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ORIGINAL ARTICLE

# A GIS-based groundwater travel time model to evaluate stream nitrate concentration reductions from land use change

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**Abstract** Excessive nitrate-nitrogen (nitrate) loss from agricultural watersheds is an environmental concern. A common conservation practice to improve stream water quality is to retire vulnerable row croplands to grass. In this paper, a groundwater travel time model based on a geographic information system (GIS) analysis of readily available soil and topographic variables was used to evaluate the time needed to observe stream nitrate concentration reductions from conversion of row crop land to native prairie in Walnut Creek watershed, Iowa. Average linear groundwater velocity in 5-m cells was estimated by overlaying GIS layers of soil permeability, land slope (surrogates for hydraulic conductivity and gradient, respectively) and porosity. Cells were summed backwards from the stream network to watershed divide to develop a travel time distribution map. Results suggested that groundwater from half of the land planted in prairie has reached the stream network during the 10 years of ongoing water quality monitoring. The mean travel time for the watershed was estimated to be 10.1 years, consistent with results from a simple analytical model. The proportion of land in the watershed and subbasins with prairie groundwater reaching the stream (10–22%) was similar to the measured reduction of stream nitrate (11–36%). Results provide encouragement that additional nitrate reductions in Walnut Creek are probable in the future as reduced nitrate groundwater from distal locations discharges to the stream network in the coming years. The high spatial resolution of the model (5-m cells) and its simplicity may make it potentially applicable for land managers interested in communicating lag time issues to the public, particularly related to nitrate concentration reductions over time.

**Keywords** Geographic information system (GIS) · Groundwater · Travel time · Land use change · Conservation · Iowa

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## Introduction

Nonpoint source (NPS) pollution from nitrate-nitrogen (nitrate) is a significant problem in the Corn-Belt region of the United States (Goolsby et al. 1999). Excessive nitrate loss to surface water has led to nutrient enrichment and eutrophication of many streams and rivers (Dodds and Welch 2000; USEPA 2000), aesthetic degradation and development of hypoxic conditions in the Gulf of Mexico (Rabalais et al. 1996). The major source of nitrate is agriculture, primarily the widespread use of nitrogen fertilizers, application of livestock manure, legume fixation and mineralization of soil nitrogen (Hallberg 1987; Burkart and James 1999; Goolsby et al. 1999). Efforts to reduce nitrate losses have considered a variety of infield and edge-of-field management practices, including crop rotations, fertilizer applications, riparian buffers and conservation tillage (see review by Dinnes et al. 2002).

Nitrate is typically leached from cropped fields and migrates with shallow groundwater to streams. Groundwater discharge as baseflow and discharge of water by artificial subsurface drainage provide the main route of nitrate delivery to streams (Hallberg

1987; Schilling 2002; Schilling and Zhang 2004). For example, in the Raccoon River in west-central Iowa, baseflow was found to contribute approximately two-thirds (17.3 kg/ha) of the mean annual nitrate export (26.1 kg/ha; Schilling and Zhang 2004). Because nitrate losses are controlled largely by subsurface leaching and transport processes, the time needed for observing water quality improvements in streams following implementation of improved land management practices can take many years. The amount of time between implementing a practice and observing a water quality response to that practice has been termed the ''lag time'' (Meals and Dressing 2006). The lag time for nitrate is governed by hydrogeology of a watershed and the velocity of groundwater flow. Considering that Quaternary aquitards are the most common surficial deposits in agricultural areas of North America and Canada (Rodvang and Simpkins 2001), in many areas, the travel time for groundwater contaminants to flow from uplands to perennial streams may take years or decades. In one Iowa example, groundwater nitrate concentrations in upland landscape positions were still influenced by the legacy of past agricultural management conducted more than 25 years earlier (Tomer and Burkart 2003). Hence improvements in water quality may substantially lag behind changes in agricultural management.

For land managers tasked with reducing stream nitrate concentrations in agricultural watersheds, it is often difficult to manage expectations from the public that demand a rapid water quality return on their conservation investment. One common conservation practice in the US Corn Belt region is retiring vulnerable row croplands to grassland as part of the United States Department of Agriculture Conservation Reserve Program (CRP). Water quality benefits from implementing this practice are typically assumed but the time needed to actually observe improved water quality, particularly with respect to nitrate, is often unknown. While groundwater travel time predictions are routinely performed using computer models such as MODFLOW (McDonald and Harbaugh 1988; Harbaugh et al. 2000) and GFLOW (Haitjema 1995), these models typically require detailed input of hydrologic properties (recharge rate, *K*, evapotranspiration, etc.) and calibration targets (hydraulic heads, stream stage, etc.). Because of intensive data input and calibration data requirements, detailed groundwater flow models are not often used to assess conservation benefits in agricultural watersheds. Others have used groundwater age dating at the groundwater-surface water interface to evaluate groundwater residence times in watersheds and the fate of nitrate (Browne and Guldan 2005; Modica et al. 1998; Bohlke and Denver 1995).

