JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
AUGUST AMERICAN WATER RESOURCES ASSOCIATION 2003

INCREASED BASEFLOW IN IOWA OVER THE SECOND HALF OF THE 20TH CENTURY[1]

Keith E. Schilling and Robert D. Libra[2]

ABSTRACT: Historical trends in annual discharge characteristics were evaluated for 11 gauging stations located throughout Iowa. Discharge records from nine eight-digit hydrologic unit code (HUC-8) watersheds were examined for the period 1940 to 2000, whereas data for two larger river systems (Cedar and Des Moines Rivers) were examined for a longer period of record (1903 to 2000). In nearly all watersheds evaluated, annual baseflow, annual minimum flow, and the annual baseflow percentage significantly increased over time. Some rivers also exhibited increasing trends in total annual discharge, whereas only the Maquoketa River had significantly decreased annual maximum flows. Regression of stream discharge versus precipitation indicated that more precipitation is being routed into streams as baseflow than as stormflow in the second half of the 20th Century. Reasons for the observed streamflow trends are hypothesized to include improved conservation practices, greater artificial drainage, increasing row crop production, and channel incision. Each of these reasons is consistent with the observed trends, and all are likely responsible to some degree in most watersheds.
(KEY TERMS: surface water hydrology; agricultural hydrology; streamflow; baseflow; land use change; Iowa; watershed.)

Schilling, Keith E. and Robert D. Libra, 2003. Increased Baseflow in Iowa Over the Second Half of the 20th Century. J. of the American Water Resources Association (JAWRA) 39(4):851-860.

INTRODUCTION

Historical trends in stream discharge provide an important context for understanding changes in watershed hydrology and pollutant delivery that have occurred in many Midwestern states since the advent of modern agriculture. If stream discharge records were available for the late 1800s through the early 1900s, they would have documented the tremendous change in discharge that occurred when Euro-American settlers cleared and cultivated the native landscape, changing the landscape hydrology that was dominated by infiltration to one dominated by excessive storm flow and erosion (Knox, 1977, 2001; Trimble and Lund, 1982; Anderson, 2000). During the second half of the 20th Century, stream gauging records have documented changes in hydrology that have resulted from improved land conservation practices. In southwestern Wisconsin, for example, several studies have noted decreased flood peaks and increased baseflow due to improved land management and changes in land use (Potter, 1991; Gebert and Krug, 1996; Knox, 2001). Gebert and Krug (1996) examined annual flood peak and the annual seven-day low flow records at 12 Wisconsin stream gauging stations and found that annual low flows increased and annual flood peaks decreased in many agriculture dominated watersheds from about 1930 to 1991. In Iowa, an increase in baseflow and decrease in storm flow was measured in four small watersheds (< 150 ac) in the loess hills of western Iowa over a 30-year period (Kramer *et al.,* 1999). In these steeply sloping watersheds, hydrologic changes resulting from conservation tillage on highly erodible lands reduced sediment discharge from storm events and provided increased infiltration of precipitation and ground water discharge to streams.

An increase in nitrate-nitrogen (nitrate) concentrations in Iowa's streams since the mid-20th Century may be linked to changes in stream discharge. Annual nitrate concentrations in the Cedar River increased from 2 mg/l (1945 to 1951) to 6 mg/l (1978 to 1998) and nearly doubled in the Des Moines River in the same time periods (IDNR-GSB, 2001). Because

[1]Paper No. 02079 of the *Journal of the American Water Resources Association.* **Discussions are open until February 1, 2004.**
[2]Respectively, Research Geologist and Supervisor, Iowa Geological Survey, 109 Trowbridge Hall, Iowa City, Iowa 52242-1319 (E-Mail/Schilling: kschilling@igsb.uiowa.edu).

nitrate is primarily delivered to streams with ground water discharge and tile drainage (Hallberg, 1987; Schilling, 2002), an increase in annual baseflow may contribute more nitrate to surface water.

The objective of this study was to determine if streamflow characteristics have changed in Iowa's streams since the early to mid-20th Century. Annual streamflow records were examined for 11 Iowa watersheds ranging in size from 526 to 14,038 mi^2 during various periods from about 1903 to 2000.

METHODS

Discharge variables, including total annual discharge, maximum annual discharge, minimum annual discharge, annual baseflow discharge, and annual baseflow percentage, were analyzed for 11 streams in Iowa (Figure 1; Tables 1 and 2). Nine of the 11 watersheds with similar areas were selected to represent conditions (eight-digit Hydrologic Unit Code, or HUC-8) (USGS, 1974) found in Iowa's major ecoregions and subecoregions (Figure 1) (Griffith *et al.,* 1994). Discharge records from these nine stations that began in 1940 were used in the analysis (Table 1).

Watershed boundaries were delineated for the area above each stream gauging station. The percentage of row crops in watersheds was determined by intersecting the watershed boundaries with a 1992 land cover map of Iowa (Giglierano, 1999) using ArcView geographic information system (GIS) software (ESRI, 1999). Precipitation data were obtained from the National Oceanic and Atmospheric Administration (NOAA, 2002). Monthly precipitation data for each year were summed to provide an annual record for nine regions of Iowa (NE, NC, NW, etc.). Precipitation data from each watershed's region were used for analysis. Precipitation for watersheds that spanned two or more precipitation regions was derived from a weighted average value.

Daily discharge at each gauging station was separated into baseflow and storm flow using an automated hydrograph separation program (Sloto and Crouse, 1996). A local minimum method was used that essentially connects the lowest points on the hydrograph and provides estimates of daily baseflow between local minimums by linear interpolation (Sloto and Crouse, 1996). Output from the program was tabulated and summarized by year. Annual storm flow was the difference between total stream discharge and baseflow calculated by the program.

Discharge records for gauging stations on the Cedar, Des Moines, and Maquoketa Rivers contain a longer period of record (Table 2). Discharge characteristics in these streams were summarized for two periods – the entire record and a 1940 to 2000 period. Mean annual precipitation was higher in the 1940 to 2000 period than for the entire record, as were median total discharge and baseflow in these streams (Table 2).

