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Hydrogeology of Hanging Bog State Preserve: The Role of Hillside Seeps in Draining the Iowan Surface

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Along the margin of the Cedar River Valley, groundwater discharges from eroded and weathered glacial materials of the Iowan Surface to modern alluvial deposits of the valley floor. Hanging Bog State Preserve, located along this topographic, geologic, and hydrologic boundary, represents one such groundwater discharge location, in the form of a perennial hillside seep. Based on detailed monitoring of surface water and groundwater levels within the preserve for a one-year period, it is shown that a significant quantity of groundwater, collected from a disproportionately large recharge area, is funneled to the valley wall at this site and subsequently carried to the flood plain. The size of the recharge area presents a challenge to land owners in terms of protecting water quality in the preserve. More broadly, the hydrologic data from this study allow quantitative testing of previous assumptions about groundwater flow to bog and fen environments on the Iowan Surface that were based on geology and qualitative observation. Theoretical considerations and the limited occurrence of fens both locally and in the region both support the conclusion that the type of groundwater discharge seen at Hanging Bog State Preserve represents only a small piece of a continuum that exists along this and similar glacial-fluvial interfaces.

INDEX DESCRIPTORS: groundwater, hydrology, hanging bog, fen, Hanging Bog State Preserve.

REGIONAL GEOLOGIC SETTING

The 16-acre Hanging Bog State Preserve (HBSP), located in NW 1/4, Section 5, T83N, R08W, Linn County, Iowa, consists of steep, heavily-wooded slopes and flood plain area on the margin of the Cedar River valley (Fig. 1, inset). The preserve derives its name from a perennial groundwater seep that discharges on the valley wall approximately 9 m (30 ft) above the flood plain. HBSP is perhaps best known for the occurrence of skunk cabbage and other unique vegetation that thrive in the consistently wet soils of the bog. Contrary to what the term “bog” may imply, there is no standing water at the site; discharge from the spring immediately flows downhill in a small stream. The division between the flood plain surface of the Cedar River and the adjacent uplands, seen in the preserve and surrounding area, represents a topographic, geologic, and hydrologic boundary. Topographically, the flood plain in the preserve lies between 15 and 30 m (50 and 100 ft) below the highest parts of the adjacent uplands (Fig. 1). Geologically, the preserve is positioned along a reentrant in the irregular southeastern boundary of the Iowan Surface, which covers a large part of northeastern Iowa and was formed by large-scale Wisconsinian erosion and mass wasting of pre-Illinoisan glacial deposits (Prior 1991). Parts of the Iowan Surface, particularly in the southern portion, are mantled by loess derived from southeastern-trending major river valleys, like the Cedar, that carried glacial meltwater and outwash during late Wisconsinan time and cut into the older glacial deposits (Prior 1991).

The current study, sponsored by the Iowa State Preserve Board, was designed to explain the geologic and hydrologic conditions that sustain the physical bog environment in the HBSP and, based on water quality protection issues, to provide an estimate of the bog’s recharge area. In addition, as the only detailed and continuous study to date of surface water and groundwater levels in a wetland environment on the Iowan Surface, the results from this research are seen as providing a basis for constraining previous assumptions about the mechanics of groundwater movement in this landscape, particularly with respect to recharge sources, rates, and areas, and the related issue of water quality protection.

RELATIONSHIP OF HBSP TO OTHER BOGS/WETLANDS ON IOWAN SURFACE

Wetlands, including fens and bogs, are characteristic of the Iowan Surface (Prior 1991) and from a hydrogeologic perspective are reflective of the extremely heterogeneous nature of the subsurface glacial deposits and the resulting concentration of groundwater flow in areas of relatively high permeability within a dominantly low-permeability system. Fens are peatlands dependent on groundwater discharge for nutrient enrichment and commonly supportive of rare plant communities (Thompson et al. 1992). Although technically not a fen because it lacks peat, the seep at HBSP shares geologic and hydrologic characteristics with many of the 44 fens on the Iowan Surface identified by Thompson et al. (1992). The authors classified the vast majority (34) of these as "inter-till" fens receiving groundwater discharge from outwash sandwiched between tills; they classified the others as abandoned channels, terrace deposits, bedrock-recharged fens, and exhumed sand and gravel ridges. Five of these fens were grouped in more than one category.

