Modernizing Wisconsin

Groundwater Management:

Reforming the High Capacity Well Laws

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MODERNIZING WISCONSIN GROUNDWATER MANAGEMENT: REFORMING THE HIGH CAPACITY WELL LAWS

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EXECUTIVE SUMMARY

Although Wisconsin has one of the most comprehensive groundwater quality protection laws in the nation, the legal framework for managing groundwater quantity has become a serious concern as demands for water increase. This report is not intended to be a comprehensive study of water resources management in the state. Rather, its focus is on high capacity wells, groundwater-surface water interactions and environmental impacts. This report discusses the potential impacts of high capacity wells on the environment, summarizes the existing law for managing groundwater quantity in Wisconsin, reviews programs in selected states, and discusses issues and strategies for improving groundwater quantity management in Wisconsin.

Groundwater is the major source of water supply in Wisconsin, where an average of 759 million gallons of groundwater is withdrawn each day. Groundwater pumping has been associated with substantial declines in groundwater levels in Wisconsin. While field data on environmental impacts of groundwater pumping is very limited, cases reported here illustrate potential problems. In Madison, water table levels have dropped three to six feet, threatening arboretum wetlands and fens. Irrigation pumping has reduced streamflow by 25-30% in the Central Sands Plain region; projected pumping rates indicate that the Little Plover River faces severe ecological impacts. Bloody Run Creek, a Class 1 trout stream, has been dewatered by high capacity wells.

The current high capacity well laws are inadequate to manage and protect Wisconsin's groundwater and related environmental resources. Water use has grown 33% over the past 15 years and is likely to continue rising into the future. The Wisconsin Department of Natural Resources (WDNR) has explicit authority to restrict permits for high capacity wells only in cases where the supply of water to a public utility well may be impacted. Further, the WDNR has not routinely required high capacity well users to report water use, except in the case of impact to a public utility well, so water use is largely based on estimates.

While increased scientific understanding of surface water and ecological impacts from groundwater withdrawals is needed in Wisconsin, several other states have modernized their statutes and management practices so as to acknowledge the hydraulic continuity between surface water and groundwater. Florida has an integrated permitting process that ensures biological input and review. Minnesota has provisions to adapt management programs and incorporate new information as it becomes available. Oregon and Washington address groundwater management in a broader watershed and planning context. All four states include public interest and environmental protection criteria in the permit review process.

To close the gaps in groundwater resource management without pursuing statutory changes, Wisconsin could pursue citizen suits involving the public trust doctrine, expand on nuisance common law, and exercise agency discretionary authority to enforce existing statutory language.

We identify several issues that any new legislation for improved groundwater quantity management should address, including: explicit legislative recognition of hydraulic continuity; expanded criteria for review and permitting; program targeting; monitoring, reporting and data acquisition strategies; exemptions; cumulative impacts and future uses; and continuing research support. As the new century begins, Wisconsin has the opportunity to be proactive in addressing these issues and enhance protection of the quantity and quality of its "buried treasure."

PREFACE AND ACKNOWLEDGMENTS

This report is the result of a project undertaken in my graduate seminar on "Water Resources Policies and Institutions." It was written, reviewed and finalized in the spring and summer of 2000 – a period when the Perrier Group of America announced plans for wells and a bottling plant in the headwaters of one of Wisconsin's outstanding trout streams. The proposal gave rise to intense public controversy and became a well-publicized statewide issue. Rather than a singular battle among interests over the allocation and use of a local resource, the issue focused public attention on the adequacy of state laws pertaining to groundwater withdrawals to protect public resources – particularly interconnected surface waters and related environmental resources. Legislative proposals for changes in the state's high capacity well laws were introduced in mid-year. Although they were not passed, the issue will clearly be revisited in upcoming legislative sessions.

The opportunity now exists to begin to address proactively the task of modernizing the legal framework for effectively managing our groundwater and related resources to meet societal demands in the new century. Although we are concerned with more comprehensive and integrated management of all of our state's environmental resources, we limit our focus in this report to the array of issues likely to arise in legislative efforts to modify the legal framework related to high capacity wells. Working within the budgetary and time constraints of a class project, the research team has attempted to illuminate key issues and provide a better information base in support of the public dialog among policy-makers, agencies, interest groups and citizens as they contemplate changes.

This project could not have been completed without the cooperation and contributions of many organizations and individuals. We would like to acknowledge the following people for their generous assistance with this undertaking:

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INTRODUCTION

Groundwater is one of Wisconsin's most vital natural resources. It is our major source of water supply, providing water for domestic, municipal, industrial and agricultural uses. Groundwater is the source of water for approximately 97% of Wisconsin communities and 70% of the population. Statewide, groundwater withdrawals in 1985 were estimated at 570 million gallons per day (gpd; Lindorff et al., 1997); in the past 15 years, that figure has increased to roughly 759 million gallons daily (Chern et al., 1999; Figure 1).

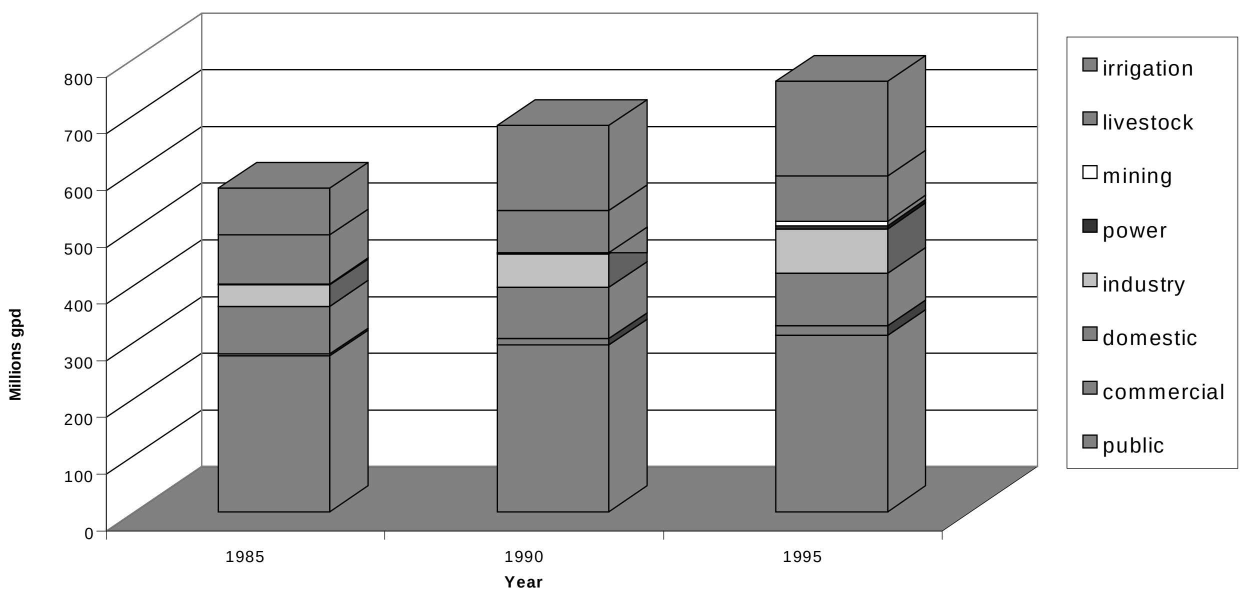

Figure 1. Groundwater use trends in Wisconsin over time (1985-1995).
Source: Lawrence & Ellefson, 1982; Ellefson et al., 1993; Ellefson et al., 1997

Recognizing both our dependence on clean adequate supplies of groundwater and increasing pollution threats to the resource, in 1983 – following several years of debate – Wisconsin enacted one of the most comprehensive groundwater protection laws in the nation. The law focused on groundwater quality and was largely regulatory in nature (Kent, 1994).

In contrast, the inextricably related issue of groundwater quantity has never been addressed comprehensively. Perhaps this lack of legislative and policy action stems from the recognition that Wisconsin's climate and geology have resulted in large, extensive aquifers that store and transmit enormous amounts of water and are readily taken for granted. The Wisconsin Department of Natural Resources (WDNR) estimates that two million billion (**2,000,000,000,000,000**) gallons of groundwater are stored in state aquifers. Groundwater supplies are not distributed homogeneously across the state; geology and hence aquifer characteristics vary. This variability, coupled with growth in regional populations and demands for water, has resulted in serious concerns in some areas of the state with regard to declining groundwater levels and the long-term adequacy of groundwater supplies (particularly southeastern Wisconsin, the Lower Fox River Valley, and Dane County). Periodic droughts have also created a sense of urgency over the years, but public and political attention tends to fade with the end of droughts.

Wisconsin enacted a high capacity well law in 1945 which regulates groundwater withdrawals greater than 100,000 gpd; applications for permits can be denied where any such well(s) adversely affect or reduce the availability of water to any public utility furnishing public water supplies. There have been numerous attempts over the years – all largely unsuccessful – to expand the scope and efficacy of laws governing the withdrawal of Wisconsin groundwater. In 1971, the Natural Resources Council of State Agencies recommended a study to identify specific groundwater use problems which could be alleviated by change of the present laws, including the relationship to surface waters. In 1977, a legislative proposal was drafted by Prof. James MacDonald, University of Wisconsin-Madison, and introduced (AB 1026) which would have established a water appropriation permit system. This comprehensive groundwater and surface water legislative proposal – developed during drought conditions – was never adopted. Wisconsin Act 60 (the Water Resources and Conservation Act), enacted in 1985 to fulfill Wisconsin's commitments under the Great Lakes Charter, addressed water quantity management by providing additional criteria (proposed withdrawals and uses "...will not be detrimental to the public interest....(and) will not have a significant detrimental effect on the quantity and quality of the waters of the state") for consideration in approving high capacity wells, but these criteria applied only to new wells with very large pumpage thresholds – more than two million gpd. Act 60 also directed the WDNR to prepare a statewide water quantity resources management plan, which was published in 1988. This nine-volume plan, a little utilized but useful summary of water quantity issues in the state, contained a number of recommendations to improve water quantity management in Wisconsin. In subsequent years, various state agency staff made recommendations to broaden the regulation of high capacity wells, with an emphasis on how to consider environmental effects of such wells. In 1994, the state Groundwater Coordinating Committee requested the WDNR to prepare a report on groundwater quantity issues. The report, completed in 1997 (Lindorff et al.) provides an excellent overview of groundwater quantity problems and issues, with several recommendations, including a call to evaluate regulation of water withdrawals.

During the past year, the Perrier Group of America, a water bottling corporation, revealed a groundwater development proposal and associated bottling plant in the vicinity of the headwater springs of one of central Wisconsin's finest trout streams. This proposal catalyzed a highly publicized and contentious controversy among an array of interests in the state, focused on the adequacy of state laws pertaining to groundwater withdrawals to protect public resources. Although the proposed locations for development of Perrier's water supply wells and related production facilities have changed, the public policy issues associated with the proposal are very much alive. Recent legislative proposals (AB 775 and SB 414) died, but the issue is likely to be revisited in upcoming legislative sessions. These proposals in general provided that if a proposed high capacity well adversely affects public rights in navigable waters, the application must be denied or conditioned to eliminate adverse impacts.

While water management in some states is still governed by laws that are blind to the hydrologic realities that ground and surface waters are interconnected – in spite of the advances in the sciences of hydrology and hydrogeology in recent decades – many states have been modernizing their laws, administrative rules, and management practices to recognize the interconnections (Glennon & Maddock, 1997). Moreover, groundwater is now increasingly recognized not only as an economic resource, but also as an environmental resource that is critical to the health of wetlands and water resources. It has become clear that groundwater pumping can directly or indirectly affect streams, rivers, wetlands, lakes and their ecologic processes. The Wisconsin Supreme Court in the benchmark 1974 decision in *State v. Michels Pipeline Construction, Inc.* recognized that we have advanced our knowledge greatly from the time of the classic 1903 *Huber v. Merkel* case, which had defined groundwater rights in Wisconsin. The Court in its *Huber* holding accepted the rationale that the ways of underground water were too mysterious and unpredictable to allow the establishment of adequate and fair rules for regulation of competing groundwater rights. In *Michels Pipeline,* the Court brought our laws more in harmony with modern scientific principles and understanding.

As the 21st century begins, there is every indication that managing the growing and competing demands on Wisconsin's ground and surface waters will be a critical public policy issue. We believe that the opportunity now exists to begin to address proactively the task of modernizing the legal framework for effectively managing our water and related resources. While the state may proceed somewhat incrementally – issue by issue – issues can and should be addressed within a more comprehensive and science-based context.

This report – limited in its focus – has been prepared to assist policy-makers, agencies, interest groups and citizens in better understanding and addressing the issues and choices associated with modernizing Wisconsin's legal framework for managing/regulating high capacity wells and the affected natural resources.

HIGH CAPACITY WELLS IN WISCONSIN

High capacity wells are wells that pump at least 100,000 gpd, or 70 gallons per minute (gpm). Operators of high capacity wells need to obtain a permit from the WDNR (§281.17(1) Wis. Stats.). Permit applications will be denied if the proposed withdrawal will adversely affect or reduce the availability of water to any public utility. The application must also comply with §281.35(5)(d) Wis. Stats. if the proposed water loss averages over two million gpd.

There are approximately 9,422 high capacity wells in Wisconsin (WDNR, 2000, http). The majority of these wells (37%) are located in west central Wisconsin, followed by northeastern Wisconsin (20%), south central (19%), southeastern (15%) and northern (9%; Figure 2). Approximately 14% of the state's high capacity wells are inactive (11%) or have been abandoned (3%).

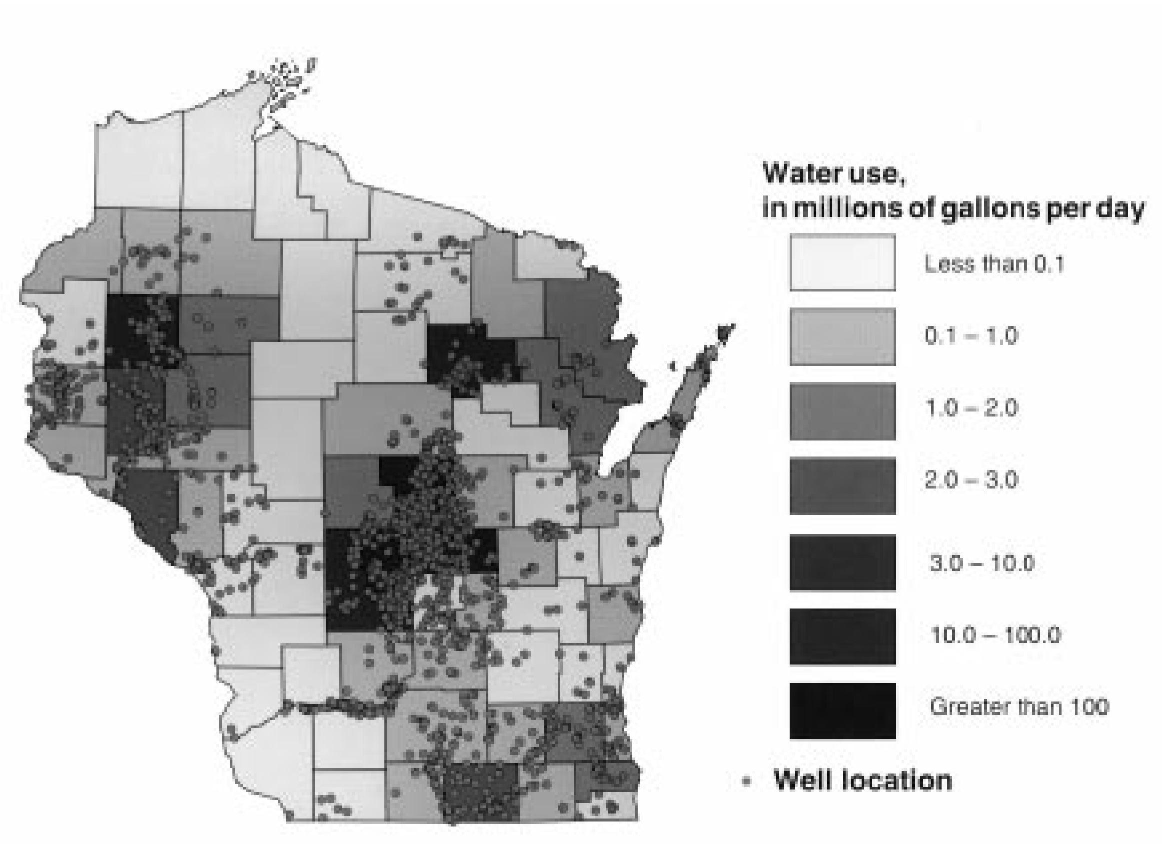

Figure 2. Distribution of high capacity wells.
Source: Ellefson et al., 1997

High capacity wells in Wisconsin are used primarily for agriculture (44%), municipal water supply (18%) and industry (12%; Figure 3). They are also used for schools, state institutions, non-municipal (e.g., mobile home parks, apartment buildings), and miscellaneous purposes (e.g., water bottling operations, breweries).

