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INVESTIGATION OF CHANGING HYDROLOGIC CONDITIONS IN THE COON CREEK WATERSHED IN THE DRIFTLESS AREA OF WISCONSIN

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Background/Need

Decreased flooding and increased baseflows in Driftless Area streams over the past century have been attributed to improved land management practices (Gebert and Krug 1996). Kent (1999) tried to relate land management to groundwater recharge (the dominant component of baseflow) in the Driftless Area but the results were largely inconclusive. An understanding of the influence of spatially distributed recharge and hydrostratigraphic properties on local groundwater flow is needed in order to evaluate effects of land management change on the hydrology of the Driftless Area.

Objectives

The purpose of this investigation was: 1) to improve our understanding of groundwater flow in the Driftless Area at various watershed scales, and 2) to evaluate focused recharge (i.e., hillslope recharge) as a driver for changes in baseflow during three different time periods.

Methods

Field data were collected to evaluate spatial variations in infiltration (an indicator for recharge) and for use as calibration targets for a numerical groundwater flow model. The numerical model (MODFLOW – Harbaugh and McDonald, 1996) was calibrated to 2001-2002 data and checked using two historic time periods (1934-1940, 1979-1981) when hydrologic data were collected in the upper Coon Creek Watershed. Specified flux boundary conditions for the numerical model were extracted from an analytic element model (GFLOW – Haitjema 1995). The influence of complexity (e.g., focused hillslope recharge) was evaluated on local (less than 1 mi^2) and catchment (75 mi^2) scales. Optimization of recharge rates with a parameter estimation code (UCODE – Poeter and Hill 1998) was used to quantify differences in recharge in the three study periods.

Results and Discussion

Optimization of recharge produced a hillslope recharge rate that was 2.3 times higher than recharge on ridge-tops, a pattern consistent with field infiltration measurements that were two to ten times higher on hillslopes than on ridges and in valleys. Numerical simulations demonstrated that baseflow in basins smaller than about 30 mi^2 differed as much as 36% when areally uniform recharge was used rather than focused recharge. Simulated baseflow in basins smaller than 15 mi^2 varied as much as 73%, a phenomenon related to the position of the basin relative to a specific hydrostratigraphic unit (Tunnel City Group). Simulated baseflows in basins larger than about 30 mi^2, on the other hand, were relatively unaffected by changes in recharge distribution, or hydraulic properties of the Tunnel City Group. The latter insensitivity is due to the Tunnel City Group being completely eroded through by streams at larger scales. Recharge amounted to 19% of annual precipitation during the 1934-1940 study period and increased to 28% of annual precipitation during the 1979-1981 and 2001-2002 study periods. Thus, the processes responsible for facilitating the conversion of precipitation into recharge appear to be relatively unchanged since the 1979-1981 study period.

Conclusions/Implications/Recommendations

- In the study watershed, influences of hydrostratigraphic properties and focused hillslope recharge were limited to local groundwater flow in basins less than about 15 to 30 mi^2. The basin scale is likely related to vertical location in the hydrostratigraphic section and can be tested using other basins in the Driftless Area.

- Focused recharge on hillslopes produced a better simulation of measured heads and baseflows in the upper Coon Creek Watershed than areally uniform recharge. Thus, focused hillslope recharge is likely a more appropriate representation of the distribution of recharge in the Driftless Area than areally uniform recharge and is especially important in small headwater basins.

- Temporal recharge estimates suggest that the land management practices instituted in the 1930s resulted in the observed increase in baseflow and recharge between the 1940s and late 1970s. However, their effect on recharge has remained relatively unchanged since the early 1980s.

Related Publications:

Hunt, R.J and P.F. Juckem. 2001. How to Collect Meaningful Data – An Example Using Parameter Estimation and a Simple Groundwater Flow Model. *in* American Water Resources Association - Wisconsin state section, proceedings, pp. 30-31.

Juckem, P.F., R.J. Hunt, M.P. Anderson. 2001. Driftless Area Hydrogeology – Preliminary Results of Temporal Change in the Coon Creek Watershed. *in* American Water Resources Association – Wisconsin state section, proceedings, p. 6.

Juckem, P.F., R.J. Hunt, D.M. Chapel and M.P. Anderson. 2002. Conceptual Groundwater Model for the Coon Creek Watershed, Wisconsin. *in* American Water Resources Association – Wisconsin state section, proceedings, p. 6.

Juckem, P.F. 2003. Spatial Patterns and Temporal Trends in Groundwater Recharge, Upper Coon Creek Watershed, Southwest Wisconsin. Master of Science Thesis. Dept. of Geology and Geophysics. University of Wisconsin – Madison. 264 p.