INVESTIGATION GOALS AND METHODS

The investigation was conducted over a 12-month period between June 2000 and June 2001. Seven soil borings within and just outside the preserve boundaries were drilled and logged to ascertain the shallow geology of the site (borings B1 through B4...
and wells W1 through W4). Four of these borings, two on the floodplain (W1 and W2) and two just upslope of the bog (W3 and W4), subsequently were used to install 2-inch PVC monitoring wells for measurement of groundwater elevations (Fig. 1). Two In-Situ-Inc. Mini TrolTM automatic water-level probes were utilized to measure groundwater levels continuously (at 2-hour intervals) in both the floodplain and uplands. Manual measurements of groundwater elevations were taken in all four wells at an average frequency of 2.5 weeks throughout the period of study. Site visits were also used to measure discharge of the small stream draining the bog, except in freezing weather when the stream was iced over (Fig. 1). Additional investigative tasks included a review of area well log available through the Iowa Geological Survey's geologic site and sample tracking system (GEOSAM); a surface survey of 18 sites within 5 miles of the preserve that were identified from various mapped data as potential areas for additional seeps; and an analysis, based on stream discharge, of the recharge area for the bog.

RESULTS OF INVESTIGATION

Geologically, the flood plain surface is characterized by Holocene age alluvial materials deposited overbank by the Cedar River during flood cycles and perhaps also during previous southerly migrations of the river channel. For example, a typical floodplain soil boring consisted of topsoil overlying approximately 0.74 m (2.5 ft) of moist, sticky, gray clay and 0.45 m (1.5 ft) of coarse sand (Fig. 2). In contrast, the adjacent upland surface is composed of glacial materials, loess, and soils developed on loess (Fig. 2). The boring log from one of the upland wells shows topsoil overlying approximately 0.60 m (2 ft) of sand and gravel outwash, and an extremely dense basal till layer. Because of its relative impermeability, the till is responsible for the location of the bog: the glacial deposits are truncated at the valley wall and, as a result, shallow groundwater is funneled through the permeable outwash to the hanging bog at the surface (Fig. 2).

Groundwater just upslope of the bog area is present in the outwash under unconfined conditions, approximately 1.5 m (5 ft) below the surface, at an elevation of approximately 236 m (775 to 777 ft). Shallow groundwater in the flood plain appears to move mainly through sand lenses and stringers contained in the finer grained matrix of overbank deposits. The water table in the flood plain areas is present at depths of approximately 0.6 and 2 m (2 and 6 ft) at elevations between approximately 226 and 228 m (741 and 747 ft). The standard deviation (SD) of groundwater levels measured manually in the aquifer upslope of the bog ("bog aquifer") was 6.1 and 6.4 cm (2.4 and 2.5 in), respectively, in the two monitoring wells over the 12-month study (Fig. 3). This compares to a SD in the two flood plain wells of 29 and 13 cm (11 and 5.1 in), respectively, over the same period (Fig. 3). Continuous (i.e., 2-hour interval) monitoring showed a similar pattern: groundwater levels in the bog aquifer indicate total fluctuation of less than one foot over the entire 12 months and negligible short term changes. Even more definitive is a comparison for the period 25 March to 4 June 2001, when both bog aquifer and flood plain aquifer wells were monitored continuously. During this interval the SD for the bog aquifer was 3.0 cm (1.2 in), while the SD in the flood plain well was 15 cm (5.9 in), a five-fold difference.

Discharge of the small stream draining the bog ("bog stream") varied between 5.7 and 40 l/min (1.5 and 10.5 gpm) during
warm weather portions of the study; typical flows were in the range 3.7 to 23 l/min (1.5 to 6.0 gpm).