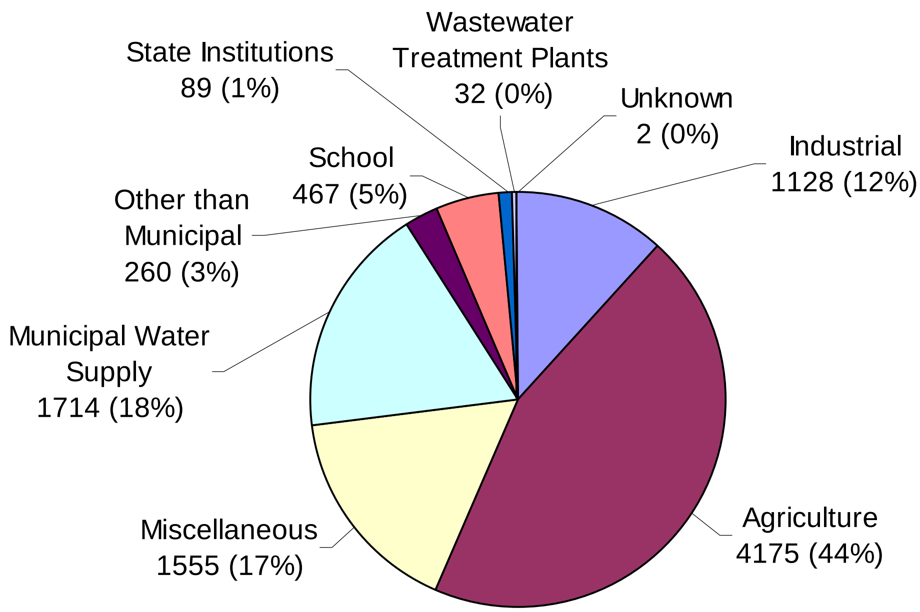

Figure 3. High capacity wells are used for a variety of purposes.
Source: WDNR, 2000, http

SOME HYDROGEOLOGIC BASICS

Hydrogeology is the study of the interrelationships of geologic materials and water (Fetter, 1994). See Appendix A for a brief discussion of groundwater concepts and terminology. The major water quantity impact of withdrawing groundwater from a high capacity well is the decline of water levels in the aquifer and the decrease in flows to surface water bodies or the inducement of flow out of surface water bodies to the underlying aquifer and ultimately to the well. The decline in water level is greatest near the well and decreases with distance from the well. This decline in water level is often referred to as the cone of depression, owing to the shape of this decline in water level in the aquifer (Figure 4).

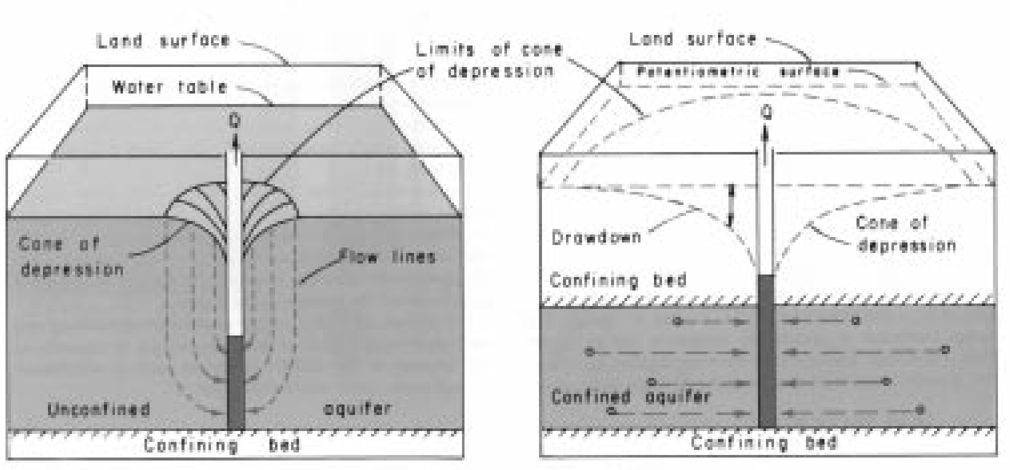

Figure 4. The cone of depression is greatest near the well.
Source: Heath, 1983

If another well is pumped nearby, the cones of depression around each well may intersect and increase the decline in water level in the aquifer, and the water level in each well. This effect is known as ***well interference***. If several wells are pumping from an aquifer and the cones of depression around each well intersect, the head throughout the aquifer will decline (Figure 5). In this case, the depth from which groundwater must be pumped in each well increases, increasing the pumping cost. The water levels in flowing artesian wells may fall, decreasing the flow rate, or if the water level falls below the land surface, the well will cease to flow without the aid of a pump. Shallower wells in unconfined aquifers go dry if the water level in the aquifer declines below the elevation of the well.

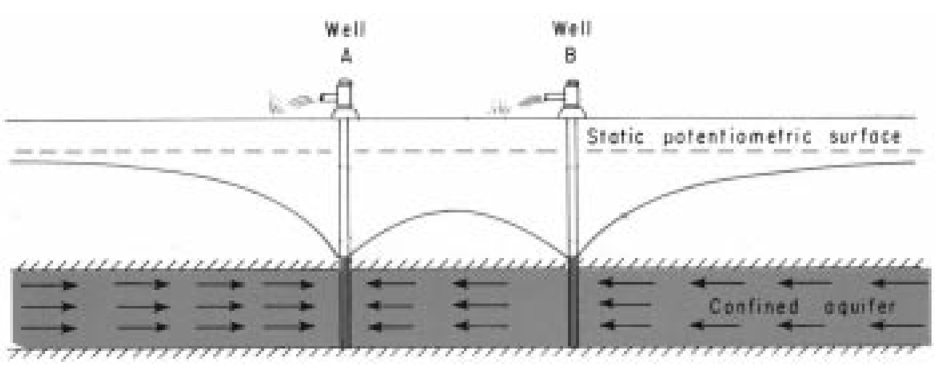

Figure 5. Intersecting cones of depression may result in well interference.
Source: Heath, 1983

Groundwater withdrawals from water table (near-surface) aquifers affect surface water bodies, including streams, lakes, wetlands and springs. As groundwater is removed from an aquifer, the amount of water that is available to provide baseflow to surface water is decreased. Some of the water that would flow to a surface water body in the absence of the well is now diverted to the well (Figure 6).

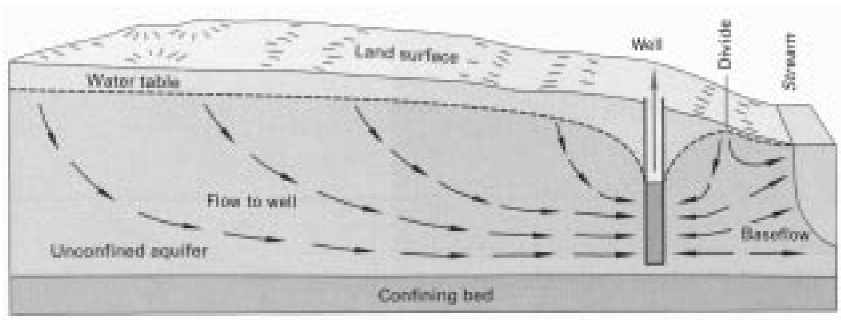

Figure 6. Pumping of a well may reduce baseflow to a stream.
Source: Modified after Winter et al., 1999

With an increased pumping rate, groundwater withdrawals may not only reduce baseflow to surface water bodies, but may also cause ***induced infiltration*** from the water body (Figure 7). Induced infiltration occurs when the water level of the aquifer falls below the level of water in the surface water body. This situation causes water to flow from the surface water body (higher water level) into the aquifer and to the well (lower water level). Quite often, wells are sited near surface water bodies to take advantage of induced infiltration (Mechenich & Kraft, 1997; Fetter, 1994).

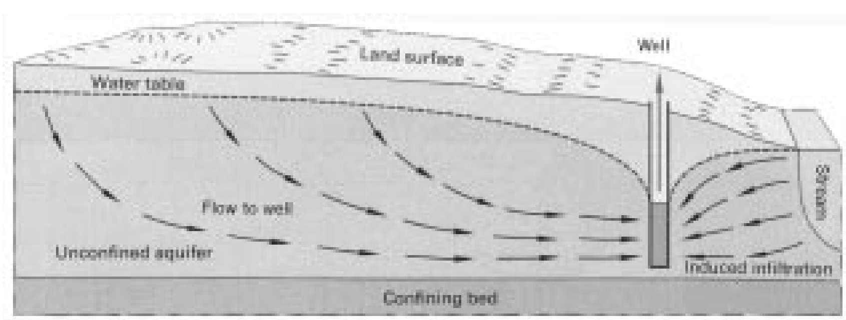

Figure 7. Induced infiltration may result from pumping of a well.
Source: Modified after Winter et al., 1999

ENVIRONMENTAL IMPACTS

High capacity wells are exempt from assessments of their impacts to surrounding environments unless over two million gpd of water is consumed. Still, the impacts of high capacity wells on water quality and quantity have the potential to seriously impact the environment and threaten ecological, economic and human health. These effects can occur within an aquifer itself and in surface water bodies (streams, lakes, wetlands and springs) that are hydraulically connected to aquifers. Groundwater withdrawals from aquifers in hydraulic continuity with surface water bodies will necessarily affect their water chemistry, temperature and quantity.

While investigation into the effect of groundwater withdrawals on wetlands and streams has been limited (Trochlell, 2000; Hunt, 2000; Siebert, 2000), legitimate reasons exist for concern. Groundwater withdrawals are associated with substantial declines in groundwater levels in several parts of the state. Cases are well documented in the Lower Fox River Valley, southeastern Wisconsin and Dane County (Lindorff et al., 1997). In the Madison area, water table levels reportedly have declined measurably near municipal wells (Furbish, 2000). Near the University of Wisconsin-Madison Arboretum, they have dropped three to six feet, which may play a factor in the degraded quality of arboretum wetlands and fens (Trochlell, 2000). Wetland plants, which depend on root saturation for a portion of the year, may decline in abundance or become locally extinct due to the altered hydrology brought about by groundwater withdrawals (Winter et al., 1999).

Hydrologic parameters can be an influential factor in wetland composition. In Wisconsin, Ashworth (1992) investigated the factors responsible for changes in wetland composition. In a wetland restoration project in Dane County, willow (*Salix*) invaded the community. Of 12 environmental variables analyzed, five hydrologic parameters and one soil parameter were statistically significant; the two most significant parameters were average depth to water level and low water levels. Preliminary findings that hydrology affects wetland composition indicate that groundwater withdrawals exert an ecological impact.

The awareness of potential effects of high capacity well operation on wetland communities has been enough for some municipalities to adjust their operations. The village of Mukwonago entered into a voluntary memorandum of understanding with the WDNR to conduct ecological monitoring when it learned that the municipality's high capacity well may threaten rare fen species at Vernon marsh (Luthin, 2000). This agreement established three steps to conserve wetland species: 1) the village agreed to allow the WDNR to conduct monitoring; 2) the village agreed to reduce water withdrawal during high stress periods; and 3) the village agreed to reduce water flow regimes based on recommendations of the WDNR.

Springs are found where the water table intersects the land surface (Alley et al., 1999) and often form the headwaters of streams in Wisconsin. Since springs are a constant source of water to the land surface, they generally have an abundance of plant life and often create unique habitats. Nearby pumping may reduce springflows, change springs from perennial to ephemeral, or even dry up springs (Alley et al., 1999).

Agricultural groundwater withdrawals for irrigation allow for the return flows of the irrigation water to the aquifer, and therefore may not affect the groundwater flow system as much as a fully consumptive use. However, 75% to 85% of irrigation water is either lost to evapotranspiration or evaporation (Winter et al., 1999). Seasonal timing of the pumping is critical as pumping will reduce baseflows or induce infiltration from surface water during pumping, even if some return flow is occurring at the same time.

Water quality issues associated with changes in water chemistry arise with high capacity groundwater withdrawals. These changes include both naturally occurring and human-induced pollution, and may appear in both groundwater and surface water. Agricultural wells, in particular, are often associated with chemical changes in water quality. Water quality can be altered in organic and nutrient composition. In areas that are both heavily irrigated and highly fertilized, the water flowing back into the watershed from agricultural fields carries some of the materials, including pesticides and nitrates, that were applied to the field (Hunt, 2000), and can pose health issues.

Groundwater pumping that causes induced infiltration or baseflow reduction affects streamflows, lake and wetland levels, as well as the chemistries of ground and surface waters. Induced infiltration from streams may carry contaminants, such as organic chemicals and pathogens, from the stream or lake to the well field. For example, in 1993 the Black River Falls municipal well field, which induces infiltration from the Black River, began testing positive for fecal coliforms and *Cryptosporidium* (Rheineck, 1995). Pumping can also induce changes in oxygen levels and nutrient concentrations of a water body (Alley et al., 1999), as well as changes in temperature (Furbish, 2000). These types of changes in the characteristics of the water body may have implications for the aquatic life present. Also, springs tend to form where there is convergence of groundwater flows that originate from different recharge areas. The effects of pumping on the chemistry of a spring may vary with the amount of groundwater withdrawals in each of the contributing recharge areas.

Another effect of pumping on stream systems may be to alter the ***hyporheic zone*** near a stream (Figure 8). The hyporheic zone is the zone below the stream in which water from the stream mixes with discharging groundwater. Groundwater pumping will cause downwelling (downward flow) of stream water into the hyporheic zone, and fine suspended sediment in the water may reduce the hydraulic conductivity of the stream bed (Browne, 2000). The hyporheic zone appears to be important to the benthic organisms (aquatic invertebrates) that represent the bottom of the food chain in stream systems; therefore, changes propagate up the food chain. With groundwater pumping, the extent of the hyporheic zone could be altered, as could the relative amounts of river water and groundwater present. Both induced infiltration and reduction in baseflow would reduce the relative proportion of groundwater in the hyporheic zone either by the reduction of groundwater or the addition of more river water. Since the chemical compositions of surface waters and groundwater are different, changing the relative proportions of each in the hyporheic zone would change the chemistry (e.g., nutrients, oxygen levels, water temperature) of the hyporheic zone (Browne, 2000). These changes may have significant effects on the benthic communities and spawning fish that depend on the chemical conditions of the hyporheic zone (Alley et al., 1999).

