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Central Sands Hydrology Working Group Report

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Central Sands Hydrology Working Group Report to the WICCI Adaptive Assessment Report

Climate Change Influences on Wisconsin Central Sands Hydrology and Aquatic Ecosystems

Executive Summary

Climate change could exacerbate already serious groundwater pumping impacts on Wisconsin Central Sands lakes, streams and wetlands. For example, if climate becomes drier or warmer, irrigation demands for groundwater may increase and further stress lakes, wetlands, and streamflows.

Getting in front of climate change could begin now, and may include doing a better job monitoring aquatic systems, and instituting groundwater pumping management schemes that explicitly consider aquatic resource health.

The Central Sands

The Central Sands covers parts of five Wisconsin counties. The region is characterized by its thick (often > 30 m) mantle of sandy glacial materials that cover an impermeable bedrock. These sandy materials comprise a productive aquifer holding an important groundwater resource that feeds the area's more than 80 lakes (> 5 ha), over 1000 km of headwater streams, and extensive wetlands. These resources are highly prized not only for the ecosystems they support (coldwater fisheries, endangered and threatened species), but also for amenity values and recreational opportunities. The aquifer is also tapped by Wisconsin's highest concentration of high capacity wells and greatest amount of groundwater pumping, used chiefly for supporting irrigated agriculture.

What makes the Central Sands region hydrologically interesting is that so much of its water cycle occurs underground. Groundwater is recharged by precipitation percolating through soils, and is ultimately conveyed to surface waters. Lakes and wetlands exist where the water table intersects depressions in the landscape, and streams occur where groundwater discharges to channels. Thus changes to the landscape's hydrologic budget that affect groundwater also affect aquatic resources and their ecosystems.

Although climate change might be expected to drive changes in the hydrology and aquatic resources of any landscape, the Central Sands region exemplifies a distinct case due to its prevalent irrigated land cover. Irrigated land has been increasing in the Central Sands for about 50 years and currently covers about 175,000 acres in the area of interest. The potential effects of irrigation on aquatic resources have been explored in classic studies in the 1960s and 1970s as well as newer works. These suggest irrigation decreases net groundwater recharge by 20-25% compared with nonirrigated lands. This reduction has been sufficient to dry up some lakes and streams in the region under only moderately dry conditions.

Anticipated Climate Change

Wisconsin's climate has changed noticeably during the last half-century (Serbin and Kucharik, 2009), and is expected to continue to change. Already in the Central Sands, warmer conditions have been observed, manifested mainly as warmer nights (1.5 ºC). The growing season has increased by 15 to 20 days. Precipitation has also increased, by an average of 50-150 mm yr^{-1} (about 10-15%). Future climate is expected to be warmer, with mean annual temperatures increasing by 2.6 to 3.6ºC (4.7 to 6.5ºF) by the mid-21st century, and 5.1ºC (9.2ºF) by late 21st century. Precipitation is expected to remain near current levels, but the time of year and amount of precipitation that arrives in extreme events may change. Wetter springs are likely, and drier summers are suggested but are less certain. Annual potential evaporation may increase by 10-20 cm across Wisconsin.

Vulnerability Assessment

We are in the early stages of assessing the vulnerability of groundwater resources in the Central Sands region. We have preliminarily qualitatively assessed how five primary climate drivers (annual precipitation, precipitation timing, temperature, humidity, frost during precipitation and snowmelt), and two secondary land drivers (irrigated land area, time under crop cover) may influence net groundwater recharge in the Central Sands region. These are summarized in Table 1.

More precipitation, especially during non-summer months, would increase net groundwater recharge and hence cause more robust water levels and stream flows; the converse would cause the opposite. Warmer temperatures, especially during summers, would increase potential evapotranspiration (PET). Greater humidity decreases PET while smaller humidity increases PET. Increased PET would only increase actual evapotranspiration (AET) on nonirrigated land when sufficient soil moisture is present, but increased PET would always result in increased AET on irrigated land during growing seasons, as irrigation makes up for any soil moisture deficit. We speculate that the timing of frost in the soil may be a consideration if frost limits percolation during what would otherwise be recharge periods.