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INTRODUCTION

Over the past century, flood peak magnitudes have decreased while baseflow levels have increased in the Driftless Area of southwestern, Wisconsin (Gebert and Krug 1996). These hydrologic trends have largely been attributed to changes in agricultural land management practices designed to reduce runoff and erosion (Trimble and Lund 1982, Potter 1991, Gebert and Krug 1996, Kent 1999). These land management practices were introduced to the Coon Creek Watershed during the nation's first watershed-scale soil and water conservation demonstration project from 1934 to 1940. However, identification of causal relationships between land management practices and baseflows have been largely inconclusive to date (e.g., Kent 1999).

Previous research in the Driftless Area suggested that focused groundwater recharge is likely on forested hillslopes (Olson 1994). However, estimation of focused hillslope recharge rates from studies of runoff are problematic in that there is uncertainty as to how much water is lost to evapotranspiration and how much water reaches the water table. A groundwater flow study in the Kickapoo River basin (Gaffield et al. 1998) suggested that focused hillslope recharge cannot be ruled out for the Driftless Area, but the results were ambiguous due to the lack of head and baseflow data. Hillslope recharge rates were quantified by groundwater studies in the Rochester, Minnesota area (Lindgren 2000), but the findings were somewhat uncertain due to use of a cross-sectional groundwater flow path model that was relatively poorly constrained by estimated fluxes.

A combination of steep topography and layered, heterogeneous, bedrock produce a complex groundwater flow system in the Driftless Area. The Driftless Area was not covered by continental glaciers during the Pleistocene (Mickelson, et al. 1982), and is typified by broad upland ridges, steep hillslopes and flat valley bottoms. Bedrock aquifers and aquitards consist of nearly flat-lying sandstones, shales and dolomites with areas in the upper layers that may have been removed by erosion in valleys. These eroded aquifers produce a system of potentiometric surfaces that have complex local groundwater flow patterns (Sartz et al. 1977). Improved understanding of factors that control local groundwater flow is necessary in order to advance the understanding of how changes in land management influence recharge (and associated baseflow) in the Driftless Area.

The purpose of this investigation was twofold: 1) to improve hydrogeologic understanding of the Driftless Area at various watershed scales, and 2) to evaluate the importance of focused recharge on hillslopes during three study periods (1934-1940, 1979-1981 and 2001-2002). The investigation focused on groundwater flow and recharge processes occurring in the upper Coon Creek Watershed, an area that includes catchment (75 mi^2) to subcatchment (less than 1 mi^2) scales. The approach utilized field measurements and numerical modeling, with data collection and simulations focused on the 2001-2002 study period; this understanding was then used to investigate past conditions. General conclusions from this investigation are applicable to many basins in the Driftless Area because the geology, landforms, land management and hydrology are relatively consistent throughout the region.

PROCEDURES AND METHODS

Measurements of streamflow, groundwater levels, precipitation, and infiltration were collected in the watershed between August 2001 and July 2002 to provide calibration data for the numerical groundwater flow model. A gaging station, located near the site of historical gaging stations at the Village of Coon Valley, was established to measure streamflow out of the upper Coon Creek Watershed and to provide contemporary data that could be compared to historical data. Four additional gaging stations located in headwater streams, along with synoptic one-time discharge measurements throughout the basin, provided spatially distributed measurements of baseflow in subbasins as small as 0.8 mi^2. Groundwater levels were measured in six valley wells and an 800-foot-deep well drilled along a ridge north of the basin. Precipitation was measured at two locations in the basin. A Guelph Permeameter and a double-ring infiltrometer were used to quantify and compare infiltration rates (used as an indicator for recharge) between ridgetops, hillslopes, and valleys, and between land use practices including: agriculture, pastures, fallow fields, and forests.

A conceptual model of groundwater flow and recharge was developed for the upper Coon Creek Watershed that incorporated the geologic framework and focused recharge on hillslopes. The conceptual model attributed diminished recharge on ridgetops to the presence of the clay-rich Rountree Formation (Knox et al. 1990) that formed as ridgetop dolomite weathered. Recharge on hillslopes was expected to be enhanced due to augmented water inputs from ridgetop runoff and permeable, well-established forest soils. It is likely the conditions that facilitate recharge improved after elimination of grazing on forested hillslopes, as evidenced by a reduction in runoff and improved soil infiltration properties on hillslopes (Sartz 1969 and Knighton 1970). The conceptual model compared favorably to historical spring occurrence and discharge behavior reported by Curtis (1963). This conceptualization was then used to guide the design of the numerical groundwater flow model.