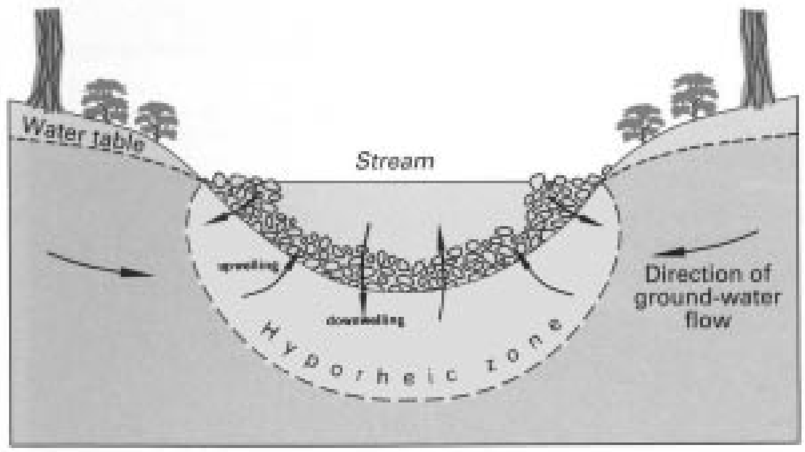

Figure 8. Pumping may cause downwelling of stream water into the hyporheic zone.
Source: Modified after Winter et al., 1999

Selected case studies

Wisconsin has observed the impacts of high capacity well withdrawals. The following are selected examples that highlight quantity and related quality issues that have been encountered across the state.

Irrigated agriculture in the Central Sands Plain

Several users share groundwater in the Central Sands Plain. Most municipalities in the region use groundwater. Industries associated with agriculture, such as canneries and potato-packing sheds, use small amounts of groundwater. Recreational users, such as anglers, boaters and swimmers, depend on groundwater to provide baseflow to streams and lakes in the area. Groundwater is also needed to maintain the natural aquatic communities (Weeks & Stangland, 1971). Approximately 167 million gpd, almost all of it groundwater, is withdrawn during the growing season to support Wisconsin's irrigated agriculture (Chern et al., 1999).

The Central Sands Plain of Wisconsin has enjoyed a strong economy, partly due to intensive development of irrigated agriculture. A 1971 report studied the impacts of irrigated agriculture on streamflow in a 650-square-mile area of the eastern part of the sand plain in Portage, Waushara, Wood and Adams counties (Figure 9; Weeks & Stangland, 1971). The main aquifer for the region is glacial outwash. Streams in the area are maintained by a stable baseflow from the aquifer.

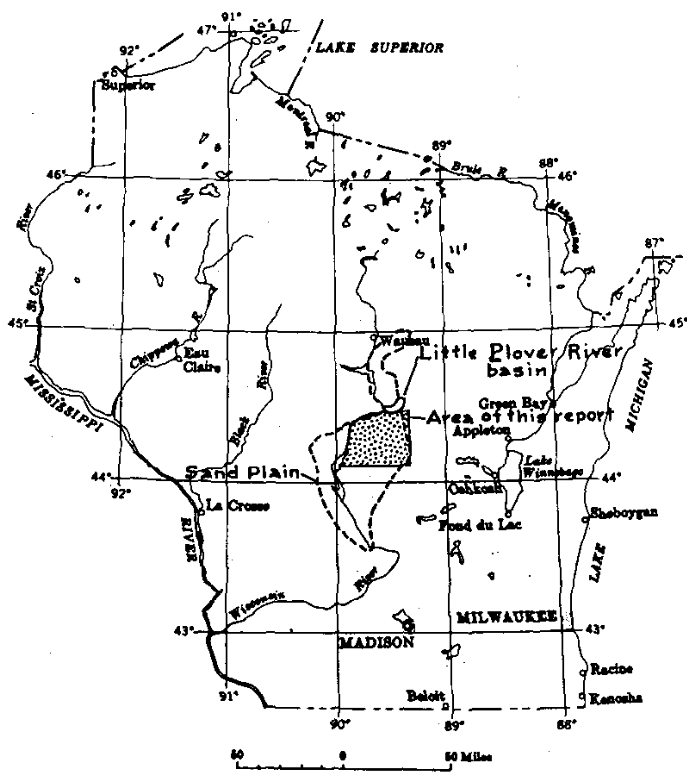

Figure 9. Irrigation pumping has affected streamflow in the Central Sands Plain.
Source: Weeks & Stangland, 1971

In general, pumping occurs primarily during the growing season with the highest rate of irrigation occurring during periods of low precipitation. In 1967, there were over 300 irrigation wells (some high capacity) in use in the study area that irrigated 30% of the land with 6,354 million gallons of water. Groundwater levels have been affected by irrigation pumping, particularly in the summer. In addition to the natural two- to three-foot seasonal water level drop, some lakes showed a 0.5-foot decline in water levels due to pumping (Weeks & Stangland, 1971). Irrigation increased the evapotranspiration by two to five inches per year, reducing groundwater recharge, which in turn reduced streamflow by 25-30%. The researchers predicted that streamflow could be reduced by as much as 70% to 90% during drought conditions due to increased crop irrigation and increased evapotranspiration (Weeks & Stangland, 1971).

Since 1971, irrigation development has increased in this area. In 1984, the maximum total irrigation pumping was estimated to be 31,700 million gallons of water (Krohelski et al., 1987). The increasing amounts of water lost to evapotranspiration have further reduced streamflow and groundwater levels.

The Central Sands Plain region clearly demonstrates the cumulative impacts of large numbers of high capacity wells. Separate studies indicate that nitrates, chlorides and pesticides contaminate the groundwater of irrigated agricultural areas in the Central Sands Plain (Mossbarger et al., 1989; Kraft et al., 1999). These impacts, linked with high capacity well use, limit the aquifer's value as a source of drinking water and reduce the potential for municipal uses and the overall environmental health of the region (Kraft et al., 1999). Agriculture in the Central Sands Plain would be much more limited, and therefore these impacts would be more limited, were it not for irrigation from high capacity wells.

Municipal high capacity withdrawals: Little Plover River

Conflicting groundwater demands (e.g., agriculture, domestic use, natural wildlife habitat) exist in the Little Plover River region. The village of Plover is located in Portage County, on the northern tip of the Central Sands Plain (see Figure 9). The Little Plover River basin is underlain by the Stevens Point-Whiting-Plover aquifer, which supplies water to irrigated agriculture, industry and at least 40,000 residents. The aquifer also provides baseflow to streams and wetlands, supporting aquatic communities such as the Little Plover River, a Class I trout stream (Mechenich & Kraft, 1997).

In 1989, the village of Plover began pumping groundwater for municipal use (Lindorff et al., 1997). Because of concerns about groundwater contamination by agricultural nitrates and pesticides, a groundwater flow model was developed to predict the behavior of the aquifer and its reactions to different agricultural practices. Using year 2005 projected pumping rates, the model predicted that groundwater withdrawals would deplete about 10% of the baseflow to the Plover River, and possibly more than 40% of the flow to the Little Plover River. The Plover River is a larger stream that might be able to sustain this impact without negative effects on the aquatic ecosystem. However, the ecology of the smaller Little Plover River would be severely impacted by a loss of 40% of normal baseflow. Even lower-than-projected pumping rates would likely impact the Little Plover River (Mechenich & Kraft, 1997).

Municipal high capacity well: Fitchburg and the Nevin Fish Hatchery

The current high capacity well permitting process falls short of considering important environmental resources in the face of development pressures. In this case in southern Wisconsin, voluntary action by the municipality alleviated concerns that a proposed new well would adversely affect natural springs, but there is no legal requirement that other municipalities be similarly cooperative in analogous future conflicts.

The city of Fitchburg in Dane County uses high capacity wells to pump groundwater for domestic use. Two aquifers underlie Fitchburg: the shallow Paleozoic bedrock units and the deeper Mount Simon sandstone, which are separated by 15 feet of the Eau Claire shale. Nitrate contamination of groundwater forced Fitchburg to discontinue use of its shallow well (Johnson, 2000). In 1999, a year of high water stress, the city of Fitchburg recognized the need to replace the discontinued shallow well.

The WDNR Nevin Fish Hatchery in Fitchburg uses springs to supply its fish propagation operations. These springs also feed wetlands. The city of Fitchburg planned to locate a new well to supply a proposed 900-house subdivision (Nine Springs subdivision) south of the fish hatchery. Staff at the hatchery expressed concerns that the well would impact the recharge area of the springs and asked that the development be postponed until information about these interactions could be researched. They requested that the WDNR be given an extended time period to assess the high capacity well permit, a request that the planning commission granted. The Mayor established a nine-person citizens' advisory committee, which studied the situation for one year. Their recommendations were that the city should employ conservation designs and not continue with development until they were certain about the impacts (Johnson, 2000).

The fish hatchery staff worked with Fitchburg's Public Works Department and geologists from the University of Wisconsin-Madison to assess the potential impacts of the proposed well using tritium tracer studies and a groundwater flow model for Dane County. They found that the proposed well would have no impacts on the fish hatchery because the well was planned to be drilled into the sandstone aquifer, which is not in hydraulic continuity with the Upper Paleozoic bedrock aquifer that fed the fish hatchery springs (Swanson, 2000). If the study had indicated that there would be an adverse impact on the fish hatchery springs, it is unlikely that the WDNR would have denied the high capacity well permit because they lack explicit statutory authority to require that the potential impacts on groundwater and surface water be assessed (Johnson, 2000). An understanding of the potential impacts of the well was achieved only because the city of Fitchburg agreed to cooperate by delaying development pending further study.

Municipal high capacity well withdrawals: Bloody Run Creek

The Wisconsin Rapids Water Works & Lighting Commission (WW&LC), a utility in central Wisconsin, has a number of high capacity wells that have raised great concern among town of Grand Rapids residents and the WDNR. The concern is over flows in Bloody Run Creek, a Class 1 trout stream that runs through Grand Rapids. The WW&LC has been pumping since 1994. The water level has dropped and, at times, has dried up one-fourth of the four-mile stream in an area that runs through the southeast corner of the town (Laack, 1999).

The WDNR is considering options for putting water back into Bloody Run Creek. Possible sources for augmentation include groundwater wells adjacent to the stream or water piped in from a nearby lake or stream (Hazuga, 2000). With the option of augmentation, there are concerns regarding iron levels in the water, which would be 6 - 8 parts per million (ppm). Because high iron levels can be toxic to trout and the aquatic insects in cold water communities, the WDNR wants levels of 1 - 1.5 ppm so as not to disturb aquatic life (Laack, 2000). The WW&LC admits that they have impacted the creek, but are not sure that they are solely responsible for covering augmentation costs (Laack, 2000).

Some Grand Rapids residents want stricter enforcement imposed upon the WW&LC (Laack, 1999). From their perspective, the only way to force remediation is through a court order; however, with the current broad laws regulating the use of water, there is little chance of success in court. At an informational meeting in Grand Rapids in March 2000, the WDNR noted that Bloody Run Creek is the most severe case in Wisconsin of environmental impact caused by high capacity wells. They point to it as an example of why there should be legislation modifying how well permits are issued (Laack, 2000).

THE LEGAL FRAMEWORK

Groundwater law

Legal authority over Wisconsin water resources is derived from the public trust doctrine. Traditional English common law informed the 1787 Northwest Ordinance, which extended United States sovereignty over the territory from which Wisconsin was formed. The Ordinance contained language declaring all navigable waters to be held by the state for the public. Article IX, Section 1 of the Wisconsin Constitution states that all navigable waters leading to the Mississippi and St. Lawrence Rivers are “common highways and forever free, as well to the inhabitants of the state as to the citizens of the United States.” Initially, only waters navigable by trading vessels were considered to be covered; over time, the test for navigability has been broadly construed, expanding the reach of the public trust doctrine. Public trust protection has not been explicitly extended to groundwater.

The 1903 Wisconsin Supreme Court decision *Huber v. Merkel* affirmed that groundwater was not covered by the public trust, and asserted that property owners have an *absolute* right to the groundwater beneath their property. In the strong language of the opinion, a property owner could use as much groundwater as could be pumped from a property, even with evident malice and waste. The justices did not, however, base their opinion on any special property rendering groundwater fundamentally different than surface water, but rather on the complete lack of knowledge of the nature and behavior of groundwater. Their decision was based on English legal precedent, *Acton v. Blundell* (1843), that “the ways of groundwater were too mysterious and unpredictable to allow the establishment of adequate and fair rules for regulation of competing rights to such water.” Two cases in 1956 failed to overturn the *Huber* rule of groundwater, *Fond du Lac v. Empire* and *Menne v. Fond du Lac*.

The case of *State v. Michels Pipeline Construction, Inc.* (1974) marked a fundamental change in Wisconsin groundwater law. In this case, a citizen's well was dewatered by the construction of a nearby municipal sewer line. Under the *Huber* rule, the citizen could have no relief from the court; however, the court saw fit to revisit the justification for the *Huber* decision: "… today, scientific knowledge in the field of hydrology has certainly advanced to the point where a cause and effect relationship can be established between a tapping of undergroundwater and the level of the water table in the area so that liability can be fairly adjudicated consonant with due process."

The rule adopted by the court in *Michels Pipeline* allowed for any reasonable use as long as it did not infringe upon reasonable uses by others. All beneficial uses of the water are not considered equal. This critical aspect of the rule means that courts can balance the utility and harm of one use versus another in adjudicating groundwater rights conflicts. A municipal well can be judged more socially useful than a private well, even if their uses are both "reasonable." Groundwater used to maintain baseflow in a stream could also be judged to be socially useful. The *Michels Pipeline* rule is still guiding nuisance common law of groundwater.

Current Wisconsin high capacity well law addresses cumulative impacts only for wells on one property for which the combined pumping rate exceeds 100,000 gpd; the property is then deemed to be a high capacity property (§281.17 Wis. Stats., Wis. Admin. Code ch. NR 812). It does not address the density of the wells. The current law also does not address the potential impacts of high densities of wells *not* on one property that *individually* have capacities of less than 100,000 gpd but *collectively* have a combined pumping rate exceeding 100,000 gpd. Under Wis. Admin. Code ch. NR 812, the WDNR may deny or modify a permit application for a proposed high capacity well or high capacity property on the basis of deleterious physical impacts *only* if the supply of water to a public utility well may be impacted.

Provisions were added to the statutes in 1985 that regulate withdrawals of any kind (surface or ground) from waters of the state. Any withdrawals (including wells) of over two million gpd are subject to review and reporting requirements, over and above those in §281.17 Wis. Stats., under §281.35 Wis. Stats. Section 281.35 Wis. Stats. also adds a series of general considerations for permitting withdrawals over two million gpd, including public rights, environmental quality, and consultation with other Great Lakes states. This allows the state to make a detailed census of water impacts and uses.

Several commentators have pointed out that there is nothing "magical" about either the 100,000 gpd limit nor the two million gpd limit. These are arbitrary markers that arguably have little to do with the actual protection of groundwater quantity in Wisconsin. Furthermore, the minimal reporting requirements imposed on any withdrawal under two million gpd, as well as the inability of WDNR to deny permits for any reason save impacts to a municipal system, have been identified as major problems in groundwater conservation.

