STAC: Lag times in the Watershed and Their Influence on Chesapeake Bay Restoration

October 16-17, 2012

Temporal Dynamics of Changes in Delivered Nutrient Loads Resulting from Various Cropland Nutrient Reduction Practices

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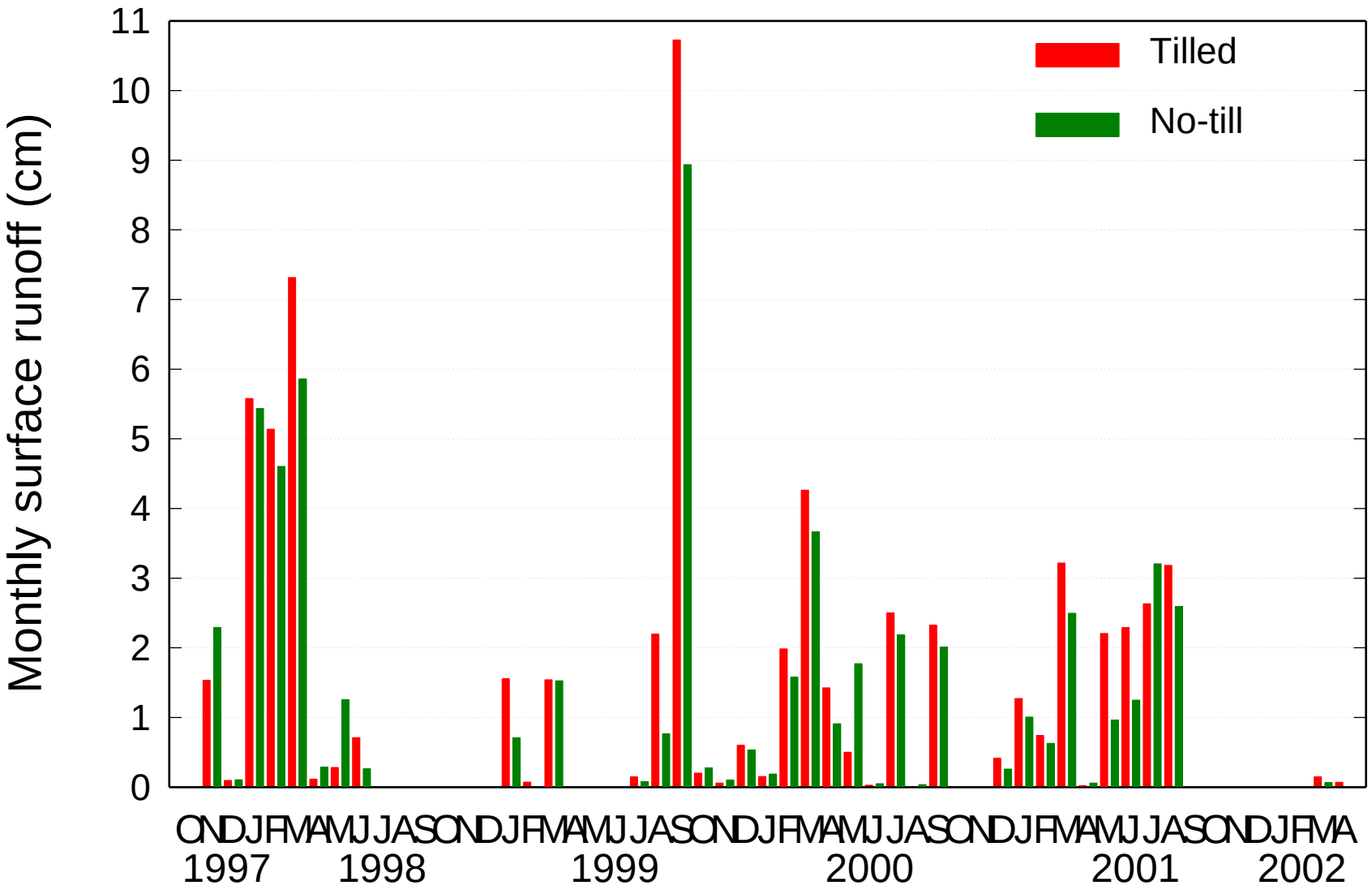
Cases Considered