A three-dimensional, steady-state, numerical groundwater flow model was constructed using MODFLOW (Harbaugh and McDonald 1996) to simulate groundwater flow in the upper Coon Creek Watershed area (Figure 1). Initial simulations of the heterogeneous, deeply eroded hydrostratigraphy of the upper Coon Creek Watershed area were problematic, in that dewatered cells caused numerical instability and perturbed local flow patterns. A modified approach using confined layers (LAYCON=0) produced a numerically stable model that realistically simulated the groundwater flow system. This modified approach required additional effort to simulate unconfined conditions; these included: 1) manual, iterative deactivation of cells where dewatered conditions were evaluated based on the geometry of the flow system, 2) use of two zones of saturated thickness for layer 1 based on water table measurements in wells, and 3) a reduction in transmissivity of bedrock units along hillslopes at seepage face cells where saturated thickness was expected to be reduced and seepage faces were observed. Boundary conditions for the MODFLOW model were extracted from a GFLOW model of the basin using the methodology of Hunt el al. (1998). The GFLOW and MODFLOW models were manually coupled in that recharge applied to the GFLOW model was updated, boundary conditions were reextracted, and recharge for the MODFLOW model was reoptimized until the recharge applied to both models agreed to within 0.1 inches/year.

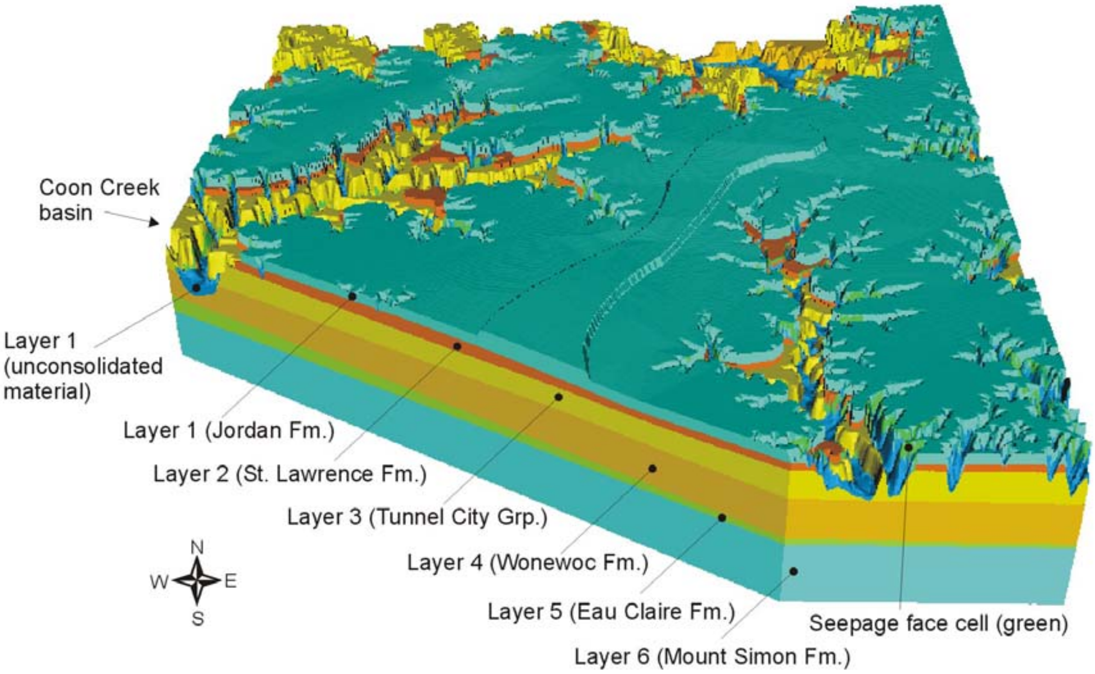

Figure 1 Three-dimensional representation of the MODFLOW model of the upper Coon Creek Watershed area. Vertical exaggeration is 20 times. Total thickness along central ridge is about 1000 feet.