Permitting and other agency responsibilities

Wisconsin has modified its groundwater laws considerably through the development of a permit system. The state enacted the high capacity well law in 1945, allowing itself to regulate to some degree larger-volume pumping. Since 1958, new wells that pump over 100,000 gpd on average over a 30-day time period must obtain the approval of the WDNR (§271.17 Wis. Stats.). The operator must report the volume and rate of pumping, as well as the estimated water loss (through evaporation or interbasin transfer). See Appendix B for a more detailed overview of Wisconsin's high capacity well permitting process.

There are numerous entities with groundwater management-related responsibilities in Wisconsin (Table 1). The WDNR, as the principal permitting agency for water withdrawal, regulates high capacity wells in addition to surface water diversions. The WDNR has broad statutory authority to "protect, maintain, and improve the quality and management of the waters of the state, ground and surface, public and private" (§281.11 Wis. Stats.).

Responsibilities for managing groundwater quantity are dispersed across several sections of the WDNR. The Bureau of Drinking Water and Groundwater (BDWG), Private Water Systems Section issues permits for high capacity wells (see Appendix B), regulates well construction and pump installation and registers well drillers and pump installers (Lindorff et al., 1997). The Public Water Systems Section regulates water supply systems. The Groundwater Section has several responsibilities, in addition to coordinating state groundwater activities. They include setting groundwater quality standards, monitoring, coordinating wellhead protection activities, regulating well construction and abandonment, and maintaining a groundwater data management system.

Table 1. Agencies with Responsibilities for Groundwater Management

Agency	**Responsibility**
Central Wisconsin Groundwater Center, University of Wisconsin-Stevens Point	Provide educational and technical assistance on groundwater issues
Groundwater Coordinating Council	Improve management of state's groundwater by sharing information and improving interagency cooperation
Local units of government through general purpose government agencies or special purpose entities	Provide adequate supply of good quality water to customers
Public Service Commission	Approve expenditures of new public water/electrical utilities, regulate setting of rates
State Lab of Hygiene	Conduct research on virus and pathogen occurrence in groundwater
U. S. Geological Survey, Wisconsin District Office	Research surface and groundwater interactions, monitor groundwater levels
University of Wisconsin-System	Provide education on groundwater protection; conduct basic groundwater research
Wisconsin Department of Agriculture, Trade and Consumer Protection	Regulate pesticide use and cleanup, oversee farm nutrient management, research where pesticides have entered groundwater
Wisconsin Department of Commerce	Inspect underground storage tanks, enforce septic system regulations
Wisconsin Department of Health and Family Services	Recommend enforcement standards for substances of health concern, investigate health effects from contamination
Wisconsin Department of Natural Resources	Protect, maintain and improve state's water quality and management; monitor groundwater, set state groundwater quality standards
Wisconsin Department of Transportation	Conduct research on road salt and groundwater
Wisconsin Geological and Natural History Survey; University of Wisconsin-Extension	Assess, characterize and map groundwater resources; provide information and education on hydrology and groundwater resources

Source: Modified after Lindorff et al. (1997) and Chern et al. (1999)

As noted previously, the Water Resources Conservation and Management Act (1985 Wisconsin Act 60) directed the WDNR to participate in regional water quantity resources management activities (Lindorff et al., 1997). The passage of the act fulfilled Wisconsin's commitment to the Great Lakes Charter to enact legislation providing authority to regulate and manage major uses of the state's water resources. The Great Lakes and Planning Section of the Bureau of Watershed Management is responsible for carrying out the mandates of 1985 Wisconsin Act 60. These activities include the development of a water withdrawal registration system, administration of a water loss program, development of a statewide water quantity resources plan, and participation in regional water quantity resources management activities.

Two other WDNR sections have groundwater management-related responsibilities. The Rivers and Regulations Section of the Bureau of Fisheries Management and Habitat Protection issues permits for surface water diversions, and the Bureau of Waste Management regulates metallic mining activities (Lindorff et al., 1997).

OTHER STATES' APPROACHES AND THE IMPLICATIONS FOR WISCONSIN

States are increasingly recognizing the interdependence of atmospheric water, surface water and groundwater in the hydrologic cycle and are developing management and allocation approaches that are based on those relationships. For example, Mississippi has a state policy that conjunctive uses of groundwater and surface water are to be encouraged, and in Massachusetts, surface water and groundwater are to be managed as a single hydrologic system (Sherk, 1990). Additionally, several states have taken action to ensure that the impacts of proposed water uses on hydrologically-interconnected waters, especially as regards public rights, are considered during regulatory review processes. For this report, we have selected four states for review that have "modernized" their statutes and management practices to address these and other concerns. A review of the laws, rules and administrative review systems in these states (Florida, Minnesota, Oregon and Washington) may help Wisconsin address issues pertinent to Wisconsin's high capacity well law. There are two aspects that make these states especially interesting for comparison. First, in all four states, the law recognizes the scientific fact of hydraulic continuity between surface water and groundwater, and this fact is considered in the permitting review process. Second, each of the four states considers protection of some or all of the following resources in every decision to grant or deny a groundwater withdrawal permit: wildlife resources, recreation, groundwater and surface water quality, and wetlands. Table 2 illustrates which of these resources receive protective consideration in each of the four states.

Minnesota law is especially relevant because of the state's geographical proximity to Wisconsin and because of the climatic and cultural similarities between the two states. Florida shows how their regional authorities, Water Management Districts, handle groundwater permitting in a comparatively integrated fashion. Oregon's proactive system highlights the benefits of comprehensive planning. Finally, Washington's experience illustrates the benefits and difficulties of managing and reviewing groundwater withdrawals in a watershed context.

Table 2. Water Resources Considerations in Other States

	Ground-water Quality	Surface Water Quality	Wildlife Resources	Recreation	Calcareous Fens	Other Wetlands
Florida	♦	♦	♦	♦		♦
Minnesota	♦	♦	♦	♦	♦	♦
Oregon	♦	♦	♦	♦		
Washington	♦	♦	♦	♦		

Florida

In Florida, the state Department of Environmental Protection has the authority to issue groundwater use permits, but they issue very few each year. The state's five Water Management Districts (WMDs), regional authorities that have been delegated many significant governmental powers by the legislature, issue the vast majority. The rules and procedures vary in the WMDs. We chose to examine the South Florida WMD (SFWMD) because of its size, hydrologic setting (it regularly experiences droughts), and the critical surface water resources within its jurisdiction.

State legislation (Fla. Stat. ch. 373) sets the permitting framework, requiring a permit for new consumptive uses of surface water or groundwater. The SFWMD exempts only single-family dwellings that are the sole users of the withdrawal facility and water used strictly for fire fighting. The permit applicant must establish that the proposed withdrawal has a “reasonable-beneficial use”, which is defined as “the use of water in such quantity as is necessary for economic and efficient utilization for a purpose and in a manner which is both reasonable and consistent with the public interest” (Fla. Stat. §373.019(13)). Furthermore, the applicant must establish that the proposed use will not interfere with any existing uses.

Another provision of the statute (Fla. Stat. §373.236) stipulates that permits have a duration of 20 years, if requested for that long and if there is a reasonable assurance that the conditions of the permit can be met for that long. If not, they may be issued for shorter periods. For 20-year permits, the SFWMD may require a compliance report every five years, and may modify the permit based on review of that report. The limit may be extended to up to 50 years for permits where municipal or similar bonds are issued to finance the facility and more than 20 years are required to retire the bonds.

Permitting process

In addition to the three requirements of the Florida statute noted above, several other “reasonable assurances” must be provided by applicants for a consumptive use permit from the SFWMD (Fla. Admin. Code §40E-2.301). Assurances germane to this report include that the proposed use:

- will not adversely impact offsite land uses
- will not cause adverse environmental impacts
- will not cause pollution of the water resources

Administrative review process

The SFWMD staff issue general permits for consumptive uses under certain thresholds. These thresholds vary from 10,000 average gpd to 500,000 gpd. Individual permits, issued by the WMD Governing Board, cover uses that exceed these thresholds (SFWMD, 1997, http). The duration of permit varies by type of permit. General permits have typically been issued for 20 years, but individual permits have been issued for five or 10 years.

For both general and individual permits, the reasonable-beneficial use criterion is judged by the need and demand for the water. The applicant must also provide reasonable assurances that the proposed type and amount of water use are compatible with local zoning regulations and a comprehensive plan. In establishing “demand” for the water, irrigators, commercial and industrial users, and municipal users must carefully document their conservation practices or plans (SFWMD, 1997, http).

Some critical water sources have restrictions on the amount of water to be withdrawn from them. For example, in the Eastern Okeechobee-Northwestern St. Lucie Basin, withdrawals from the Florida aquifer are limited to 1.5 acre-inches per property acre per month (SFWMD, 1997, http). When the SFWMD has a special concern about the adverse impacts from a proposed irrigation use and reclaimed water is not feasible, then the permit may limit the amount of water used to that needed for micro-irrigation. *Withdrawal of water must not adversely impact natural water bodies, watercourses, or wetlands, nor habitat for threatened or endangered species, nor any other “environmental features” dependent on water resources* (SFWMD, 1997, http) [emphasis added].

Withdrawals that would lead a stream of pollutants into a previously unpolluted area are not permitted (SFWMD, 1997, http). Permits shall also be denied if the withdrawal would have an unmitigated adverse impact on existing land use, such as crops or other vegetation, or other water uses. All water users are required to monitor and report the quantity of water they use. Monitoring of the level of water tables or surface water, and other environmental monitoring are required with some types of permits. In times of water shortage, the SFWMD may restrict withdrawals under existing permits. Any adverse impacts occurring at any time must be mitigated by the user.

The permit applications are reviewed by the staff at the Water Use Division, who are generally trained as geologists or hydrogeologists. Copies of the submitted permit applications are sent to Natural Resource Management staff for review by biologists, thus selectively allowing broader interdisciplinary review. Very few permits are denied, but many permits are granted only after various modifications or revisions to the original project design have occurred within the permitting process.

Evaluation

It is hard to say whether the process has effectively protected watercourses, as many tend to be canals supplied by some other surface water source (Scott, 2000). Naturally occurring lakes are considered a Type I (permanently inundated) wetland and therefore are protected. Wetlands are protected, with drawdown one foot or greater considered an adverse impact not allowed within the permitted process (current rulemaking may make this provision more stringent).

Minnesota

In Minnesota, all appropriations and uses of surface water or groundwater are regulated under the same permit system from the Minnesota Department of Natural Resources (MDNR). It should be noted that the Minnesota use of "appropriation" does not imply any connection with the doctrine of prior appropriation. "Appropriating" is defined as "withdrawal, removal, or transfer of water from its source regardless of how the water is used" (Minn. Stat. §103G.005, subd. 4). While there is no specific high capacity well law, a permit is required to appropriate groundwater in quantities greater than 10,000 gpd and/or 1 million gallons per year (Minn. Stat. §103G.271). Minnesota takes connections between the groundwater and surface water into account in the permitting process, and a permit for groundwater appropriation can be limited or denied if the appropriation would have adverse impacts on surface waters. Furthermore, the MDNR Commissioner has broad authority to deny a permit application, or require that it be modified, in order to protect the public interest (Minn. Stat. §103G.315, subd. 5).

Permitting process

When applying for a permit, the applicant has the burden of proof to show that "the proposed project is reasonable, practical, and will adequately protect public safety and promote the public welfare" (Minn. Stat. §103G.315, subd. 6(a)). Permits must be consistent with state, regional and local land resources management plans (Minn. Stat. §103G.271, subd. 2). If the application is for an area where the commissioner has inadequate groundwater availability data, the applicant must gather and include information about the aquifer to be tapped and the area of influence of the proposed well (Minn. Stat. §103G.295, subd. 3-4).

In reviewing the permit application, the commissioner is instructed to consider, among other factors, the hydrology and hydraulics of the water resources; the quantity, quality and timing of any waters returned after use and their impact on the receiving waters; and comments received from governmental agencies, private persons, and other interested parties (Minn. R. §6115.0670, subp. 2A). *Any groundwater appropriation permit must be limited in amount and timing when a direct relationship between surface water and groundwater is determined to exist, and when the appropriation would threaten to have an adverse impact on surface waters, either through reducing in-stream flows below designated protected levels or lowering lakes below designated protected elevations* (Minn. R. §6115.0670, subp. 3C(2)) [emphasis added].

Minimum flows are set at Q90 (the flow which is exceeded 90% of the time) for most streams. The MDNR believes that using Q90 does not necessarily protect instream flow needs, and MDNR fisheries staff are gathering data to determine adequate flow requirements to protect fishery resources. Calcareous fens, the rarest wetland plant community in the state, are mentioned specifically as being protected from any disturbance, including draining (Minn. Stat. §103G.223).

The precautionary principle is applied to groundwater appropriations where the available hydrologic data are insufficient to give an adequate picture of the effects of the proposed appropriation. The MDNR shall then either deny the permit application or grant it conditionally, subject to modification or denial when further data become available (Minn. R. §6115.0670, subp. 3C(3)).

The permitting process is also used to gather data for better management of surface water and groundwater. All permit holders are required to record the amount of water they use on a monthly basis and report this to the MDNR (Minn. R. §6115.0750, subp. 3A) by February 15 each year. All permits are held conditionally, and can be cancelled or modified unilaterally by the MDNR to protect the public interests, or if the relevant law is changed (Minn. Stat. §103G.315, subd. 11). The only exceptions are certain permits related to mining, which are irrevocable (Minn. Stat. §103G.315, subd. 14).

Other than the mining exemptions, existing consumptive users of water enjoy no special protection. When there is conflict over use, existing and proposed future users vie on equal terms. Conflict is deemed to exist “whenever the total withdrawals and uses of ground or surface waters would exceed the available supply based on established resource protection limits...” (Minn. R. §6115.0740). In other words, protecting natural resources is a principal tenet of state water policy. After technical remedies, like conservation, are exhausted, then the water is apportioned according to priorities set by the legislature, with domestic water supply having the highest priority (Minn. Stat. §103G.261).

Administrative review process

After the water appropriation permit application is submitted to the MDNR, it is sent by the MDNR to the city (if the appropriation takes place within a city’s limits), the county-level Soil and Water Conservation District, and the appropriate Watershed Management Organization or Watershed District. Any application for groundwater extraction is sent to the area MDNR hydrologist, who may request assistance from MDNR’s groundwater hydrologists in St. Paul.

Well hydraulic equations are used to evaluate most permit applications, with more sophisticated models used if the hydrologist(s) deem it necessary. If it appears that the proposed extraction could have an adverse impact on some public resource, then the hydrology is examined in greater detail. A trout stream would be one example of a public resource that the permitting process is designed to protect.

Evaluation

While the law and rules as written seem adequate to protect surface flows from the effects of excessive groundwater extraction (Japs, 2000), there is not sufficient scientific information to allow the law to be fully implemented. Questions that need more scientific clarification include how much stream flow must be protected to achieve a desired level of ecological protection and what affect individual wells have on surface water flows. The statutory language placing the burden of proof on a permit applicant to show that “the proposed project is reasonable, practical, and will adequately protect public safety and promote the public welfare” would seem to give some room for a similar burden of proof to be placed on the groundwater appropriation permit holder when low water levels threaten a public resource. In practice, however, the burden of proof is placed on the MDNR to justify permit denials, modifications, or suspensions (Japs, 2000).

