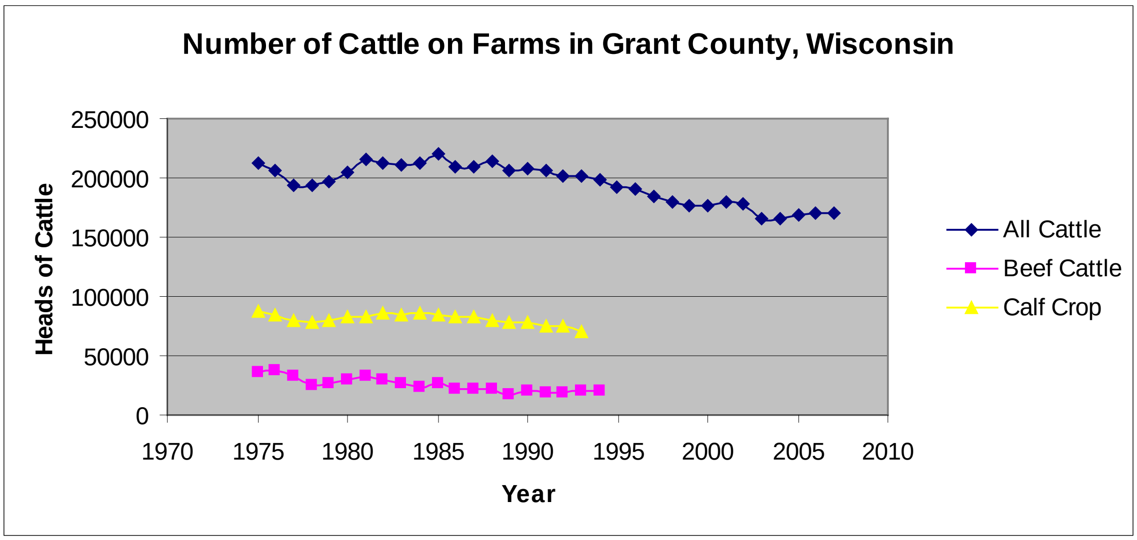

Figure 25 USDA 2008.

Soil erosion in the watershed, as calculated by the Universal Soil Loss Equation (USLE) has decreased from 1999 to 2007 (figure 26). The upper reach, which experiences the highest rate of soil erosion due its highly dissected landscape, decreased from losing 6.6 tons per acre in 1999 to losing 5.3 tons per acre in 2007. The middle reach of the watershed, which has the most farming, decreased from 3.4 tons per acre in 1999 to 2.3 tons per acre in 2007. The lower reach did not experience an increasing or decreasing trend in soil erosion. Rather, soil erosion in the lower reach varied between three and four tons per acre during 1999 through 2007. Overall, changes in soil erosion show neither a correlation with changes in acres of crops grown in the watershed nor with changes in acres of specific crop types grown in the watershed. Therefore, this decreasing trend in soil erosion must be related to factors other than area of land used for agriculture and crop type.

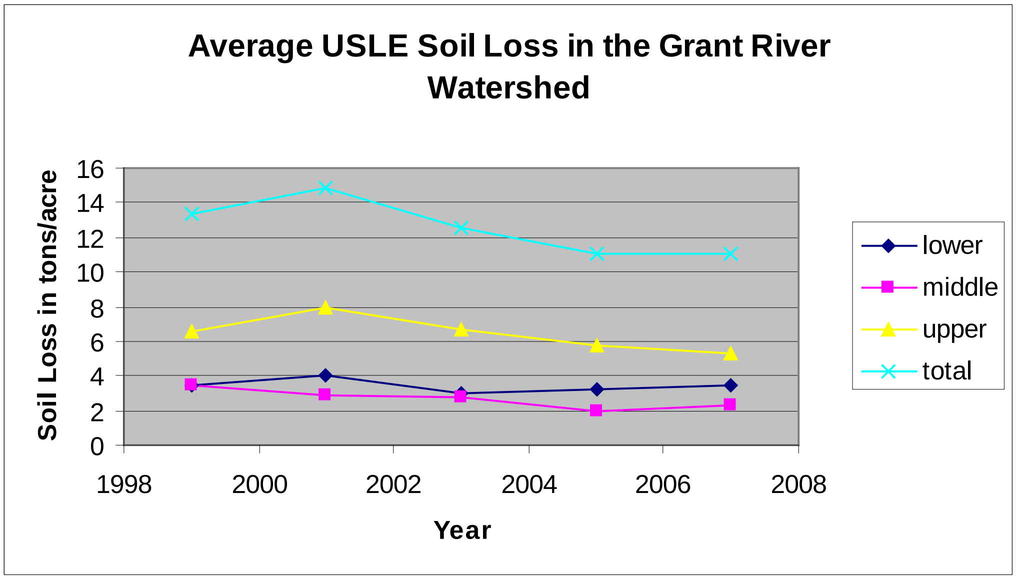

Figure 26 NRCS Transect Survey data. Obtained in 2008.

The discharge of the Grant River was measured by the gage at Burton, Wisconsin, which is in the downstream section of the Grant River. A plot of the discharge values from the gage for the years from 1934 water year until May 2008 shows a slight increase in the baseflow discharge (figure 27). More specifically, there is a significant drop in discharge from 1986 to 1988 and then discharge starts to increase again. The decrease in discharge during 1986-1988 is most likely a result of a major drought that occurred from 1988 to 1989. While the baseflow discharge has been steadily increasing since 1935, peak discharge has been showing a calmer pattern. Peak discharge on the Grant River shows an increasing pattern during the 1930s and 1940s, but then decreases starting in the 1950s and continuing to recent years.