The MODFLOW model was calibrated to 2001-2002 head and baseflow measurements using the automated parameter estimation code (UCODE - Poeter and Hill 1998) and trial-and-error adjustments. Hillslope and ridgetop recharge in the numerical model were optimized (whereby the sum of squared weighted residuals, SOSWR, is minimized) individually with UCODE (Poeter and Hill 1998); recharge applied to valleys was specified as 1.25 times the optimized recharge for ridges, based roughly upon infiltration data, because UCODE was unable to converge when valley recharge was included in the optimization due to insensitivity. Hydraulic conductivity parameters were calibrated via manual trial-and-error because the confined formulation lumped all nodes into transmissivity arrays. The trial-and-error calibration included: 1) horizontal and vertical hydraulic conductivity of bedrock in each layer, 2) horizontal and vertical hydraulic conductivity of unconsolidated valley fill material in two zones that were assigned by stream slope, 3) vertical hydraulic conductivity of streambed sediments in two zones assigned by stream slope, and 4) a percent reduction in bedrock hydraulic conductivity at seepage face cells (described above). Two vertical hydraulic conductivity values were also used to simulate the Tunnel City Group (Layer 3), whereby a lower value (0.0003 ft/d) was used to calculate leakance between layers 3 and 4 compared to the vertical hydraulic conductivity of 0.003 ft/d used to calculate leakance between layers 2 and 3. This adjustment reflects the heterogeneity within the layer as characterized by borehole geophysics (Chapel et al. 2003).

After calibrating the model to 2001-2002 conditions, historic (1934-1940 and 1979-1981) conditions were simulated by adjusting recharge values. Recharge applied to valleys and ridges during the historic periods was prorated according to the difference in average annual precipitation during the period compared to that during the 2001-2002 period. Hillslope recharge was then optimized for each period with UCODE to match observed heads and fluxes.

RESULTS AND DISCUSSION

Field Investigation:

Stream flow data showed that baseflow during the 2001-2002 study period increased by about 60% compared to baseflow during the 1934-1940 study period, while flood peaks during the 2001-2002 study period appeared smaller than flood peaks during both the 1934-1940 and 1979-1981 study periods (see Juckem 2003). Slug tests in six valley wells provided hydraulic conductivity estimates that ranged from 0.1 ft/d to over 2 ft/d for unconsolidated valley sediments. Infiltration measurements from both a Guelph Permeameter and a double-ring infiltrometer ranged between two to ten times higher on hillslopes than on ridgetops and valleys, and increased with decreased land-use intensity (Figure 2). Additional discussion of the methods and results is available in Juckem (2003).

Figure 2. Infiltration rates measured using a Guelph Permeameter and a double-ring infiltrometer in three topographic settings with various land uses. Only one method was used at some sites. Land-use intensity within a topographic setting generally decreases from left to right.

Numerical Simulations:

After calibration, simulated heads and fluxes generally matched measured values in the upper Coon Creek Watershed area. Calibrated recharge and hydraulic conductivity values are shown in Tables 1 and 2. The average difference between simulated and observed fluxes was 2.2% for the five gaging stations, while the three targets with the largest percent differences were seepage run targets that were considered the least accurate of all flux targets (Figure 3). Heads residuals were generally randomly distributed, with a mean absolute difference of 29 feet (n = 72). Optimization of hillslope and ridgetop recharge in the calibrated model resulted in a hillslope recharge rate of 14.3 in/yr, 2.3 times larger than the optimized ridgetop recharge rate of 6.3 in/yr for the 2001-2002 study period. While only comprising 34% of the watershed area, hillslopes contributed 53% of the recharge to the groundwater system.

Table 1. Optimized recharge values for the upper Coon Creek Watershed during the 2001-2002 study period.

	Valleys	Hillslopes	Ridgetops	Equivalent areal average
Recharge	7.9 in/yr	14.3 in/yr	6.3 in/yr	9.0 in/yr

Table 2. Hydraulic conductivity (K) values used to simulate groundwater flow in the upper Coon Creek Watershed.

Layer	Geologic Unit	Horizontal K (ft/day)	Vertical K (ft/day)
1	Jordan Formation	10	1
2	St. Lawrence Formation	2.5	0.001
3	Tunnel City Group	2.5	Upper: 0.003 Lower: 0.0003
4	Wonewoc Formation	12	1.2
5	Eau Claire Formation	2.5	0.0003
6	Mt. Simon Formation	12	1.2
1-3	Unconsolidated material	Steep slope: 120 Shallow slope: 40	Steep slope: 12 Shallow slope: 4
1	Riverbed sediments	-	Steep slope: 12 Shallow slope: 4
1-3	Seepage face cells (% of bedrock horizontal hydraulic conductivity)	Layer 1: 10% Layer 2: 25% Layer 3: 75%	-

Focused hillslope recharge produced a better calibration than uniform areal recharge in the numerical model of groundwater flow in the upper Coon Creek Watershed area. The SOSWR was 75% higher (worse) when a uniform areal recharge rate was optimized with UCODE, compared to the calibrated model that incorporated different recharge rates for ridgetops, hillslopes and valleys.