We anticipate that warmer temperatures will result in longer growing seasons, with an adoption of longer season crops and perhaps more double crops. Both would drive increased irrigation demand. Similarly, we anticipate that the trend toward more irrigated fields will increase, perhaps spurred by both the challenges (timing of moisture with respect to crop need) and opportunities (longer growing seasons) brought about by climate change.

Adaptation Strategies

Adaption strategy ideas are in very initial stages. The working group suggests for two initial adaptation strategies: First, prepare for adaptive management. This can begin now by improving systems for monitoring water levels and stream flows. Second, groundwater management capacity needs to be developed. Currently there is no framework for managing groundwater withdrawals consistent with societal goals for surface water health.

Participants

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Description of Topic Area and Geographic Region

The topic area involves how climate change may exacerbate (or potentially alleviate?) the tension between groundwater consumed for irrigation and that available for maintaining healthy aquatic resources (lakes, streams, wetlands, and their ecosystems) in the Wisconsin Central Sands region. The working group's goal is to quantify the climate change – landscape hydrology – aquatic resource relation, assess system vulnerabilities, and lay out potential adaptation strategies for adjusting to climate change impacts.

The Central Sands is geologically characterized by a thick (often > 30 m) mantle of sandy materials overlying low permeability rock, and landforms comprising outwash plains and terminal moraine complexes associated with the Wisconsin Glaciation. As the region's extent is loosely-defined, we bound a region of interest by the Wisconsin River to the west and by the downstream portions of headwater streams in the Fox-Wolf Watershed in the east (Figure 1). The Sands region contains more than 80 lakes (> 5 ha), over 1000 km of headwater streams, and wetlands. These are highly prized not only for the ecosystems they support (coldwater fisheries, endangered and threatened species), but also for amenity values and recreational opportunities. What makes the region hydrologically interesting is that much of its water cycle occurs underground, i.e., the landscape's runoff is mostly conveyed by groundwater. Groundwater intimately supports surface water resources; lakes and wetlands exist where the water table intersects depressions in the landscape, and streams occur where groundwater discharges to channels. Thus changes to the landscape's hydrologic budget that affect groundwater also affect aquatic resources and their ecosystems.

Although climate change might be expected to drive changes in the hydrology and aquatic resources of any landscape, the Central Sands region exemplifies a distinct case due to its prevalent irrigated land cover (Figure 2). Irrigated land has been increasing in the Central Sands for about 50 years and currently covers about 175,000 acres in the area of interest. Irrigation utilizes groundwater to supply moisture to otherwise droughty soils, diverting baseflow from the region's streams and lowering water levels. The potential effects of irrigation on aquatic resources in the Central Sands were already explored in 1960s and 1970s studies (Weeks et al., 1965; Weeks and Stangland, 1971). These suggested net groundwater recharge (net recharge = precipitation – evapotranspiration – runoff) was 20-25% smaller on irrigated lands compared with nonirrigated lands, and that the decrease in net recharge would stress baseflows and water levels. (New estimates of net recharge amounts using improved techniques are being produced by B. Lowery and W. Bland at the University of Wisconsin-Madison Department of Soil Science. They provisionally estimate that irrigated crops have about 5 cm less recharge than native perennial covers.) Predicted baseflow and water level stresses have already come to realization (Figure 3).

Irrigation diversions are likely reducing baseflow by 30-50% of headwater stream discharges, and lake levels by 1 to 1.5 m in places (Kraft and Mechenich, 2010; Clancy et al. 2009).

Though the present and anticipated work here is specifically important to the Centrals Sands of Wisconsin, the setting and potential problem of increasing groundwater consumption for irrigation in a changing climate is applicable to other regions of Wisconsin and the Great Lakes states. Comparatively, the Central Sands region has the best known hydrology and modeling assets for exploring climate change and irrigation consumption issues in the Midwest region.