DISCUSSION

Groundwater Discharge along Slopes

The Iowan Surface is known to consist of highly heterogeneous glacial materials including till, outwash, loess, colluvium and paleosols (Prior 1991). This suggests that the locations and rates of groundwater recharge and discharge are also highly variable. Consider three general cases of groundwater movement through a hillside between an upland area and flood plain. In the idealized case where geologic materials are homogeneous and isotropic, and the slope of the hillside is small and uniform, groundwater moves smoothly through the hillside, with no refraction or convergence of flow lines, in one continuous aquifer. Discharge of this water to the surface occurs in the flood plain; i.e., a seepage face is not present on the hillslope (see Fig. 4, Case A). If the slope of the hillside is steeper and/or more convex in shape (see Fig. 4, Case B), a seepage face can develop at the base of the hillside near the inflection point of the slope (Freeze and Cherry, 1979). A mild layered heterogeneity (i.e., $K_x = K_y \geq K_z$, where $K_x$, $K_y$, and $K_z$ represent the hydraulic conductivity along the three principal axes) can also force a seepage face to develop at the base of a slope by diverting some fraction of the total discharge from the hillslope aquifer but without subsurface disconnection between the hillside and flood plain aquifers (variation of Case B). Both variants of Case B illustrate an important point: the presence of hillside seepage does not necessarily indicate a "perched" aquifer hydraulically disconnected from groundwater under the floodplain. The presence of an extremely low-permeability layer (i.e., $K_x = K_y \gg K_z$) can block downslope movement of groundwater and effectively move the position of the seepage face upslope and divert flow to a degree sufficient to create a hydraulic discontinuity between the flood plain and upland aquifers, the situation documented for the Hanging Bog hillside seep (see Fig. 4, Case C).

Based on the above theoretical considerations and the known geologic heterogeneity and sheer size of the Iowan Surface, Cases A, B, and C, and variations thereof, can all safely be assumed present and likely grade into one another through a type of continuum. Case A can be seen as representative of areas along the Cedar River valley where outwash deposits are absent and groundwater discharge is in the form of relatively diffuse flow from areas of clay-dominated till and colluvium to fine-grained flood plain deposits. Case A likely grades into Case B where the hillside slope becomes steeper and/or more convex, and Case B grades into Case C where relatively uniform slope deposits transition laterally to discontinuous pockets of outwash overlying till or discontinuous outwash within or between till units. Thus, the concentrated groundwater flow through outwash deposits observed at the HBSP, and similar sites on the Iowan Surface, including many of the fens of Thompson et al. (1992), represents an end member of a continuum of discharge modes along this hydrologic boundary.
Distinction between Cases B and C requires simultaneous monitoring in both upland and floodplain environments for an extended period of time to determine if two discrete aquifer systems are present. Further, the major evidence necessary to verify such a hypothesis is a distinct contrast in variance between the potentiometric surfaces in the upland and floodplain environments, a condition clearly indicative of differing aquifer boundary conditions. Comparison of continuous data from the Cedar River (USGS gauging station No. 05464500) and groundwater levels at the HBSP show clearly that the floodplain aquifer is responsive to frequent variation in river stage, while the bog aquifer shows relatively little variation, suggestive of a steady subsurface source (Esolato and Niemann 2001). Conclusions of this type require data obtained from long-term, continuous, and site-specific groundwater and surface water monitoring, a unique aspect of the Hanging Bog investigation. It should be noted that this kind of monitoring is also necessary to distinguish between true perennial seepage and transient seepage limited to periods of storm drainage. The standard deviation (SD) of groundwater levels in the bog aquifer, particularly the continuous measurements, indicates remarkably consistency, whereas groundwater levels in the flood plain aquifer show significantly greater variation. The contrasting variances over the 12-month study clearly establish the two aquifers as hydraulically disconnected, corresponding to a Class C scenario.