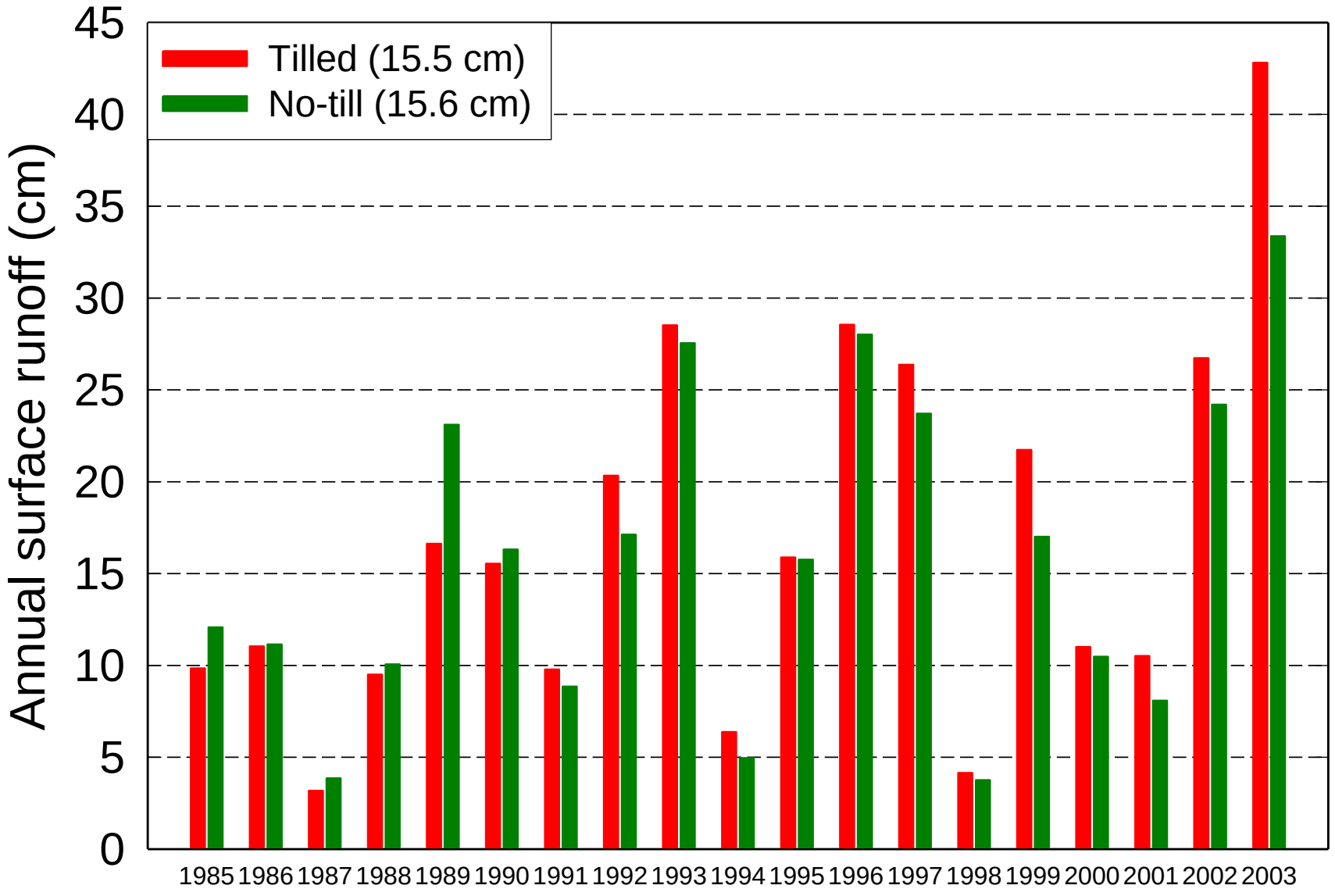
- Edge-of-field sediment
- Surface runoff N
- Surface runoff P – short term
- Surface runoff P – soil related
- Subsurface N – in-field processes
- Subsurface N – Jarmin Branch

Watershed Management

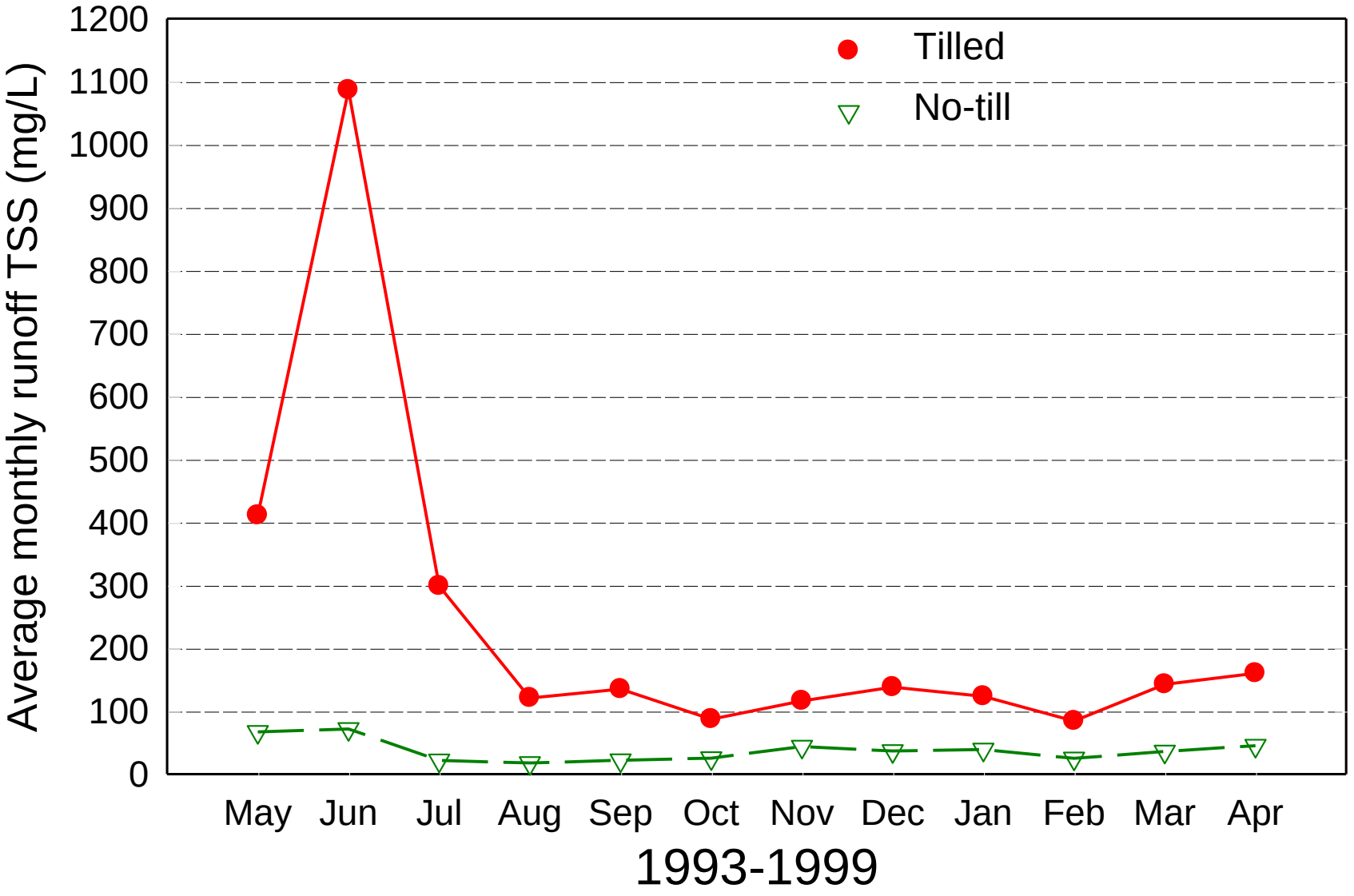
- 1985-97 continuous corn, CT/NT
- 1988-97 rye winter cover crops
- 1990 installed grass waterways
- 1994-97 No P applications
- 1998-2003 corn/wheat/dc soybean
- 1998-2003 CT/NT poultry litter
- 2004-07 surface/subsurface N
- 2008-09 NT/turbotill poultry litter