Future Climate Impacts

Anticipated climate change

Wisconsin's climate has changed noticeably during the last half-century (Serbin and Kucharik, 2009). In the Central Sands, warmer conditions have been observed, manifested mainly as warmer nights (1.5 ºC). The growing season has increased by 15 to 20 days. Precipitation has also increased, by an average of 50-150 mm yr^{-1} (about 10-15%).

Future climate predictions are briefly summarized here from downscaled IPCC models (WICCI Climate Change Workgroup, in progress). The warming trend is expected to continue, with mean annual temperatures increasing by 2.6 to 3.6ºC (4.7 to 6.5ºF) by the mid-21st century, and 5.1ºC (9.2ºF) by late 21st century. The greatest warming is projected during winters and nights. Wetter springs are likely. Drier summers are suggested but are less certain. Annual potential evaporation may increase by 10-20 cm across Wisconsin.

The frequency of extremes is also expected to change. The number of hot days annually (temperatures >32.2ºC (90ºF)) are projected to double (currently 12 days per year in southern Wisconsin and 5 days in the north). Cold days (those with lows less than -17.8ºC (0ºF)) are expected to decrease from the current 18 (south) to 40 (north) by 10 - 25 days. As a result, growing seasons may lengthen by nearly 4 weeks by the late 21st century and the first 50ºF day may occur 2 weeks earlier than at present. Precipitation extremes are also projected to increase. Currently, daily precipitation events in excess of 50.8 mm (2 inches) per day occur about 12 times per decade in southern Wisconsin and 7 times per decade in the north. The frequency may increase by 2-3 days per decade. Precipitation falling in the heaviest events will increase across Wisconsin for all seasons, even the summer, when a higher likelihood of mean drying is predicted. By mid-21st century, the top precipitation events year-round may become 20% heavier.

In summary, the climate is expected to be warmer, precipitation is expected to remain near current levels, but the time of year and amount of precipitation that arrives in extreme events may change. Warmer conditions will drive a longer growing season and greater potential evapotranspiration.

Vulnerability Assessment

A vulnerability assessment for this issue is in initial stages. The assessment will address if and how climate change primary drivers directly alter landscape hydrology, both on irrigated and nonirrigated lands, with implications for the health of aquatic resources. The assessment will also consider that changing climate may set off the secondary drivers of changing land use, land cover, and land management with consequences for landscape hydrology and aquatic resource health. We have developed conceptual models to help explore causes-and-effects and of system vulnerabilities; one for physical hydrology, and a second for land change. Future work will include translating conceptual models into quantitative models, using them to explore “what-if” scenarios of climate change, and assessing how the landscape’s hydrology and aquatic resources might be affected.

Physical hydrology conceptual model

A physical hydrology process conceptual model for Central Sands hydrology was developed as an adaptation of a general model by Dingman (2002). Reservoirs of stored water are shown (Figure 4) in boxes (e.g., snowpack, soil moisture, groundwater), and the mechanisms that transfer water between reservoirs are shown with lines (e.g., snow, rain, throughfall, infiltration).

All water entering the landscape arrives as precipitation and all water leaves as evapotranspiration or channel (stream) flow export. Incoming water is routed to evapotranspiration through interception (precipitation landing on plants that then directly evaporates), sublimation (direct evaporation from snow), evaporation from bare soil, and transpiration from vegetation. Water is routed to channel flow through percolation (groundwater recharge) and subsequent groundwater discharge, or through overland flow.