Recharge Area for HBSP and Implications

Total precipitation during the 12 months of study, June 2000 to June 2001, was 99.0 cm (39.9 in), which is 13.3 cm (5.36 in), or 13%, above average, based on continuous measurements at the Cedar Rapids Municipal Airport since 1953 (NOAA 2004). ArcView® 3.2 was used in conjunction with a digital topographic map to outline and calculate the area of the topographic basin above the bog at HBSP. Schilling and Wolter (2005) have estimated approximately 20 cm (8 in) as an average annual groundwater recharge rate for the Iowan Surface based on a study of stream baseflows. Recognizing that the volume of water draining to the bog from the 1,200 m² (13,000 ft²) basin is equal to the product of recharge and area, and assuming 20 cm (8 in) of annual recharge, the resulting volume of water would sustain a discharge of only 0.46 l/min (0.12 gpm), far below any of the measured flow events in the study. Even if total annual recharge for this period is assumed to be 100 cm (40 in), approximately equal to total precipitation, over the entire 1,200 m² (13,000 ft²), the resulting 2.3 l/min (0.61 gpm) discharge is less than half of the lower end of the range measured in the bog stream over the 12 months of study. This analysis shows clearly that the size of the recharge area must be larger than the topographic basin in order to supply enough water to the hanging bog to account for the measured stream flow. In order for the hanging bog to discharge 10 l/min (2.6 gpm), the approximate median value of measured flow, and again assuming a reasonable annual recharge quantity of 20 cm (8 in), the size of the topographic basin necessary to supply this water is approximately 26,000 m² (280,000 ft²), or 0.026 km² (0.01 mi²), 22 times the size of the topographic basin. In the unlikely event that water is lost to the subsurface from the bog stream in the reach between the seepage area and the stream gauging point, then the median discharge of the hanging bog is something greater than 10 l/min (2.6 gpm) and the size of the recharge area must be proportionately greater than 26,000 m² (280,000 ft²).

Allowing that groundwater discharge along the Cedar River valley wall occurs in a variety of ways, a subsequent question is: which mode or modes are most important? The estimated recharge area for the seep in HBSP of 0.026 km² (0.01 mi²), is equal to only 1% of the area of a standard 1 mi² (2.6 km²) section. Even if all 44 of the fens identified by Thompson et al. (1992) on the Iowan Surface had recharge areas of a similar order of magnitude to HBSP, the cumulative area would be less than 4 mi² (10 km²). What about the possibility that groundwater discharge from many less prominent, undocumented, seeps in this landscape adds up to a significant quantity? A survey of multiple potential Type B or C seep locations in an approximately 8-km (5-mile) radius of HBSP revealed only one confirmed seep and several others where slumping soils suggestive of saturated conditions were observed (Smith and Niemann 2001). Thus, although Type B and C seeps in this region, including HBSP, probably funnel groundwater from regions of the subsurface much larger than their adjacent surface drainage areas, the scattered occurrence of these features suggests that these account for a inconsequential fraction of the total groundwater discharge along the Cedar River valley wall. This conclusion is consistent with the limited number of fens reported by Thompson et al. (1992) for the Iowan Surface as a whole.
Thompson et al. (1992) identified only one bedrock fen on the studied in detail. Conceptual Model of Hanging Bog