In this paper, a groundwater travel time model based on a geographic information system (GIS) analysis of readily available soil and topographic variables was used to evaluate the time needed to observe stream nitrate concentration reductions from large-scale land use change. The study area encompassing the Walnut Creek watershed in Iowa is the site of an ambitious project to convert large tracts of land from row crop to native prairie and it provides an ideal analogy for assessing water quality benefits for placement of lands in the CRP program. Our goal was to link the locations and ages of conservation prairie plantings with a GIS-based travel time model to evaluate whether there has been sufficient time for groundwater beneath prairie plantings to flow to a perennial stream and begin impacting water quality.

The objectives of this study were to (1) develop a GIS model for evaluating the groundwater travel time distribution in a watershed; and (2) assess the proportionality of measured stream nitrate reductions to the groundwater travel time distribution in the watershed.

## Study area

The study was conducted in the 5,218 ha Walnut Creek watershed in Jasper County, Iowa (Fig. 1). The watershed is located in the Southern Iowa Drift Plain landscape region, an area characterized by steeply rolling hills and well-developed drainage (Prior 1991). Soils within the Walnut Creek watershed fall primarily within four major soil associations: Tama-Killduff-Muscatine; Downs-Tama-Shelby; Otley-Mahaska and Ladoga-Gara (Nestrud and Worster 1979). Most of the soils are silty clay loams, silt loams or clay loams formed in loess and till. Loess mantled pre-Illinoian till typifies much of the geology of the watersheds. Outcrops of pre-Illinoian till and Late Sangamon paleosols are occasionally found in hillslope areas. Pre-Illinoian till is typically 6–30 m thick overlying Pennsylvanian Cherokee Group shale, limestone, sandstone, and coal. In the floodplain of Walnut Creek, Holocene alluvial deposits consist of predominantly silt (60–80%; Schilling et al. 2004), with occasional stratified sands, silts, clays and peat.

The study area is in a humid, continental region with average annual precipitation of around 750 mm. Highest monthly rainfall totals typically occur in May and June, although large storms occurring throughout the summer can lead to rapid rises in discharge.

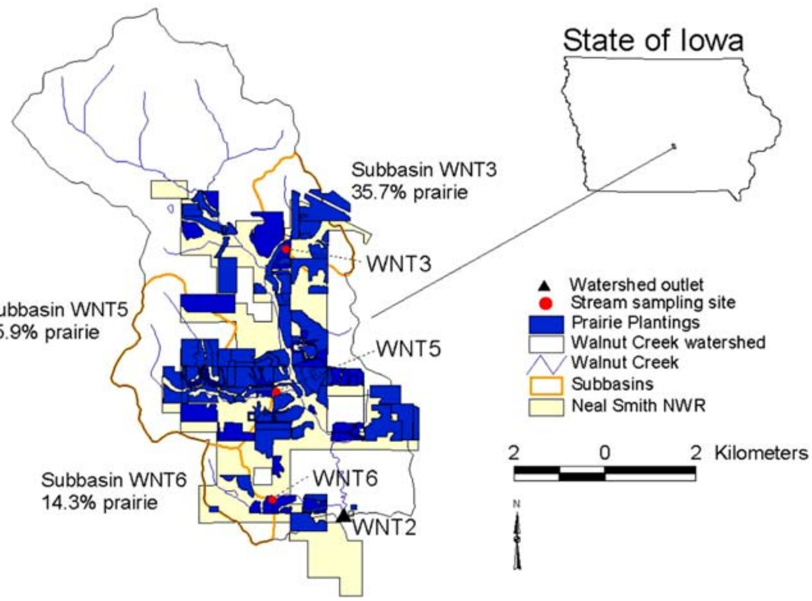



**Fig. 1** Location of Neal Smith National Wildlife Refuge and sampling sites in Walnut Creek watershed, Iowa

Discharge tends to be flashy, displaying rapid responses to precipitation. Stream discharge at a stream gauge at the Walnut Creek outlet has ranged from a high of 56,276 $m^3$/h to a low of 2 $m^3$/h (Schilling et al. 2006a, b).

## Monitoring project

The study was conducted as part of the Walnut Creek Watershed Monitoring Project, a project established in 1995 as a 10-year NPS monitoring effort in conjunction with watershed habitat restoration and agricultural management changes implemented by the US Fish and Wildlife Service (USFWS) at the Neal Smith National Wildlife Refuge (Refuge) in Jasper County Iowa (Fig. 1). A large portion of the Walnut Creek watershed is being restored from row crop agriculture to native prairie and savanna (Drobney 1994; Schilling et al. 2006a). Before restoration, land cover in the Walnut Creek watershed was predominantly agricultural, consisting of nearly 70% row crops (combined corn and soybeans). Between 1990 and 2005 row cropland decreased from 69.4 to 54.5% as a result of prairie restoration by the USFWS at the Neal Smith refuge (Table 1). From 1992 to 2005, an average of approximately 90 ha of prairie were planted each year, with areas planted in 1994 and 1995 exceeding 150 ha (Fig. 2). As of 2005, 1,224 ha of land in Walnut Creek watershed were planted in native prairie, representing 23.5% of the watershed. Most of the prairie plantings occurred in former row crop fields but some prairie was also planted in cool season (brome) grass. In three monitored subbasins, restored prairie accounted for 14.3–45.9% of the land area with the greatest percentage of prairie conversion occurring in the WNT5 subbasin (Fig. 1).