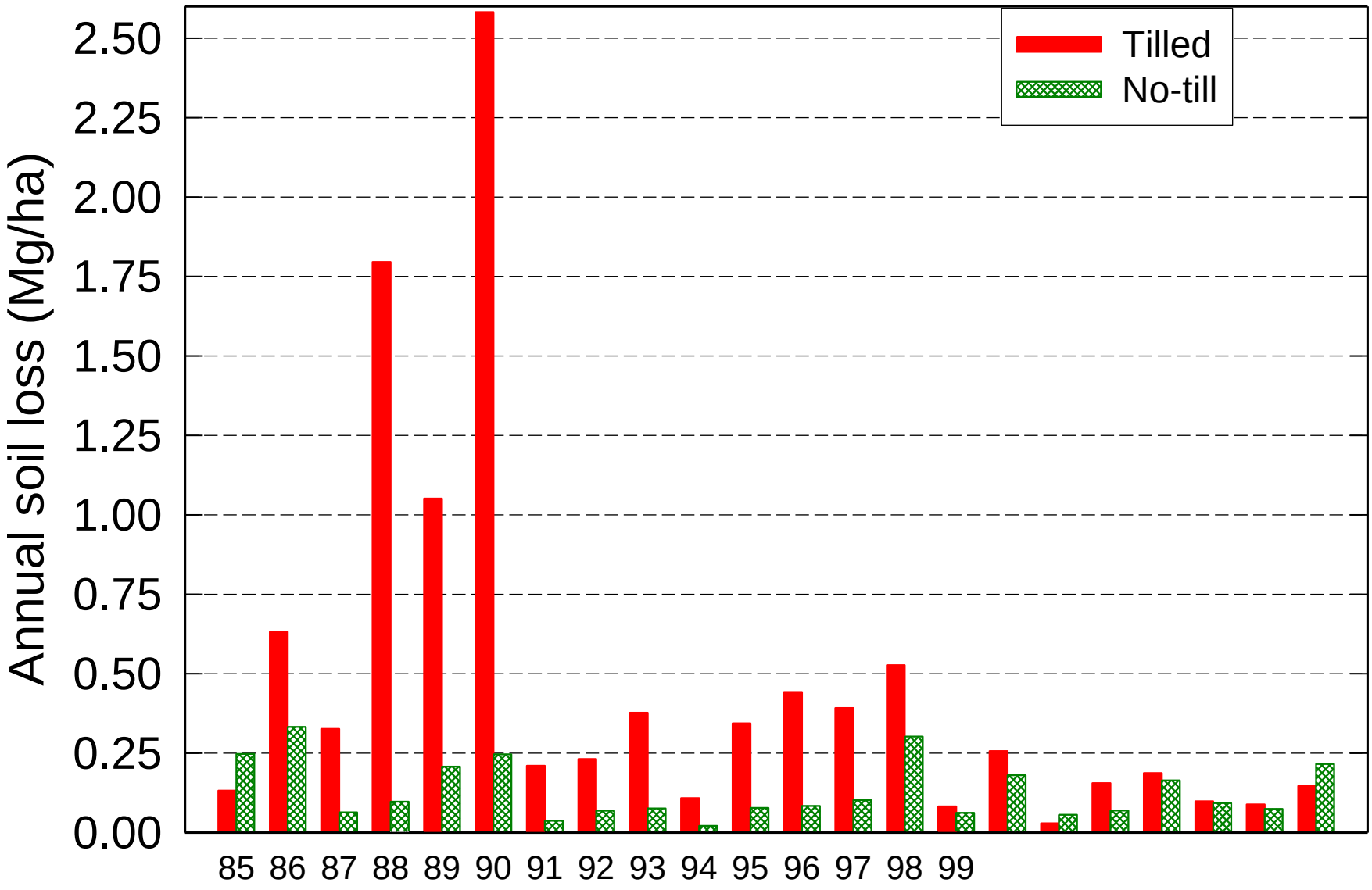
Water is always the short term driver!