Using the transmissivity distributions of the confined model, unconfined conditions were identified over much of the model domain in the top four layers. Although it is not surprising that layer 1 (Jordan Formation), being the uppermost layer, represents the water table; heads were unconfined (below the top elevation of a layer) in layers 2 (St. Lawrence Formation) and 3 (Tunnel City Group) in localized areas along ridges and hillslopes that were adjacent to rivers. Unconfined cells were simulated throughout appreciable areas of layer 4 (Wonewoc Formation), which implied the presence of an extensive partially saturated zone between the overlying Tunnel City Group and the Wonewoc Formation (Figure 4). Simulated heads in layers five and six were confined throughout the model domain. Thus, the presence and distribution of several perched water tables were identified from results of the numerical model and were consistent

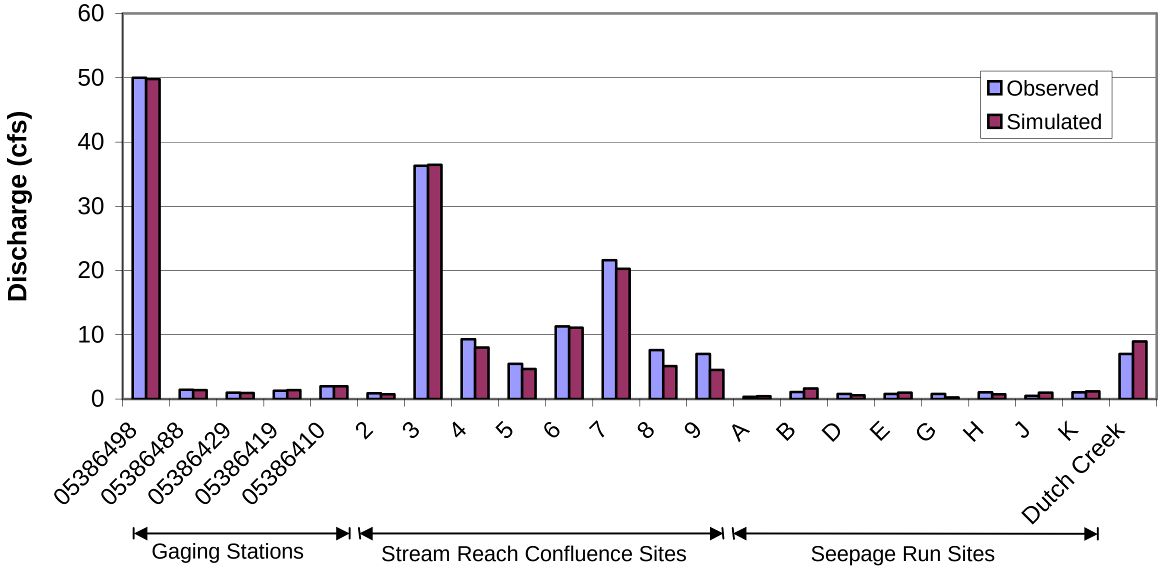

Figure 3. Simulated versus measured fluxes at target sites

with initial results from a simulation of groundwater flow near an 800 foot-deep-well (Juckem 2003 – Appendix B).

Given the flow system configuration derived from the calibrated confined model, an unconfined solution (which incorporated deactivated cells from the confined model) was obtained for the MODFLOW model. This sensitivity simulation showed that simulated regional heads and fluxes compared well with results from the calibrated confined model, but dry cell problems confounded simulation of local flow systems in the headwaters. That is, the SOSWR for the unconfined (LAYCON 1 and 3) solution increased by 250% over the calibrated confined solution, but only 1% of the increase in SOSWR was caused by differences in simulated heads and 11% of the increase was caused by only a 1.5% change in baseflow at the regional gaging station at the Village of Coon Valley. Dewatered cells in the

