Streamflow Changes in the Upper Mississippi River Basin

Fall view of Mississippi River, Clayton County *photo by Gary Hightshoe*

Keith Schilling, Iowa DNR - Geological Survey, Iowa City, Iowa

Why is this important?

- MR is the longest and largest river in N. America covering all or parts of 31 states and 2 provinces
- MR and its basin provide important habitat for fish, wildlife and living ground for American people
- **Human activities have greatly altered this river ecosystem**
- Much of the basin is intensively cultivated and cultivation has reduced biodiversity, altered biogeochemistry, and impacted regional climates and basin hydrology;
- Many tributaries deliver substantial amounts of sediment, nutrients, and contaminants into the river contributing to many problems, including Hypoxia of the Gulf of Mexico.
- It is important to know the difference in amounts of nutrients and contaminants carried by surface runoff and baseflow order to effectively and efficiently deal with the problems

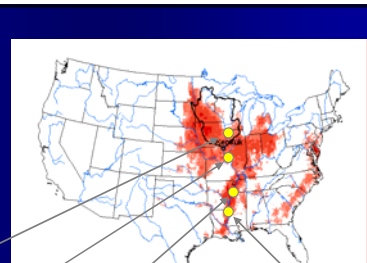
Is the MR flow increasing ?

We selected 8 USGS gauging stations and checked their Q

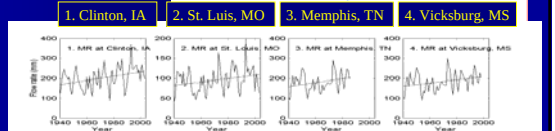
Station 1 – 4: Along the MR

Station 5 – 8: Outside the MR basin

Q at 4 USGS stations along MR since 1940s: An increasing trend

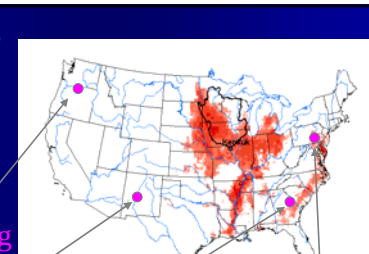


1. Clinton, IA | 2. St. Luis, MO | 3. Memphis, TN | 4. Vicksburg, MS

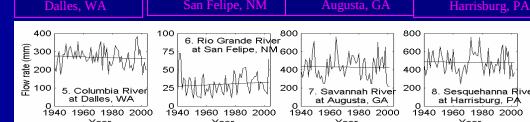


45% | 31% | 35% | 38%

Q at 4 USGS stations outside the MR basin since 1940s: Constant or decreasing



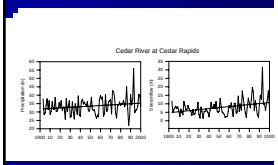
5.Columbia River at Dalles, WA | 6. Rio Grande River at San Felipe, NM | 7. Savannah River at Augusta, GA | 8. Sesquehanna River at Harrisburg, PA

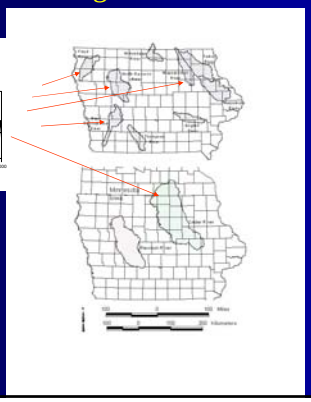


What we observed…

- Large increases in Q were observed in most stations since 1940s around the red area;
  - these increases are statistically significant ($p < 0.01$)
- But increasing Q is not observed in some stations, i.e., Arkansas River.
- Increasing Q is not observed in some major rivers outside the MR basin;
- The finding of increasing Q is consistent with other studies
  - Lins and Slack (1999)
  - Schilling and Libra (2003)

Is Streamflow Increasing in Iowa?