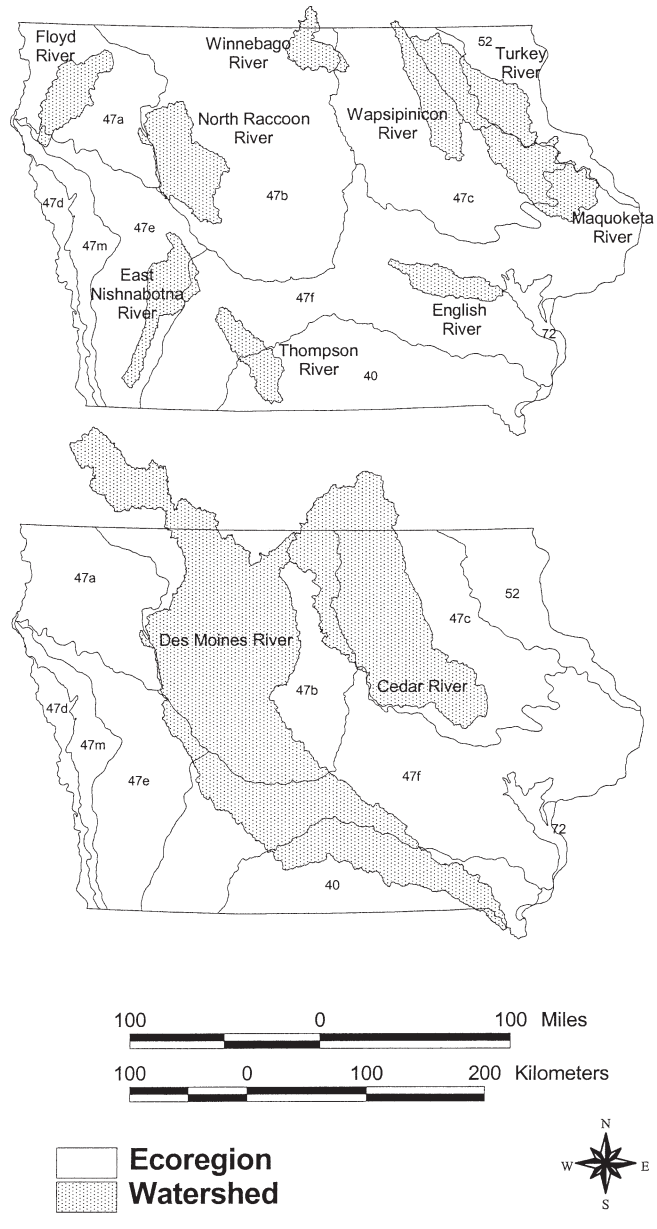

Figure 1. Location of HUC-8 Watersheds (top) and Two Larger Watersheds (bottom) Evaluated in This Study. Ecoregions and subecoregions (47a-m) notations from Griffith *et al.* (1994): where 40 = Central Irregular Plains, 47a = Northwest Iowa Loess Prairies, 47b = Des Moines Lobe, 47c = Iowan Surface, 47d = Missouri Alluvial Plain, 47e = Loess Hills and Rolling Prairies, 47f = Southern Iowa Rolling Loess Prairies, 47m = Loess Hills, 52 = Paleozoic Plateau, and 72 = Interior River Lowland.

TABLE 1. Summary of Streamflow Gauging Stations, Precipitation, and HUC-8 Watersheds Evaluated in This Study.

Station	Drainage Area (mi^2)	Period of Record Evaluated in This Study*	Mean Annual Precipitation (in)**	Average Basin Slope (percent)	1992 Row Crop Acreage (percent)	Mean Annual Baseflow Fraction (percent)
1. Winnebago River (05459500)	526	1940 to 2000 (1933)	32.2 (NC)	2.3	69.1	57.5
2. English River (05455500)	573	1940 to 2000 (1937)	35.7 (SE)	5.7	54.6	38.9
3. Thompson River (06898000)	701	1942 to 2000 (1942)	34.9 (SC)	7.5	23.5	29.6
4. Floyd River (06600500)	886	1940 to 2000 (1936)	28.5 (NW)	3.1	80.1	52.3
5. East Nishnabotna River (06809500)	894	1940 to 2000 (1937)	34.0 (SW)	6.3	65.5	47.2
6. Wapsipinicon River (05421000)	1,048	1940 to 2000 (1934)	34.7 (E)	1.8	71.0	44.8
7. Turkey River (05412500)	1,545	1940 to 2000 (1933)	33.8 (NE)	6.4	49.2	56.1
8. Maquoketa River (05418500)	1,553	1940 to 2000 (1914)	33.8 (NE)	5.4	60.4	61.9
9. North Raccoon River (05482500)	1,619	1941 to 2000 (1942)	30.7 (W)	1.4	87.1	52.0

*Parenthesis value is the year of continuous record.
**Parenthesis includes region of Iowa containing precipitation station used in this study.

TABLE 2. Summary of Gauging Stations, Precipitation, and Streamflow Characteristics Associated With Longer Period of Record at Larger Rivers.

Station	Drainage Area (mi^2)	Period of Record	Mean Annual Precipitation (in)	Median Stream Discharge (in)	Median Annual Flood Peak (cfs)	Median Annual Minimum Flow (cfs)	Median Annual Baseflow Discharge (in)	Mean Annual Baseflow Fraction (percent)
Maquoketa River	1,553	1914 to 2000	33.3	8.86	12,500	280	5.31	61.0
(05418500)		1940 to 2000	33.8	9.46	12,500	289	5.88	61.9
Cedar River at Cedar	6,510	1903 to 2000	33.6	6.95	23,100	600	4.25	61.9
Rapids (5464500)		1940 to 2000	34.3	7.86	26,600	660	4.72	62.1
Des Moines River at	14,038	1912 to 2000	32.9	5.11	34,800	358	2.60	53.3
Keosauqua (5490500)		1940 to 2000	33.4	6.31	34,600	366	2.77	54.8

Regression was used to determine if temporal changes occurred in the relationship of precipitation and various discharge components [annual stream discharge (Q), annual storm flow (Qs), annual baseflow discharge (Qb), and baseflow percentage (Q%)]. Regression residuals were calculated and plotted over time. If the relationship between discharge and precipitation had not changed, there would be no trend in the regression residuals. A change is indicated if the slope of the regression line is significantly different from zero ($p < 0.05$) (Tables 3 and 4). The t-value of the slope indicates the strength of the trend, and the sign of the slope indicates the sign of the trend.