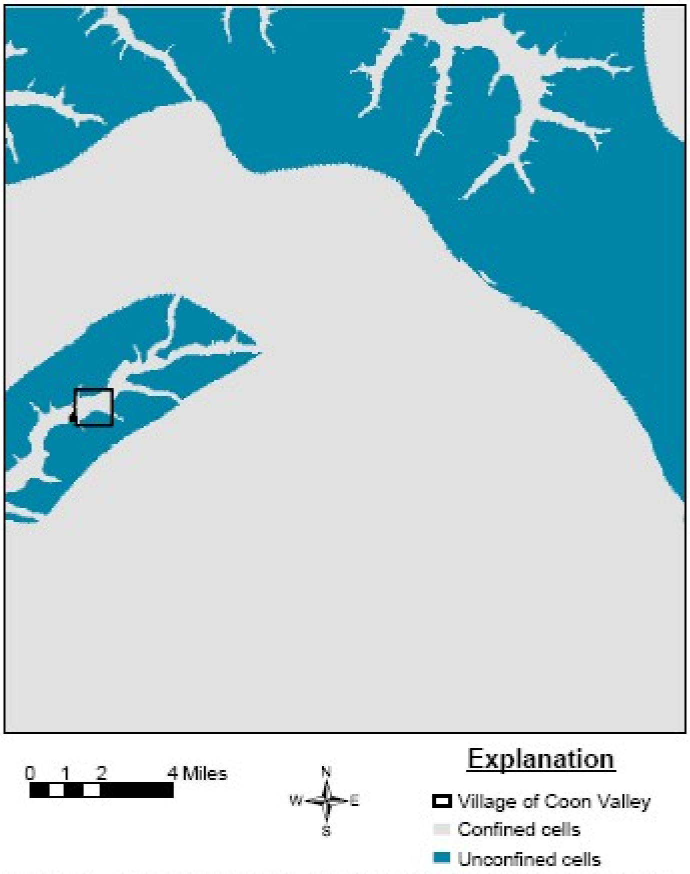

Figure 4 Distribution of simulated confined and unconfined cells in layer 4 of the calibrated MODFLOW model.

unconfined solution locally disrupted groundwater discharge to headwater stream targets, and contributed 88% of the increase in the SOSWR. Thus, we conclude that regional heads and groundwater flow were acceptably simulated by both the confined and unconfined versions of the model, but the sensitivity simulation using unconfined options produced a solution that was unable to locally maintain a hydrologic connection to headwater streams, a process needed to address the recharge objectives of this research.

Changes to the conceptual model were evaluated using the numerical model and UCODE, where an increase in the SOSWR indicated that simulated heads and/or fluxes differed from measured values by a larger amount than the calibrated model. During the analysis, the following conceptualizations were found to be important for simulating flow in this Driftless Area basin: 1) reduction of vertical hydraulic conductivity of the Tunnel City Group (layer 3) with depth, 2) spatially variable recharge, 3) spatial variability of horizontal hydraulic conductivity of unconsolidated material, and 4) simulation of a relative reduction in transmissivity at seepage face cells. Of these results, the factors listed above as numbers 1 and 2 were noteworthy in that they addressed scale issues important for simulating groundwater flow in the Driftless Area. The percent change in simulated baseflow between the calibrated model and a simulation with optimized uniform areal recharge was less than 2% in basins larger than 30 mi^2, but was up to 36% in basins smaller than 30 mi^2. These results indicate that the size of a basin in the Driftless Area is an important consideration for recharge conceptualization. Use of a uniform areal recharge may be sufficient for regional studies dealing with groundwater flow in basins larger than about 30 mi^2 in the Driftless Area. Conversely, future investigations should consider spatially distributed recharge in basins smaller than about 30 mi^2.

A similar scale pattern was observed when comparing simulated baseflows from the calibrated model to a simulation that used a harmonic average vertical hydraulic conductivity to represent the Tunnel City Group. For this case, the percent change in simulated baseflow was less than 3% in basins larger than 15 mi^2, but differed up to 73% in basins smaller than 15 mi^2. The influence of hydrostratigraphy on baseflow in small basins appears to be related to the portion of the stratigraphic section drained by a stream (Figure 5). That is, a good correlation ($R^2 = 0.77$) was observed when the percent change in simulated baseflow in basins less than 15 mi^2 was compared to the stream elevation (and location with respect to the Tunnel City Group); a poorer correlation ($R^2 = 0.24$) resulted when the percent change in simulated baseflow in basins less than 15 mi^2 was simply compared to basin area. These results indicate that an understanding of the influence of hydrostratigraphic properties on groundwater flow distribution is necessary for studies at local scales (<15 mi^2) in this region of the Driftless Area. Conversely, studies of regional groundwater flow using regional flux targets (e.g., Hunt et al. 2003) may not need to explicitly simulate high-elevation hydrostratigraphic units that are completely eroded in large river valleys.

The model was also used to evaluate the hypothesis that changes in recharge on hillslopes, likely associated with cessation of grazing, could account for differences in measured baseflow in Coon Creek when the two other study periods (1934-1940, 1979-1981) were investigated. Optimization of hillslope recharge for the 1934-1940 historic study period required a reduction in hillslope recharge (64%) that was larger than the difference (6%) in annual precipitation between the 1934-1940 and 2001-2002 study periods in order to match measured baseflows.