Surface water samples collected at upstream and downstream locations and three subbasin sites in Walnut Creek watershed from 1995 to 2005 documented the effect of the land use change on water

**Table 1** Summary of changes in land cover (1990–2005) and nitrate concentrations in Walnut Creek watershed (1996 and 2005)

| Watershed and subbasins | Watershed area (ha) | Year | Row crop (%) | Prairie (%) | Nitrate decrease 1996–2005 (mg/l) | Change in stream nitrate 1996–2005 (%) |
|---|---|---|---|---|---|---|
| Walnut Creek | 5,217.0 | 1990 | 69.4 | 25.4 | 1.2 | 15.4 |
| | | 2005 | 54.5 | | | |
| WNT3 | 295.1 | 1990 | 71.3 | 35.7 | 3.4 | 27.9 |
| | | 2005 | 43.9 | | | |
| WNT5 | 791.8 | 1990 | 77.5 | 45.9 | 1.2 | 11.0 |
| | | 2005 | 45.8 | | | |
| WNT6 | 200.7 | 1990 | 74.8 | 14.3 | 2.7 | 36.5 |
| | | 2005 | 71.8 | | | |

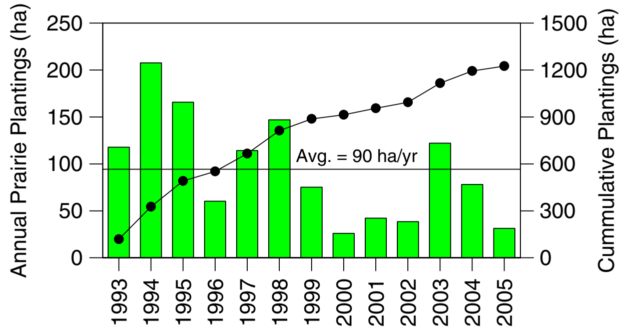



**Fig. 2** Summary of annual prairie plantings by the USFWS at the Neal Smith NWR

quality. Nitrate concentrations ranged between <0.5 and 14 mg/l at the Walnut Creek outlet (WNT2) and typically showed high concentrations in the spring and early summer months coinciding with periods of fertilizer application, greatest precipitation, soil mineralization and high stream flow (Fig. 3). In the subbasins, mean stream nitrate concentrations decreased over time to low values of 8.0, 7.7 and 3.1 mg/l in subbasins WNT3, WNT5 and WNT6, respectively (Fig. 3). At all monitoring sites, statistically significant changes in stream nitrate concentrations were detected during the project (Table 1; Schilling et al. 2006a; Schilling and Spooner 2007). At the Walnut Creek outlet (WNT2), trend analysis indicated that nitrate concentrations decreased 1.2 mg/l over the 10-year project period. Nitrate concentrations decreased significantly in each

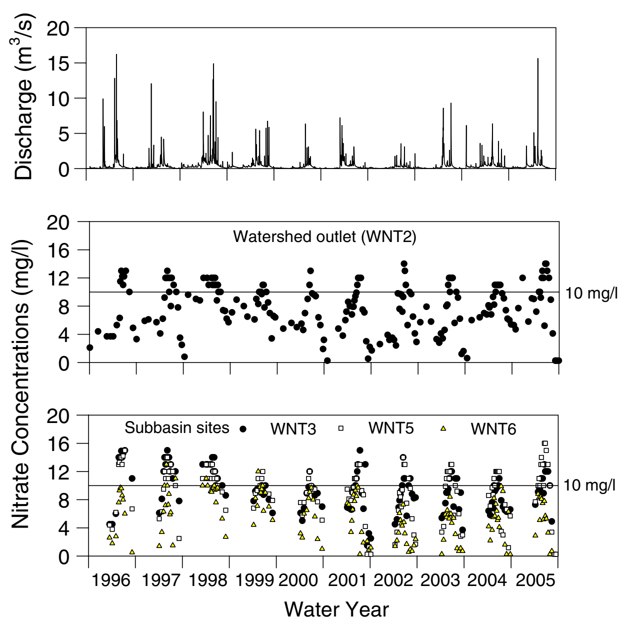



**Fig. 3** Time series of daily discharge (Q) at watershed outlet (WNT2) and stream nitrate concentrations at WNT2 and three subbasin sampling sites

of the Walnut Creek subbasins and the decreases were of greater magnitude than the trend observed at WNT2. Nitrate concentrations decreased 3.4, 1.2, and 2.7 mg/l at WNT3, WNT5, and WNT6, respectively.