Regression was also used to determine if changes in annual precipitation, annual total discharge, maximum annual discharge, minimum annual discharge, annual baseflow, and annual baseflow percentage occurred over time (Tables 3 and 4). Precipitation and baseflow percentage were normally distributed, whereas the other parameters were skewed and required log transformation before regression analyses were conducted. Gebert and Krug (1996) compared parametric and nonparametric tests (Kendall's tau) and found that regression analysis of log transformed discharge data identified the same significant trends and yielded nearly identical p-values as nonparametric tests. All statistical analyses were performed using the MINITAB Release 13 statistical software package (MINITAB, 2000).

TABLE 3. Summary of t-Values (p-values in parentheses) Corresponding to Regression of Precipitation (P) Versus Stream Discharge (Q), Storm Flow Discharge (Qs), Baseflow Discharge (Qb), and Baseflow Fraction (Q%) at HUC-8 Watersheds. Also shown is a summary of t-values and p-values corresponding to regression of precipitation and various streamflow characteristics over time. Larger t-values show stronger relationships and positive numbers indicate increasing trends.

Station	Q vs P Regression Residuals									
	Q vs P	Qs vs P	Qb vs P	Q% vs P	Precip.	Stream Discharge	Max. Annual Flow	Min. Annual Flow	Baseflow Discharge	Baseflow Fraction
1. Winnebago River (05459500)	2.18 (0.033)	0.33 (0.742)	3.04 (0.004)	3.83 (< 0.001)	1.39 (0.171)	1.96 (0.054)	-0.03 (0.980)	2.02 (0.048)	2.70 (0.009)	3.81 (< 0.001)
2. English River (05455500)	0.61 (0.542)	0.20 (0.841)	1.23 (0.222)	1.92 (0.059)	1.72 (0.091)	1.51 (0.137)	1.37 (0.176)	1.64 (0.107)	1.82 (0.074)	1.55 (0.127)
3. Thompson River (06898000)	0.15 (0.882)	-0.42 (0.679)	1.21 (0.232)	3.06 (0.003)	1.37 (0.175)	0.36 (0.718)	0.46 (0.648)	0.97 (0.334)	1.08 (0.285)	2.72 (0.009)
4. Floyd River (06600500)	2.91 (0.005)	0.18 (0.854)	4.47 (< 0.001)	5.36 (< 0.001)	0.88 (0.380)	2.74 (0.008)	0.54 (0.591)	4.97 (< 0.001)	4.13 (< 0.001)	5.09 (< 0.001)
5. East Nish-nabotna River (06809500)	3.02 (0.004)	1.17 (0.247)	2.72 (0.009)	5.17 (< 0.001)	1.03 (0.308)	2.46 (0.017)	-0.22 (0.830)	5.06 (<0.001)	2.80 (0.007)	5.38 (< 0.001)
6. Wapsipinicon River (05421000)	2.64 (0.011)	0.38 (0.707)	4.86 (< 0.001)	6.77 (< 0.001)	1.29 (0.204)	2.41 (0.033)	-0.08 (0.937)	5.24 (< 0.001)	4.68 (< 0.001)	6.56 (< 0.001)
7. Turkey River (05412500)	1.94 (0.057)	-0.94 (0.353)	3.67 (0.001)	6.15 (< 0.001)	1.06 (0.296)	1.86 (0.067)	-1.30 (0.199)	3.48 (0.001)	3.53 (0.001)	4.96 (< 0.001)
8. Maquoketa River (05418500)	0.97 (0.334)	-1.26 (0.212)	2.59 (0.012)	5.98 (< 0.001)	1.06 (0.296)	1.47 (0.146)	-1.78 (0.080)	1.84 (0.071)	2.94 (0.005)	4.69 (< 0.001)
9. North Raccoon River (05482500)	2.37 (0.021)	1.34 (0.187)	2.84 (0.006)	2.75 (0.008)	0.82 (0.418)	1.45 (0.153)	-0.63 (0.532)	2.28 (0.026)	2.05 (0.045)	2.43 (0.018)

RESULTS

Relation of Streamflow to Watershed Characteristics

Discharge characteristics for the HUC-8 watersheds show variability in stream discharge conditions between 1940 and 2000 (Figure 2). Discharge reflects the geology and relief of the watersheds (Table 1). Discharge in higher relief watersheds dominated by fine grained glacial till and loess deposits (e.g., English, Thompson, East Nishnabotna Rivers) exhibited greater storm flow and small annual minimum discharge. Watersheds consisting of fractured, highly permeable carbonate rocks found in northeastern Iowa (Turkey and Maquoketa Rivers) produced more baseflow and higher annual minimum flows. The North Raccoon and Winnebago River watersheds are located in the recently glaciated Des Moines Lobe landform region (Figure 1) with low relief and poor surface drainage (Prior, 1991). These watersheds produced lower maximum discharge than higher relief watersheds (Figure 2). Artificial subsurface drainage (tiling) is widespread on the Des Moines Lobe.

Relation of Streamflow to Precipitation

There has been a significant change in the relationship between discharge and precipitation over time in many Iowa watersheds (Tables 3 and 4). Discharge data from five watersheds showed that significant increase occurred in the rainfall/total discharge relationship (Q versus P) since 1940 ($p < 0.05$) (Table 3). Discharge in two rivers that did not indicate significant change in Q versus P (English and Thompson Rivers) had a higher ratio of storm flow to baseflow (mean annual baseflow less than 39 percent) than the other streams (Table 1). The Maquoketa River showed no change in the Q versus P relation from 1940 to 2000 but did show a significant increase from 1914 to 2000 (Table 4).

Discharge data from seven streams indicated a significant increase in the ratio of precipitation to baseflow (Qb versus P), and all streams produced a significant increase in the baseflow fraction of precipitation (Q percent versus P) (Table 3). From 1940 to 2000, there was no change in the relation of storm flow to precipitation in any of streams (Qs versus P).