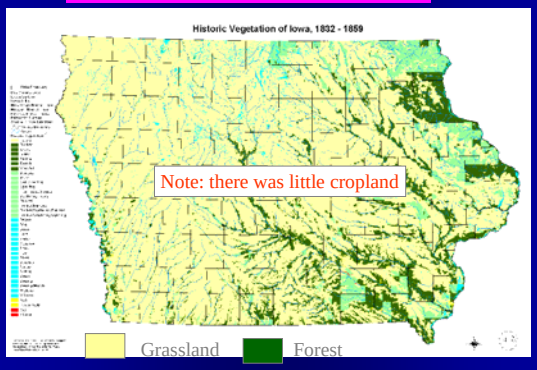


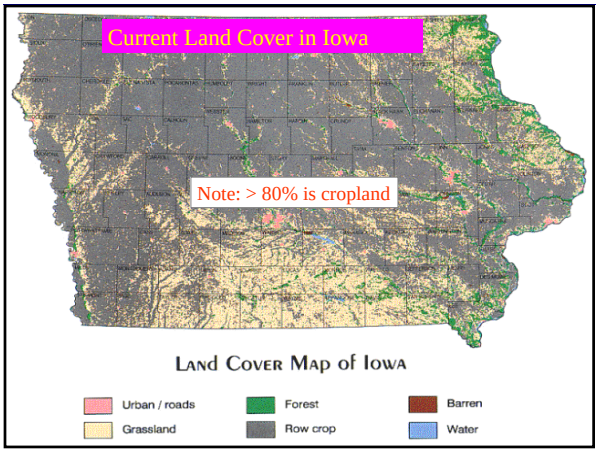


What has caused increased streamflow?

- Precipitation has increased - P increased about 7% during the last 60 years
- However, increasing P alone not sufficient to explain magnitude of increase
- Fundamental change in rainfall/runoff relationship – Q increasing at greater rate than increasing P alone can explain
- **Changes in land use/land cover**

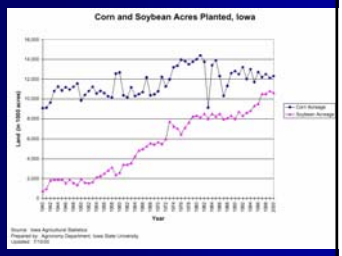
Land Cover in Iowa around 1850





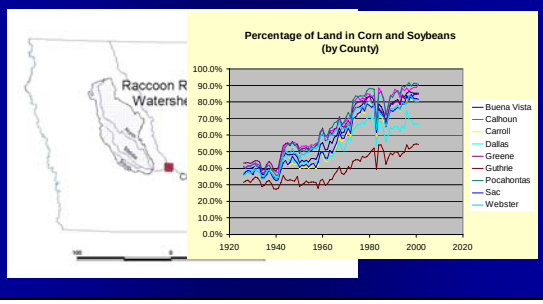
How has agriculture changed?

- In Iowa, changes in agricultural land use began around 1940
- Soybean acreage increased from 1 to 11 million acres from 1940 to 2000
- With corresponding increase in corn acreage, row crop acreage in Iowa increased approximately 30-40% from 1940-2000

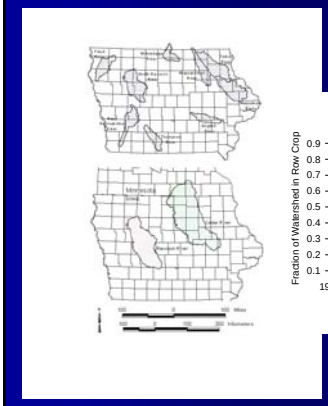


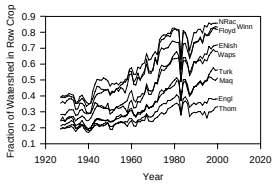
How has the agriculture changed?