Given the magnitude of land use change in the watershed, improvements in stream nitrate concentrations were lower and more delayed than expected. In fact, a lag time of 3 years was needed before the first statistically significant change in stream nitrate was detectable (Schilling et al. 2006a). In a watershed dominated by low-permeable glacial materials and glacial-derived alluvium, it was hypothesized that the rate of nitrate decrease observed in the watershed was proportional to how much time was needed for groundwater beneath new prairie plantings to flow to the stream network.

## Methods

### GIS travel time model

The groundwater travel time distribution in the Walnut Creek watershed was evaluated using a GIS platform (ArcView 3.3; ESRI 2002) to estimate the average linear velocity in 5-m cells in the watershed. Average linear velocity was estimated by:

$$V = -K(\mathrm{d}h/\mathrm{d}l)/n \qquad (1)$$

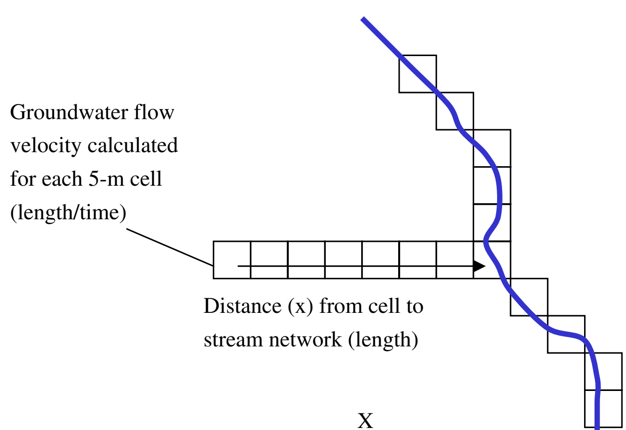
where $v$ is the average linear velocity (m/s), $K$ is the hydraulic conductivity (m/s), $\mathrm{d}h/\mathrm{d}l$ is the hydraulic gradient (dimensionless) and $n$ is the porosity. For model inputs, common topographic and soil variables were used as surrogates for $K$ and hydraulic gradient. Because the water table generally mimics the land surface, a digital elevation model (DEM) was used as the basis for estimating the hydraulic gradient. A triangular regular network (TIN) was created from elevation mass points obtained from the Jasper County GIS department (http://www.co.jasper.ia.us/gis.htm) and converted to a 5-m DEM for the watershed. The "hydraulic gradient" in each 5-m cell was then estimated by calculating the percent slope in each cell (i.e., slope of the cell based on neighboring cells). $K$ was estimated from Soil Survey Geographic (SSURGO) soil data for Jasper County (http://www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/). The digital soil coverage included a soil permeability (mm/hr) field that was converted to a grid (in m/s) and used as a surrogate for $K$. Using the soil permeability GIS coverage to estimate $K$ allowed for finer-scale spatial resolution of this parameter. Porosity was assumed equal to 0.3 as reported for pre-Illinoian till in eastern Iowa (Helmke et al. 2004). Using these inputs into Eq. 1, a daily groundwater flow velocity (m/day) was calculated for each 5-m cell in the watershed using the slope grid, $K$ value grid and 0.3 constant for porosity.

A drainage network was developed from the DEM using a stream initiation area of 100 acres. The Hydro script in ArcView was then performed on the DEM to fill the DEM, create a flow direction grid and create a flow accumulation grid. Thus, all 5-m cells in the watershed had a flow pathline from the cell to the stream network according to the land surface terrain. A flow length grid was subsequently created from this coverage with a null value for the drainage network and a flow length value assigned to each cell determined by the distance from the cell to the nearest stream. The time needed for groundwater in each 5-m cell to travel from the cell to the stream network was then determined by averaging all the individual cell velocities over the flowpath length from the cell to the stream (Fig. 4). Thus, 5-m grid coverage was created with each cell having an attribute representing the time (in years) for groundwater to migrate from the cell to the stream network. This coverage represented the travel time distribution for the watershed (Fig. 5).

### Prairie plantings

Conversion of row crop lands to native habitat has been directed by the USFWS at the Neal Smith refuge. With ongoing refuge expansion, various tracts of ground are removed from row crop production and converted to native habitat according to the political, ecological and operational needs of the refuge. Because of the varied needs, placement of land use changes in the watershed has been rather piecemeal based on field boundaries and property ownership. Annual prairie planting sites were tracked by the USFWS and made available as GIS shapefile coverages. Locations of prairie plantings were identified by the year in which they were planted and a GIS coverage of this information was developed showing the length of time since the prairie was planted (in years before 2005; Fig. 6).