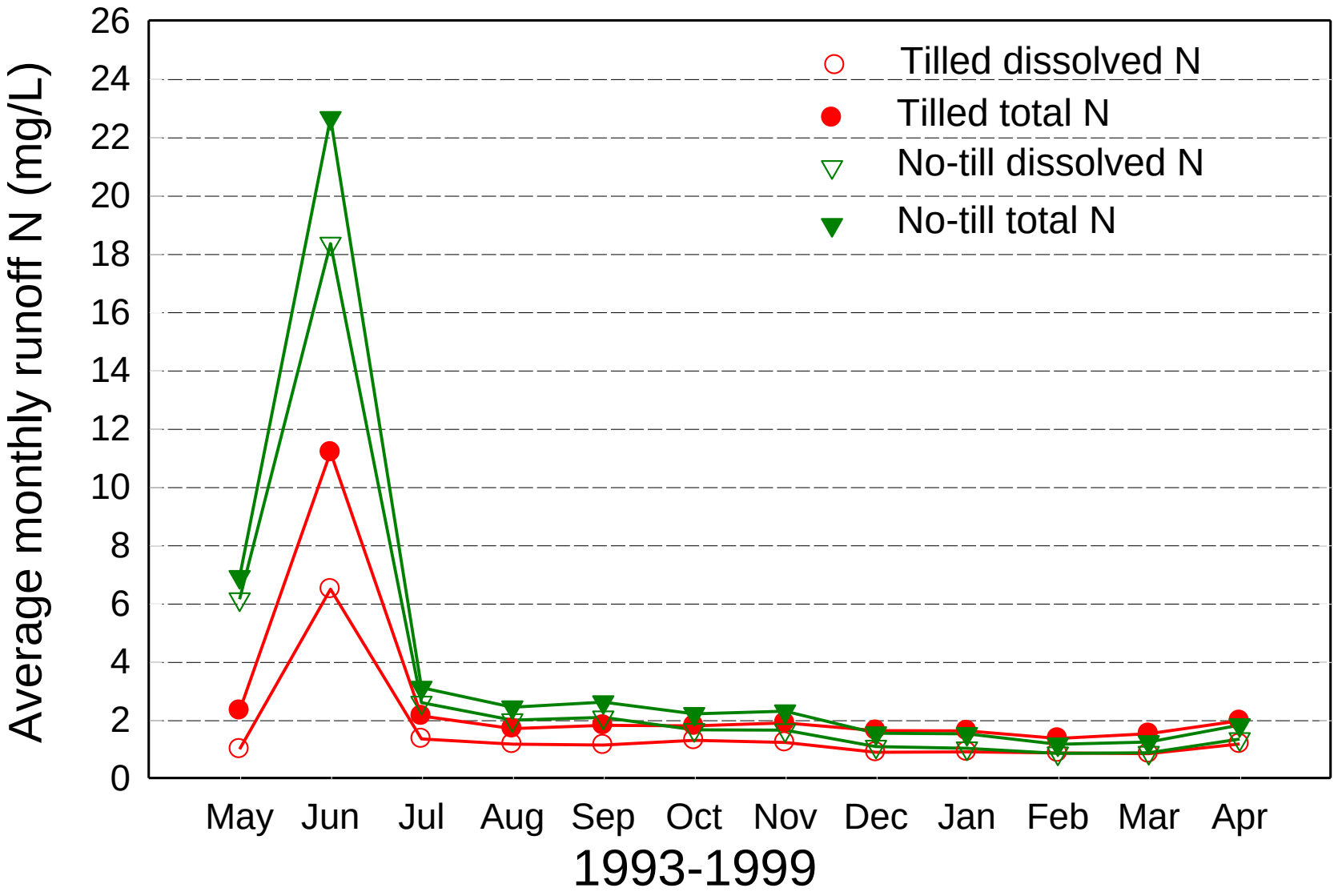

Monthly surface runoff (cm)
11
10
9
8
7
6
5
4
3
2
1
0
Tilled
No-till
OND JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND JFMAMJJASOND JFMA
1997
1998
1999
2000
2001
2002