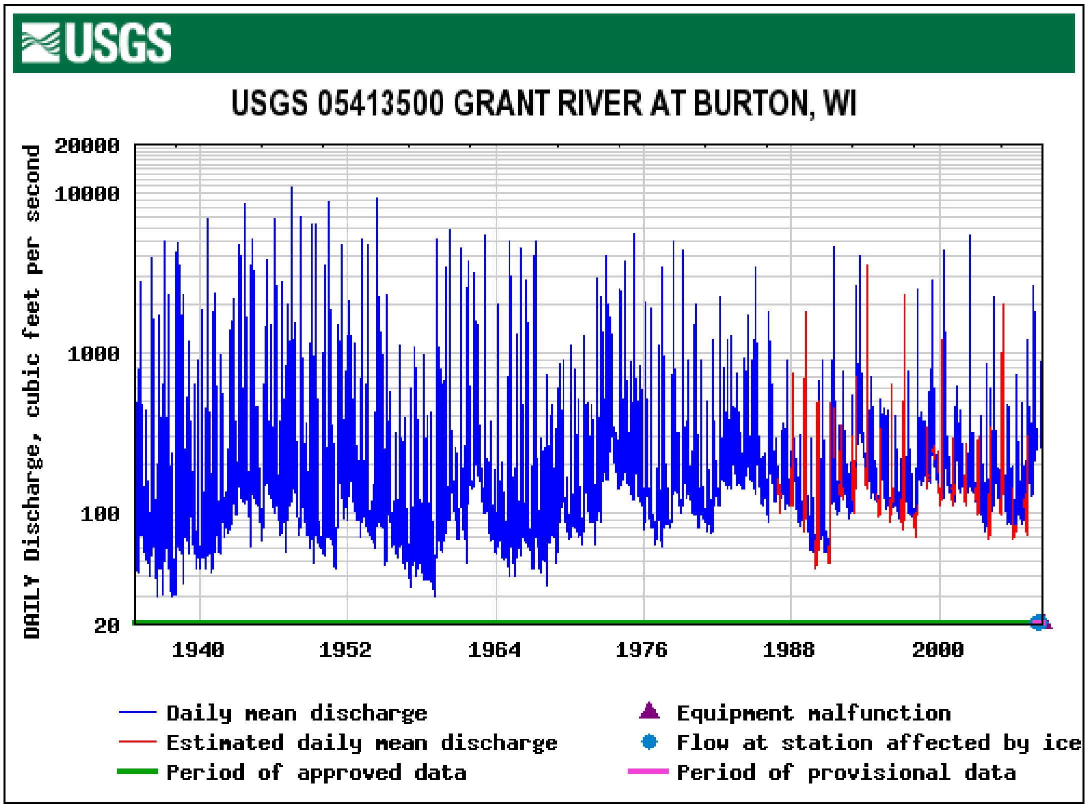

Figure 27 USGS 2008.

To ensure that discharge changes are not a result of precipitation, the precipitation data for Lancaster, Wisconsin, which is located at the north-eastern edge of the Grant River watershed, was analyzed. The average annual precipitation from 1893 to 2007 is 32.6 inches, with a standard deviation of 6.05 (figure 28). Over the past century, annual precipitation has stayed relatively constant, not experiencing an increasing nor decreasing trend (figure 28 and 29). However, the second half of the century has been experiencing slightly higher rates of precipitation than the first half of the century. From 1893 to 1950 precipitation varies from 0.25 standard deviations to -1.0 standard deviations (figure 28). Then, from 1950 to present, precipitation increased but stays relatively constant throughout the period, usually varying around 0.5 standard deviations above the long-term precipitation (figure 28).

During the years when soybeans are planted in large numbers, climate has been relatively stable, with a few years when precipitation was extremely high and a year when precipitation was extremely low (figure 29). The largest flood year was in 1993; however, 1991 and 2007 experienced high amounts of precipitation as well. There was a large drought in 1988 that continued through 1989. The driest year in the soybean record was 1988, with a standard deviation of -1.5.

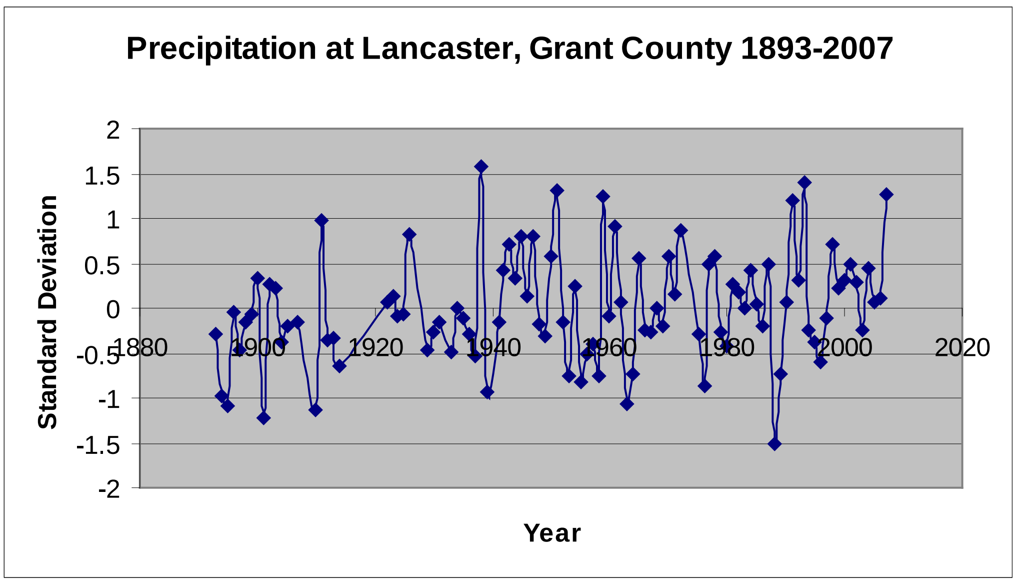

Figure 28 National Climate Data Center 2008. Standard deviation of total annual precipitation at the Lancaster station in Grant County, Wisconsin.

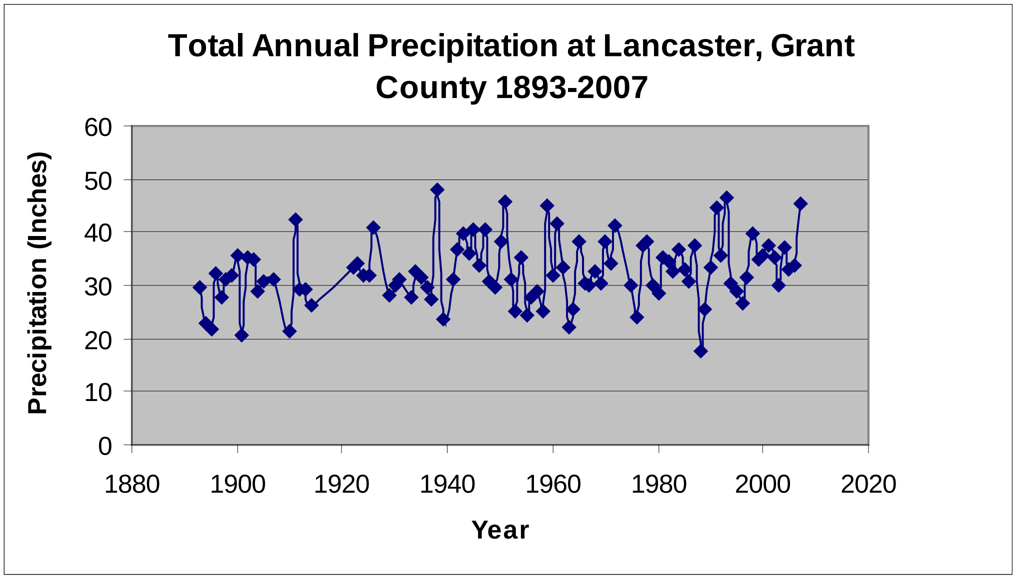

Figure 29 National Climate Data Center 2008.