Subtracting the travel time grid from the prairie-planting grid determined whether groundwater in each 5-m cell would have had sufficient time to migrate to the nearest stream since the planting date of the prairie (expressed in years; Fig. 7). If the difference was positive, then groundwater beneath the planting would have had time to flow to a stream, discharge as baseflow and begin affecting stream water quality. If the difference was negative, water quality benefits from converting agricultural land to prairie are still in transit from the field to the stream. Water quality benefits from a planting with a negative value have not had a chance to affect water quality yet but may do so in the future. The concept of a delayed benefit to a conservation practice is simply another way of expressing the lag time of a watershed.




$$\text{Cell travel time} = \frac{X}{\frac{1}{n}\sum_{i=1}^{n} V_{\text{cell } i}}$$

**Fig. 4** Conceptual model of cell travel time calculation

## Results

The groundwater travel time distribution for the Walnut Creek watershed varied from 2 days to a maximum travel time of 308 years (Table 2). The mean travel time was 10.1 years, suggesting that, on average, a decade would be needed for groundwater to "turn over" in the watershed. In the three monitored subbasins, the mean travel times ranged between 8.9 and 10.0 years with maximum travel times less than approximately 72 years (Table 2). Because groundwater flow paths in upland areas were considerably longer than flow paths near streams, upland regions were clearly delineated by groundwater travel times greater than 20 years (Fig. 5). Long travel times in the watershed are consistent with local hydrogeological conditions typified by loess mantled glacial till in upland regions.

Intersecting the travel time model with the prairie planting dates suggests that there has been sufficient time for groundwater beneath 50.3% (574.3 ha) of the plantings to flow to the stream network (Table 3). Likewise, groundwater originating from the other half of the prairie plantings (49.7% of all plantings) may still be in transit to the nearest stream. Overall, 11% of

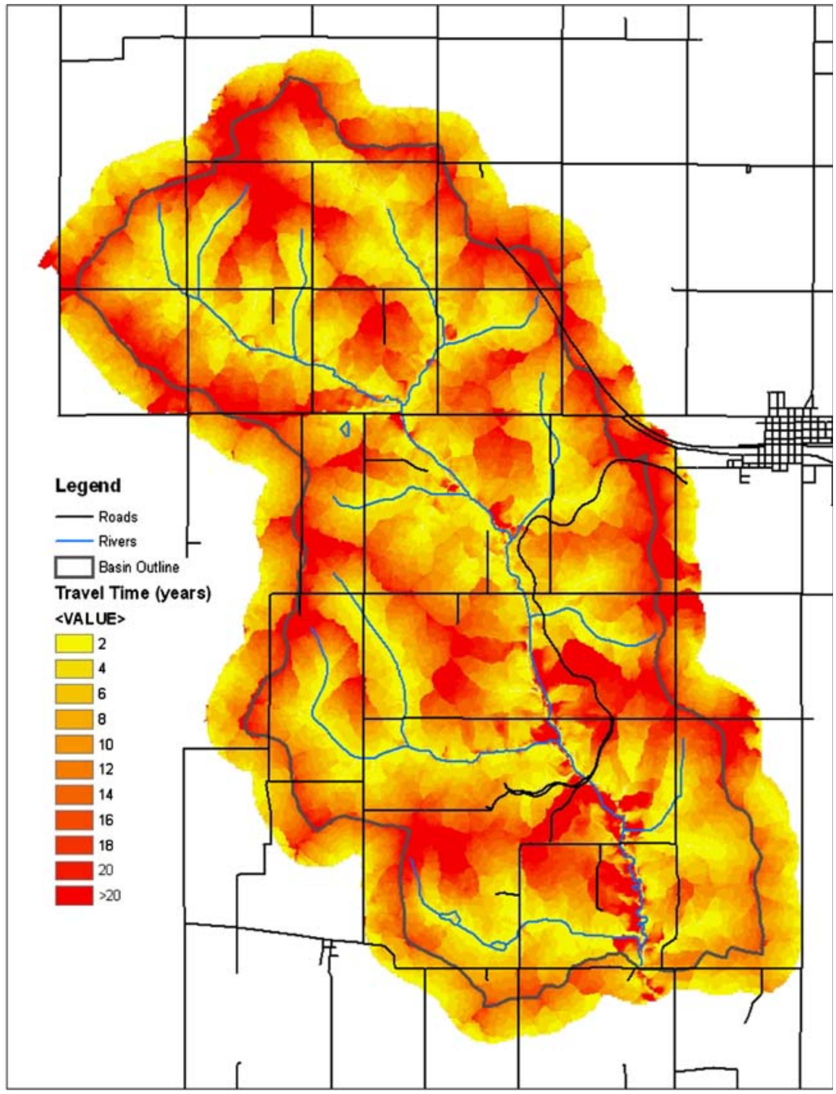



**Fig. 5** Groundwater travel time distribution in Walnut Creek watershed estimated by GIS model

the Walnut Creek watershed had groundwater from a prairie planting reaching the stream network within the 10-year monitoring period (Table 3). In the three subbasins, groundwater from a greater percentage of prairie plantings had sufficient time to reach a stream (60.2–74.3%). Overall, 10.1–22.0% of the subbasin areas had prairie groundwater reaching the stream network within the 10-year period.