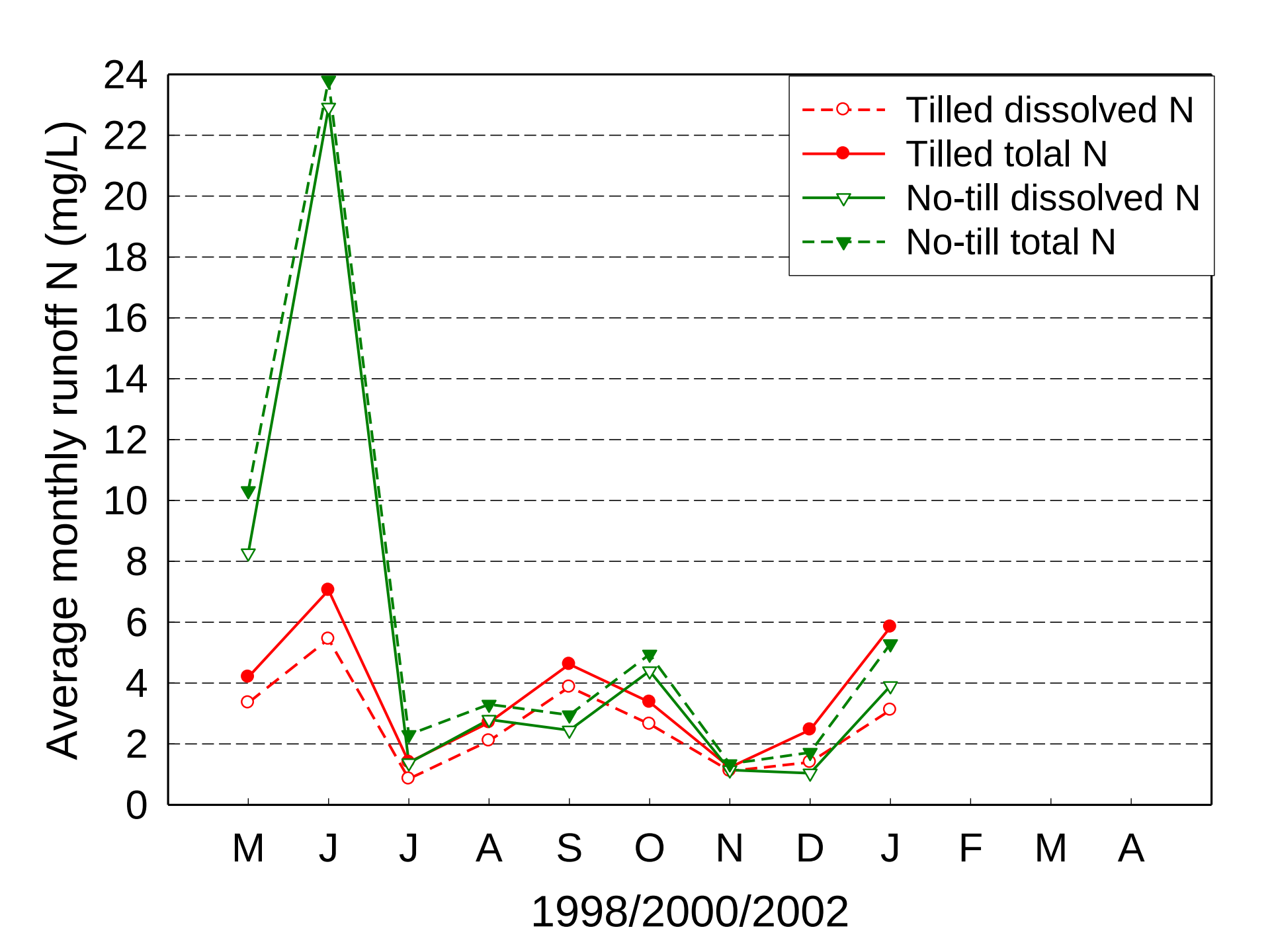

Tilled (15.5 cm)
No-till (15.6 cm)
Annual surface runoff (cm)
0
5
10
15
20
25
30
35
40
45
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003

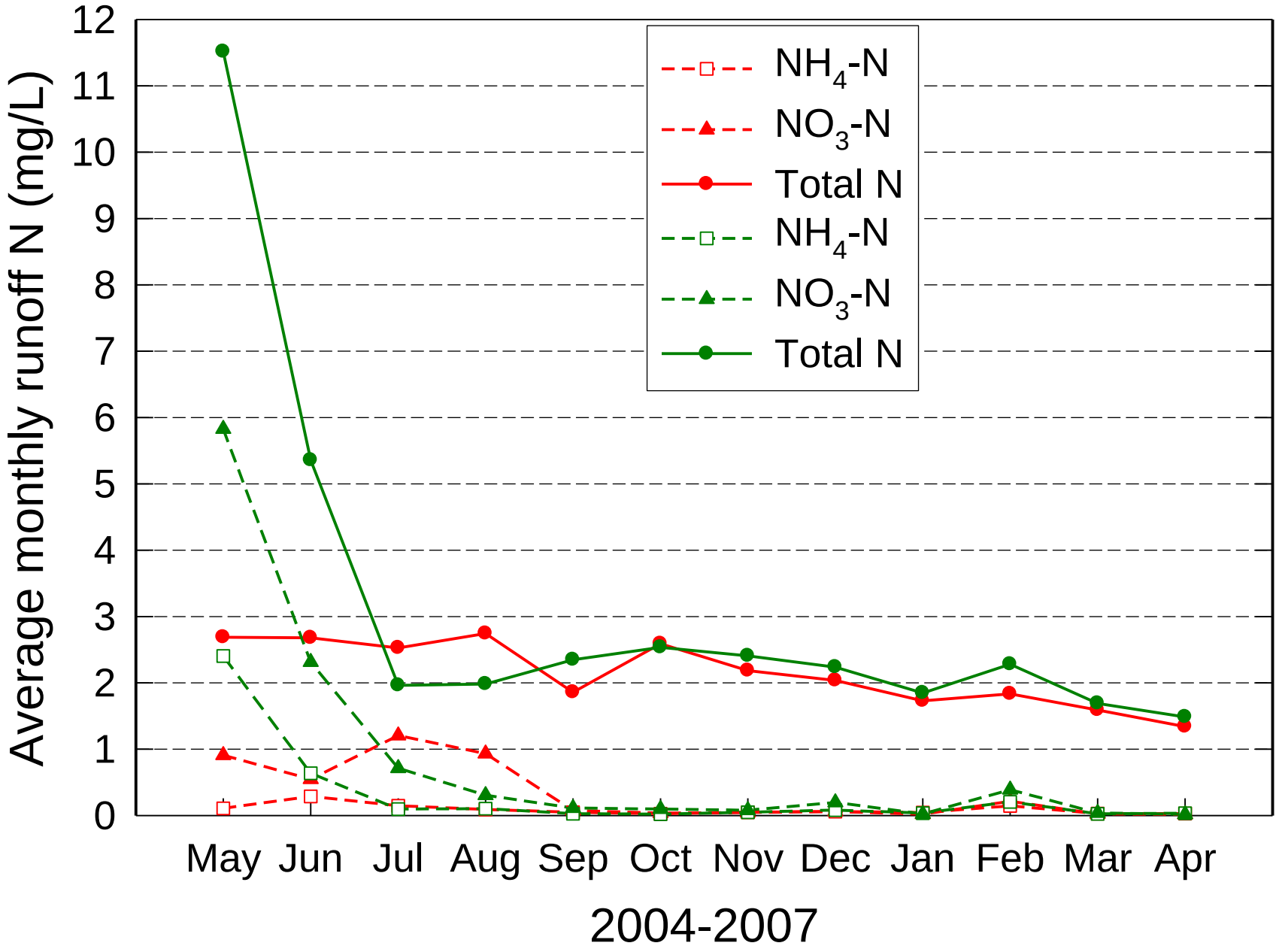
What about erosion?