- Watershed scale

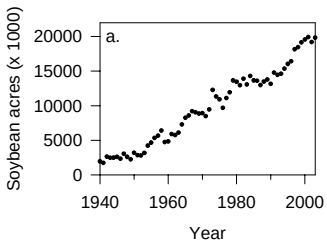


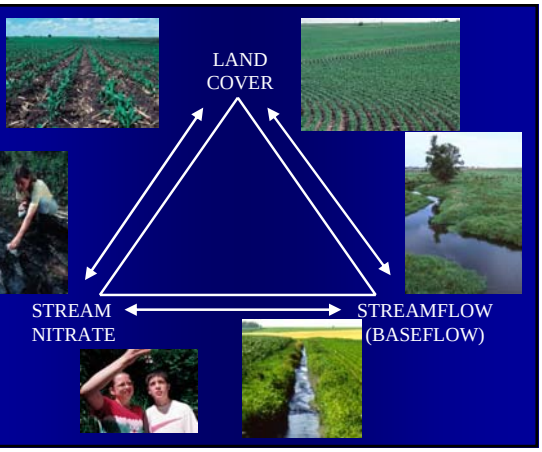
- Regional scale - Iowa



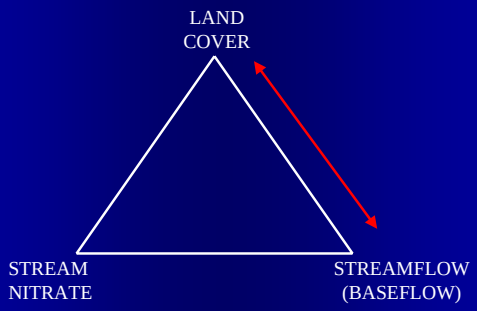


Continental Scale: Mississippi River Basin





What has changing land cover done to watershed hydrology?



Difference in ET between perennial vs. annual crops

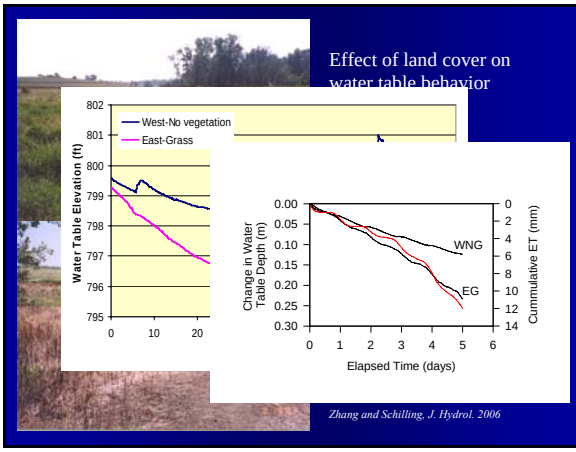
Single crop ET coefficients (Kc)

Estimated crop ET = Kc * PET

Cover	Initial	Mid-season	Late season
trees	0.5	1.10	0.65
pasture	0.4	1.5	0.85
grass	0.85	0.9	0.9
corn	0	1.2	0.35
soybeans	0	1.15	0.5

Food and Agriculture Organization of the United Nations, 1998

Effect of land cover on water table behavior



Zhang and Schilling, J. Hydrol. 2006

LONG-TERM WATER BALANCE FOR THE MR BASIN

$$P = Q + ET$$

P – Precipitation
Q – River flow
ET – Evapotranspiration

Effect of land use change on river flow

A basin covered by perennial grass

$P_P = Q_P + ET_P$

A basin covered by seasonal crops

$P_S = Q_S + ET_S$

$P_P = P_S$

$ET_P > ET_S$

$Q_P < Q_S$

Q before 1940 is smaller than Q after 1940.

Effect of land cover on groundwater recharge (R)

$$R - Qb = \Delta S$$

↑ more ET_P

↓ less R_P

↑ less ET_S

↓ more R_S

Over long period of time $\Delta S = 0$ and thus R = Qb

$R_s > R_p$ so $Qb_s > Qb_p$

Thus, changing land cover from perennial to seasonal crops would result in an increase in baseflow

What else has accompanied changing land use patterns?

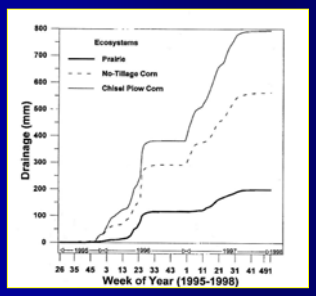
- Tile drainage

What else has accompanied changing land use patterns?

- Improved conservation practices

Relation of land use to baseflow

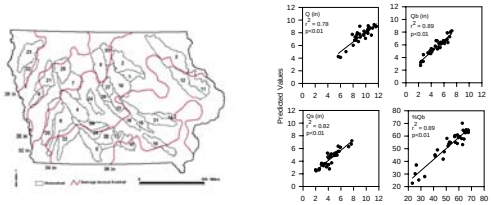
Plot studies



Corn and soybeans have greater drainage and less ET than perennial grasses

Brye et al., Soil Sci. Am. J. 64:715-724 (2000)

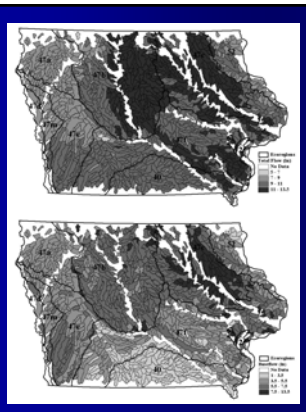
Prediction of Baseflow using Multiple Linear Regression