The measured change in stream nitrate concentrations in Walnut Creek and three subbasins (Table 1) was similar to the proportion of their watershed areas with prairie groundwater reaching the stream network (Table 3). At the Walnut Creek outlet, nitrate concentrations decreased approximately 15.4%, whereas the time of travel analysis suggested that 11.0% of watershed had groundwater beneath a prairie planting reaching a stream. In subbasin WNT3, the reduction in stream nitrate concentration measured from 1996 to 2005 (27.9%) was similar to the proportion of the watershed that had prairie groundwater reaching the stream (19.3%). In WNT5 subbasin, an 11% decrease in stream nitrate concentrations was less than the percentage of land with prairie groundwater reaching the stream (22.0%), whereas in WNT6 subbasin, nitrate concentrations decreased (36.5%) more than the land area alone would suggest (10.1%).

## Discussion

### Travel time model

The groundwater time of travel model developed for the Walnut Creek watershed used readily available topographic and digital soil data to evaluate the time needed for groundwater to flow to and discharge into a

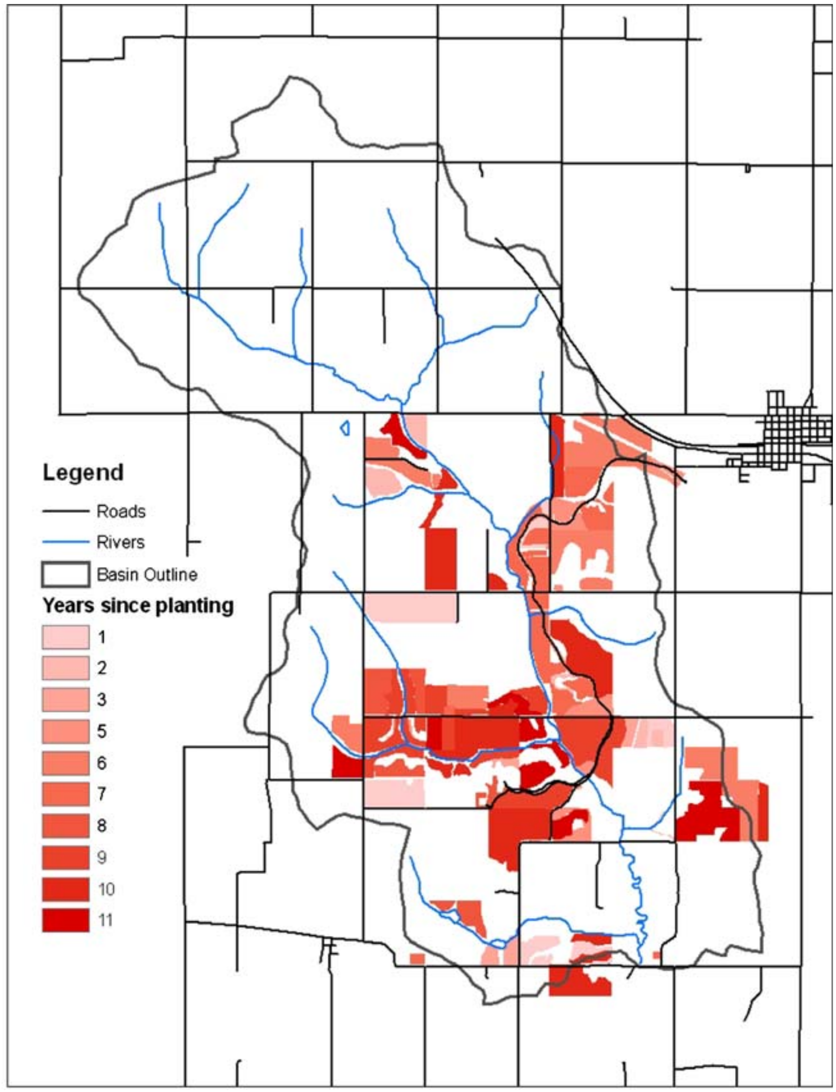



**Fig. 6** Location of prairie plantings and their time since planting (time before 2005)

stream. While the spatial resolution of the input data was quite good, the accuracy of their use in this application required confirmation. Haitjema (1995) developed an analytical expression to estimate the mean residence time for groundwater in a groundwatershed:

$$F(T) = nH/N \quad (2)$$

where $n$ is the aquifer porosity, $H$ is the saturated aquifer thickness, and $N$ is the areal recharge rate due to precipitation. For Walnut Creek watershed, $n$ was assumed to be 0.3, $H$ was estimated to be 6.1 m and $N$ was equal to the long-term average baseflow in Walnut Creek 129.5 mm (Schilling et al. 2006a). The mean residence time for groundwater in Walnut Creek using Eq. 2 was estimated to be approximately 14 years. Although considerable uncertainty lies in the estimate of $H$, it was derived as an approximation of the thickness of saturated loess and oxidized till in upland settings, and a midrange estimate of saturated alluvium in the floodplains. In actuality, $H$ could be less than 3 m in sloping bluffs where pre-Illinoian till outcrops, or greater than 12 m in some floodplain settings. The residence time was essentially the mean of a cumulative frequency distribution of travel times in the watershed and would imply that, on average, 14 years is needed for groundwater to drain from the watershed, with some groundwater draining faster to streams and some draining much slower.