Reservoirs representing aquatic resources of interest (bold boxes) are the baseflow portion of streamflow and wetlands and lakes. Baseflow is key to the health of streams and their ecosystems, as (1) the overland flow part of streamflow is small, and (2) the aquatic ecology of central sands streams is chiefly determined by robust and cool groundwater discharge. Lake and wetland health (water quality, extent, and depth) may similarly be controlled by groundwater discharge when they are hydraulically connected with streams. But more often the lakes and wetlands in the central sands have groundwater seepage features, i.e., they have no inlet nor outlet, and their status is controlled by groundwater levels (head). Clearly, groundwater storage is paramount to aquatic resource health: greater amounts of groundwater storage increase baseflow discharge to streams and the depth and extent of lakes and wetlands. If groundwater storage is viewed as the governing control on aquatic resource health, groundwater recharge (“percolation”) and processes that affect it (precipitation, evaporation and transpiration, runoff) are the indirect controls.

Groundwater withdrawn by irrigation pumping affects groundwater storage in a somewhat convoluted way. Pumped groundwater may be lost to the atmosphere through evapotranspiration or return to groundwater storage. Thus accounting for groundwater withdrawn for irrigation perhaps is best done by evaluating the amount of evapotranspiration increase that it allows over nonirrigated landscapes.

A Conceptual Model of Changing Land Use, Cover, and Management

Climate change has the potential to drive changes in current land use, cover, and management (Figure 5). The hydrologic process conceptual model demonstrated that climate drives groundwater recharge which in turn determines the amount of groundwater in storage, and thus drives aquatic resource state and ecological health. More subtly and indirectly, climate may influence an evolution in land which further alters in landscape hydrologic processes. For instance, changes in timing and amounts of precipitation may cause increases in irrigated land. Land may be managed differently to take advantage of a longer growing season – longer season crops or double cropping - and thus affect groundwater recharge amounts. Perhaps changes will be driven from forest covers to other land covers.

How climate may influence land use and land cover is illustrated in Figure 5. In this conceptual model, land use and climate are two drivers that determine landscape distributed hydrologic processes. The "agent" of hydrologic processes, groundwater recharge, determines sequentially the state of groundwater, the state of surface water, and the state of aquatic ecology.

Qualitative Assessment of Impacts

In Table 1, we qualitatively assess how five primary climate drivers (annual precipitation, precipitation timing, temperature, humidity, frost during precipitation and snowmelt), and two secondary land drivers (irrigated land area, time under crop cover) may influence net groundwater recharge in the Central Sands region. Where the direction of some of the drivers is presently ambiguous, such as total precipitation or timing of precipitation, the effects of either direction are assessed.

More precipitation and more precipitation during non-summer months would increase net groundwater recharge and hence cause more robust water levels and stream flows; the converse would cause the opposite. Warmer temperatures, especially during summers, would increase potential evapotranspiration (PET). Greater humidity decreases PET while smaller humidity increases PET. Increased PET would only increase actual evapotranspiration (AET) on nonirrigated land when sufficient soil moisture is present, but increased PET would always result in increased AET on irrigated land during growing seasons, as irrigation makes up for any soil moisture deficit. We speculate that the timing of frost in the soil may be a consideration if frost limits percolation during what would otherwise be recharge periods.

We anticipate that warmer temperatures will result in longer growing season, with an adoption of longer season crops and perhaps more double crops. Both would drive increased irrigation demand. Similarly, we anticipate that the trend toward more irrigated fields will increase, perhaps spurred by both the challenges (timing of moisture with respect to crop need) and opportunities (longer growing seasons) brought about by climate change.

Planned Assessment Work

Ultimately, a goal of this work group is to present plausible climate-driven scenarios of future aquatic resource health and make to recommendations for adaptation strategies. We see as a first step quantifying the relations shown in the hydrologic process conceptual model and incorporating anticipated future climate scenarios. This physical hydrology will be evaluated in the context of aquatic ecology impacts. We anticipate the physical hydrology will be manipulated with potential land use/land management scenarios as well.

The tools we will use to explore future landscape hydrology will be a soil-vegetation – climate model ("IBIS") that generates a landscape water balance coupled with a groundwater flow model ("MODFLOW") that computes groundwater elevations and routes groundwater recharge to streams.