The requirement of monthly reporting of groundwater use for all permit holders has yielded many years of data on which to base the formation of management plans. The MDNR is cooperating with appropriators, although often the most difficult aspect of cooperation is convincing them that there is a resource problem that needs to be addressed. In addition, the MDNR is doing Geographic Information Systems (GIS) modeling of all permitted wells in the state as a reconnaissance measure, to see where a concentration of groundwater appropriation near a stream may be significantly affecting the stream. Location-specific studies to further examine the relationship between groundwater and surface water are also being conducted.

Oregon

In Oregon, a water right permit or certificate is required from the Water Resources Department (WRD) for all new water uses, including groundwater, lakes and streams. Once granted, water rights are administered under the system of prior appropriation (with an exception for drought conditions; Or. Rev. Stat. §536.720-536.780).

In Oregon, the Water Resources Commission has adopted basin programs for all but two of the state's 18 major river basins. Basin programs set policies for managing river basins. River basins are defined to include all the land area, water bodies, aquifers and tributary streams that drain into the major namesake river. Each basin program lists all of the water uses within the basin eligible for receiving a groundwater permit, and all of the uses within the basin eligible for receiving a surface water permit. If a proposed groundwater withdrawal is not used for one of the uses eligible in that basin, the permit is denied. If hydraulic continuity exists, the proposed withdrawal must be for an eligible surface and groundwater use in the basin.

If hydraulic continuity is determined to exist between the aquifer from which the proposed withdrawal will be made and a nearby surface water body, the WRD must consider the effects of the proposed withdrawal on senior surface water rights holders, natural resources, water quality, minimum instream flows, and scenic waterways. The WRD has the authority to deny permits if they interfere with any of the aforementioned criteria, as well as to grant conditional permits.

Minimum instream flows are set by the WRD (Or. Rev. Stat. §536.235) in consultation with various agencies. For example, the WRD will consult the Department of Fish and Wildlife to determine the minimum instream flows necessary to support fish populations, and the Department of Environmental Quality to determine the flows necessary to protect water quality (Szramek, 2000). When setting minimum instream flows, consideration is given to natural resource issues, including sensitive, threatened, or endangered species of wildlife, plus recreation, fish and wildlife on a scenic waterway.

The Water Resources Commission can declare a critical groundwater area in the most severely threatened areas (i.e., where pumping exceeds the long-term natural replenishment of an aquifer, where there is interference between wells and senior surface water users, or there is deterioration of groundwater quality). Once a critical groundwater proceeding is initiated by the Commission, no new well permits are issued until a final order is made. The final order may restrict both existing and future uses in order to stabilize the resource. Additionally, the order setting the limits of the critical area may give certain water uses priority over other uses, regardless of the establishment dates for water rights priority holders (Or. Rev. Stat. §537.730- 537.740).

If existing groundwater withdrawals are causing substantial interference with surface water, the WRD has the authority to restrict withdrawals when the well is located less than 500 feet from the surface water body. If the well is greater than 500 feet from the surface water body, the WRD may limit withdrawals if doing so would provide effective and timely relief to the surface water body. If the affected surface water body is greater than one mile from the well, withdrawals may only be regulated through a critical groundwater area designation (Or. Rev. Stat. §537.143, Or. Admin. R. §690-009-0050). The current system has been in effect since 1988. Users with permits from before 1988 may or may not be subject to the same flow restrictions as users who acquired their permit since the new system was adopted, depending on specific permit conditions (Szramek, 2000).

Permitting process

The WRD is required by statute to process all permit applications in eight months or less (Or. Rev. Stat. §537.153), and permits take two to eight months to process. This includes an initial review period of two months or less, and a period of six months or less in which the impacts of the proposed withdrawal may be investigated. Applicants are advised not to drill a well before a permit is approved because permits can be, and often are, denied. Groundwater uses exempt from the permitting process are stock watering, lawn or non-commercial garden watering not exceeding one-half acre in area, domestic purposes not exceeding 15,000 gpd, industrial or commercial purposes not exceeding 5,000 gpd, down-hole heat exchange uses, and watering school grounds with an area of less than 10 acres in critical groundwater areas (Or. Rev. Stat. §537.545).

Administrative review process

After data from permit applications are entered into a database, and the WRD carries out an initial review, the permit application is sent to the groundwater section where a determination is made regarding whether there is significant potential for surface water interference (Szramek, 2000). If the proposed well would be withdrawing from an unconfined aquifer located less than one-fourth mile from a surface water source, it is automatically assumed to have the potential to substantially interfere with the surface water unless the applicant or appropriator provides satisfactory documentation to the contrary.

If the well is greater than one-fourth mile away from surface water, the basis of the determination is a calculation of interference using information from a Water Well Report. When information in the report is not available or adequate, other best available information is used to make the determination (Or. Admin. R. §690-009-0040). This may include topographic maps, hydrogeologic maps or reports, water level and other pertinent data collected during a field inspection, and any other available data or information that is appropriate, including any that are provided by potentially affected parties.

If the proposed well is determined to have the potential to interfere substantially with surface water, the WRD must then determine whether there is surface water available for additional appropriation. If there is, the groundwater permit may be issued. If there is not, the groundwater permit may not be issued.

Evaluation

The system reportedly is working well for Oregon. The WRD's Groundwater Section has not had difficulty completing necessary investigations within the required time frame. Citizens who are denied permits often challenge the WRD's decision; however, there have been no significant court cases to date that have limited the WRD's authority (Szramek, 2000).

Washington

In Washington, all appropriations and uses of water are regulated under a permit system from the Department of Ecology (DOE). In 1917, the riparian water rights system was replaced with a permit system, which grandfathered in existing riparian rights but required that any new rights be acquired by appropriation through a state administered permit system (Wash. Rev. Code §90.44.060, 90.03.250-90.03.340).

In 1945, groundwater was brought into the appropriation-administrative permitting system. Previously, groundwater was treated in a similar manner to surface water riparian rights, i.e., correlative with other users and in existence as a coincidence of land ownership (Wash. Rev. Code §90.44.050). The only exemptions to the permit requirements are domestic and industrial users of less than 5,000 gpd, and withdrawals used for stock-watering or watering a lawn or a noncommercial garden not exceeding one-half acre in area (WDOE, 1998a, http).

Groundwater withdrawal permits can be denied if the appropriation interferes with the flow of appropriated water from a spring, lake, river or other body of surface water (Wash. Rev. Code §90.22.030). A permit may also be denied if it will interfere with minimum flows or levels for streams, lakes, or other public waters. The DOE has the authority to set these levels when it is in the public interest, when requested by the Department of Fish and Wildlife to protect fish, game or other wildlife resources under the jurisdiction of the requesting state agency, and when it is necessary to preserve water quality (RCW 90.44.035).

Permitting process

Parties wishing to obtain a groundwater withdrawal right must apply to the DOE for a permit and may not use or divert water until a permit has been secured (Wash. Rev. Code §90.03.250). Upon receipt of a proper application, the DOE instructs the applicant to publish notice in a newspaper of general circulation in the counties in which the storage, diversion, and use is to be made. They also send the relevant information to the director of the Department of Fish and Wildlife (Wash. Rev. Code §90.03.280). Before issuing a permit, the DOE must make four determinations:

- whether any water is available for appropriation and how much
- what the beneficial uses are to which the requested water is to be applied
- whether the appropriation will impair existing rights
- whether the appropriation will detrimentally affect the public welfare

They have the authority to approve any permit for an amount of water less than that applied for, if there is a reason for doing so.

Administrative review process

Historically, the DOE has processed well permits in the order that applications were made. However, after legislative budget cuts reduced staff and forced them to process applications more efficiently, they began doing watershed assessments and then synchronously processing all of the applications in the investigated watershed. This “batch” permit processing was challenged in 1997, in *Hillis v. State Department of Ecology*. In this case, the Supreme Court ruled that since it was in conflict with historical precedent, the DOE did not have the authority to do batch processing without an official change of administrative rules following public comment. The DOE did this and currently processes applications in watershed-based “batches”, which allows some assessment of cumulative impacts of withdrawal requests. However, the DOE still considers the specifics of each application and decides on each permit individually (McChesney, 2000).

In the administrative review process of permit applications, a variety of models are used, ranging from water balance calculations to computerized numerical codes such as MODFLOW. The most common natural resource consideration taken into account when permitting is the impact on salmon.

Previously, in keeping with the aim of the prior appropriation system of allocating all surface waters to beneficial use, almost 100% of permit applications were approved. However, as use increases and instream flows are adopted to protect aquatic habitat, many surface water bodies in the state are closed or subject to intense competition. Consequently, groundwater is increasingly being sought as a source of water supply.

The DOE examines water right applications in the context of watershed assessments that evaluate the availability of water for new uses. In areas where stream flow was judged to be too low to support existing uses or instream flows that protect fish, groundwater permits for proposed wells that would capture surface water have been denied. Permits for wells capturing water from lakes or wetlands have also been denied in areas where lake or wetland levels were judged to be too low. The DOE issued approximately 600 water rights decisions in 16 watersheds in 1996. Roughly half of these were denials (WDOE, 1998b, http).

The authority of the DOE to deny permits in order to protect minimum instream flows has recently been challenged. Declining surface flows in the Seattle area prompted them to deny groundwater withdrawal permits for wells in hydraulic continuity with those surface water bodies. Several of the individuals who were denied permits sued. The Washington Supreme Court is currently deciding the case.

Evaluation

The success of the law at protecting surface water and natural resources associated with surface water flows has been mixed (McChesney, 2000). Reasons for the mixed success of the legislation include increasing population and land use pressures, limited resources for obtaining the scientific data necessary for permitting decisions, and hydrologic uncertainty and variability.

Conclusions from reviewed states

Groundwater law in Florida, Minnesota, Oregon and Washington is science-based and clearly acknowledges the hydraulic continuity between surface water and groundwater. These resources are managed and regulated conjunctively in all four states. All reviewed states have broad criteria for permit review, including public interest and environmental protection criteria. Both Oregon and Washington place groundwater management in a broader watershed context, with Oregon proactively using watershed plans and Washington conducting permit reviews at the watershed scale. Washington's approach allows, at least in theory, an assessment of potential cumulative impact of groundwater withdrawals in a region. In their efforts to protect sensitive surface waters and environmental resources, the reviewed states tend to put the burden of proof on the applicant for a groundwater withdrawal permit as opposed to the regulatory agency. At least two of the reviewed programs, Florida's and Minnesota's, are data sensitive – they specifically make provisions to use the best available data and incorporate new information as it becomes available, including provisions for modifying permits. Additionally, reporting requirements incorporated in management and regulatory programs (if faithfully carried out) help develop the database essential to sound management of groundwater and surface water resources over the long term. All reviewed programs employ computer models in their regulatory and management programs, subject to the nature of the permit application and data availability. Florida provides a particularly good example of an integrated permitting process that ensures biological input and review into the regulation of groundwater use permits.

Implementation of these modernized groundwater protection and management laws is not without problems. As noted by one agency manager, "The science needs to catch up with the law" (Japs, 2000). Baseflow standards in lakes, water courses, and wetlands are still being defined. In Minnesota, the MDNR is struggling to collect data to determine whether a stream's ecological community is protected at Q90, or whether flows below Q75 can lead to lasting damage. Water managers in Florida wonder whether wetlands really can tolerate the one-foot drawdown that is now the trigger for action, and wonder what are the minimum baseflow levels for which to manage at different times of year. Washington is grappling with the development of watershed-scale groundwater models to facilitate a timely and scientifically sound assessment of potential withdrawals and the subsequent effects on surface water flows.

Where standards for flows and levels are established, groundwater extraction management strategies are needed to ensure that those levels are maintained. The MDNR will be looking to restrict surface water permits, but not groundwater permits, in the summer of 2000 on those streams in which flows go below protected levels. The MDNR does not feel they have an adequate knowledge base to identify the wells where groundwater extraction is causing flow problems in the stream. States have tried to cope with this scientific uncertainty by giving agency staff variable degrees of discretion in permitting procedures.

In short, agency staff indicate that a better scientific understanding of surface water and ecological impacts from groundwater withdrawals is needed to better protect and allocate natural resources in practice. These concerns suggest that an adaptive management approach such as Minnesota's – one that allows adjustments in management and regulatory programs as new knowledge and information becomes available and is based on the precautionary principle – has great value in managing groundwater-surface water conjunctively.

GAPS IN WISCONSIN WATER RESOURCE MANAGEMENT AND POSSIBLE REMEDIES

As noted earlier, gaps in Wisconsin's institutional arrangements for managing groundwater quantity, and related issues, have been pointed out over the years. In the early 1990s, the WDNR voiced several internal agency concerns when the issue of environmental impacts of groundwater withdrawals was brought up by the Public Intervenor (Lindorff et al., 1997). The WDNR noted that evaluating the potential environmental impacts of every application for a high capacity well permit would be a time-consuming process and that the issue was considered to have low priority. Furthermore, modeling capability was inadequate at the time to accurately predict the interaction between groundwater and surface water. Concerns over cumulative impacts and the lack of consensus on how to resolve competing water uses were also raised. The WDNR did propose restricting high capacity wells within 1,000 feet of trout streams and outstanding resource waters (Lindorff, 2000).

One responsibility of the state Groundwater Coordinating Council (GCC) is to assist state agencies in program coordination and information exchange (§160.51 Wis. Stats.). The eight-member council is comprised of five department secretaries, the University of Wisconsin system president, the state geologist and a representative of the Governor. The GCC convened a meeting of state and federal agency representatives in July 1994 to discuss issues of groundwater quantity. Three recommendations were made: 1) restrict high capacity wells in sensitive areas unless no impact can be shown, 2) allow flexibility in regulating high capacity wells that may jeopardize water resources, and 3) formally bring the groundwater quantity issue to the GCC (Lindorff et al., 1997).

The third recommendation was advanced when the issue was brought before the GCC one month later (no action was taken on the other two recommendations). The GCC asked the WDNR Groundwater Section to prepare a report on groundwater quantity in Wisconsin. The report was published in 1997, in collaboration with several other state and federal agencies, and presents an overview of the major groundwater issues in the state. The report included several recommendations (Lindorff et al., 1997):

- establish regular meetings of federal, state, and local agencies to address issues of concern
- assign the WDNR Groundwater Monitoring Team, or other work group, the responsibility of evaluating groundwater quantity issues and propose a course of action
- evaluate regulation of water withdrawals
- prioritize information needs identified in the report
- evaluate existing databases for quantity information
- develop an information and education plan
- review and update the Water Quantity Resources Management Plan

None of these recommendations have been actively pursued (Furbish, 2000; Hennings, 2000; Lindorff, 2000). It should be noted that the GCC has a system to pool resources among agencies to address cooperatively and strategically areas needing research (UW WRI, 1999a, http). In the Joint Solicitation of Groundwater and Related Research/Monitoring Proposals for fiscal year 2001, the WDNR identified groundwater-surface water interactions as a topic of concern (UW WRI, 1999b, http):

> **Groundwater - surface water interaction -** Monitoring of surface and groundwater flow to determine hydrologic connections and pathways between them to assess the potential movement and fate of contaminants from one hydrologic regime to another. *Examples: investigation of the occurrence and causes of aquifer drawdowns that affect surface water features such as springs, streams and wetlands; identification of areas of the state sensitive to groundwater withdrawals; quantification of environmental, social and economic impacts of groundwater withdrawals; impact of induced flow of surface water to groundwater* [emphasis added].