Overall, the estimated mean residence time using Eq. 2 was very similar to the mean travel time developed using the GIS model (10.1 years). This suggests that the GIS model would be appropriate for estimating the mean travel times (residence time) in watersheds. Because the model was constructed as a grid

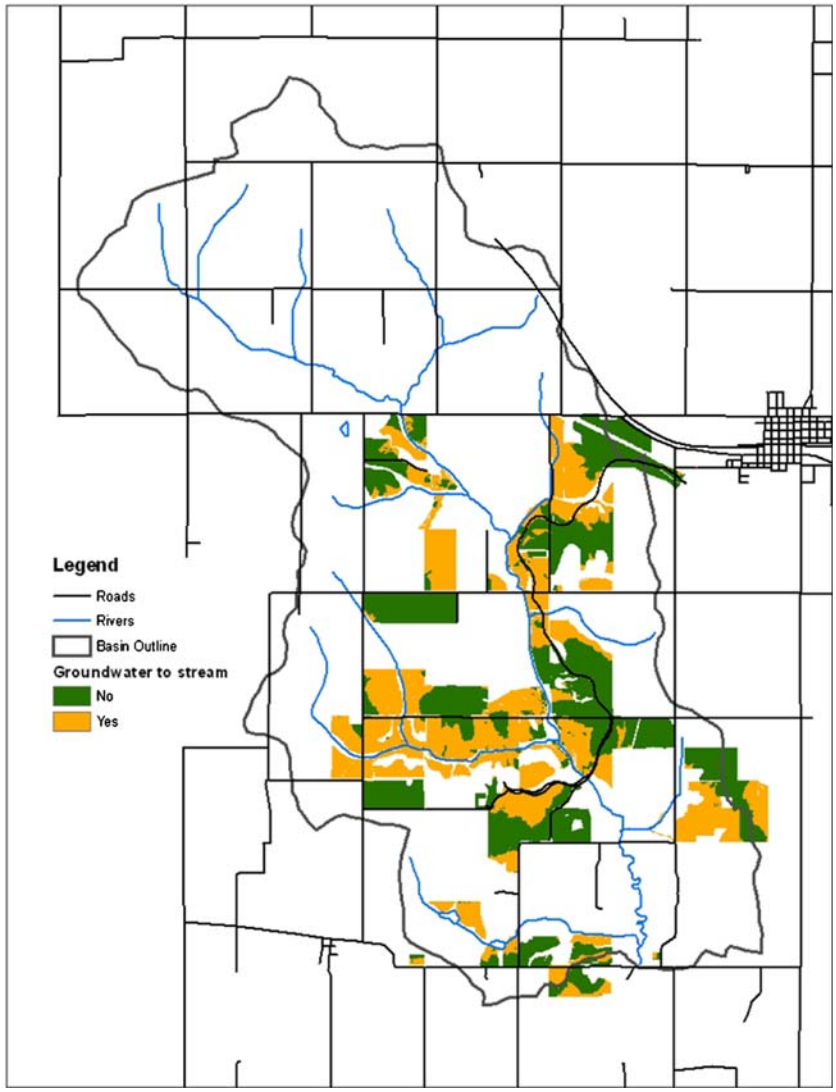



**Fig. 7** Determination of whether groundwater from a 5-m cell in a prairie planting has reached the stream network prior to 2005

**Table 2** Summary of groundwater travel time estimates for Walnut Creek watershed and monitored subbasins

| Watershed and subbasins | Mean travel time (years) | Minimum travel time (days) | Maximum travel time (years) |
|---|---|---|---|
| Walnut Creek | 10.1 | 2 | 308 |
| WNT3 | 9.7 | 4.6 | 71.9 |
| WNT5 | 8.9 | 5.1 | 67.0 |
| WNT6 | 10.0 | 3.6 | 51.1 |

network of 5-m cells, the model was capable of estimating travel times from small features rather than providing a simple global estimate. Hence, model resolution may be sufficient to estimate groundwater travel times from individual farm fields or other features where improved management or conservation practices may be affecting groundwater quality. The model would provide improved understanding of the time needed for land management changes to arrive at a stream. Information such as this may assist land managers in communicating the ''lag time'' issue to the general public.

Limitations for the travel time model are primarily related to its use of surrogate measures of *K* and hydraulic gradient for estimating cell groundwater flow velocity. Field monitoring of upland loess and till in Walnut Creek watershed has estimated *K* to range from $1 \times 10^{-7}$ to $3 \times 10^{-8}$ m/s (Schilling and Wolter 2001). This *K* range is lower than assumed with the soil permeability values likely because soil permeability is typically increased due to macropores and soil development. Thus, the travel time predictions with the GIS model may have overestimated the travel time distribution in the watershed and resulted in predicted travel times being faster than true groundwater flow values. Similarly, use of topography, as a surrogate for