The daily precipitation pattern from 1893 to present shows no increase in storms that result in a large amount of precipitation (figure 30 and 31). However, when comparing the record from before the soybean era, which starts in 1988, to the record of the soybean era, there is an increase in the frequency of precipitation that is larger than three inches of rain (figure 30 and 31). However, this increase in frequency of precipitation larger than three inches is not reflected in the stream flow record of the Grant River since there has been no significant increase in peak discharge since 1988. However, since the discharge record and precipitation record after 1988 is short, it is difficult to identify more subtle trends that may become clearer with a longer record.

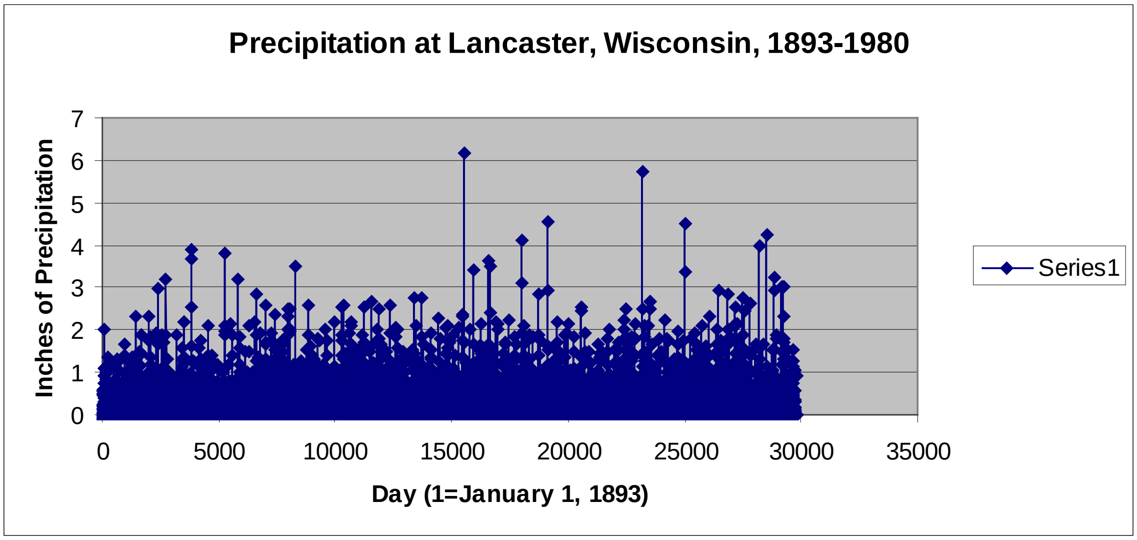

Figure 30 NCDC 2008. Daily precipitation at the Lancaster Station in Grant County, Wisconsin from 1893-1980.

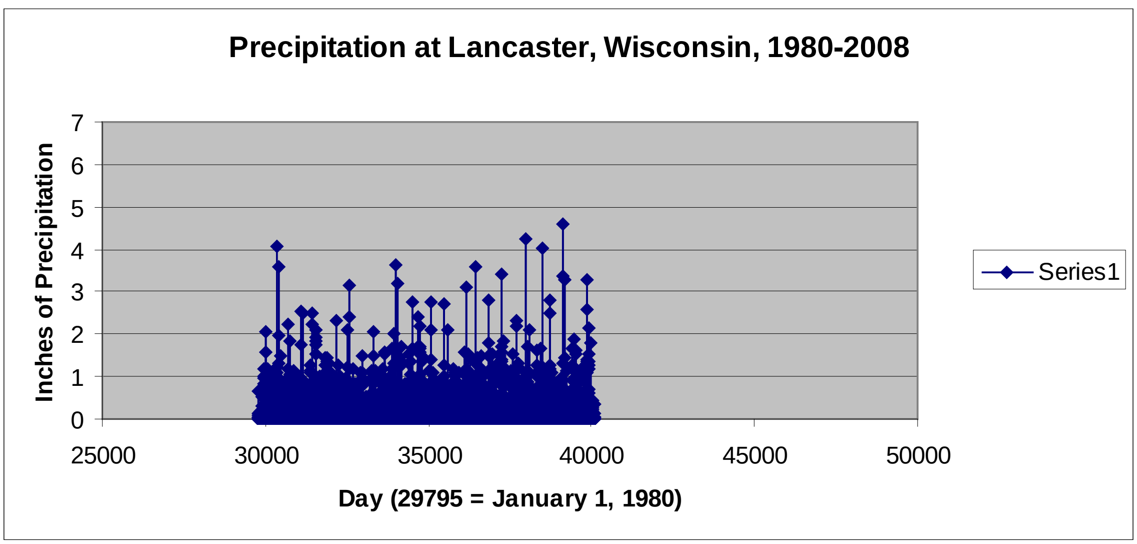

Figure 31 NCDC 2008. Daily precipitation at the Lancaster Station in Grant County, Wisconsin from 1893-1980.

Floodplain sedimentation history reflects flood and drought periods, along with details of the effects of agriculture on erosion and sedimentation in watersheds. In 2006, Knox published a study of floodplain sedimentation in the UMV where he documents historical sedimentation rates at the Yager Site, located in the lower reach of the Grant

River (figure 32). In his study, he found that sedimentation rates increased drastically between 1940 and 1954, and then has were lower since 1954 to the present. The high rates of sedimentation between 1940 and 1954 were primarily a consequence of several very large floods during this time.