The Perrier case may mark a turning point for public attention and systematic review. As part of granting a well withdrawal permit, the WDNR would monitor the effects of withdrawals on wetland communities (incorporating aquifer stress tests during the dry season of the year, when plants are water-limited, would strengthen the design of this monitoring plan). In this proposed agreement, the WDNR would have authority to adjust the allowable water quantity withdrawals based on surface water and wetland impacts.

This proposed plan bears many similarities to the ***adaptive management*** approach, which has gained attention among ecologists and resource managers (e.g., Lee, 1993). Adaptive management is the incorporation of a research component into an iterative management process; data analysis and conclusions serve as the basis to modify allowable resource extraction. In the Perrier-WDNR partnership, the WDNR would gain a better understanding of the hydrological-ecological system because monitoring, data collection and analysis would be on-going. In the long term, data and conclusions from this project could be coordinated with data from other projects to develop a larger scale understanding of the system.

Some drawbacks to using the Perrier case as a model for management do exist. This approach is expensive (Furbish, 2000). It entails multiple data collection points over an extended period. In addition, given the current legal framework for groundwater, it is completely voluntary (Trochlell, 2000). Environmental Assessments (EA) and Environmental Impact Statements (EIS) are required by state and federal laws if the proposed action may significantly affect the quality of the human environment. While the draft EA in this case considers the potential impacts of the high capacity well on groundwater, surface water and water quality, the WDNR cannot consider the impacts on other factors (e.g., traffic, economy) in its decision on whether or not to grant the permit. With this in mind, the preliminary finding of the WDNR in the Perrier case is that the proposed wells will not significantly impact the environment (Brixey, 2000). See the draft environmental assessment on the World Wide Web (http://www.dnr.state.wi.us/org/water/dwg/).

Upon examination of the existing statutes and administrative codes that govern the installation and use of high capacity wells in the state of Wisconsin, it is doubtful whether the current laws are adequate to ensure sound long-term management and protection of Wisconsin's groundwater and interconnected surface water resources. Two of these deficiencies might be addressed without new legislation: 1) permit denial criteria based only on potential impact on a public utility well, and 2) lack of enforcement of legislation requiring the reporting of water use.

The inability of the WDNR to deny a permit proposal except in the case where it is expected to adversely impact a public utility severely limits the agency's ability to protect Wisconsin's groundwater resources. Further, the statutes do not address the issue of the cumulative impacts of multiple high capacity wells in rural areas. For example, in central Wisconsin there is a high density of high capacity wells that are used for irrigation (see Figure 2) but in a rural area, it is unlikely that these wells will impact a public utility well.

Lack of enforcement by the WDNR regarding the requirement of high capacity well users to report water use and consumption is a major problem. The WDNR has not routinely required high capacity well users to report water use since the late 1980s (Krohelski, 2000) unless it is suspected that the well may impact a public utility. This water use reporting requirement is not enforced largely due to the inaccuracy of self-reported data as well as a lack of resources allocated to the program (Furbish, 2000). As a result, quantification of water use in Wisconsin by the U. S. Geological Survey has been based largely on estimations over the past decade (Krohelski, 2000). This creates a huge gap in the information base for resource managers and policy makers. It is impossible to assess the current status of and intelligently manage Wisconsin's groundwater resources without a reliable understanding of how the resource is currently being used, and the issue could be resolved administratively.

Legal strategies under existing laws

Three legal strategies that might be pursued *without* any statutory change are outlined below. These include strategies related to the public trust doctrine, nuisance common law, and enforcement of existing statutory language. The most recent attempt to address groundwater through statutory provisions is also reviewed.

Public trust doctrine

Many states have sections in their constitution directing the state to hold certain resources in the public trust, but Wisconsin has developed an especially strong legal tradition of broadly interpreting the meaning of public trust. In the case of navigable waters, the Wisconsin courts have established a pattern over the past century of gradually widening the aspects of water that are held under the public trust (*Olson v. Merrill*, 1877). As the timber economy of the state declined and the recreation economy grew, the courts saw several cases that placed increasingly shallow waters (not suitable for log transport, but suitable for hunting and boating) in the public trust. In the landmark case of *Muench v. Public Service Commission* (1952), a decision which has laid the foundation for all subsequent public trust law in Wisconsin, the court found that the rights protected by the public trust extended beyond commerce to all areas of recreation and scenic beauty connected with navigable waters.

The obvious obstacle to the expansion of public trust to groundwater is the concept of navigability which underlies the public trust doctrine, and which would seem to limit the concept, even in the extreme, to surface waters. However, several cases involving surface waters suggest that offsite activities that impact the rights affirmed in *Muench* might also be covered to some degree by the public trust doctrine. The decision in *Omernik v. State* (1976) extended the WDNR's permitting program outlined in ch. 30 Wis. Stats. to include diversions from non-navigable waters as well as navigable ones. Two other cases, *DeGayner & Co. v. DNR* (1975) and *Just v. Marinette County* (1972), held that impacts in a non-water area, which might affect navigable waters, could be enjoined by the public trust. The *DeGayner* decision can be read as condoning regulation of activities in an upland area where navigable waters are affected. Groundwater, which provides the baseflow to navigable waters, might be included in a very broad construction of the state's public trust responsibilities.

The citizen suit provisions attached to the protection of the public trust have been interpreted with unusual strength. In *Gillen v. City of Neenah* (1998), the court forced the WDNR to adequately regulate an impact to a public water, citing §30.294 Wis. Stats.: "A citizen may bring suit under this section, pursuant to the public trust doctrine, directly against a private party for abatement of a public nuisance when the citizen believes that the DNR has inadequately regulated the private party." The tradition of citizen suits in environmental affairs has grown rapidly in this country since the early 1970s and might be a viable legal strategy given a favorable "facts situation" involving public interest in groundwater and possible applicability of the public trust doctrine.

Nuisance common law

A second possible strategy might be to expand on the evolution of nuisance common law represented by the *Michels Pipeline* decision. In that case the court clearly recognized the role of increasing scientific understanding in changing what is considered a nuisance. The linkages between groundwater and surface water are the focus of research; new knowledge and a scientifically based rationale might allow for considering particular groundwater withdrawals to be public or private nuisances.

Enforcement of existing statutory language

While common law strategies are possible, the long-term solution may lie in statutory enforcement (Dawson, 2000). While the WDNR could conceivably request the Attorney General to file a nuisance suit against a person withdrawing groundwater in violation of the public trust, the burden of proof in such a case would rest entirely on the state. Conversely, enforcement of existing statutory or administrative language would force the permit applicant to document their case and prove compliance with statutory provisions.

Wisconsin Administrative Code uses strong language in directing the WDNR to protect the public trust and the state's environment. Under Wis. Admin. Code §NR 142.06(3), the WDNR is obliged to approve water withdrawals only if "no public or private water rights in navigable waters will be adversely affected," and if the "proposed withdrawal and uses are consistent with the protection of public health, safety and welfare and will not be detrimental to the public interest," or "the environment and ecosystem of the Great Lakes basin or the upper Mississippi river basin." This mandate is very broad. Given that courts traditionally grant considerable discretion to agencies in the interpretation of their own code, the possibilities of using the existing groundwater code may be worth pursuing.

Aside from the existing specific language covering high capacity groundwater wells, the most relevant statutory language can be found in two places. Chapter 160 Wis. Stats. was the product of Wisconsin Act 410, and lays out agency programs to deal with issues of groundwater contamination and agency enforcement procedures. As such, it has little to say about the protection of groundwater *quantity* and the maintenance of baseflow through aquifer management.

However, in the opening clause, the statute is relatively clear on its purpose: "The legislature intends, by the creation of this chapter, to minimize the concentration of polluting substances in groundwater…regulatory agencies are free to establish any type of regulation which assures that regulated facilities and activities will not cause the concentration of a substance in groundwater…to exceed the enforcement standards." The dilution of pollutants through management of groundwater quantity might be a possible regulatory strategy, consistent with the goals of ch. 160.

Chapter 281 Wis. Stats. broadly relates to the protection of water quality and quantity. In §281.11 Wis. Stats., the WDNR is given the extensive authority and mission "to protect, maintain and improve the quality and management of the waters of the state, ground and surface, public and private." Moreover, in §281.12(1) Wis. Stats. it is stipulated, "the Department shall have general supervision and control over the waters of the state." These outline broad general powers for the WDNR in setting acceptable water resource policy in Wisconsin consistent, in the WDNR's view, with the general purposes of ch. 281 Wis. Stats., and could serve as the basis for stronger groundwater management.

Against this broad reading, Kavanaugh (2000) notes that opponents of increased groundwater protection/regulation might point to §281.17 and §281.35 Wis. Stats., which are quite specific in setting water quality standards and daily pumping quantities. The legislature, it can be argued, has been specific in circumscribing the purpose of ch. 281 Wis. Stats. There is potentially contradictory language here that may find resolution only through court cases.

New legislation – options and issues

Attention surrounding proposed Senate Bill 414 in Spring 2000 addresses the issue in terms of new legislation. WDNR Secretary George Meyer said in testimony on the bill, "There's a gap in the law" and only new legislation can fill it. SB 414 would have amended §281.17(1) Wis. Stats. in order to extend the WDNR's authority to deny high capacity well permits, allowing them to protect "high-quality spawning areas or habitat for fish, rare wetland types or habitat for threatened and endangered species." One clause allowed WDNR to deny permits that would have an "adverse effect on scarce resources." However, the bill exempted all agricultural uses, all municipal wells, and all industrial uses from review using these criteria. In testifying for the bill, Secretary Meyer clearly indicated the many difficulties associated with bringing a synoptic view of hydrology to the law.

Another straightforward avenue for statutory reform would be to apply the rules guiding the actual permitting process in §281.35(5)(d) Wis. Stats. (the "grounds for approval"), which is aimed only at water withdrawals over two million gpd, to *all* high capacity well permitting (§281.17 Wis. Stats.). Also, locational criteria for wells and specific classes of protected features (as opposed to "scarce resources") could be named and added to the list of considerations for permit approval.

There are numerous issues that should be considered in any new legislation for improved groundwater quantity management; we briefly summarize a selection of those below.

➥ *Explicit legislative recognition of hydraulic continuity*

Statutory recognition of groundwater-surface water interconnections (hydraulic continuity) is an important first step towards protecting both groundwater and surface water resources. In an unconfined or water-table aquifer, surface water bodies are inherently connected to the aquifer. In a confined aquifer, the water contained in the aquifer will be strongly connected to surface waters only through fractures and faults, or if the overlying confining bed is absent or varies in hydraulic characteristics. If hydraulic continuity is demonstrated, then a well's impacts on both surface water and groundwater resources should be assessed.

➥ *Expanded criteria for review and permitting*

The basis for reviewing applications for high capacity wells is too narrow. At a minimum, criteria for assessing and permitting wells should be expanded to include protection of public rights in the state's waters (public interest criteria) and of environmental resources related to interconnected surface waters (springs, wetlands, rivers and streams, lakes, and fish and wildlife). The basis for denying a permit application could also be expanded beyond the singular criterion of adverse impacts on a public utility, and could include consideration of impacts on other public and private water supplies, as well as possible water quality/public health impacts. The administering agency could be required to determine acceptable levels of environmental impact from high capacity well proposals in administrative rules.

➥*Scope/geographic targeting*

The substantive reach and geographic scope could be limited to categories of highly-valued environmental resources (outstanding resource waters, Class I trout streams, rare wetlands, habitat for threatened and endangered species, or other sensitive public resources such as parks and scientific areas); or targeted at priority hydrogeologic regions, watersheds, or other management units where groundwater and/or related surface water problems are known to exist. Reducing the scale of management attention would allow resource managers to focus on priority issues/regions, and more efficiently deploy personnel and fiscal resources.

➥ *Monitoring, reporting and strategies for data acquisition*

Sound long-term management of state water resources requires adequate information about the resource and uses. There are currently large data gaps that a) limit present management as well as b) impair the development of better understanding of the effects of high capacity wells on surface waters and ecosystems. Monitoring and reporting requirements associated with high capacity well permits need to be enforced. Voluntary reporting of water use information from other groundwater users should be encouraged. Funding for data management and analysis is essential. Such information, when added to long-term monitoring data gathered by state and federal agencies, will lead to an increased understanding of the hydrogeologic system in Wisconsin and better management of both groundwater and related surface waters. Additionally, monitoring and reporting "feedback" is essential to an adaptive management approach.

➥ *Exemptions and retroactivity*

Most states exempt one or another category of wells from state regulation (Glennon & Maddock, 1997). The most common exemption is for groundwater used for domestic purposes, which might also include some limited amount of stock watering, and other designated uses. These uses are presumably low-volume in comparison to high capacity wells, and a policy judgment has been made that it is probably not worth the time and trouble to require domestic users to obtain a permit (Glennon & Maddock, 1997). However, high capacity well legislative proposals that provide regulatory exemptions and review limitations for various uses, such as agricultural irrigation, really represent unregulated "loopholes." They may seriously impact surface waters and related resources; moreover, failure to ensure monitoring and reporting at exempted well categories undermines the goal of gaining adequate data and information regarding the state's water resources. In short, the decision regarding regulatory review exemptions for particular categories of wells is a political decision and in many respects impairs the state's ability to scientifically manage its water resources. Similar reasoning pertains to whether or not to include existing wells in any reform of the high capacity well law. New legislation could consider whether existing wells that are causing demonstrable damage to surface water and related resources (the burden of proof would presumably be on the regulatory agency) should be subjected to another round of regulatory review and possible permit modification or denial. In the interest of gaining essential information about groundwater and groundwater uses, pre-existing high capacity wells should be required to adhere to reporting requirements.

➥ *Addressing cumulative impacts and future uses*

The cumulative effect of new wells being installed every year, together with the recognition that the impacts of these wells/uses occurs over time, is well illustrated by the Central Sands Plain case study. High capacity well permit decisions are made incrementally – one at a time – without considering future demands on the aquifers and societal preferences. While this is admittedly a difficult issue, one mechanism for addressing future needs, resource availability and cumulative impacts is *planning*. A variety of plans either exist or are being developed (watershed plans, WDNR Geographic Management

Unit plans, other natural resource plans, "Smart Growth" land use plans). Where possible, an assessment of groundwater resources and development potentials and threats might be conducted as part of preparing or modifying such plans. Where comprehensive water management plans exist, they may be of use in anticipating future uses and conflicts or environmental problems. Plans are of limited value if they do not influence decision-making. Reviewing high capacity well applications for consistency with any relevant plans, where they exist, offers one option for incorporating cumulative impacts in future years into decision-making.

➥ ***Administrative review issues***

There are a number of issues related to the administrative review procedures used by regulatory agencies that could be addressed in any new high capacity well regulation initiatives. Provisions could be made to ensure that any application for a high capacity well permit with potential impact on surface waters and related resources is reviewed not only by hydrologists, engineers and hydrogeologists, but also by agency staff trained in ecology and biology. Achieving a more integrated, interdisciplinary permit review may be considered an internal agency management issue, but could also be specifically addressed in legislative language. The burden of proof to show that the public's waters and related resources will not incur significant adverse effects as a result of high capacity well development could be placed explicitly on the permit applicant (as is being done voluntarily in the case of the Perrier Group permit application in central Wisconsin). Placing this burden on a permit applicant rather than the regulatory agency internalizes the full costs of any groundwater development, and additionally generates data and information to further water management in the state. Legislation could also incorporate specific language establishing realistic streamlined permit review procedures and timelines, akin to the Oregon approach; however, any such measures should be sensitive to the need to have sound multi-seasonal information as a basis for decision-making. Of course, the degree of administrative discretion accorded the regulatory/management agency is an important legislative prerogative.