The question of climate influence on future land cover, use, and management will be investigated after future hydrology is better understood. We anticipate that answering this question will require the expertise of social scientists, agronomists, and agricultural economists.

Sensitivity Analysis and Uncertainties

Formal sensitivity analyses have not yet been done, but informal inspection reveals the change and direction of change of key climate variables (precipitation increase or decrease; precipitation timing) will be key in making improved analyses of risk.

Adaptation Strategies

Adaptation strategy 1: Prepare for adaptive management!

1. Improve systems for monitoring water levels, stream flows.
2. Improve models relating weather, soil hydrology, groundwater hydrology, and groundwater discharge to streams
3. Use models for evaluating vulnerabilities and potential adaptation strategies.

Adaptation strategy 2: Improve groundwater management capacity.

Propose and adopt a framework for managing groundwater withdrawals consistent with societal goals for surface water health.

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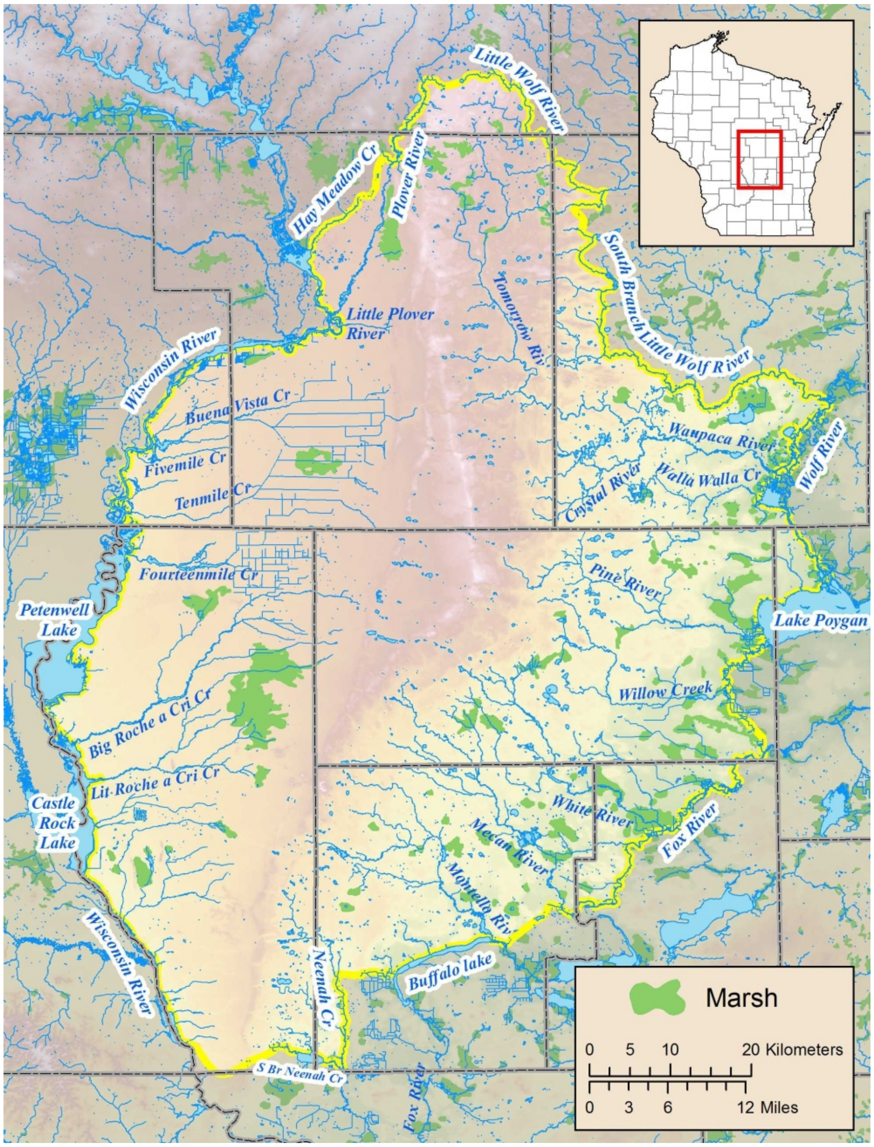

Figure 1. The Wisconsin Central Sands and its aquatic resources.