TABLE 4. Summary of t-Values (p-values in parentheses) Corresponding to Regression of Precipitation (P) Versus Stream Discharge (Q), Storm Flow Discharge (Qs), Baseflow Discharge (Qb), and Baseflow Fraction (Q%) at Three Larger Rivers. Also shown is a summary of t-values and p-values corresponding to regression of precipitation and various streamflow characteristics over time. Larger t-values show stronger relationships and positive numbers indicate increasing trends.

Station	**Period of Record**	**Q vs P Regression Residuals**				**Precip.**	**Stream Dischg.**	**Max. Annual Flow**	**Min. Annual Flow**	**Baseflow Dischg.**	**Baseflow Fraction**
		Q vs P	**Qs vs P**	**Qb vs P**	**Q% vs P**						
Maquoketa River (05418500)	1914 to 2000	3.24 (0.002)	-0.31 (0.757)	3.24 (0.002)	4.68 (< 0.001)	1.69 (0.094)	2.17 (0.032)	-1.61 (0.112)	1.48 (0.141)	3.45 (0.001)	3.88 (< 0.001)
	1940 to 2000	0.97 (0.334)	-1.26 (0.212)	2.59 (0.012)	5.98 (< 0.001)	1.06 (0.296)	1.47 (0.146)	-1.78 (0.080)	1.84 (0.071)	2.94 (0.005)	4.69 (< 0.001)
Cedar River at Cedar Rapids (5464500)	1903 to 2000	3.46 (0.001)	2.12 (0.037)	3.93 (< 0.001)	2.28 (0.025)	2.04 (0.044)	3.07 (0.003)	0.47 (0.639)	2.20 (0.030)	3.49 (0.001)	1.70 (0.092)
	1940 to 2000	3.02 (0.004)	1.43 (0.159)	3.70 (<0.001)	3.50 (0.001)	1.34 (0.185)	2.76 (0.008)	0.57 (0.568)	2.49 (0.016)	3.48 (0.001)	2.90 (0.005)
Des Moines River at Keosauqua (5490500)	1912 to 2000	3.41 (0.001)	1.78 (0.079)	2.83 (0.06)	2.94 (0.004)	2.27 (0.026)	2.83 (0.006)	0.14 (0.892)	1.38 (0.170)	2.53 (0.013)	3.55 (0.001)
	1940 to 2000	2.29 (0.025)	0.95 (0.346)	2.62 (0.011)	2.97 (0.004)	2.21 (0.031)	1.99 (0.051)	-0.10 (0.920)	1.57 (0.122)	3.02 (0.004)	3.63 (0.001)

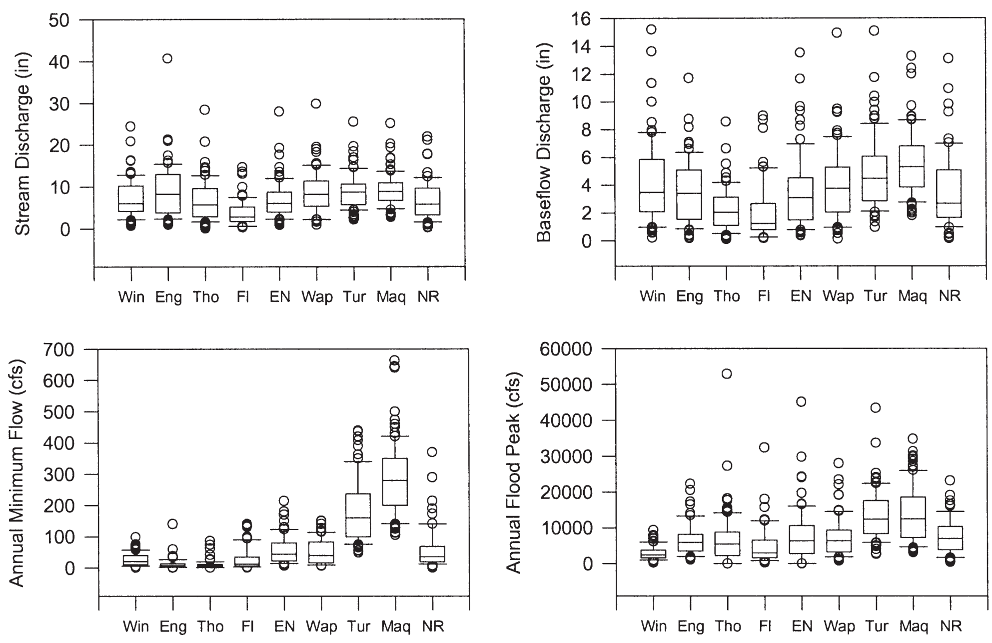

Figure 2. Box Plots of Stream Characteristics for HUC-8 Watersheds for the 1940 to 2000 Period of Record. Box plots illustrate the 25th, 50th, and 75th percentiles; the whiskers indicate the 10th and 90th percentiles; and the circles represent data outliers. Win = Winnebago River, Eng = English River, Tho = Thompson River, Fl = Floyd River, EN = East Nishnabotna River, Wap = Wapsipinicon River, Tur = Turkey River, Maq = Maquoketa River, and NR = North Raccoon River.

Thus, assuming no net change in storage in the ground water reservoir since 1940, more precipitation is being routed to streams as baseflow than as storm flow in the second half of the 20th Century.

Both the Cedar and Des Moines Rivers show that discharge characteristics have changed relative to precipitation during both the early and later time periods (Table 4). Interestingly, both streams underwent nominally significant change in the storm flow-precipitation ratio when analyzed using the entire streamflow record ($p < 0.08$), but this trend was not significant after 1940. Both rivers had a highly significant increase in the ratio of precipitation to baseflow and baseflow fraction during both periods (Table 4).

Trends in Streamflow Characteristics Over Time

Discharge data from nine streams show significant trends in many discharge characteristics (Table 3). Plots of discharge variables for the Wapsipinicon and East Nishnabotna Rivers are shown in Figures 3 and 4, respectively. Total discharge, annual minimum discharge, annual baseflow, and baseflow percentage have increased substantially during the 1940 to 2000 period. The Floyd River discharge also had similar increases in these streamflow characteristics (Table 3). In the other six streams, increases in total stream discharge are significant or nearly so. Discharge in most of these rivers had highly significant increases in annual minimum flow, annual baseflow, and baseflow fraction ($p < 0.05$) (Table 3). Annual precipitation increased throughout Iowa since 1940, but the trend was not significant ($p < 0.1$).