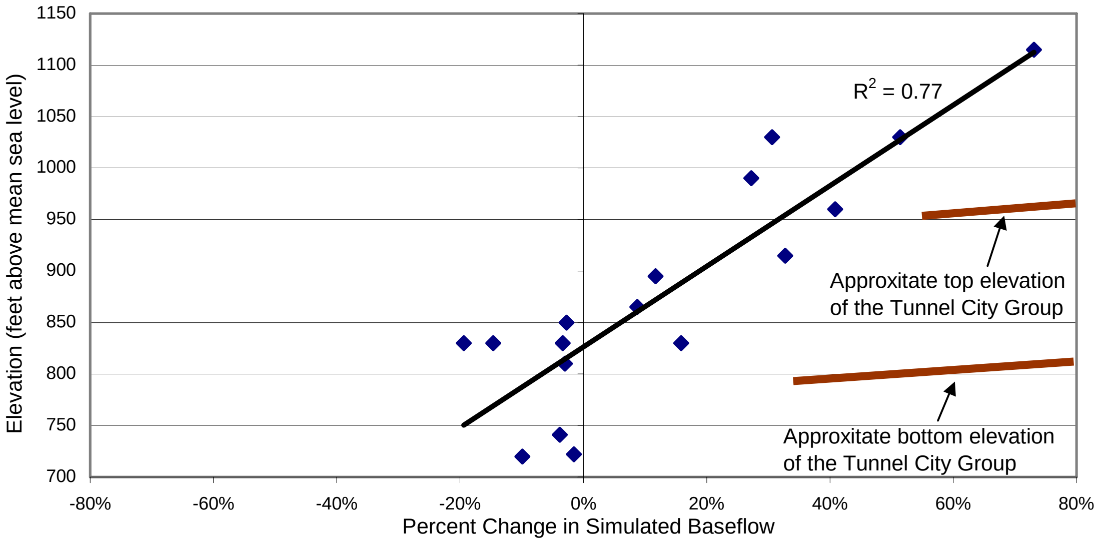

Figure 5. Percent change in simulated baseflow at flux target sites between the calibrated model and the simulation using a harmonic average vertical hydraulic conductivity for Tunnel City Group for basins smaller than 15 mi^2, plotted against elevation.

Optimization of hillslope recharge for the 1979-1981 study period required an increase (10%) that was slightly larger than the difference in annual precipitation (9%). The historic valley and ridgetop recharge rates were prorated according to the difference in annual precipitation. Simulation of an extreme case, where valley and ridgetop recharge rates were not changed from the 2001-2002 calibrated values, demonstrated that changes in hillslope recharge could account for all of the trends in measured baseflow in Coon Creek even though hillslopes represent only 34% of the basin area. Hillslopes, however, are likely to be more susceptible to changes in recharge due to geologic properties (permeable sandstones on hillslopes as opposed to clay-rich soils on ridges) and hydrologic processes (runoff from ridges and high infiltration rates on hillslopes) than other areas of the basin.

Finally, simulated results showed that recharge in the upper Coon Creek Watershed increased from 19% of average annual precipitation during the 1934-1940 study period to 28% during the 1979-1981 study period, with no subsequent change (recharge was estimated to be 28% of average annual precipitation during the 2001-2002 study period). Based on these results, it appears that the processes responsible for the conversion of a greater percentage of precipitation into recharge since the 1930s and 1940s have remained relatively unchanged since the 1979-1981 study period. Thus, the hydrologic trends described by Gebert and Krug (1996) are likely not linear and should be revisited to improve estimates of when changes in land management produced the most significant changes in recharge. However, it is intriguing that flood peaks continue to diminish in magnitude even though recharge appears to have stabilized.

CONCLUSIONS AND RECOMMENDATIONS

Difficulty with simulating groundwater flow in the upper Coon Creek Watershed with unconfined layers (LAYCON 1 and 3) required labor-intensive modifications to the MODFLOW model in order to properly simulate groundwater flow using confined layers (LAYCON=0).

Modifications included: 1) manual, iterative deactivation of cells where dewatered conditions were evaluated based on the geometry of the flow system, 2) use of measured water levels in wells to estimate saturated thickness and improve transmissivity calculations for layer one, and 3) reduction of transmissivity in seepage face cells to incorporate a reduction in saturated thickness in bedrock units near stream valleys.

