springs exist near ridge tops and edges of valleys where tree cover is relatively low. Dominance by trees (tall and mid-canopy) increases along valley slopes, which are often composed of the St. Peter Fm., the Prairie du Chien Group, or the Cambrian sandstones. Herbaceous plants are more dominant near valley bottoms. Herbaceous plants tend to dominate in Waukesha County, regardless of stratigraphic unit.

![Graph showing vegetation distribution in Iowa and Waukesha Counties](image)

**Figure 10.** Distribution of Vegetative Strata Cover in a) Iowa County and b) Waukesha County.

For dominant vegetative strata cover classes within each stratigraphic group, i.e., those that exceed 30% cover (Fig. 10), Shannon’s index of diversity (H’), the percent cover of native plants, and the percent cover of invasive plants were plotted (Appendix E). Results are similar among stratigraphic groups in Iowa County. Diversity ranges from 0.20 to 0.35 for trees (tall and mid-canopy) and herbaceous plants. The percent cover of native plants ranges from 65 to 100%, and the percent cover of invasive plants ranges from 10 to 38%. Results are also similar among stratigraphic groups of springs in Waukesha County, but diversity is generally higher for herbaceous plants (0.53 – 0.71). The percent cover of native plants ranges from 53 to 77%, and the percent cover of invasive plants is ranges from 21 to 52%.

**CONCLUSIONS AND RECOMMENDATIONS**

**Status of Spring Ecosystems**

Iowa County is rich in spring resources, and any loss of spring resources over the last 50 years is minimal. When compared to springs in northwestern Illinois (Webb et al., 1998), the species richness and diversity for plants at the Iowa County springs appears to be a bit lower. However, the percent cover of native species is relatively high and the percent cover of invasives is relatively low. Agricultural and historical uses of spring water clearly impact the ecological status of springs in this region. Cattle currently have or have recently had direct access to nearly 30% of the springs that were surveyed, and three of the springs emerge from spring houses that were originally built as part of a farmstead.

Plant diversity is somewhat higher at the Waukesha County springs, but the percent cover of native plants is lower and the percent cover of invasive plants is higher. The historical use of spring water and associated modifications to springs in the City of Waukesha are very well-documented (Schoenknecht, 2003). None of the springs within the City of Waukesha were surveyed, but results suggest that the ecological status of springs elsewhere in the county has been similarly compromised by historical uses of the water. Approximately 45% of the springs surveyed have been significantly modified in some way. Some springs have pipes that direct flow and others have concrete boxes or spring houses that fully encase the spring and hinder recovery of the natural system.

**Conceptual Models and Vulnerability of Springs to Withdrawals**

Field data support conceptual models for springs in Iowa County that are based on typical contact springs, where water emerges along slopes and at lithologic contacts with differences in hydraulic conductivity. Springs are associated with every major stratigraphic unit in Iowa County, but are most commonly found in association with the Sinnipee Group, near the upper contact of the St. Peter Fm., or near the upper
contact of the Cambrian sandstones (Fig. 3, Appendix C). This indicates that aquifer heterogeneities like vertical and horizontal fractures, both of which are prevalent throughout the Sinnipee Group rocks, or partings along major stratigraphic contacts may be particularly important in promoting discrete flow in the region. There is some evidence that flow is more variable in springs discharging from stratigraphically higher geologic units, which supports a model that includes the influence of fractures. However, isotope levels and concentrations of most ions at these springs are relatively stable, indicating mixing along flow paths and/or a component of flow through porous media. In regions with high topographic relief, like Iowa County, groundwatersheds are more likely to coincide with surface watersheds (Toth, 1963). Therefore, stratigraphically higher springs may have small recharge areas that could be easily delineated by relying on topography. The wide range of nitrate concentrations in water discharging from these springs further supports the existence of small and shallow watersheds, where local land use influences geochemistry. There is also some evidence that flow is less variable in springs discharging from stratigraphically lower geologic units, which indicates longer or less direct flow paths. There is less variability in nitrate concentrations at these springs, and concentrations are generally lower. This indicates broader or deeper groundwatersheds, with a greater degree of mixing along flow paths.

The vulnerability to pumping of individual springs in Iowa County will require site-specific investigation because perched water tables and local aquitards are common in the Driftless Area (Krohelski et al., 2000). However, some generalizations can be made on the basis of the models presented above and the distribution of high-capacity wells in the county. Springs discharging from stratigraphically higher units are likely to be vulnerable to pumping from wells along ridge tops that are installed in these aquifers or that span multiple aquifers. Because recharge areas for these springs are probably small and shallow, pumping could result in substantially reduced spring flow or complete loss of flow to small springs. Springs discharging from stratigraphically lower units are probably less vulnerable, due in part to broader contributing areas, but also because most high-capacity wells that pump water from the Cambrian sandstones are located in the floodplain of the Wisconsin River, where few springs exist (Appendix F).

The spatial distribution of springs in Waukesha County is influenced by the glacial topography and the position of the Maquoketa shale subcrop. Springs were historically concentrated along the western margin of the Kettle Moraine and within the drumlinized zone the east (Fig. 2). Very few springs were mapped northwest of the Maquoketa shale subcrop, which is recognized as an important recharge area for the deep sandstone aquifer (Feinstein et al., 2005). The four geochemical groups of springs presented above require more thorough testing; however, results suggest that while flow paths originate in the unlihited aquifer, groundwater may flow through shallow bedrock before discharging as depression springs in low-lying wetlands or near streams. Regional flow modeling for southeastern Wisconsin supports this conceptual model, and shows local, topographically-controlled flow systems near the Kettle Moraine and other areas of relief. Particle tracking shows that groundwater intersects shallow bedrock before discharging to surface water bodies or at the water table (Feinstein et al., 2005). Although they are not explicitly modeled, groundwater may flow along similar paths to springs.

Feinstein et al. (2005) conclude that the widespread regional pumping in southeastern Wisconsin (Appendix F) has affected some shallow flow patterns, especially those west of the Maquoketa shale subcrop, and that downward flow from the shallow to the deep parts of the system occurs. Furthermore, their work shows that shallow high-capacity wells derive water primarily from diverted baseflow or induced flow from streams. Therefore, springs in Waukesha County are likely to be vulnerable to additional groundwater withdrawals from both the shallow and deep parts of the system. However, Group 3 springs are probably most vulnerable to withdrawals from the unlihited aquifer, and Group 1, 2, and 4 springs are most vulnerable to withdrawals from the shallow bedrock aquifer.

The approach to developing conceptual models of springs and assessing their vulnerability to pumping relies on gaining confidence in the positional accuracy of historical springs, as well as interpreting the
site-specific geochemical and spring flow data that were collected as part of this study. In Iowa County, 92% of the property owners that were interviewed confirmed the location of one or more springs on their property. Fewer springs remain in Waukesha County, but many owners recall the existence of a spring on their property in the past. Therefore, the overall confidence in historical spring locations is high, which allows their use in association with patterns of regional geology and topography. These regional data are complemented by the depth of the site-specific information collected using the Springer et al. (in prep.) system. At least 20 springs were surveyed in each county. This number of springs provided sufficient data to develop conceptual models and preliminarily assess vulnerability to pumping, suggesting that the overall approach may also be successful elsewhere in the state.

REFERENCES
Southwest WI Regional Planning Commission (SWWRPC), 2005, Iowa County Comprehensive Plan: SWWRPC Planning Report No. 05/188.