The strongest trend in discharge variables is the significant increase in annual baseflow percentage (Table 3). A plot of the annual baseflow percentage regression for all nine rivers indicates greater increases in the Wapsipinicon, East Nishnabotna, and Floyd Rivers (Figure 5). Annual baseflow percentage has increased 20 to 30 percent in these rivers, while

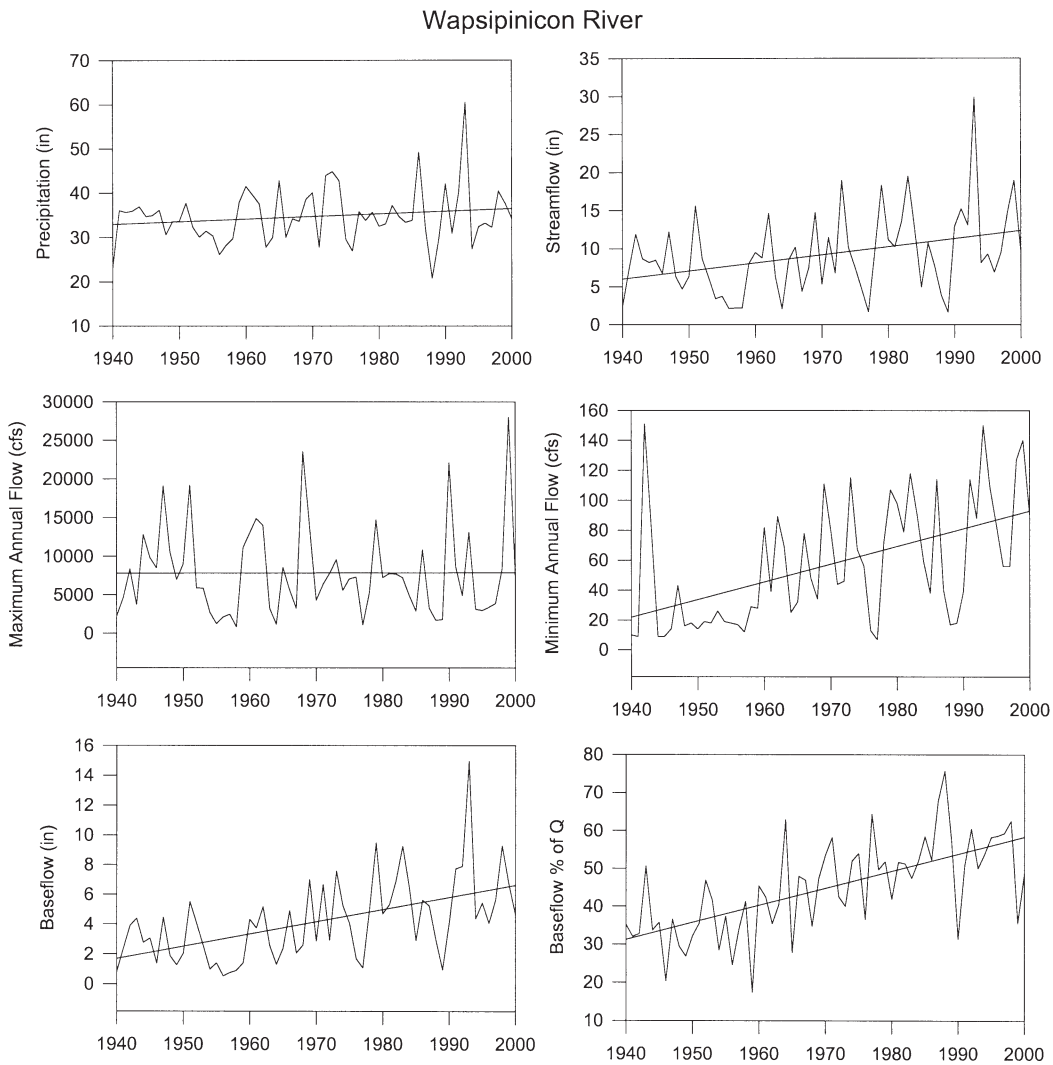

Figure 3. Graphs Showing Annual Precipitation and Annual Streamflow Characteristics Plotted Against Time for Wapsipinicon River at Independence, Iowa.