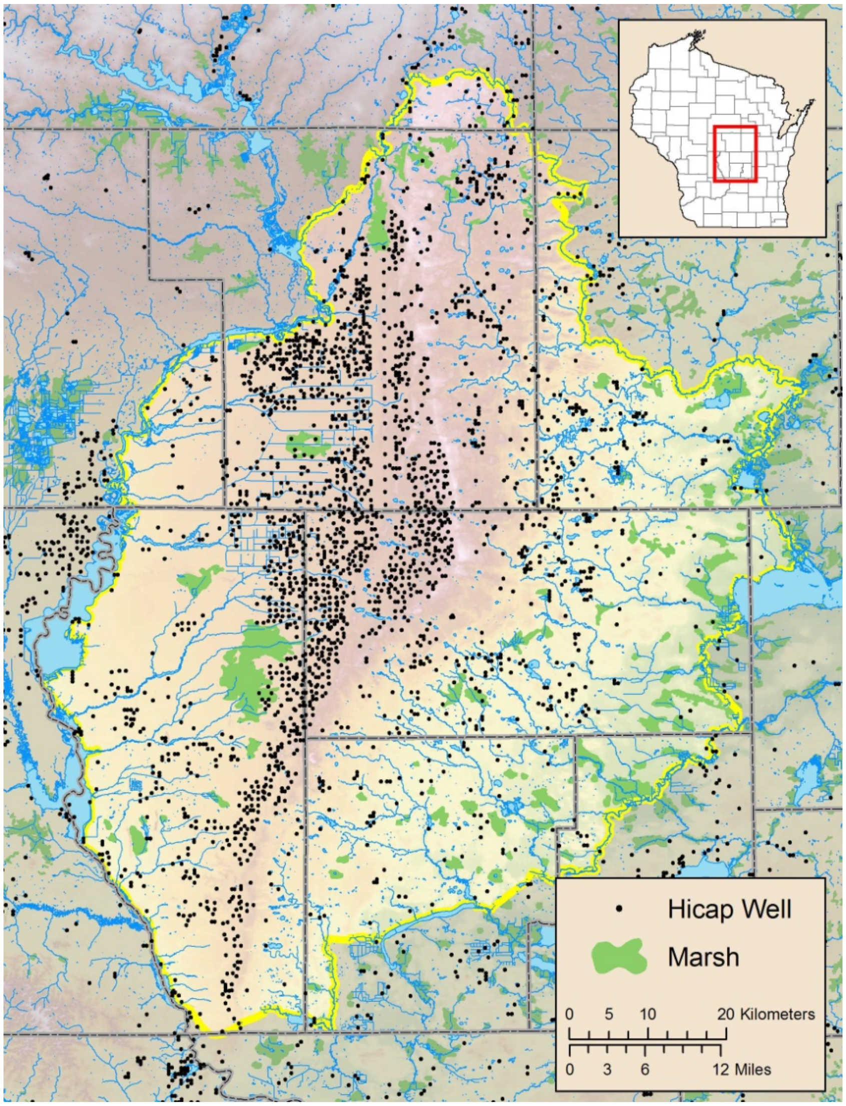

Figure 2. High capacity wells in the Wisconsin Central Sands.

Figure 3. Stressed aquatic resources in the central sands. Left: a stretch of the dried up Little Plover River. Right: Long Lake near Plainfield, WI.