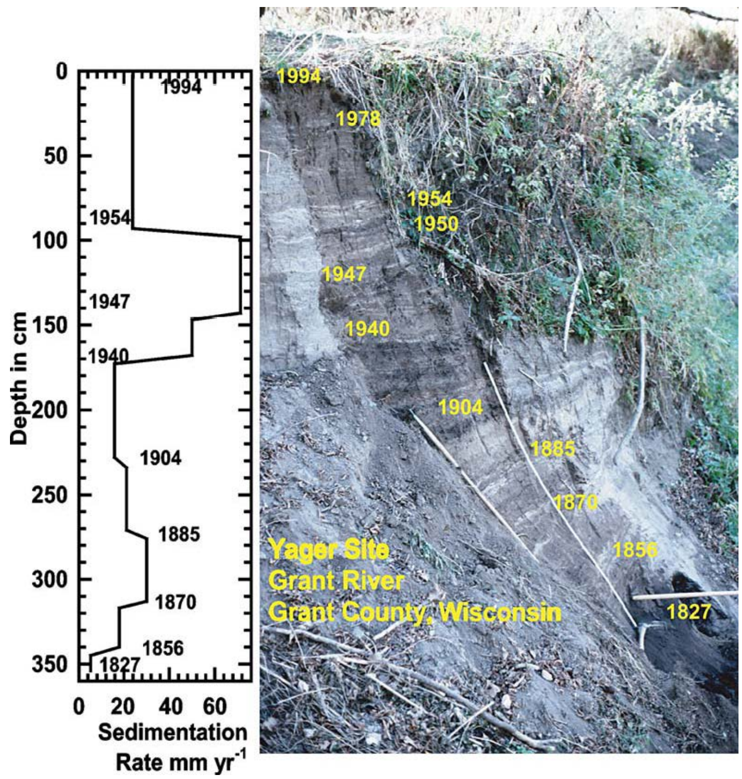

Figure 32: Floodplain sedimentation at the Yager Site on the Grant River. Knox, J.C. 2006. Floodplain sedimentation in the Upper Mississippi Valley: Natural verse human accelerated. Geomorphology 79: 286-310.

Conclusion: Soybean Agriculture and the Grant River Watershed

Discharge Relationships

Correlating the precipitation data for Lancaster, Wisconsin with the discharge data for Grant River shows that precipitation has had little impact on changes in discharge along the Grant River. While the baseline discharge has been slowly increasing, precipitation has remained relatively constant during the 20th century.

One notable impact of precipitation on discharge occurs during the drought years of 1987-1989 when the Grant River discharge experiences a large decrease. The drought coincidently coincides with the year that planted acres of corn decreased and before soybean acreage started to increase. I interpret this decrease in discharge as a result of the drought rather than a result of corn acreage decreasing. After the decrease in discharge during the drought years, the Grant River baseflow discharge began to steadily increase again. If the decrease in discharge were due to a decrease in corn acreage, the discharge should not have started to increase again because the amount of corn planted did not increase.

After the drought in the late 1980s, the baseflow discharge increases rapidly, coinciding with the sharp increase in soybean acreage. When the drought ended, an increase in baseline discharge is expected. However, the increase in baseflow has been continuing even though the drought is over and the amount of precipitation has been relatively constant. Since soybeans are thought to increase surface runoff, thereby decreasing infiltration, this would lead to a decrease in baseflow discharge. However, baseflow discharge has increased rather than decreased, implying that soybeans have not been affecting infiltration and surface runoff to a degree which would influence baseflow discharge.

The decrease in peak discharge shows no correlations with soybean acreage over the past century. Instead, the decline in peak discharge is probably due to improved land use conservation practices which were introduced by the Soil Conservation Service in the 1930s and widespread by the 1950s (Knox 2001, 2006). Included in these improved land use conservation practices are techniques such as contour plowing, strip cropping, fencing woodland, incorporation of crop residue into the soil, crop rotation, and filling of erosion-prone gullies (Johansen 1969; Knox 1977, 1987; Trimble and Lund 1982; Baker 1990; Potter 1991; Argabright et al. 1995; Knox and Hudson 1995; Gebert and King 1996). A study completed by Trimble and Lund (1982) documents the positive influence of improved land management practices on runoff and sedimentation from the years of 1935 through 1975 for the Coon Creek Watershed in the Driftless Area.

Additional agricultural land management that includes conservation tillage practices became widely adopted by the 1970s (Potter 1991). Conservation tillage is defined by the Conservation Technology Information Center as “any tillage or planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water; or where soil erosion by wind is the primary concern, maintains at least 1,000 pounds of flat, small grain residue equivalent on the surface during the critical erosion period.” Christopher Kent (1999), in his study of agricultural land management practices on baseflow discharge in southwest Wisconsin, found that the increasing baseflow trend is due in part to the diffusion of conservation tillage practices.

Figure 5 above shows no significant increase in yearly discharge magnitude for the Grant River after soybean planting started to increase. This is most likely due to increased forest cover, decrease in grazing intensity, and higher density planting of corn (Gebert and King 1996). The combination of these three factors reduces surface runoff, increasing infiltration. As a result, the baseflow discharge experiences an increase while peak flows do not increase with increased soybean acreage.

Floodplain Sedimentation

Because of the development of the historical meander belt in the upper reach of the Grant River, floodplain sedimentation in the lower reach should show a significant increase in the 1980s if soybean farms increase sediment yield to the rivers. However, floodplain sedimentation, as observed at the Yager Site, shows no impacts from the increased acreage of soybeans. The decrease in overbank sedimentation is due at least in part to the increased bank height over the past century. As the bank height rises, it takes increasingly larger floods to result in overbank sedimentation. Additionally, overbank sedimentation that has occurred within the past three years may be attributed more to the large increase in corn agriculture for corn-derived ethanol rather than soybeans. If soybeans caused measurable increases in overbank sedimentation, it would have been shown on the floodplain sediments during the 1990s when soybean agriculture reached its peak.

Since 1954, the reduced rate in erosion and sedimentation is probably due to improved land use practices that include reduced cultivation and grazing of steep hill slopes, introduction of contour plowing, strip cropping, terracing, and high density planting of row crops in association with the heavy use of commercial fertilizer and herbicides (Knox 2006). Additionally, forage crops cover twice as much land in the Grant River watershed than soybeans. This may be a factor in the decreasing soil erosion trend since forage crops provide better coverage of the soil surface, protecting against erosion. Extended crop rotations which include forage crops increase carbon retention in the surface horizon, thereby improving soil physical quality. However forage crops can not be a major factor in the decreasing soil erosion trend since the number of acres planted with forage has not increased. Instead, forage crops may be minimizing the impacts of soybeans through their improvement of soil quality and ability to reduce surface runoff. The forage crop fields may absorb surface runoff from the soybean fields, reducing erosion from fields down hill of the soybean fields and reducing peak river discharge.

The decrease in cattle farming in Grant County may also be responsible for the decrease in eroded soil reaching the Grant River. Cattle accelerate soil erosion through compaction of the soil and depletion of soil of nutrients, leading to increased surface runoff that in turn may erode gullies and downstream channel margins. Hill slope erosion also has been reduced from the reforestation of the steep hill slopes in the Grant River watershed (Woltemade 1994, Potter 1991).