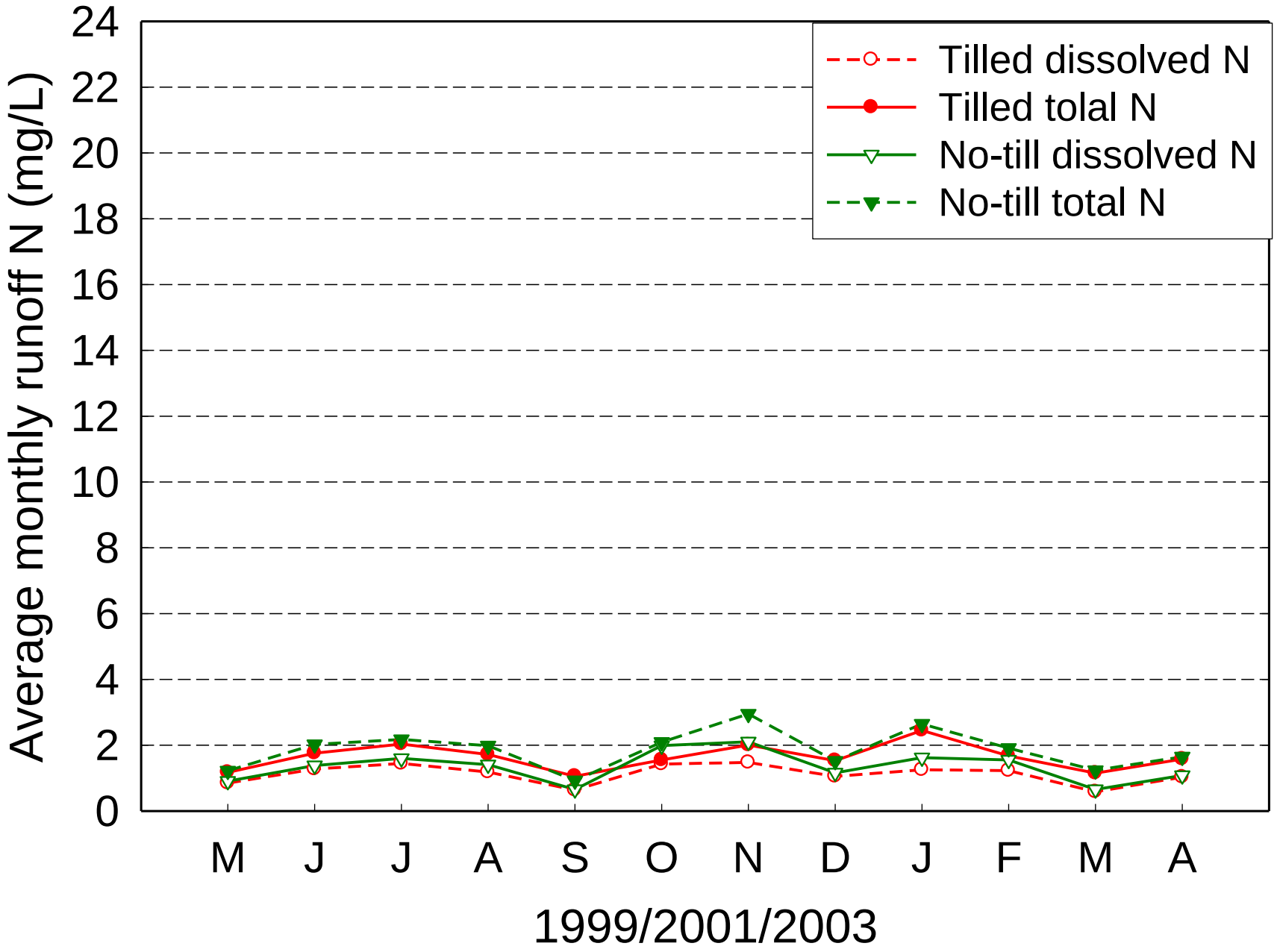

Average monthly runoff TSS (mg/L)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Tilled
No-till
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1993-1999