$Q = 0.645(RAIN) + 0.0607(\%SAND) + 0.0519(\%RC) - 16.3$

$Qb = 0.247(RAIN) + 0.047(\%SAND) + 0.063(\%RC) + 0.0142(PERM) + 0.0528(\%ALLUV) - 11.2$

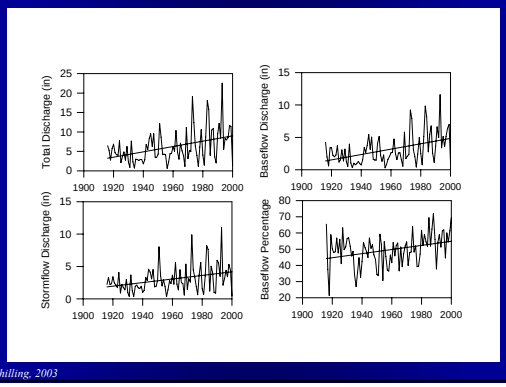
Schilling and Wolter, JAWRA, 2006



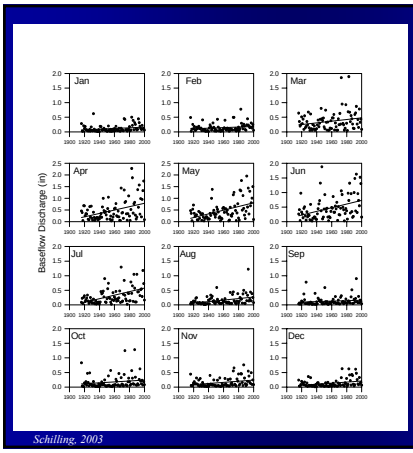
Ecoregion	n	Mean Q (in)	Mean Qb (in)	Mean NO3-N Load (lb/ac)
Central Irregular Plains (40)	82	9.8	2	3.6
Northwest Iowa Loess Prairie (47a)	58	7.8	4.4	14.8
Des Moines Lobe (47b)	179	11	6.1	20.7
Iowan Surface (47c)	114	11.8	7.7	20.0
Loess Hills and Rolling Prairies (47e)	54	9.4	5.3	14.7
Southern Iowa Rolling Loess Prairies (47f)	190	10.4	4.5	12.5
Loess Hills (47m)	3	7.0	3.8	6.7
Paleozoic Plateau (52)	30	8.7	4.1	6.7

Schilling and Wolter, JAWRA, 2006

Historical evidence – Raccoon River watershed scale



Schilling, 2003



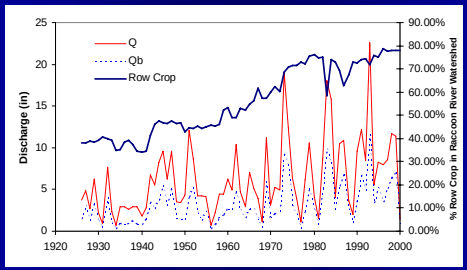
Seasonal Changes

Sig. increases in Q, Qb in all months but Feb, Mar

Largest increases occurring in Apr – July

Increasing Qb relative to P in all months but Feb and Mar

Schilling, 2003

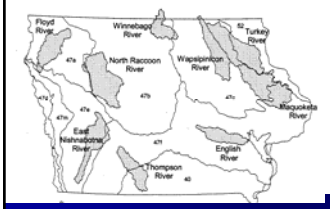


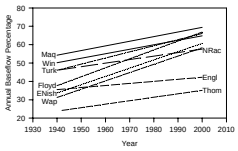
- Streamflow changes in Raccoon River significantly correlated to changing land use patterns

Schilling, 2003

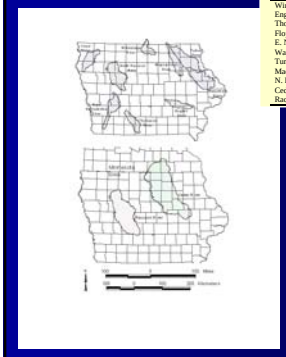
Historical evidence – regional scale - Iowa