Overall, floodplain sedimentation along the Grant River shows no measurable increase in flood rate or size that can be related to soybeans. I hypothesize that the formation of the meander belt allows the river to carry more water in the upper reach of the stream, which might be hiding the negative effects of soybean cultivation by reducing the number of floods that result in overbank flow and floodplain sedimentation. Therefore, to better assess the effects soybean agriculture has on erosion and sedimentation into streams, smaller tributary floodplains should be studied to see if they have more visible evidence of increased erosion. Smaller tributaries located closer to soybean cropland will be more sensitive to the effects of changes in cropping practices. Additionally, agricultural study plots, such as those of Purdue University, should be set up to measure runoff and erosion when under continuous soybeans and a two-year corn and soybean rotation.

Conservation Programs beginning post-1980

Since the mid-1980s, additional conservation programs have been put into effect by the Farm Services Agency (FSA) to reduce soil erosion and improve water quality. The most advertised and popular of these programs is the Conservation Reserve Program (CRP). CRP was officially initiated in 1985 when Congress passed the Food Securities Act. Since 1985, CRP has been modified twice, once in 1990 by the Food, Agriculture, Conservation, and Trade Act and in 1996 by the Federal Agricultural Improvement and Reform Act (USDA 1997). The first enrollment period for CRP began in 1986. CRP aims to enroll fragile cropland into the program, setting aside acreage from normal cultivation (USDA 1997). Other CRP programs involve planting trees, grass, buffers, and restoring wetlands (USDA 1997). These programs are voluntary on the behalf of the farmers, and farmers can choose to enroll only part of their fields or all of their fields (USDA 1997). Partial field enrollment requires grass filters at field edges and riparian buffers that intercept sediment, nutrients, and other contaminants before entering the waterway (USDA 1997).

The FSA believes that by planting trees, grass, buffers, and restoring wetlands, wildlife populations will increase due to the increased acreage devoted to resource-conserving vegetation covers. FSA also uses these programs to protect groundwater through reducing surface runoff and sedimentation in streams, lakes, rivers, and ponds. By increasing vegetation cover on cropland, topsoil has increased protection from erosion, which in turn reduces the concentration of nitrogen. phosphorous, and sediment in surface runoff and percolate from agricultural fields that enters lakes and streams. It was recently estimated by the Food and Agricultural Policy Research Institute that for the year 2007, CRP reduced nitrogen runoff and percolate by 278 million pounds and phosphorous by 59 million pounds. Overall, this represents a 95% reduction in nitrogen loss and 86% reduction in phosphorous loss from fields.

In addition to decreasing contaminants entering waterways and increasing biodiversity, FSA claims that CRP has improved carbon sequestration. By reducing topsoil erosion, more carbon stays sequestered in the soil. The USDA estimates that CRP has reduced erosion by 470 million tons in 2007 from pre-CRP levels, and as a result, CRP sequesters more carbon on private lands than any other federally-administered program.

CRP data for Wisconsin can be obtained at a county level; however, the watershed level is more difficult due to farmers' privacy rights. Grant County data are available for the years of the program, starting in 1986 through the end of 2007, with data missing for 1989-1996 (figure 33). The acreage used to calculate total CRP land for each year is the amount calculated at the end of the year. However, CRP acreage changes almost daily due to constant revisions in the data (e-mail exchange with Joanne Reynolds from Lancaster FSA Field Office, view appendix C).

From the inception of the program in 1986 to present, there has been a sharp increase in the acreage of land in CRP (figure 33). Acreage of CRP land has been increasing at a rate of 1583.4 acres per year. The first year of CRP, 4884.3 acres were enrolled in Grant County, but by the end of 2007, 44,829.1 acres were enrolled. From 1986 through 2001, CRP enrollment experienced an extremely high rate of increase. In fact, 2001 had nearly a 10-fold increase in acres of CRP from 1986. From 2001 to present, CRP enrollment has leveled off, experiencing increases and decreases by only hundreds of acres (figure 33).

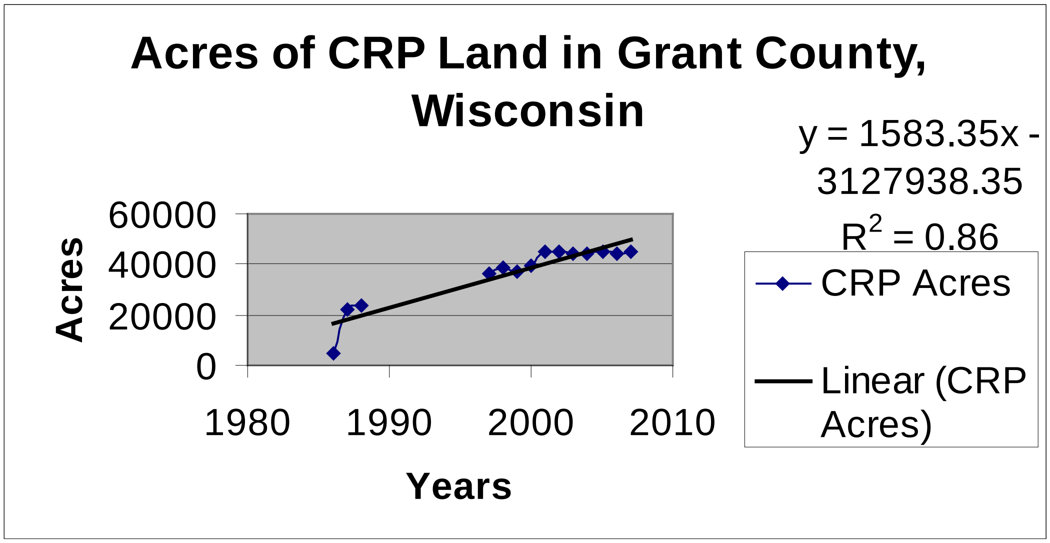

Figure 33 Data obtained from Joanne Reynolds and John Weiderholt from the Grant County Farm Services Agency. 2008.

Of total agricultural land, CRP land currently accounts for over 20% in Grant County (figure 34). When the program first began it accounted only for a mere two percent of the agricultural land. While the percent of agricultural land in the CRP has increased over the past twenty years, the amount of total agricultural land in the county has remained relatively unchanged. Therefore, this increase is due mostly to increases in enrollment rather than decreases in farm land. The increase in participation among farmers shows their concern of erosion and water quality and a desire to decrease their environmental impacts. Other landowners, such as lawyers and doctors, are also common participants because it gives them an easy income without having to farm their land (Knox, written communication 2008).