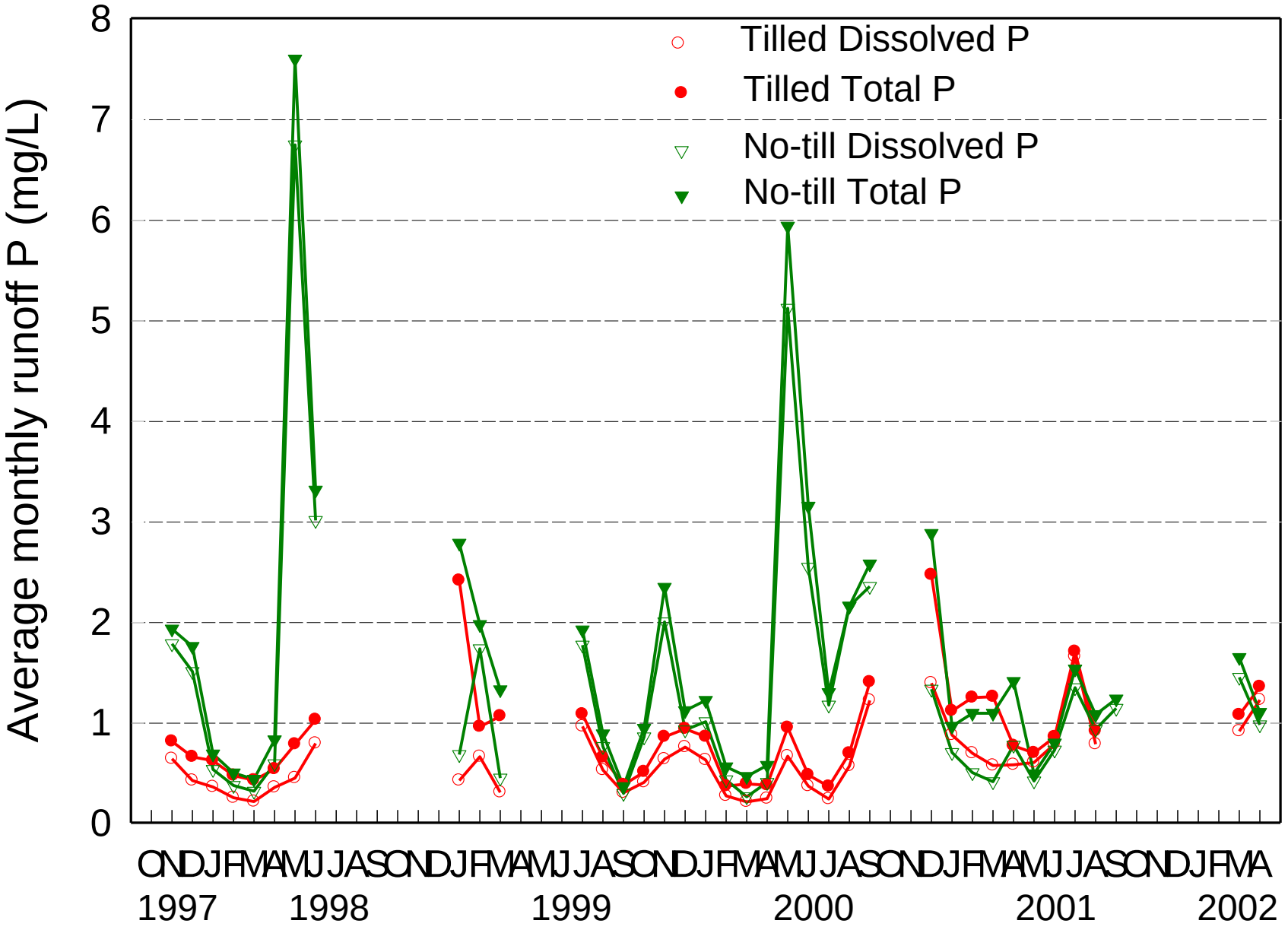

Annual soil loss (Mg/ha)
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Tilled
No-till
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99