Baseflow increased in Iowa since mid-20th century

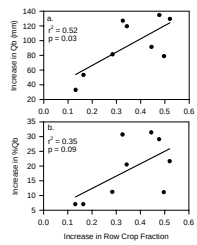




Schilling and Libra, JAWRA, 2003

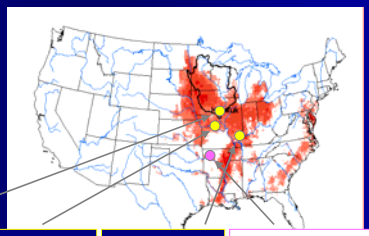


Watershed	Period of Analysis	LogQb t-value	LogQb p-value	%Qb t-value	%Qb p-value
Winnebago	1933-2000	4.08	(<0.001)	5.43	(<0.001)
English	1937-2000	1.78	(0.081)	1.21	(0.231)
Thompson	1942-2000	0.33	(0.740)	2.04	(0.046)
Floyd	1936-2000	4.40	(<0.001)	4.95	(<0.001)
E. Nishnabotna	1937-2000	4.20	(<0.001)	5.14	(<0.001)
Wapsipinicon	1934-2000	5.45	(<0.001)	6.55	(<0.001)
Turkey	1933-2000	4.51	(<0.001)	4.52	(<0.001)
Maquoketa	1927-2000	3.60	(<0.001)	4.10	(<0.001)
N. Raccoon	1942-2000	2.03	(0.047)	2.40	(0.019)
Cedar River	1927-2000	4.42	(<0.001)	2.08	(0.041)
Raccoon River	1927-2000	4.20	(<0.001)	3.88	(<0.001)

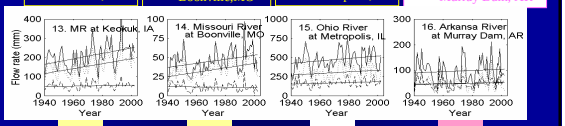


Schilling,, Agriculture Ecosystems & Environment, 2005

Q, BF & OF at 4 major tributaries in MR basin since 1940

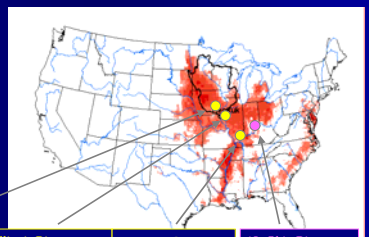


13. UMR at Keokuk, IA | 14. Missouri River at Boonville,MO | 15. Ohio River at Metropolis, IL | 16. Arkansas River at Murray Dam, AR

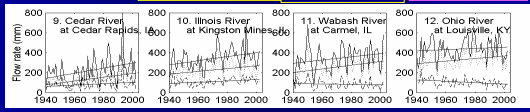


51% | 38% | 24% | 9.3%

Q, BF & OF in 4 tributaries in the MR basin since 1940

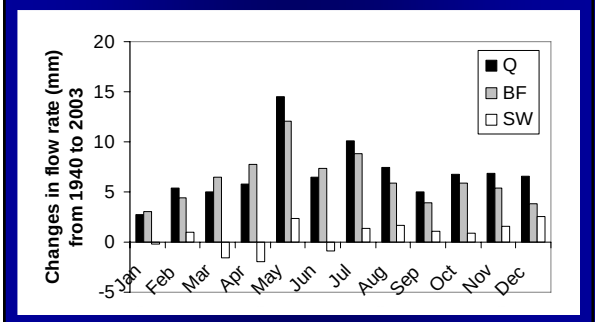


9. Cedar River at Cedar Rapids, IA | 10. Illinois River at Kingston Mines, IL | 11. Wabash River at Camel, IL | 12. Ohio River at Louisville, KY