➥ *Continuing research support*

Wisconsin, through the state Groundwater Coordinating Council, has been innovative in directing research to state priorities to solve/clarify management problems and strategies. Continuing research support is essential to better understand Wisconsin's groundwater and related resources, use impacts, and management alternatives.

CONCLUDING COMMENTS

We have assembled information in this report that will hopefully be of value to policy-makers and others concerned about the future management of Wisconsin's "buried treasure" – groundwater, and related resources. We have provided information on the potentially negative impacts of high capacity wells, including the effects on interconnected surface waters. By examining experiences in other states that have modernized their groundwater quantity management laws and practices, we have tried to suggest the range of choices that might be considered for legislative change in Wisconsin. Our aim has been to illuminate key issues and better inform upcoming legislative initiatives. While we are concerned about more comprehensive and integrated management of all of our state's environmental resources and have interest in broader reforms, we have limited our focus here to dimensions likely to attend efforts to modify the legal framework related to high capacity wells. Based on our study, we believe that changes are needed to maintain the integrity of Wisconsin's waters while ensuring an adequate supply of high-quality water for future uses. We hope that a future historian, perhaps as the state looks ahead to the 22nd century, will conclude that we have contributed positively to that goal.

APPENDIX A. GROUNDWATER TERMINOLOGY, CONCEPTS, AND APPLICATION: A BRIEF REVIEW

The following discussion of the properties and flow of groundwater is drawn from Heath (1983) and Fetter (1994). An ***aquifer*** is a geologic material (rock or sediment) that provides water in useable quantities to wells or springs (Figure 10). A ***confining bed*** is a geologic material that restricts the flow of groundwater between aquifers. Any geologic material may be ***saturated***, meaning that water fills all the spaces between grains of the material, or ***unsaturated***, meaning that at most, the spaces between grains are only partially filled with water. The ***water table*** demarcates the boundary between geologic materials that are unsaturated (above) and geologic materials are saturated with water (below).

Groundwater may occur in ***unconfined aquifers*** (also known as ***water table aquifers***) in which the water table in the aquifer is free to rise and fall. Wells open to unconfined aquifers are called ***water table wells***, as the water level in the well generally indicates the elevation of the water table in the aquifer. Where an aquifer is saturated with water and overlain by a confining bed, the aquifer is referred to as a ***confined aquifer***. The water level in wells within confined aquifers will rise above the top of the aquifer because of ***artesian pressure***. Artesian pressure accumulates because water cannot flow easily into the overlying confining unit. Wells in these aquifers are known as ***artesian wells***, and if the water level in the well is above the land surface, water will flow to the surface without being pumped. The ***potentiometric surface*** of a confined aquifer is the surface that represents the level to which water will rise in tightly cased wells open to the aquifer. The water levels in tightly cased artesian wells represent the level of the potentiometric surface of the aquifer, somewhat analogous to the water table of an unconfined aquifer.

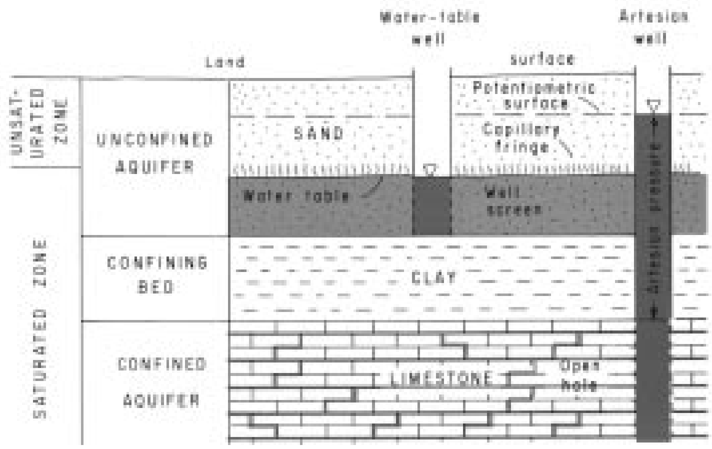

Figure 10. The groundwater system consists of aquifers that supply water to wells.
Source: Heath, 1983

Groundwater flows from areas of high water levels to areas of low water levels, i.e., from areas where the water table in unconfined aquifers is high to areas where it is low, and from areas where the potentiometric surface of confined aquifers is high to areas where it is low. The ***hydraulic gradient*** is the slope of the water table in unconfined aquifers and the slope of the potentiometric surface in confined aquifers (Figure 11). Groundwater flows in the direction of the steepest hydraulic gradient, and the rate of groundwater flow is proportional to the magnitude of the gradient. The steeper the gradient, the greater the rates of groundwater flow. The rate of groundwater flow is also proportional to the ***hydraulic conductivity*** of the aquifer geologic materials, a measure of how easily the aquifer materials transmit water.

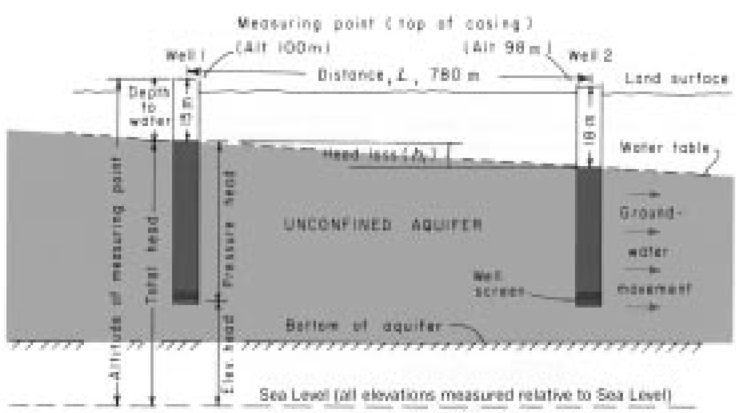

Figure 11. Hydraulic gradient is the slope of water flow from high to low areas.
Source: Modified after Heath, 1983

Water enters groundwater systems at recharge areas, moves through aquifers, and exits at discharge areas. In relatively humid areas, such as Wisconsin, ***recharge areas*** generally include all areas, except lakes, streams and adjoining floodplains. Lakes and streams are generally ***discharge areas*** meaning that they receive water from groundwater flow, as well as surface runoff (Figure 12). This flow of groundwater to surface water bodies is referred to as ***baseflow*** (Figure 13). Baseflow is generally the minimum constant flow in a stream or a lake in the absence of surface runoff.

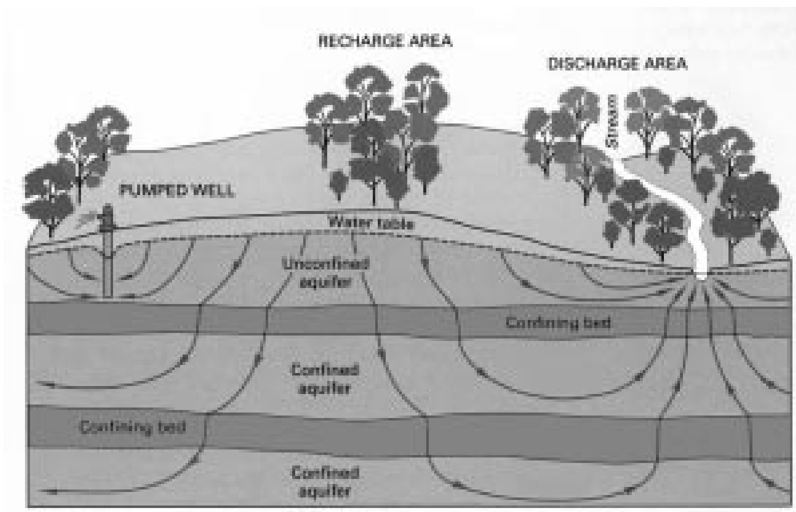

Figure 12. Groundwater flows from recharge areas to pumping wells or natural discharge areas, such as streams. The arrows show the paths of groundwater flow. Longer groundwater flow paths may require thousands of years for groundwater to travel from a recharge area to a discharge area, while shorter paths may require only days.

Source: Modified after Winter et al., 1999

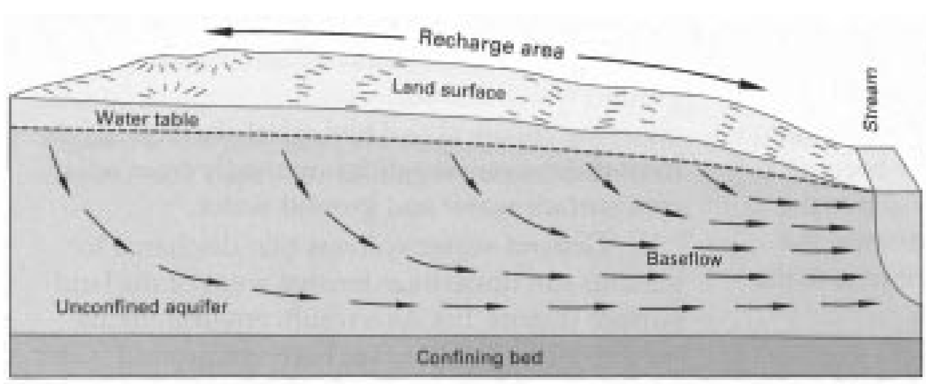

Figure 13. Baseflow is the flow of groundwater to surface water.

Source: Modified after Winter et al., 1999

The impacts of groundwater withdrawal from a well depend on several factors, including the pumping rate, the distance of the pumping well to other wells, the distance to surface water bodies, the properties of the aquifer (permeability and storage capacity), and the timing of the pumping (e.g., cyclical vs. constant, seasonal vs. year-round; Alley et al., 1999). The greater the pumping rate, the larger the cone of depression that will form in a given aquifer, both in terms of the magnitude of the water level decline and the area over which that decline occurs. The nearer a well is to other wells, the more likely the cones of depression around each will intersect, and the greater the well interference. Similarly, the nearer a well is to surface water bodies, the greater the impact (reduced baseflow, induced infiltration, chemical changes) on the surface waters. The permeability and storage properties of the aquifer will determine the size of the cone of depression around a well, and how quickly that cone of depression will form and stabilize. It is not possible to derive a single rule of thumb about the optimal distance between a well and features of interest (e.g., other wells, wetlands, rivers, aquifer recharge zones) because prospective well sites are all physically different (Hunt, 2000). Finally, the timing of pumping will determine how much time the aquifer and surface water bodies have to recover between pumping periods. In reviewing permits, the relative locations of the proposed well, other nearby wells and surface water bodies, along with the properties of the aquifer should be considered.

Period of operation should be considered in an analysis of a well's potential impact on the surrounding biophysical systems. Wells that operate year-round, such as municipal or commercial wells, affect groundwater patterns very differently that those that operate on a seasonal basis, such as irrigation wells. Seasonal withdrawals allow for periods of recharge, whereas year-round withdrawals do not allow for the same degree of recharge. If a pump is drawing water for only a couple of months a year, it has a different effect than a pump that is in production year-round (Hunt, 2000). For example, an irrigator that is pumping 1,000 gpm for 0.10 year is pumping as much water as a commercial well that is pumping 100 gpm year-round. Yet, the two wells affect the hydrology differently, because the land surface near the seasonal well has a recharge period. This aspect of the temporal dimension should factor into review of the well permit.

For the purposes of reviewing permits, hydrogeologists can analyze and predict the effects of well interference and aquifer water level declines using several different methods. Several analytical methods exist for predicting the declines in water levels due to pumping (Heath, 1983; Fetter, 1994). Jenkins (1968) provides an analytical method for determining the reduction in streamflow over time caused by a pumping well. Unfortunately, these methods require knowledge of aquifer properties that are often uncertain, and these methods make simplifying assumptions about aquifer systems that may not be valid under certain conditions. However, such analytical solutions may provide reasonable estimates of the effects of wells. Numerical modeling techniques (e.g., use of computer codes such as MODFLOW) allow for reductions in some of the simplifying assumptions made about the aquifer system, but are still subject to errors resulting from uncertainties in aquifer properties. For many aquifer systems, however, numerical modeling of the flow system allows investigators to explore the likely effects of different scenarios relatively quickly. While the predictions from both analytical and numeric models are not precise, they may be the best available information for decision-making (Alley et al., 1999).

Appendix B. Wisconsin's High Capacity Well Permitting Process

The Private Water Systems Section of the WDNR requires an approval for any well or system of wells that is classified as a high capacity extraction system (WDNR, 2000). The Private Water Systems Section reviews approximately 150-200 high capacity well applications per year (Rock, 2000). There are 9,422 high capacity wells in Wisconsin; approximately 4,175 (44%) for agriculture, 1,714 (18%) municipal water supply wells, and 1,128 (12%) industrial wells; the remainder serve schools, commercial establishments, and other purposes (see Figure 3; WDNR, 2000, http).

The specific classification of a water system dictates what information is required for the proposal of a high capacity well. High capacity wells can be categorized under public water systems or private water systems (Figure 14). As a result, the proponent of a high capacity well must look to the requirements in the specific state statute(s) that are relevant to their water system classification.

A public water system means "a system for the provision to the public of piped water for human consumption, if a system has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year. A public water system is either a 'community water system' or a 'non-community water system '" (Wis. Admin. Code §NR 811.02(21)). A community water system can either be a municipal water system or other than municipal (OTM) water system. The difference between the two is that a municipal water system is owned by a municipality, i.e., city, town, village, county, or sanitary district, whereas an OTM water system is not. Usually, public water systems serving seven or more homes, 10 or more mobile homes, 10 or more condominiums, or 10 or more apartments are identified as OTMs.

A private water system is "any water system supplying water that is not a public water system" (Wis. Admin. Code §NR 812.07(78)). The following sections provide a summary of the permitting process as described in Wis. Admin. Code chs. NR 811 and NR 108 for public water systems and ch. NR 812 for private water systems.

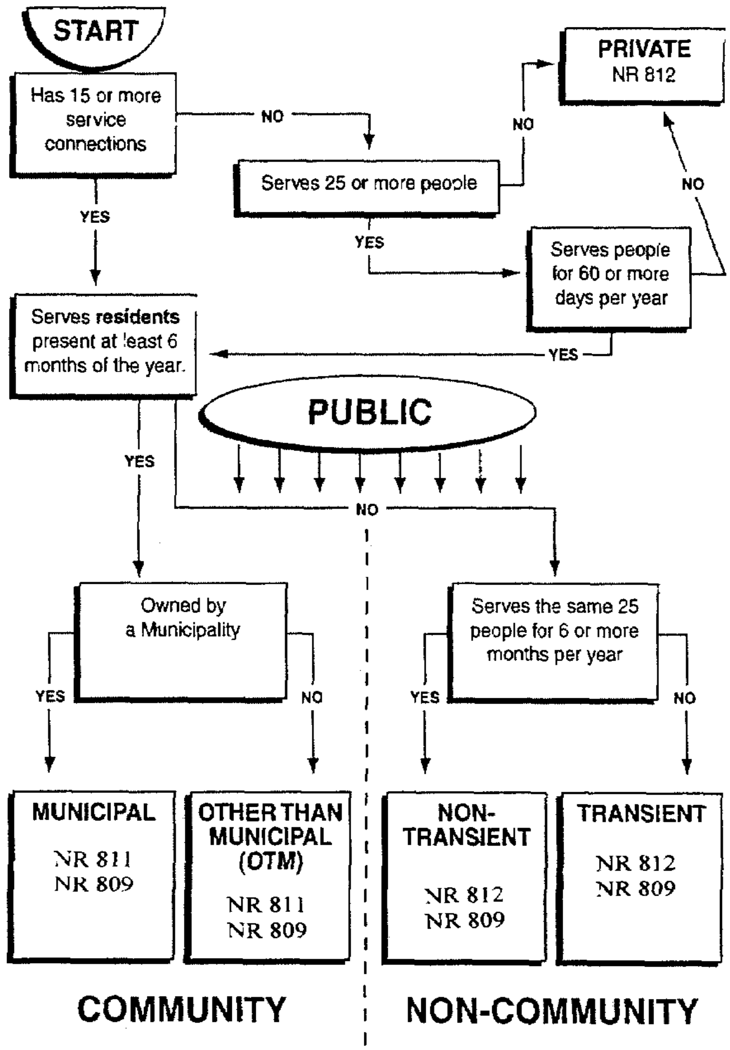

Figure 14. Water systems may be private or public.