The high enrollment of CRP land in Grant County may be partially responsible for the increased baseflow discharge and decreased sedimentation experienced in the

Grant River watershed. A study done by Christopher Kent (1999) on the hydrologic impacts of CRP showed a possible positive relationship between CRP as a percent of subbasin area and two hydrologic variables, subbasin baseflow and comtemporary baseflow. While these two positive relationships are consistent with one another and conform to isolated CRP field observations, they are based on a small sample, and therefore, are not statistically significant. When Christopher Kent looked at a larger scale, no relationships were present. However, this is most likely because the subbasins he studied had a low percentage of CRP land. Therefore, it would be useful to repeat his study for the Grant River watershed, where CRP land accounts for nearly 20% of total agricultural land.

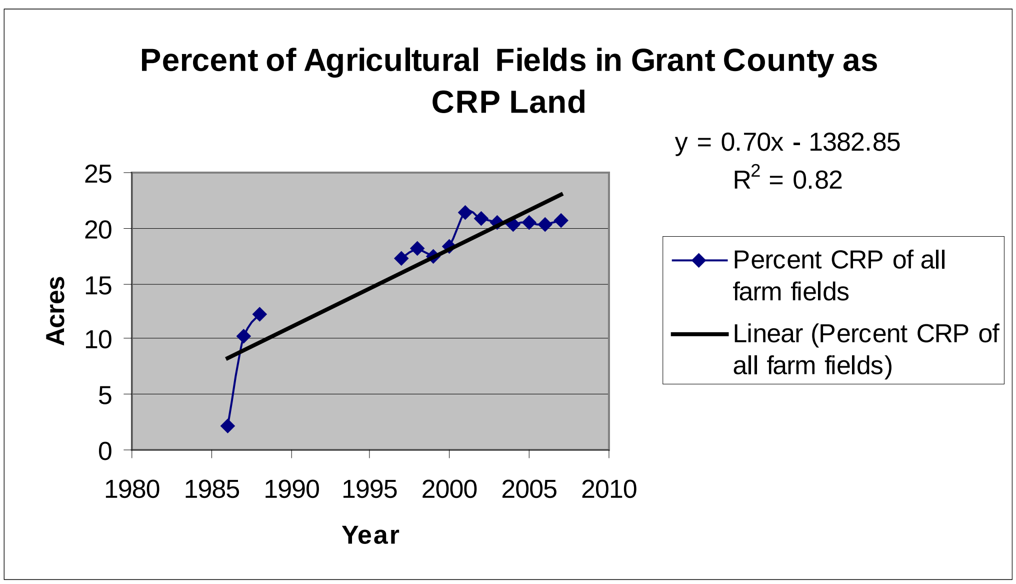

Figure 34 CRP data obtained from Joanne Reynolds and John Weiderholt from the Grant County Farm Services Agency. 2008. Total acres of land used for agriculture obtained for USDA 2008.

Other than the CRP, there are two other new conservation programs in Grant County, the Grassland Reserve Program (GRP) and the Conservation Reserve Enhancement Program (CREP). Both the GRP and CREP are sister programs of CRP that specialize in specific conservation aims of CRP. GRP is a voluntary program where landowners enter into an easement, rental agreement, or restoration agreement with the FSA to conserve their fragile grasslands. The GRP aims to prevent the conversion of vulnerable grassland to other uses, as well as to conserve valuable grasslands by helping maintain viable cattle farming operations. GRP especially supports working grazing operations through funding and planning assistance.

CREP is a voluntary land retirement program that helps agricultural producers protect environmentally sensitive land. CREP is a partnership among producers, and therefore can address larger areas of land than the CRP. However, the overall aims of CREP are the same as those of CRP, including decreasing soil erosion, increasing wildlife habitat, and protecting water sources. The combination of CRP, GRP and CREP all help agricultural producers minimize their impacts on the landscape by reducing soil erosion and surface runoff.

Farmers in Grant County are taking on new methods to conserve their soil and water resources while expanding the types of crops they grow. This combination may be reducing the amount of sediment and runoff from soybean fields entering the Grant River watershed, masking the damaging effects that soybean agriculture has on soil physical quality. As a result, increased precipitation is probably infiltrating the soil, increasing the baseflow discharge of the Grant River watershed and other watersheds in Grant County.

Overall, I believe that the increase in soybean acreage has yet to have any significant impacts on fluvial processes in the Grant River watershed. Since the baseflow discharge of the Grant River watershed has increased, soybeans have had no visible impacts on surface runoff and infiltration. Soil conservation practices are known to increase baseflow discharge in catchment basins (Potter 1991). The combination of new conservation programs, such as CRP, GRP, and CREP, as well as changes in land use, such as increased forest cover, lack of grazing intensity, and higher density planting of corn, is most likely responsible for the increased baseflow discharge.

Appendix A

Soil Abbreviation	Soil Type
Ar	Arenzville silt loam
DoC2	Downs silt loam, 6 to10 percent slopes, moderately eroded
DsB	Dubuque silt loam, 2 to 6 percent slopes
DsB2	Dubuque silt loam, 2 to 6 percent slopes, moderately eroded
DsC2	Dubuque silt loam, 6 to 10 percent slopes, moderately eroded
DsD2	Dubuque silt loam, 10 to 15 percent slopes, moerately eroded
DsE2	Dubuque silt loam, 15 to 20 percent slopes, moderately eroded
DsF2	Dubuque silt loam, 20-30 percent slopes, moderately eroded
DtB	Dubuque silt loam, deep, 2 to 6 percent slopes
DtB2	Dubuque silt loam, deep, 2 to 6 percent slopes, moderately eroded
DtC2	Dubuque silt loam, deep, 6 to 10 percent slopes, moderately eroded
DtD2	Dubuque silt loam, deep, 10 to 15 percent slopes, moderately eroded
DtE2	Dubuque silt loam, deep, 15 to 20 percent slopes, moderately eroded
DtF2	Dubuque silt loam, deep, 20 to 30 percent slopes, moderately eroded
DuC2	Dubuque soils, 6 to 10 percent slopes, moderately eroded
DuD2	Dubuque soils, 10 to 15 percent slopes, moderately eroded
DuE2	Dubuque soils, 15 to 20 percent slopes, moderately eroded
DuF2	Dubuque soils, 20 to 30 percent slopes, moderately eroded
DvB2	Dubuque soils, deep, 2 to 6 percent slopes, moderately eroded
DvC2	Dubuque soils, deep, 6 to 10 percent slopes, moderately eroded
DvD2	Dubuque soils, deep, 10 to 15 percent slopes, moderately eroded
DvE2	Dubuque soils, deep, 15 to 20 percent slopes, moderately eroded
DvF2	Dubuque soils, deep, 20 to 30 percent slopes, moderately eroded
FaB2	Fayette silt loam, 2 to 6 percent slopes, moderately eroded
FaC2	Fayette silt loam, 6 to 10 percent slopes, moderately eroded
FaD2	Fayette silt loam, 10 to 15 percent slopes, moderately eroded
FaE2	Fayette silt loam, 15 to 20 percent slopes, moderately eroded
FaF2	Fayette silt loam, 20 to 30 percent slopes, moderately eroded
TaA	Tama silt loam, 0 to 2 percent slopes
TaB	Tama silt loam, 2 to 6 percent slopes
TaB2	Tama silt loam, 2 to 6 percent slopes, moderately eroded
TaC2	Tama silt loam, 6 to 10 percent slopes, moderately eroded
TaD2	Tama silt loam, 10 to 15 percent slopes, moderately eroded