**Table 3** Summary of watershed areas with groundwater beneath prairie plantings reaching the perennial stream network during the 10-year monitoring period

| Watershed and subbasins | Watershed area (ha) | Total prairie planting area (ha) | Prairie planting area with groundwater reaching stream (ha) | Percentage of prairie plantings with groundwater reaching stream | Percentage of watershed with prairie planting reaching stream network |
|---|---|---|---|---|---|
| Walnut Creek | 5,217.0 | 1,141.3 | 574.3 | 50.3 | 11.0 |
| WNT3 | 295.1 | 94.7 | 57.0 | 60.2 | 19.3 |
| WNT5 | 791.8 | 272.6 | 173.9 | 63.8 | 22.0 |
| WNT6 | 200.7 | 27.2 | 20.2 | 74.3 | 10.1 |

hydraulic gradient would not account for variations in hydraulic head that inevitably occur in an agricultural watershed from spatial variations in recharge rates, vegetation cover, drainage tile density, and other factors.

Nonetheless, the GIS model presented herein may serve an important function to bridge the gap between simple residence time analysis (Eq. 2) and more detailed computer models. The GIS model provided spatially explicit travel time analysis using readily available datasets. GIS users would be capable of developing a travel time model for other watersheds with only a basic set of information and a rudimentary understanding of groundwater principles.

## Groundwater travel time and nitrate reductions

Nitrate monitoring results suggest that there is proportionality between the travel time of groundwater beneath restored prairie flowing to streams and changes in stream nitrate concentrations measured at the watershed outlets. The percent decrease in nitrate concentrations measured at four watershed outlets over a 10-year period was similar to the percentage of the watershed with groundwater from restored prairie reaching the stream network. This relation clearly makes intuitive sense, as evidenced by results from the overall paired watershed project that identified land use change as the cause of reduced stream nitrate (Schilling and Spooner 2007). Study results provide additional information to account for the magnitude of decrease among the watershed areas. An 11–37% decrease in stream nitrate concentrations appeared to be proportional to 10–22% of their watershed having groundwater beneath restored prairie reaching a stream.

However, the GIS study did not provide a simple one-to-one relation between the travel time analysis and the magnitude of nitrate decrease in the watersheds. Other equally important factors likely contributed to the variations in measured nitrate decrease. An important element not considered in the model was the rate in which prairie restoration on former row crop ground would reduce groundwater concentrations over time. The simple travel time analysis assumed that concentrations changed soon after the prairie was planted, when in fact, it probably takes several years to reduce nitrate-leaching losses after land use change. Current monitoring is attempting to derive a functional expression of the rate by which nitrate losses are reduced when row crop ground is converted to native prairie. Preliminary results suggest a rate of nitrate reduction of approximately 0.7 mg/l/year (Schilling and Wolter 2006), but this rate remains to be substantiated by additional measurements. For the GIS travel time model to fully reflect the rate of nitrate reductions anticipated after land use change, it should take into account a decay coefficient for nitrate reductions over time occurring beneath a prairie planting. A second important element not considered in the nitrate reduction analysis was naturally occurring nitrate transformations that occur in the landscape. Denitrification has been shown to be an important mechanism in the silty, organic-rich floodplain alluvium of Walnut Creek (Schilling et al. 2006b). Nitrate that flows along a path line from an upland field through the silty alluvium may be denitrified naturally and have little to do with the time since a prairie was planted.

Despite the limitations, the travel time model is instructive to illustrate the concept of lag time involving reduced stream nitrate concentrations following land use change. By simply accounting for the time needed for a groundwater particle to flow from a prairie planting to a stream, a portion of the stream nitrate reductions can be explained. Model results do suggest that additional improvements from land use change may be forthcoming. As of 2006, the model suggests that groundwater from only one-half of the planted prairie has reached the stream network. With additional time, more groundwater affected by the prairie plantings may discharge into the streams and continue to lower stream nitrate concentrations over time.

## Conclusions

The time needed for a conservation practice to begin reducing nonpoint source pollutants in stream is an important consideration for many water quality projects. Because nitrate losses are controlled largely by leaching and subsurface transport, many years or decades may be needed for improvements in stream water quality in watersheds underlain by low permeable glacial aquitards. A new GIS-based travel time model provided insights to the groundwater travel time distribution in the Walnut Creek watershed where large portions of the watershed were converted from row cropland use to native prairie. The travel time model used readily available soil and topography variables to predict a mean groundwater residence time of 10.1 years for the watershed that was consistent with other estimates. The high spatial resolution of the model (5-m cells) and its simplicity may make it applicable for land managers interested in communicating lag time issues to the public, particularly related to nitrate concentration reductions over time.

In Walnut Creek where stream nitrate concentrations were observed to decrease from large-scale land use change, the GIS model was used to assess the contribution of prairie groundwater to the stream network. The nitrate decrease in streams was found to be proportional to the time needed for groundwater to flow from a new prairie planting to the stream network. Although the model has limitations for evaluating nitrate transport, results provide encouragement that additional nitrate reductions in Walnut Creek are probable in the future as reduced nitrate groundwater from distal locations discharges to the stream network in the coming years.

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