Source: WDNR, 1999

Community

The approval requirements for developing a community water system that will have a source capacity greater than 70 gpm can be found in Wis. Admin. Code ch. NR 108. The requirements for submitting a community water system plan are described in Wis. Admin. Code §NR 108.04(2). All final plans and specifications submitted to the WDNR "shall be accompanied by a request for approval and by information pertinent to the design of the system, including general plans, construction details, specifications and an engineering report." The plans and specifications and pertinent information shall be submitted at least 90 days prior to the date upon which the construction of the project is planned to commence.

Design requirements for community water systems can be found in Wis. Admin. Code ch. NR 811. Clarifications to the plan submittal requirements for community water systems are covered under Wis. Admin. Code §NR 811.13. Proposals must contain information describing the locale of the well in relation to existing water supplies, its features of sanitary significance and specific information pertaining to well construction. In addition to the general plan, a well site investigation report shall also be submitted to the WDNR for all final wells. The site investigation report shall include such information as history of the proposed site, potential contamination sources within one-half mile of the well location, pumping capacity of the well, recharge area for the well, and other relevant information about the proposed site (Wis. Admin. Code §NR 811.13(3m)).

Private and non-community

As stated in Wis. Admin. Code §NR 108(10), a non-community water system is "a public water system that is not a community water system. A non-community water system typically serves a transient population rather than permanent year round residents." Examples of these systems are churches, parks, motels, resorts, taverns and restaurants. However, if the public water system serves at least 25 of the same people for six or more months per year, it is identified as non-transient. Schools, day-care centers and factories are examples of non-transient, non-community water systems.

The overall purpose of Wis. Admin. Code ch. NR 812 is to establish criteria and standards for the location, construction, reconstruction and maintenance of water systems; the abandonment of drill holes and wells; and the installation of pumping and treatment equipment. The established minimum standards and methods conform to chs. 280 and 281 Wis. Stats. which govern standards for pure drinking water and general water quality, respectively. The provisions of Wis. Admin. Code §NR 812.02 apply to the construction and installation of all new and existing water systems with the exception of those governed under Wis. Admin. Code chs. NR 811 and NR 141, which cover community water systems and nonpotable surface water systems.

Wis. Admin. Code ch. NR 812 lists restrictions to well placement based on location relative to buildings and contamination sources. In addition, there are specific design requirements for various well types depending on both the geology of the well site and the proposed use of the well (WDNR, 2000). Information that must be submitted to the WDNR in order to receive approval of a high capacity well system includes general information about water need and owner information, design information, possible impacts, and capacity evaluation requirements (when applicable). Under general information, a description of the purpose of the well (e.g., irrigation, school supply) must be provided along with the identity and contact information of the property owner and well operator.

Information on the possible impacts of the well that must be provided includes the location of nearby municipal and private wells, the proximity to local contamination sources and the potential impacts of the well on nearby wetland communities (WDNR, 2000). For all OTM systems, the applicant must also provide the WDNR with a capacity evaluation form [WDNR Form 3300-247]. The capacity evaluation form is submitted with the final plan to be reviewed by the WDNR. The Capacity Development Program was developed by the WDNR "to address the technical, managerial, and financial capacity of water systems to comply with the Safe Drinking Water Act (SDWA) and thereby provide safe drinking water" (WDNR, n. d., http). If the proposal and capacity evaluation are approved by the WDNR, an approval letter and capacity certification will be sent to the applicant.

Application approval process

Upon completion of the proposal for a high capacity well, the applicant submits the application to the Private Water Systems Section of the WDNR. Proposals are reviewed by the WDNR on a first come, first served basis. The regulatory review time mandated by state statutes for processing is to be no more than 65 working days (three months) from the date of receipt of a complete submittal (WDNR, 2000). It is possible to receive emergency approval to install a high capacity well system such as in the case of fire hazard or imminent crop damage (Wis. Admin. Code §NR 812.09(4)(a)4).

There are two reasons why the WDNR may reject or modify the permit proposal. The first reason is administrative – the application is incomplete. If this is the situation, the WDNR will send the proposal back to the applicant and will not review it until it is complete and meets all the requirements. The second reason why the WDNR would deny an approval is if the proposed project would have an adverse effect on public utility wells. As defined in Wis. Admin. Code §NR 812.09(4)(a)1), "The department may deny approval, grant a limited approval or modify an approval under which the location, depth, pumping capacity or rate of flow and ultimate use is restricted so that the supply of water for any public utility, as defined by s. 196.01, Stats., will not be impaired." The WDNR also has the authority to revoke any approval if it determines that the applicant submitted an incomplete proposal, or if the system is not constructed and operated in accordance with all the conditions of the WDNR (WDNR, 2000).

REFERENCES

Acton v. Blundell. Ex. 1843. 12 Mees. & W. 324, 350, 351, 152 Reprint 1223.

Alley, W. M., Reilly, T. E., & Franke, O. L. 1999. Sustainability of ground-water resources (USGS Circular 1186). Denver, CO: U. S. Government Printing Office.

Ashworth, S. M. 1992. Vegetation analysis of the South Beltline wetland restorations. Unpublished master's thesis, University of Wisconsin-Madison.

Brixey, E. July 26, 2000. DNR: No big impact from Perrier wells. Wisconsin State Journal, pp. 1A, 3A.

Browne, B. March, 2000. Personal communication. Assistant Professor, College of Natural Resources, University of Wisconsin-Stevens Point.

Chern, L., Mecozzi, M., & Johnson, D. 1999. Groundwater: Protecting Wisconsin's buried treasure. Wisconsin Natural Resources, 23(4).

Dawson, T. J. March, 2000. Personal communication. Director, Wisconsin Strategic Pesticide Information Project.

DeGayner & Co. v. DNR. 1975. 70 Wis. 2d 936, 236 N. W. 2d 217.

Ellefson, B. R., Sabin, T. J., & Krohelski, J. T. 1993. Water use in Wisconsin, 1990. U. S. Geological Survey Open-File Report 93-118.

Ellefson, B. R., Fan, C. H., & Ripley, J. L. 1997. Water use in Wisconsin, 1995. U. S. Geological Survey Open-File Report 97-356.

Fetter, C. W. 1994. Applied hydrogeology (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Fond du Lac v. Empire. 1956. 273 Wis. 333, 77 N. W. 2d 699.

Furbish, W. B. April, 2000. Personal communication. High Capacity Well Coordinator, Bureau of Drinking Water and Groundwater, Wisconsin Department of Natural Resources.

Gillen v. City of Neenah. 1998. 291 Wis. 2d 806, 580 N. W. 2d 628.

Glennon, R. J. & Maddock, T., III. 1997. The hydrology and law of stream/aquifer interactions. Proceedings of the 43rd Annual Rocky Mountain Mineral Law Institute, pp. 22-1 – 22-89.

Hazuga, M. J. July, 2000. Personal communication. Water Resource Specialist, Central Wisconsin Basin, Wisconsin Department of Natural Resources.

Heath, R. C. 1983. Basic ground-water hydrology (USGS Water Supply Paper 2220). Denver, CO: U. S. Government Printing Office.

Hennings, R. G. April, 2000. Personal communication. Assistant Director, Wisconsin Geological and Natural History Survey.

Hillis v. State Department of Ecology. 1997. 131 Wn. 2d 373, 932 P. 2d 139.

Huber v. Merkel. 1903. 117 Wis. 355, 94 N. W. 354.

Hunt, R. J. April, 2000. Personal communication. Research Hydrologist, Wisconsin District Office, Hydrogeologic Studies and Data Section, U. S. Geological Survey.

Japs, J. April, 2000. Personal communication. Program Manager, Water Appropriation Permit Program, Minnesota Department of Natural Resources.

Jenkins, C. T. 1968. Techniques for computing rate and volume of stream depletion by wells. Groundwater, 6: 37-42.

Johnson, K. G. April 2000. Personal communication. Lower Rock Basin Leader, Wisconsin Department of Natural Resources.

Just v. Marinette County. 1972. 56 Wis. 2d 7, 201 N. W. 2d 761.

Kavanaugh, E. C. March 2000. Personal communication. Lawyer, Wisconsin Department of Natural Resources.

Kent, P. G. 1994. Wisconsin water law: A guide to water rights and regulations. Stevens Point, WI: University of Wisconsin-Extension, University of Wisconsin-Stevens Point.

Kraft, G. J., Stites, W. & Mechenich, D. J. 1999. Impacts of irrigated vegetable agriculture on a humid north-central U. S. sand plain aquifer. Groundwater, 37(4): 572-580.

Krohelski, J. T., Ellefson, B. R. & Storlie, C. A. 1987. Estimated use of groundwater for irrigation in Wisconsin, 1984. U. S. Geological Survey Water Resources Investigations Report 86-4079.

Krohelski, J. T. April 2000. Personal communication. U. S. Geological Survey-Wisconsin District Chief Supervisory Hydrologist.

Laack, T. August 31, 1999. DNR plans to study Bloody Run Creek. Daily Tribune, Wisconsin Rapids, WI, pp. 1A, 6A.

Laack, T. March 23, 2000. Residents near Bloody Run resent well’s impacts. Daily Tribune, Wisconsin Rapids, WI, p. 1A.

Lawrence, C. L. & Ellefson, B. R. 1982. Water use in Wisconsin, 1979. U. S. Geological Survey Open-File Report 82-444.

Lee, K. N. 1993. Compass and gyroscope: Integrating science and politics for the environment. Washington DC: Island Press.

Lindorff, D., Helmuth, J., Johnson, D., & Karklins, S. (Eds.). 1997. Status of groundwater quantity in Wisconsin (WDNR Publication No. PUBL-DG-043-97). Madison, WI: Wisconsin Department of Natural Resources.

Lindorff, D. E. April 2000. Personal communication. Hydrogeologist, Bureau of Drinking Water and Groundwater, Wisconsin Department of Natural Resources.

Luthin, C. March 2000. Personal communication. Executive Director, Wisconsin Wetlands Association.

McChesney, D. April 2000. Personal communication. Water Resources Program, Washington Department of Ecology.

Mechenich, D. J., & Kraft, G. J. 1997. Contaminant source assessment and management using groundwater flow and contaminant models in the Stevens Point-Whiting-Plover wellhead protection area. Stevens Point, WI: Central Wisconsin Groundwater Center, Cooperative Extension Service, University of Wisconsin-Stevens Point.

Menne v. Fond du Lac. 1956. 273 Wis. 341, 77 N. W. 2d 703.

Mossbarger, W. A., & Yost, R. W. 1989. Effects of irrigated agriculture on groundwater quality in corn belt and lake states. Journal of Irrigation and Drainage Engineering, 115(5): 773-790.

Muench v. Public Service Commission. 1952. 53 N. W. 2d 517, 64 Wis. 2d 6, 218 N. W. 2d 734.

Olson v. Merrill. 1877. 42 Wis. 204.

Omernik v. State. 1976. 71 Wis. 2d 370, 238 N. W. 2d 114.

Rheineck, B. D. 1995. River-groundwater interactions and implications for wellhead protection at Black River Falls, Wisconsin. Unpublished master's thesis, University of Wisconsin-Madison.

Rock, W. T. August 2000. Personal communication. Chief, Private Water Systems, Bureau of Drinking Water and Groundwater, Wisconsin Department of Natural Resources.

Scott, J. 2000. Personal communication. Regulation Department, Water Use Division, South Florida Water Management District.

Sherk, G. W. 1990. Eastern water law: Trends in state legislation. Virginia Environmental Law, 9(2): 287-321.

Siebert, D. R. April 2000. Personal communication. Community Ecologist, Bureau of Integrated Science Services, Wisconsin Department of Natural Resources.

South Florida Water Management District. 1997. Basis of Review for Water Use Permit Applications within the South Florida Water Management District. [Online.] <http://www.sfwmd.gov/org/reg/rules/wubor_1997.pdf>[July 29, 2000].

State v. Michels Pipeline Construction, Inc.1974. 63 Wis. 2d 278, 217 N. W. 2d 339.

Swanson, S. K. April 2000. Personal communication. Research Assistant, Department of Geology and Geophysics, University of Wisconsin-Madison.

Szramek, J. J. April 2000. Personal communication. Permit Licensing Review, Oregon Water Resources Department.

Trochlell, P. A. April, 2000. Personal communication. Wetland Ecologist, Bureau of Fisheries Management and Habitat Protection, Wisconsin Department of Natural Resources.

University of Wisconsin Water Resources Institute. 1999a. Joint Solicitation of Groundwater and Related Research/Monitoring Proposals for Fiscal Year 2001. [Online]. University of Wisconsin Water Resources Institute. <http://wri.wisc.edu/Joint_Solicitation_2001/JS2001_home.html> [July 29, 2000].

University of Wisconsin Water Resources Institute. 1999b. Wisconsin Department of Natural Resources Groundwater Management Practice Monitoring Program. [Online]. University of Wisconsin Water Resources Institute. <http://wri.wisc.edu/joint_solicitation_2001/dnr_priorities.html> [July 29, 2000].

Washington Department of Ecology. 1998a. Water Resources Program. [Online]. Washington Department of Ecology. <http://www.wa.gov/ecology/pie/98overvu/98aowr.html> [July 29, 2000].

Washington Department of Ecology. 1998b. Technical Advisory Committee on Capture of Surface Water by Wells. [Online]. Washington Department of Ecology. <http://www.wa.gov:80/ecology/wr/plan/tachc.html> [July 29, 2000].

Weeks, E. P. & Stangland, H. G. 1971. Effects of irrigation on streamflow in the Central Sand Plain of Wisconsin. U. S. Geological Survey Open-File Report 1970-362.

Winter, T. C., Harvey, J. W., Franke, O. L., & Alley, W. M. 1999. Groundwater and surface water, a single resource (USGS Circular 1139). Denver, CO: U. S. Government Printing Office.

Wisconsin Department of Natural Resources. 1999. An operator's handbook for safe drinking water. Madison, WI: Wisconsin Department of Natural Resources.

Wisconsin Department of Natural Resources. 2000. High Capacity Supply Wells Guidance Packet. Madison, WI: Bureau of Drinking Water and Groundwater, Wisconsin Department of Natural Resources.

Wisconsin Department of Natural Resources, N. d. Capacity Development Program. [Online]. Wisconsin Department of Natural Resources. <http://www.dnr.state.wi.us/org/water/dwg/CapDevl/FAQFactSheet2.htm> [April 6, 2000].

Wisconsin Department of Natural Resources. 2000. Wisconsin Department of Natural Resources Drinking Water System High Capacity Wells. [Online]. Wisconsin Department of Natural Resources. <http://oraweb.dnr.state.wi.us/inter1/plsql/HICAP%24.Startup> [February 21, 2000].