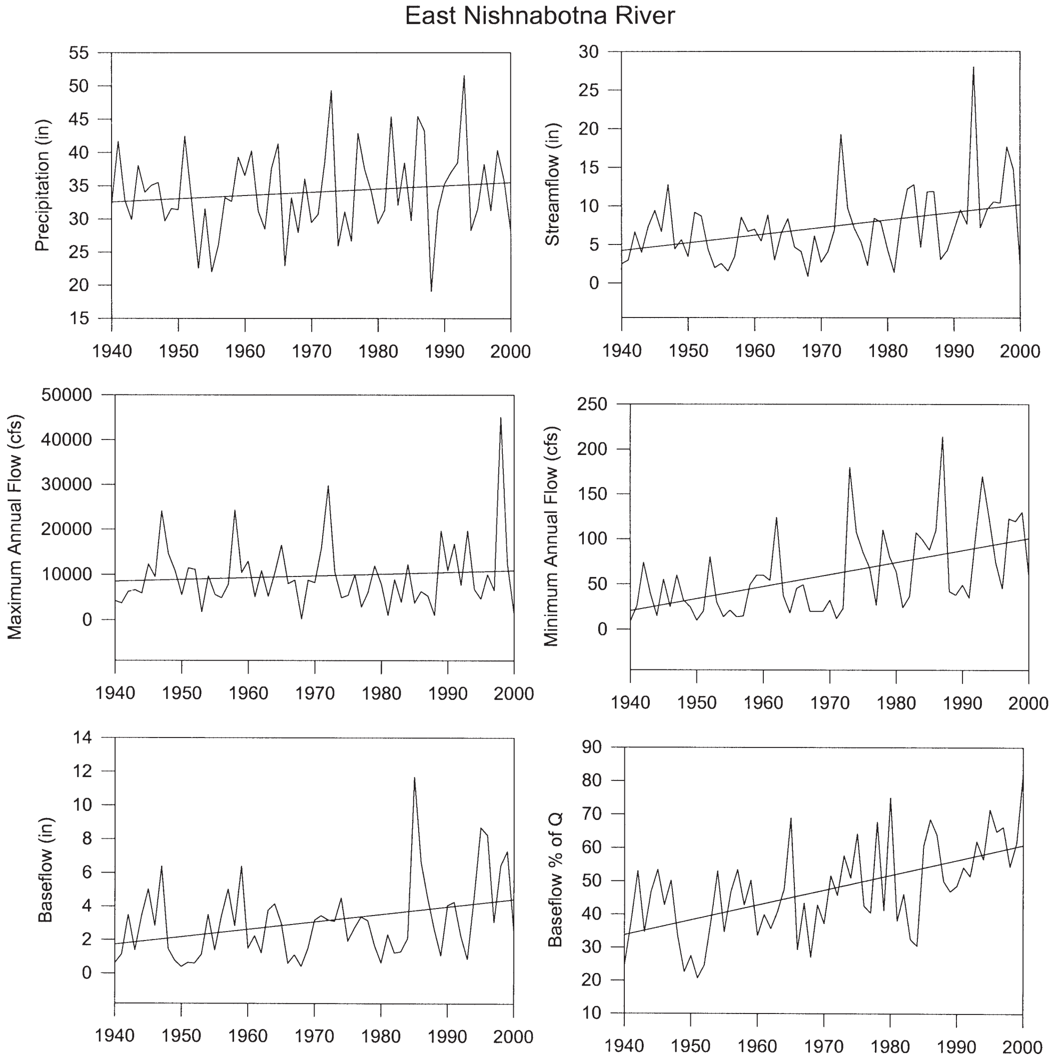

Figure 4. Graphs Showing Annual Precipitation and Annual Streamflow Characteristics Plotted Against Time for East Nishnabotna River at Red Oak, Iowa.

increases of 10 and 20 percent were measured in other rivers (Figure 5). Thus, a substantial change has occurred in the annual distribution of discharge in Iowa rivers, with a higher percentage of water being baseflow since 1940.

A decrease in annual maximum discharge in the Maquoketa River was nominally observed ($p < 0.08$), but no other trends were significant ($p < 0.1$). The decrease in annual maximum discharge in the Maquoketa River is similar to historical discharge from the Wisconsin driftless area (Gebert and Krug, 1996). Although agricultural variables may be similar in the Maquoketa River and the driftless area, the relief in the driftless area is greater. The Turkey River in Iowa has a greater average basin slope than the Maquoketa River (Table 1), but the trend of annual maximum flow was not significant in the Turkey River. However, the Turkey River watershed contains less area in row crop than does the Maquoketa River watershed (49.2 percent versus 60.4 percent, respectively).

Similar baseflow trends were apparent in the larger Iowa rivers during the longer period of record (Table 4). Both the Cedar and Des Moines Rivers had a significant increase in baseflow and baseflow fraction (Table 4). Increasing trends in annual minimum flows were less significant, and the trends had greater significance from 1940 to 2000. Increasing trends in annual precipitation and annual total discharge were more significant over the entire record than in the 1940 to 2000 period (Table 4).

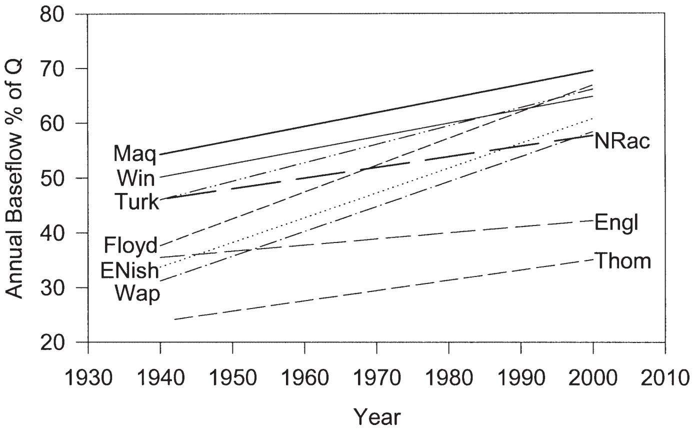

Figure 5. Regression Lines of Annual Baseflow Percentage Over Time for HUC-8 Watersheds. Engl = English River, Enish = East Nishnabotna River, Floyd = Floyd River, Maq = Maquoketa River, Nrac = North Raccoon River, Thom = Thompson River, Turk = Turkey River, Wap = Wapsipinicon River, and Win = Winnebago River.

DISCUSSION

Although annual precipitation has increased in Iowa during the 20th Century (Table 4), discharge variables, particularly baseflow, changed more than precipitation alone can explain. As similarly observed in Wisconsin, changes in precipitation alone cannot account for discharge changes (Potter, 1991; Gebert and King, 1996).

In Iowa, where cropland comprises more than 70 percent of the land area (NRCS, 2003), changes in discharge are most likely related to agricultural land use. Several important changes have occurred in Iowa agriculture that would be consistent with historical discharge trends. Improvements in land management practices, such as terraces, conservation tillage, and contour cropping, may have played a role in modifying discharge variables in high relief agricultural watersheds. Many of these conservation practices were implemented to decrease field erosion during storm flow and increase infiltration. Greater infiltration increases ground water levels and sustains higher baseflow and minimum low flows in streams. In Wisconsin, many soil conservation practices began to be implemented by the U.S. Conservation Service in the late 1930s and the 1940s (Trimble and Lund, 1982; Johnson, 1991). In Iowa, implementation of conservation practices has been less documented but was probably similar to that in Wisconsin. In the Walnut Creek watershed in south central Iowa, a comparison of aerial photographs taken in 1940 and 1971 noted that in 1940, many farm plots were rectangular in shape with little regard for natural topography or drainage, but by 1971, soil conservation practices were common in the watershed, including contour cropping, terraces, and grass waterways (Schilling, 2000). By 1982, the National Resources Inventory (NRI) reported many regions of Iowa with more than 30 percent of the land containing one conservation practice or more (Burkart *et al.,* 1994).