The recharge analysis presented above indicates that groundwater feeding the hanging bog originates from an area larger than the adjacent topographic basin. Possible explanations include extension of the outwash beneath the surface divide to a remote area of surface or bedrock recharge. Although technically not a fen, the geological conditions responsible for HBSP are consistent with the inter-till or exhumed sand and gravel ridge categories of Thompson et al. (1992). The authors generalize that fens in eastern Iowa are subject to rapid fluctuations in water supply due to direct precipitation-derived recharge through weathered and fractured pre-Illinoian deposits in the case of inter-till lenses, and, in the case of exhumed sand and gravel ridges, due to recharge limited by erosional dissection of these landforms. In contrast, the water level in the bog aquifer at HBSP exhibits a remarkably constant water level. Thus, the observed conditions at HBSP demand not simply a larger recharge area than is present in the adjacent topographic basin, but also a steady recharge supply, which raises the possibility that part or all of the recharge is from bedrock or an extensive outwash deposit. The elevation of water in the bog aquifer at the location of the surface seep in HBSP is between approximately 236 m (775–775 ft). According to 13 well logs obtained from IGS (2005) for sites within 4 km (2.5 miles) of HBSP, the median depth to bedrock in the uplands is 14 m (47 ft). Based on estimated surface elevations for these wells from 7.5-minute topographic maps, it is estimated that the median elevation of bedrock in these wells is approximately 233 m (765 ft). The IGS (2005) identifies shallow bedrock in the vicinity of HBSP as limestone breccia belonging to the Rapid Member of the Little Cedar Formation (Cedar Valley Group, Devonian). In the closest drilled well in the vicinity, located 150–300 m (500–1,000 ft) from the surface seep, bedrock was encountered at a depth of 7.6 m (25 ft) and an estimated elevation of 233 m (765 ft) [IGS 2005]. This well yielded less than 57 l/min (15 gpm) at the time of installation (IGS 2005). Bedrock is exposed at the surface in roadside ditches and in a quarry approximately 5 km (3 miles) southeast of the HBSP. The surface exposures occur at an elevation of approximately 210 m (800 feet), suggesting a surface gently sloping toward the Cedar River and HBSP. Thus, the geologic evidence suggests that the outwash representing the bog aquifer could easily lie in contact with the bedrock surface in close proximity to HBSP, allowing flow of groundwater from the bedrock or the bedrock-overburden interface. On the other hand, given its shallow nature, bedrock in the area is itself likely recharged directly by precipitation, or nearby directly via weathered or fractured pathways in surface materials. As a result, it is uncertain if enough water could be stored in the shallow bedrock and/or overburden to account for the lack of fluctuation in water levels seen in the bog aquifer. Another possibility, much more speculative, is that the seep at HBSP is fed by a bedrock aquifer that is part of a regional flow system. Thompson et al. (1992) identified only one bedrock fen on the Iowan Surface but acknowledge that this category has not been studied in detail.

Conceptual Model of Hanging Bog

Coarse-grained, permeable outwash is sandwiched between two layers of relatively impermeable till and exposed along the bluffs of the Cedar River Valley in HBSP. The lower till unit, an extremely dense clay, prevents hydraulic connection between the outwash and flood plain and creates a seepage face where the outwash meets the valley wall. Although the lateral extent of the outwash is not known, the magnitude of groundwater discharge at the seepage face demonstrates that it is connected to recharge sources extending beneath the immediately adjacent upland area. These hydrogeologic factors permit the hillside seep in HBSP to funnel a disproportionate volume of groundwater from the uplands to the valley bottom.

CONCLUSIONS

The hydrogeological study of HBSP summarized in this article was unique in that groundwater levels were monitored continuously for a year-long period. The monitoring indicated an extremely small variation in the water table in the outwash aquifer feeding the hillside seep, whereas groundwater levels in the adjacent floodplain area fluctuated significantly during the same periods. It can be concluded that:

- Beyond mere circumstantial evidence, these data provided a body of evidence sufficient to firmly support the conclusion that two discrete aquifer systems are present at the preserve.
- These data strongly suggest a steady subsurface source, such as a bedrock or extensive outwash body, as the supply of groundwater to the hillside seep.
- Larger-than-expected seepage volume measured during the study supports the idea that recharge to the seep must be derived from a larger source than what is supplied by simple gravity drainage of precipitation.
- Despite the need to account for the disproportionate volume of groundwater discharged from the hillside seep at HBSP, the relative scarcity of seeps, both in the area of the preserve and the region in general, indicates that the volume of water discharged to this and similar sites is a very tiny fraction of the overall groundwater flow to the surface and margins of the Iowan Surface.
- While acknowledging the prominence, aesthetic value and ecologic importance of seeps such as the one at HBSP, the dominant mode of groundwater discharge along the Cedar River valley wall appears to be through diffuse flow through low-permeability glacial till to more low-permeability alluvium on the valley floor.

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LITERATURE CITED