Appendix B

E-mail exchange between Joanne Reynolds and Samantha Greene:

From	"Reynolds, Joanne - Lancaster, WI" <Joanne.Reynolds@wi.usda.gov>
Sent	Friday, April 11, 2008 2:02 pm
To	SAMANTHA LAUREN GREENE <greene1@wisc.edu>
Subject	RE: CRP data

I do not have a breaddown of CRP acres that are located in the Grant River watershed. And the acreage in CRP changes almost daily, due to constant revisions. As of 01/24/08 there were 1435 contracts totalling 44829.1 acres. I also cannot run this report for prior years, and do not have a record of contract acreage as of the end of each year, or anything like that. I am forwarding your request to Jack in case he has an annual report in the minutes that could help you.

Good luck with your project.
Jo

-----Original Message-----
From: SAMANTHA LAUREN GREENE [mailto:greene1@wisc.edu]
Sent: Tuesday, April 08, 2008 9:01 PM
To: Reynolds, Joanne - Lancaster, WI
Subject: CRP data

Dear Ms. Reynolds,

I am currently a student at UW-Madison working on my honors thesis which is focusing on erosion and sedimentation in the Grant River watershed. I was at the FSA office last friday (April 4) to talk to John Wiederholt and collect some data. I was hoping to get some information on the Conservation Reserve Program in Grant County, and if possible, Grant River watershed and was advised to contact you.

I was wondering if you would have numbers on how much land in the Grant River Watershed is in the CRP for years dating back as far as possible. If you do not have it at the watershed scale, county scale would be fine as well.

I am trying to find reasons for the decrease in erosion and sedimentation that has taken place in the last 20 years so any information on the CRP would be helpful. My e-mail is greene1@wisc.edu and phone is 301-675-9014. I look forward to hearing from you.

Sincerely,
Samantha Greene
greene1@wisc.edu

E-mail exchange between John Weiderholt and Samantha Greene:

From	"Wiederholt, John - Lancaster, WI" <John.Wiederholt@wi.usda.gov>
Sent	Tuesday, April 15, 2008 9:14 am
To	greene1@wisc.edu
Subject	Grant County CRP

Samantha,

I believe Jo Reynolds gave you the 2007 acreage numbers. After checking all my sources and records I was able to come up with some incomplete numbers. These are all we have:
1986- 4884.3 (first year of CRP)
1987-22118.7
1988-23377.0
1989 through 1996 are not available
1997 - 36300.3
1998 - 38662.1
1999 - 37422.2
2000 - 39673.9
2001 - 45192.5
2002 - 45166.8
2003 - 44508.7
2004 - 44538.5
2005 - 44799.6
2006 - 44309.3

John L. Wiederholt, County Executive Director
Grant County Farm Service Agency
Phone 608-723-7697
FAX 608-723-7793

References

Adams, C. 1940. Modern Sedimentation in the Galena River Valley. M.S. Thesis, University of Iowa, Iowa City, Iowa, 72pp.

Adams, C. 1942. Accelerated Sedimentation in the Galena River Valley. Ph.D. Thesis, University of Iowa, Iowa City, Iowa, 67pp.

Argabright, S., R.G. Cronshey, J.D. Helms, G.A. Pavelis. and R. Sinclair. 1995. Historical Changes in Soil Erosion, 1930-1992, the Northern Mississippi Valley Loess Hills. Economic Research Service, Natural Resources Conservation Service. U.S. Department of Agriculture: Washington, D.C.

Baker, J.P. 1990. An Analysis of the Surface Hydrology in the Galena Watershed: 1940-1987. Masters Thesis, Department of Geography, University of Wisconsin-Madison.

Baker, R.G., E.A. Bettis III, R.F. Denniston, L.A. Gonzalez, L.E. Strickland, J.R. Kreig. 2002. Holocene Paleoenvironments in Southeastern Minnesota – Chasing the Prairie-Forest Ecotone. Paleogeography, Paleoclimatology, Paleoecology 177 (1-2): 103-122.

Beach, T. 1994. The Fate of Eroded Soils: Sediment Sinks and Sediment Budgets of Agrarian Landscapes in Southern Minnesota, 1851-1988. Annals of the Association of American Geographers 84: 5-28.

Blanchard, W.O. 1924. The Geography of Southwestern Wisconsin. Wisconsin Geological and Natural History Survey, Bulletin, vol. 65. Madison, Wisconsin. pp. 117.

Boardman, J. 1993. The Sensitivity of Downland Arable Land to Erosion by Running Water. In: Thomas, D.S.G., Allison, R.J. (Eds.), Landscape Sensitivity. Wiley, Chichester, pp. 211-228.

Doolittle, W.E. 1992. Agriculture in North American on the Eve of Contact: A Reassessment. Annals of the Association of American Geographers 82: 386-401.

Doran, J.W. and T.B. Parkin. 1996. Quantitative Indicators of Soil Quality: A Minimum Data Set. In: J.W. Doran and A.J. Jones (ed.), Methods for Assessing Soil Quality. SSSA Special Publication 49. SSSA, Madison, WI.

Fahad, A.A., L.N. Mielke, A.D. Flowerday, and D. Swatzendruber. 1982. Soil Physical Properties as Affected by Soybean and other Cropping Sequences. Soil Science Society of America Journal 46: 377-381.

Gebert, W.A. and W.R. Krug. 1996. Streamflow Trends in Wisconsin's Driftless Area. Water Resources Bulletin 32(4): 733-744.

Havlin, J.L., D.E. Kissel, L.D. Maddux, M.M. Classen, and J.H. Long. 1990. Crop Rotation and Tillage Effects on Soil Organic Carbon and Nitrogen. Soil Science Society of America Journal 54: 448-452.