Improved conservation practices may have had their greatest impact on discharge in higher relief areas such as northeastern Iowa (Maquoketa and Turkey Rivers) and western Iowa (East Nishnabotna River). Conservation practices to reduce sheet and rill erosion in the loess hills were found to result in reduced sediment loads but increased baseflow (Kramer *et al.,* 1999). Where high relief watersheds have not included substantial row crop agriculture, fewer streamflow trends were noted. The Thompson River, and to a lesser extent the English River, have less row crop production per unit area than other Iowa watersheds studied. These southern Iowa watersheds are also underlain by fine grained glacial till that tends to promote excessive runoff relative to infiltration. Hence, conservations practices on limited row crop lands in low permeable watersheds may not have affected discharge as much as other Iowa watersheds.

In watersheds with low relief dominated by row crop agriculture, historical discharge trends may be linked to artificial drainage. Subsurface drainage tiles and ditches are used extensively throughout the Midwest to lower the water table and drain soils that are seasonally or perennially wet (Hallberg *et al.,* 1987; Zucker and Brown, 1998). Discharge from drainage tiles contributes to both baseflow and storm flow because surface inlets are connected to subsurface tiles. However, discharge from tiles results predominantly in increases in baseflow discharge, annual minimum discharge, and a higher percentage of total discharge as baseflow.

In Iowa, 25 to 35 percent of all cropland is artificially drained, representing approximately 8 million acres (Zucker and Brown, 1998). Historically, major periods of agricultural drainage in the United States occurred during 1870 through 1920 and during 1940 through 1960 (Beauchamp, 1987; Zucker and Brown, 1998). Following relatively steady increases in artificial drainage during the Depression years, passage of the Flood Control Act of 1944 and the 1954 Federal Watershed Protection and Flood Prevention Act increased artificial drainage, with the latter act authorizing the USDA to provide assistance with drainage projects (Beauchamp, 1987). The 1940 to 1960 period coincides with the period of significant increase in baseflow and baseflow percentage observed in nearly all streams studied. A large proportion of artificial drainage in Iowa is concentrated in the low relief, poorly drained Des Moines Lobe landform region, represented in this study by the North Raccoon and Winnebago Rivers. Land use in these two watersheds consists of 87 percent and 69 percent row crop, respectively, and significant increases in annual minimum discharge, baseflow, and baseflow percentage were measured in both streams. However, drainage tiles have been installed, to varying degrees, in all regions of Iowa so the effects of drainage tiles on streamflow changes are probably incorporated in historical discharge records from all gauging sites.

Another factor correlating with discharge trends is a large increase in soybean production that occurred in Iowa between 1940 and 2000. Soybean production increased from 1 million acres in 1940 to approximately 11 million acres in 2000 (Iowa Agricultural Statistics, 2001). Corn production remained relatively constant during the 1940 to 2000 period, averaging 10 to 12 million acres (Iowa Agricultural Statistics, 2001). Most land for soybeans probably came out of previously untilled land or other cover crops (i.e., oats, alfalfa, hay). The total increase in row crop area in Iowa was approximately 30 to 40 percent between 1940 and 2000.

Effects of changing land use on streamflow have been well documented (e.g., Bosch and Hewlett, 1982; Dunn and Mackay, 1995; Peel *et al.,* 2002; Zhang *et al.,* 2002). Converting previously untilled land or other perennial cover crops to row crops would increase baseflow because annual crops limit annual evapotranspiration (ET). While forest and grasses transpire throughout the spring, summer, and fall, substantial transpiration from row crops typically does not occur until mid-growing season. For example, single crop ET coefficients (K_c) during initial, mid-season, and late season growing periods vary substantially for different vegetation types. Initial, mid-season and late season K_c values for trees (walnut trees: 0.50, 1.10, 0.65, and 0.2 after leaf drop), rotational pasture (0.40, 1.05, and 0.85), and fallow grass (0.85, 0.90, and 0.90) compared to field corn (0.00, 1.20, and 0.35) and soybeans (0.00, 1.15, and 0.5) indicate much greater ET in the initial and late growing seasons for the perennial vegetation types (FAO, 1998). Less ET in row crop fields in the spring and fall would make infiltrating water more available for ground water recharge and lead to higher sustained baseflow in streams.

Lastly, channel incision of streams and rivers in Iowa is speculated to have contributed to observed streamflow trends. The combined effects of intensive row crop production, stream channelization, removal of riparian vegetation and agricultural tiling caused many stream channels in Iowa to incise into their floodplains through downcutting and widening processes. Channel downcutting would lower the bottom of the stream channel to intercept a greater proportion of the water table and result in an increase in baseflow discharge to the stream channel. During drier periods, where once a stream channel was intermittent, a channel incised deeply enough could flow throughout the year. If Iowa streams behaved similarly to other Midwestern watersheds, much of the channel incision probably occurred during the early part of the 20th Century. Trimble and Lund (1982) noted that pervasive land deterioration occurred in the Coon Creek watershed in southeastern Wisconsin primarily between 1910 and 1940. In response to rapid base-level changes in the main stems, channel incision would eventually migrate into tributary streams and lower water tables throughout the watershed. Hence, baseflow discharge and baseflow fraction would increase through time as a greater proportion of watersheds are drained by incised streams.

CONCLUSIONS

Annual stream discharge in Iowa changed during the 20th Century. In nearly all watersheds evaluated, annual baseflow, annual minimum flow, and annual baseflow percentage increased over time. The same discharge trends were found in rivers draining watersheds ranging from 526 mi^2 to more than 14,000 mi^2. Some rivers also had increasing trends in total annual discharge, whereas only the Maquoketa River had significantly decreased maximum flows. All streams had a statistically significant increase in the baseflow percentage in relation to precipitation. Thus, there has been a fundamental change in the routing of precipitation across the Iowa landscape, with more discharge to streams from ground water than stormflow in the second half of the 20th Century.