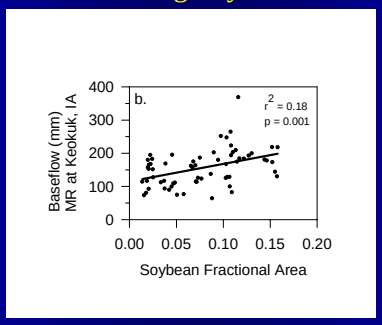
102% | 46% | 35% | 9.2%

Seasonal changes in Mississippi River at Keokuk

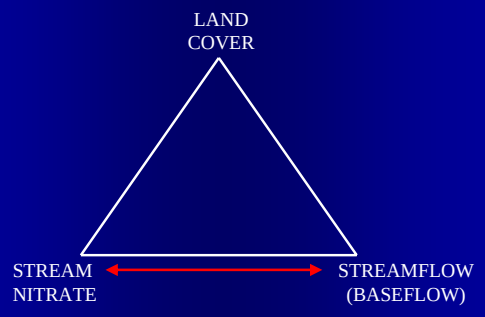


Zhang and Schilling, J. Hydrol., 2006

Relation of Baseflow in Mississippi River to Increasing Soybean Production

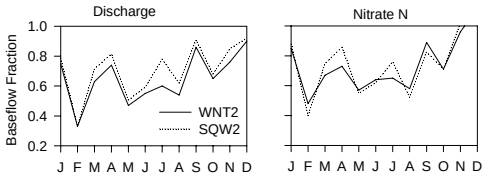


Zhang and Schilling, J. Hydrol., 2006



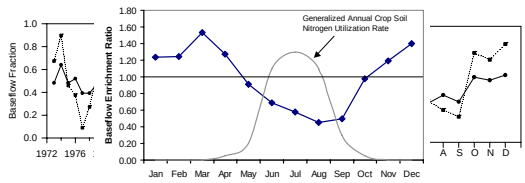
Groundwater discharge as baseflow provides main source of nitrate to streams

For example, in two central Iowa watersheds, export of nitrate occurred primarily with baseflow (61-68%)



Schilling, JEQ, 2002

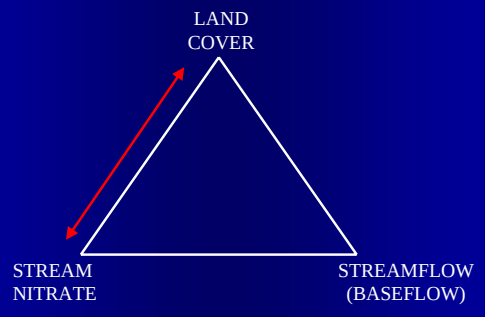
Baseflow contribution to N-loads in Raccoon River



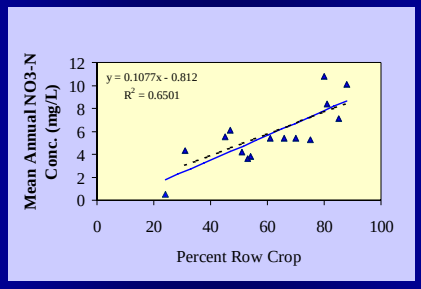
66.7% of nitrate delivered by baseflow

Schilling and Zhang, J. Hydrol, 2004

Tile Drainage Contributes to Baseflow and Nitrate Concentrations and Loads

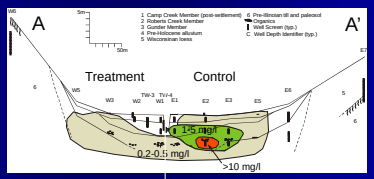


Relation of Row Crop Land Use to Nitrate Concentrations

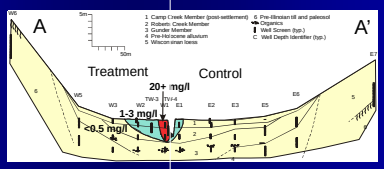


Schilling and Libra, JEQ, 2000

NH4 Concentrations



NO3-N Concentrations

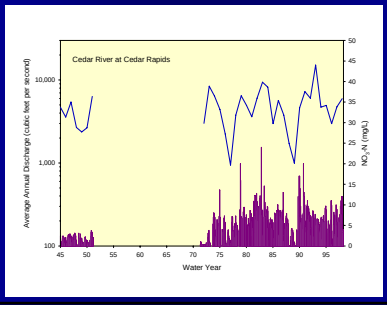


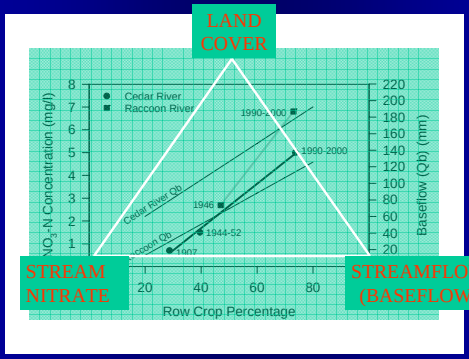
No Grass Cover | Grass Cover

Schilling and Jacobson, In prep.

Historical Perspective

Nitrate concentrations in Iowa's streams have increased since the mid-20th century





Schilling,, Agriculture Ecosystems & Environment, 2005

Conclusion

Changing land cover from perennial mixed cropping systems to row crops of corn and soybeans increased baseflow and has likely contributed to increasing nitrate-N losses from the agricultural Midwest.