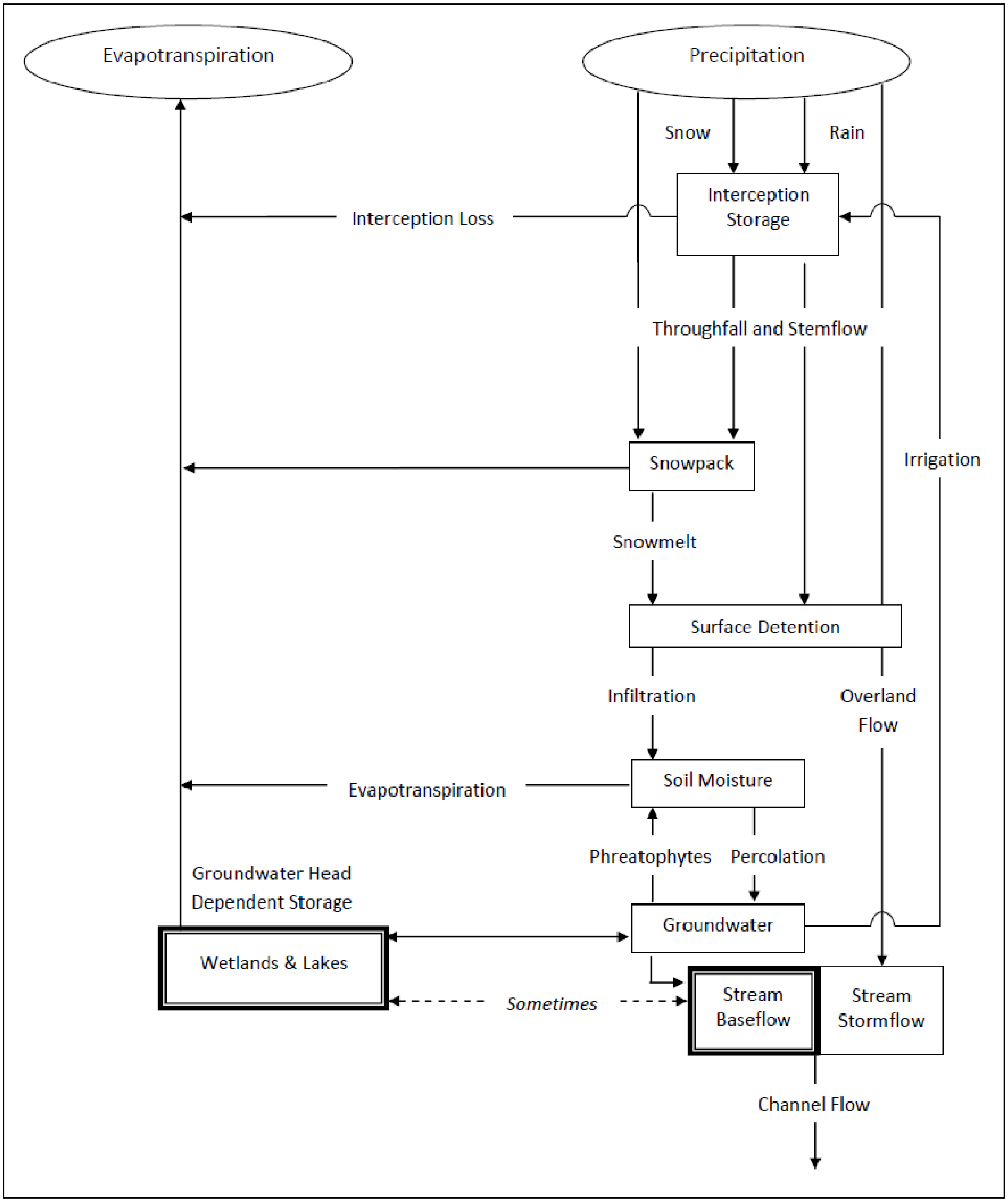

Figure 4. A Conceptual Model of Hydrologic Processes.