Reasons for the observed streamflow trends are hypothesized to include improved land management and conservation practices, greater artificial drainage, increasing row crop production, and channel incision. These explanations are consistent with the observed trends, and all are likely responsible to some degree in most watersheds. The clear signal in the discharge trends is the impact of intensive agriculture on the nature of streamflow in Iowa.

LITERATURE CITED

Anderson, K. L., 2000. Historic Alteration of Surface Hydrology on the Des Moines Lobe. Iowa Geology 25, Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, Iowa.

Beauchamp, K. H., 1987. A History of Drainage and Drainage Methods. *In:* Farm Drainage in the United States: History, Status, and Prospects, George A. Pavelis (Editor). Economic Research Service, U.S. Department of Agriculture Miscellaneous Publication No. 1455, pp. 13-28.

Bosch J. M. and J. D. Hewlett, 1982. A Review of Catchment Experiments to Determine the Effect of Vegetation Changes on Water Yield and Evapotranspiration. Journal of Hydrology 55:3-23.

Burkart, M. L., S. L. Oberle, M. J. Hewitt, and J. Pickus, 1994. A Framework for Regional Agroecosystems Characterization Using the National Resources Inventory. Journal of Environmental Quality 23:866-874.

Dunn, S. M. and R. Mackay, 1995. Spatial Variation in Evapotranspiration and the Influence of Land Use on Catchment Hydrology. Journal of Hydrology 171:49-73.

ESRI (Environmental Systems Research Institute), 1999. ArcView GIS Version 3.1.1. ESRI. Redlands, California.

FAO (Food and Agriculture Organization of the United Nations), 1998. Crop Evapotranspiration, Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, Italy, 300 pp.

Gebert, W. A. and W. R. Krug, 1996. Streamflow Trends in Wisconsin's Driftless Area. Water Resources Bulletin 32(4):733-744.

Giglierano, J. D., 1999. Iowa's Statewide Land Cover Inventory. Iowa Geology 1999. Iowa Dept. of Natural Resources, Geological Survey Bureau, Iowa City, Iowa.

Griffith, G. E., J. M. Omernik, T. F. Wilton, and S. M. Pierson, 1994. Ecoregions and Subecoregions of Iowa: A Framework for Water Quality Assessment and Management. The Journal of the Iowa Academy of Science 101(1):5-13.

Hallberg, G. R., 1987. Nitrates in Ground Water in Iowa. *In:* Rural Ground Water Contamination, F. M. D'Itri and L. G. Wolfson (Editors). Lewis Publishers, Chelsea, Michigan, pp. 23-68.

Iowa Agricultural Statistics, 2001. Crop and Land Use Tables and Charts, Iowa State University Agronomy Extension. *Available at* http://extension.agron.iastate.edu/soils/tables_charts.html. *Accessed on* February 7, 2001.

IDNR-GSB (Iowa Department of Natural Resources, Geological Survey Bureau), 2001. Nitrate Nitrogen in Iowa Rivers: Long-Term Trends. Water Fact Sheet 2001-5, Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, Iowa, 4 pp.

Johnson, L. C., 1991. Soil Conservation in Wisconsin: Birth to Rebirth. Department of Soil Science, University of Wisconsin, Madison, Wisconsin, 332 pp.

Knox, J. C., 1977. Human Impacts on Wisconsin Stream Channels. Annals of the Association of American Geographers 77:224-244.

Knox, J. C., 2001. Agricultural Influence on Landscape Sensitivity in the Upper Mississippi River Valley. Catena 42:193-224.

Kramer, L. A., M. R. Burkart, D. W. Meek, R. J. Jaquis, and D. E. James, 1999. Field-Scale Watershed Evaluations in Deep-Loess Soils: II. Hydrologic Responses to Different Agricultural Land Management Systems. Journal of Soil and Water Conservation 54(4)705-710.

MINITAB, 2000. Release 13. MINITAB Statistical Software, Minitab, Inc. State College, Pennsylvania.

NOAA (National Oceanic and Atmospheric Administration), 2002. *Available at* ftp://ftp.ncdc.noaa.gov/pub/data/cirs/. *Accessed in* June 2002.

NRCS (Natural Resources Conservation Service), 2003. 1997 NRI, Iowa, *Available at* http://www.ia.nrcs.usda.gov/News/Brochures/brochures.htm. *Accessed in* January 2003.

Peel, M. C., T. A. McMahon, B. L. Finlayson, and F. G. R. Watson, 2002. Implications of the Relationship Between Catchment Vegetation Type and the Variability of Annual Stormflow. Hydrological Processes 16:2995-3002.

Potter, K. W., 1991. Hydrological Impacts of Changing Land Management Practices in a Moderate-Sized Agricultural Catchment. Water Resources Research 27(5):845-855.

Prior, J. C., 1991. Landforms of Iowa. University of Iowa Press, Iowa City, Iowa, 154 pp.

Schilling, K. E., 2000. Patterns of Discharge and Suspended Sediment Transport in the Walnut and Squaw Creek Watersheds, Jasper County, Iowa: Water Years 1996-1998. Iowa Dept. of Natural Resources, Geological Survey Bureau, Iowa City, Iowa, 47 pp.

Schilling, K. E., 2002. Chemical Transport from Paired Agricultural and Restored Prairie Watersheds. Journal of Environmental Quality 31:1846-1851.

Sloto, R. A. and M. Y Crouse, 1996. HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis. U.S. Geological Survey Water Resources Investigation Report 96-4040, USGS, Lemoyne, Pennsylvania.

Trimble, S. W. and S. W. Lund, 1982. Soil Conservation and the Reduction of Erosion and Sedimentation in the Coon Creek Basin, Wisconsin. U.S. Geological Survey Professional Paper 1234, 35 pp.

USGS (U.S. Geological Survey), 1974. Hydrologic Unit Map, 1974, State of Iowa. USGS, Denver, Colorado.

Zhang, L., W. R. Dawes, and G. R. Wallace, 2001. Response of Mean Annual Evapotranspiration to Vegetation Changes at Catchment Scale. Water Resources Research 37(3):701-708.

Zucker, L. A. and L. C. Brown (Editors), 1998. Agricultural Drainage: Water Quality Impacts and Subsurface Drainage Studies in the Midwest. Ohio State University Extension Bulletin 871, The Ohio State University, 40 pp.