Heyl, A.V., A. F. Agnew, E.J. Lyons, A.E. Behre. 1959. The Geology of the Upper Mississippi Valley Zinc-Lead District. U.S. Geological Survey Professional Paper, vol. 309. Washington, D.C., 310pp.

Holford, C.N. 1900. History of Grant Country, Wisconsin. The Teller Print, Lancaster, WI, 783 pp.

Johansen, H.E. 1969. Spatial Diffusion of Contour Strip Cropping in Wisconsin. Masters Thesis, Department of Geography, University of Wisconsin-Madison.

Karlen, D.L., G.E. Varvel, D.G. Bullock, and R.M. Cruse. 1994. Crop Rotations for the 21st Century. p. 1-45. In: D.L. Sparks (ed.) Advances in Agronomy. Vol. 54. Academic Press, San Diego.

Karlen, D.L., E.G. Hurley, S.S. Andrews, C.A. Cambardella, D.W. Meek, M.D. Duffy, and M.P. Mallarino. 2006. Crop Rotation Effects on Soil Quality at Three Northern Corn/Soybean Belt Locations. Agronomy Journal 98: 484-495.

Kent, Christopher. 1999. The Influence of Changes in Land Cover and Agricultural Land Management Practices on Baseflow in Southwest Wisconsin, 1969-1998. Dissertation, University of Wisconsin-Madison.

Knox, J.C. 1977. Human Impacts on Wisconsin Stream Channels. Annals of the Association of American Geographers 67(3): 323-342.

Knox, J.C. 1987. Historical Valley Floor Sedimentation in the Upper Mississippi Valley. Annals of the Association of American Geographers 77: 224-244.

Knox, J.C. 2001. Agricultural Influence on Landscape Sensitivity in the Upper Mississippi River Valley. Catena 42: 193-224.

Knox, J.C. 2006. Floodplain Sedimentation in the Upper Mississippi Valley: Natural versus Human Accelerated. Geomorphology 79: 286-310.

Knox, J.C. 2007. The Mississippi River System. Department of Geography, University of Wisconsin, Madison, 58pp.

Knox, J.C. and J.C. Hudson. 1995. Physical and Cultural Change in the Driftless Area of Southwest Wisconsin. In: *Geographical Excursions in the Chicago Region*, ed. by M.P. Conzen. Association of American Geographers: Washington, D.C. pp. 107-131.

Lecce, S.A. 1997. Spatial Patterns of Historical Overbank Sedimentation and Floodplain Evolution, Blue River, Wisconsin. Geomorphology 18: 265-277.

Lecce, S.A. and R.T. Pavlowsky. 2001. Use of Mining-Contaminated Sediment Tracers to Investigate the Timing and Rates of Historical Flood Plain Sedimentation. Geomorphology 38: 85-108.

Liebig, M.A., G.E. Varvel, J.W. Doran, and B.J. Wienhold. 2002. Crop Sequence and Nitrogen Fertilization Effects on Soil Properties in the Western Corn Belt. Soil Science Society of American Journal 66: 596-601.

Martens, D.A. 2000. Management and Crop Residue Influence Soil Aggregate Stability. Journal of Environmental Quality 29: 723-727.

Mason, J.A. and J.C. Knox. 1997. Age of Colluvium Indicates Accelerated Late Wisconsin Hillslope Erosion in the Upper Mississippi Valley. Geology 25: 267-270.

Natural Resources Conservation Service. 1999-2007. Transect Survey. Natural Resources Conservation Service: Lancaster, Wisconsin.

Ostergren, R.C. and Vale, T.R. 1997. *Wisconsin Land and Life*. University of Wisconsin Press, Madison 567pp.

Potter, K.W. 1991. Hydrological Impacts of Changing Land Management Practices in a Moderate-Sized Agricultural Catchment. Water Resources Research 27: 845-855.

Robinson, G.H. and A.J. Klingelhoets. 1961 and 2007. Soil Survey, Grant County Wisconsin. U.S. Department of Agriculture, Soil Conservation Service. In cooperation with the Wisconsin Geologic and Natural History Survey and

Wisconsin Agricultural Experiment Station, University of Wisconsin. Series 1951, Number 10. U.S. Government Primting Office: Washington, D.C.
Shafer, J. 1932. The Wisconsin Lead Region. State Historical Society of Wisconsin, Madison, 314 pp.
Soper, J. D. Judd, D. Schmidt, S.Sullivan. 2003. The Future of Biotechnology in Soybeans. Journal of Agrobiotechnology Management and Economics 6: 8-10.
Starkel, L. 1987. Man as a Cause of Sedimentological Changes in the Holocene: Anthropogenic Sedimentological Changes During the Holocene. Striae 26: 5-12.
Storey, H.C., R.L. Hobba, and J.M. Rosa. 1964. Hydrology of Forest Lands and Rangelands. In: Chow, V.T. (ed.), Handbook of Applied Hydrology. McGraw-Hill, New York, pp. 1-22.
Studdert, G.A. and H.E. Echeverria. 2000. Crop Rotations and Nitrogen Fertilization to Manage Soil Organic Carbon Dynamics. Soil Science Society of America Journal 64: 1496-1503.
Trewartha, G.T. 1940. The Vegetal Cover of the Driftless Cuestaform Hill Land: Presettlement Record and Postglacial Evolution. Transactions of the Wisconsin Academy of Sciences, Art and Letters 32: 361-382.
Trimble, S.W. and S.W. Lund. 1982. Soil Conservation and the Reduction of Erosion and Sedimentation in the Coon Creek Basin, Wisconsin. U.S. Geological Survey Professional Paper 1234. U.S. Government Printing Office: Washington, D.C.
Trimble, S.W. 1999. Decreased Rates of Alluvial Sediment Storage in Coon Creek Basin, Wisconsin, 1975-93. Science 285: 1244-1246.
U.S. Department of Agriculture. 1997. The Conservation Reserve Program. Farm Service Agency, U.S. Department of Agriculture: Washington, D.C.
U.S. Department of Agriculture. 2002. National Bulletin 450-2-2: 2002 National Crop Residue Management Survey. Natural Resources Conservation Service: Washington, D.C.
Varvel, G.E. 1994. Rotation and Nitrogen Fertilization Effects on Changes in Soil Carbon and Nitrogen. Agronomy Journal 86: 319-325.
Woltemade, C.J. 1994. Form and Process: Fluvial Geomorphology and Flood-Flow Interaction, Grant River, Wisconsin. Annals of the Association of American Geographers 84: 462-479.
Wisconsin Department of Agriculture, Trade and Consumer Protection. 1998. T by 2000-Soil Erosion Control Efforts and Accountability. Presentation by Dave Jelinski, Director. Land and Water Resources Bureau.