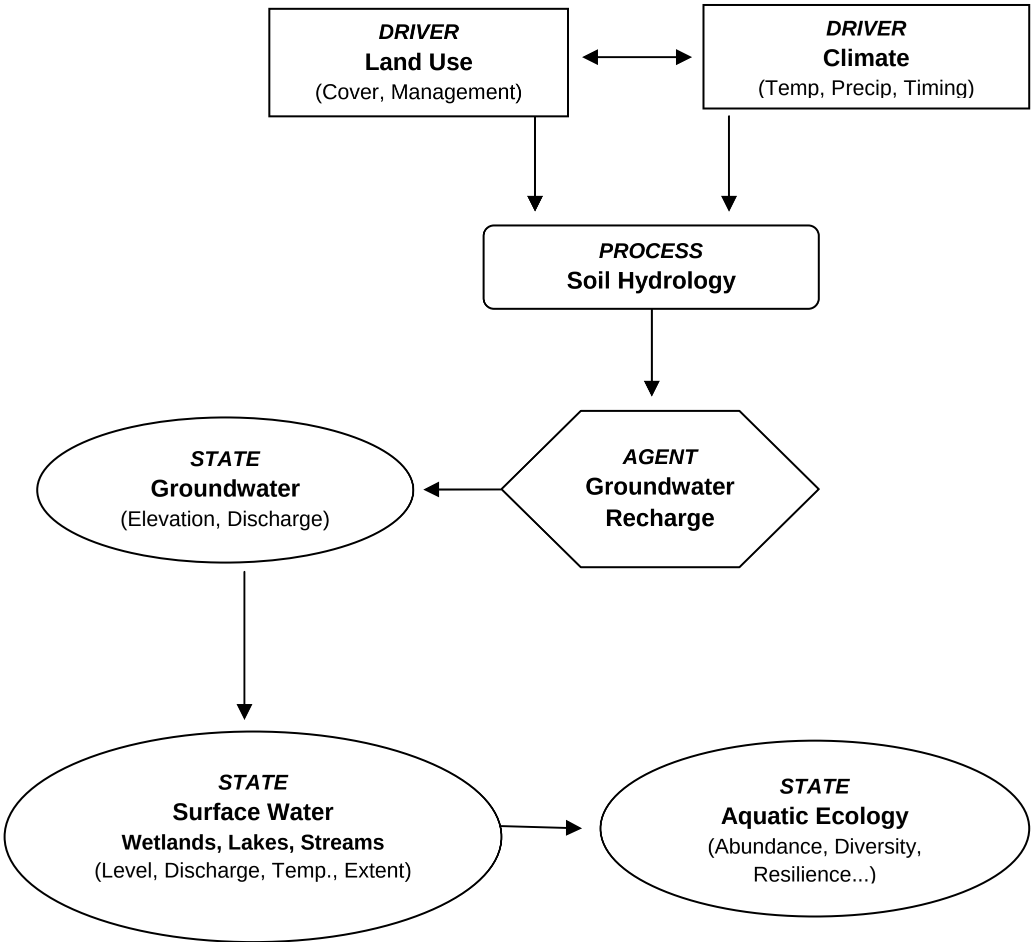

Figure 5. A Conceptual Model of Evolving Land Cover and Management

Table 1. Potential effects of climate change on groundwater recharge.

Climatic or hydrologic driver	**Recharge Direction**	**Rationale / Comment**
Primary		
Precip, annual total		
More	**+**	**Increased water into system**
Less	**-**	**Decreased water into system**
Precip, timing		
More Fall, Winter, Spring	**+**	**PET is lower this time of year**
More summer	**-**	**PET is greater this time of year**
Temperature		
Warmer	**-**	**PET increases**
Humidity		
More	**+**	**PET decreases**
Less	**-**	**PET increases**
Frost during thaw/precip periods		
More	**-**	**Frost encourages runoff**
Less	**+**	**Lack of frost encourages recharge**
Secondary and cultural drivers		
Crop cover, longer or double crops		
More	**-**	**Greater LAI for more of the year**
Irrigated land		
More	**-**	**Greater AET for more of the year**