Focused recharge on hillslopes, initially identified by previous researches (Curtis 1966a, Olson 1994) and supported by infiltration measurements made during this research, produced a better fit to measured head and flux targets than uniform areal recharge. The optimized hillslope recharge rate of 14.3 in/yr was 2.3 times greater than the optimized ridgetop recharge rate of 6.3 in/yr for the 2001-2002 study period. In addition, hillslopes accounted for only 34% of the area in the upper Coon Creek Watershed, but recharge to hillslopes accounted for 53% of the total recharge to the upper Coon Creek Watershed. These results indicate that focused recharge on hillslopes is a more appropriate representation of recharge distribution than uniform recharge over all landscapes in the upper Coon Creek Watershed area, and that efforts to preserve hillslope forests might be a cost-effective method for preserving high baseflows in Coon Creek. A similar distribution of recharge is expected in other Driftless Area basins because the geology, landform, land management and hydrology are relatively similar throughout the region. Nonetheless, use of uniform areal recharge may be sufficient for simulations of basins larger than about 30 mi^2 in this region of the Driftless Area, depending upon the objectives of the study.

Differences in annual precipitation among the three simulated study periods could not account for changes in baseflow; optimized hillslope recharge changed more than precipitation changed among the different study periods. Hillslope recharge was a powerful driver for the system, where temporal differences in hillslope recharge only could explain all of the observed baseflow change. The processes responsible for apportioning precipitation into recharge evidently improved between the 1934-1940 and 1979-1981 study periods, but have remained relatively unchanged since the 1979-1981 study period; the percentage of annual precipitation converted to recharge increased from 19% for the 1934-1940 study period to 28% for the 1979-1981 and 2001-2002 study periods. Our results suggest that cessation of grazing on forested hillslopes at high elevations shortly after the 1934-1940 demonstration project likely accounted for the increase in recharge between the 1934-1940 and 1979-1981 study periods.

The influence of vertical hydraulic conductivity of the Tunnel City Group on baseflow distribution in the upper Coon Creek Watershed appears to be minimal in subbasins larger than about 15 mi^2 (approximately where the Tunnel City Group is eroded), but appears to be correlated with stream elevation in subbasins that are less than about 15 mi^2. The correlation between baseflow in small basins and stream elevation is related to the location of streams relative to hydrostratigraphic units. Additional research is needed in other Driftless Area basins to generalize the relation between baseflow and stream location within the hydrostratigraphic section.

Results from the three-dimensional model of the upper Coon Creek Watershed area showed that unconfined conditions are expected to occur within the top four hydrostratigraphic units (the Jordan Formation, the St. Lawrence Formation, the Tunnel City Group, and the Wonewoc Formation). The small difference between regional heads and fluxes simulated by the calibrated confined model and an unconfined model solution indicated that the confined model correctly simulated both the regional and local flow systems. Although the confined approach was found to be appropriate in this effort, it was labor intensive. Improved methods for rewetting of dewatered cells and simulating seepage face boundary conditions in MODFLOW would facilitate simulation of groundwater flow in complex hydrogeologic systems with steep vertical and horizontal gradients and highly eroded hydrostratigraphic units.

An analysis of some aspects of the conceptual model indicated that several concepts were necessary for proper simulation of groundwater flow in the upper Coon Creek Watershed area. As mentioned above, spatially variable recharge and a reduction in vertical hydraulic conductivity of the Tunnel City Group with depth were important components of the conceptual model for simulating groundwater flow at small basin scales.

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Appendix A: Awards, Reports and Presentations

Awards:

Best Student Presentation – 2002 American Water Resources Association - Wisconsin state section annual meeting. Juckem, P.F., R.J. Hunt, D.M. Chapel and M.P. Anderson. "Conceptual Groundwater Model for the Coon Creek Watershed, Wisconsin."

Reports:

Juckem, P.F. 2003. Spatial Patterns and Temporal Trends in Groundwater Recharge, Upper Coon Creek Watershed, Southwestern Wisconsin. Master of Science Thesis. Dept. of Geology and Geophysics. University of Wisconsin – Madison. 249 p.

Presentations:

Hunt, R.J and P.F. Juckem. 2001, March 30. How to Collect Meaningful Data – An Example Using Parameter Estimation and a Simple Groundwater Flow Model. American Water Resources Association - Wisconsin state section annual meeting, Green Lake. Proceedings, pp. 30-31.

Juckem, P.F., R.J. Hunt, M.P. Anderson. 2001, March 29. Driftless Area Hydrogeology – Preliminary Results of Temporal Change in the Coon Creek Watershed. American Water Resources Association – Wisconsin state section annual meeting, Green Lake. Proceedings, pp. 6.

Juckem, P.F., R.J. Hunt, D.M. Chapel and M.P. Anderson. 2002, March 7. Conceptual Groundwater Model for the Coon Creek Watershed, Wisconsin. American Water Resources Association – Wisconsin state section annual meeting, Wisconsin Dells. Proceedings, pp. 6.