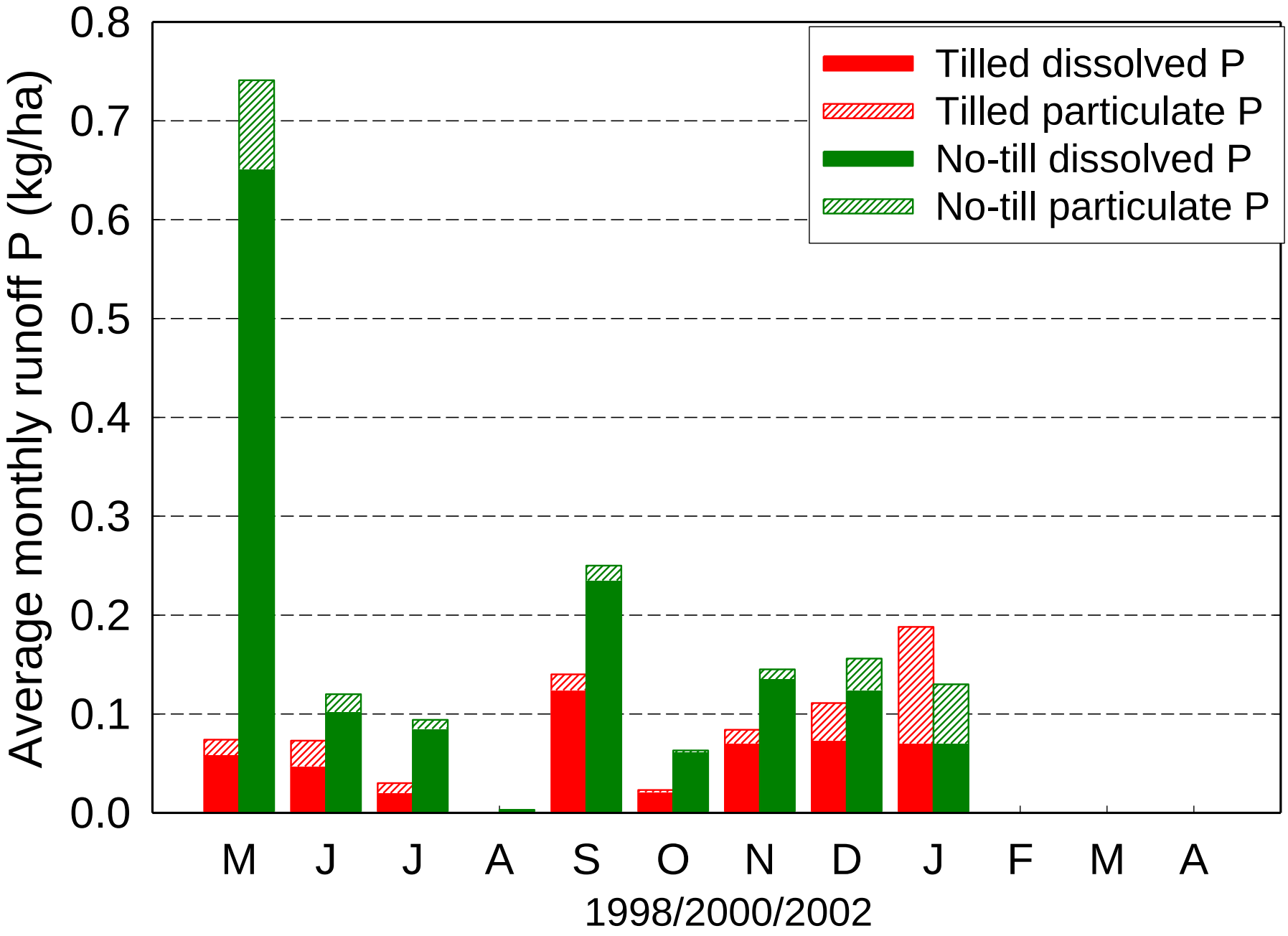

Average monthly runoff N (mg/L)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Tilled dissolved N
Tilled total N
No-till dissolved N
No-till total N
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1993-1999


Average monthly runoff N (mg/L)
24
22
20
18
16
14
12
10
8
6
4
2
0
M
J
J
A
S
O
N
D
J
F
M
A
1998/2000/2002
Tilled dissolved N
Tilled tolal N
No-till dissolved N
No-till total N


Average monthly runoff N (mg/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
2004-2007
NH4-N
NO3-N
Total N
NH4-N
NO3-N
Total N

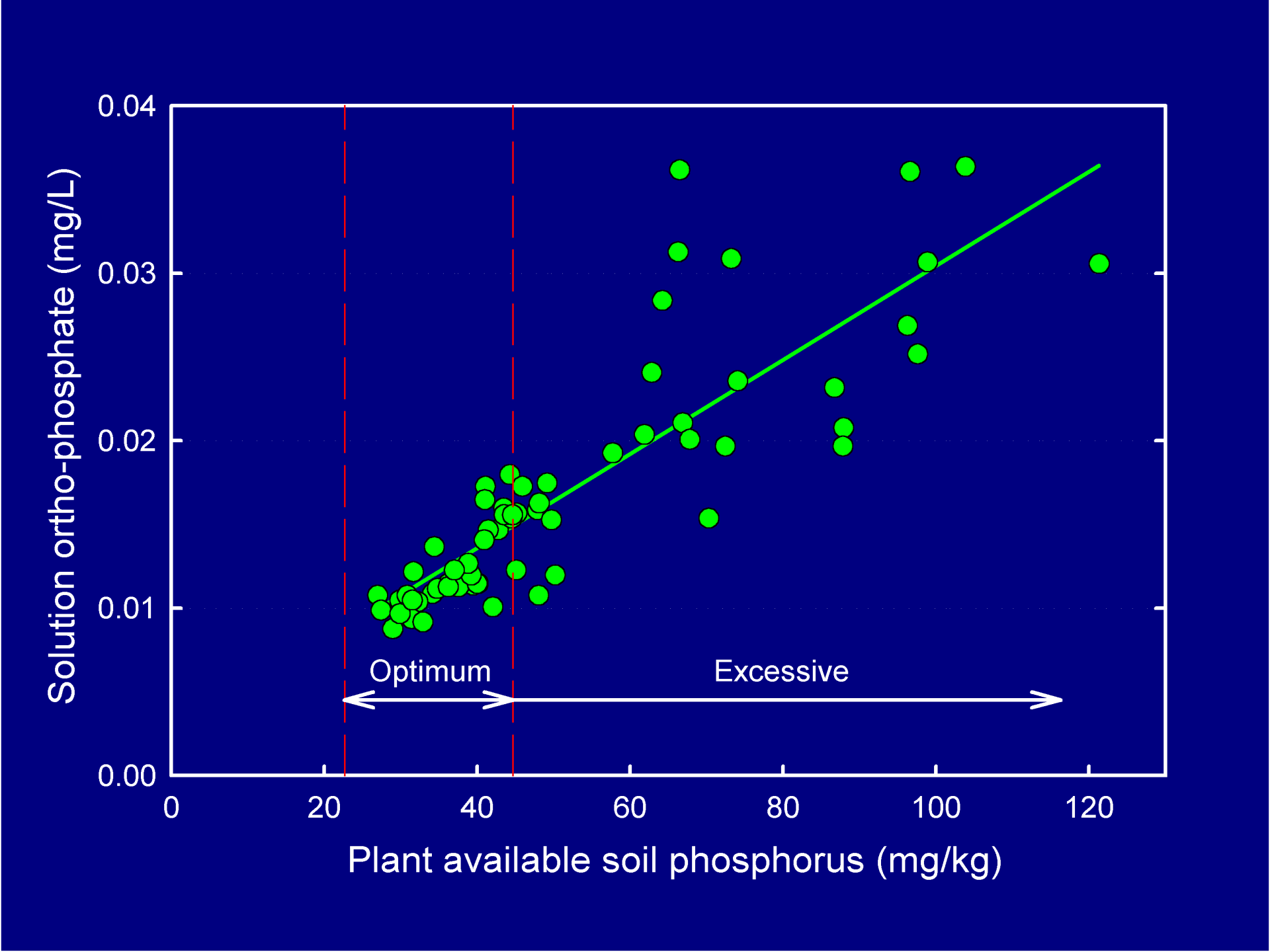

Average monthly runoff N (mg/L)
24
22
20
18
16
14
12
10
8
6
4
2
0
M
J
J
A
S
O
N
D
J
F
M
A
1999/2001/2003
Tilled dissolved N
Tilled tolal N
No-till dissolved N
No-till total N

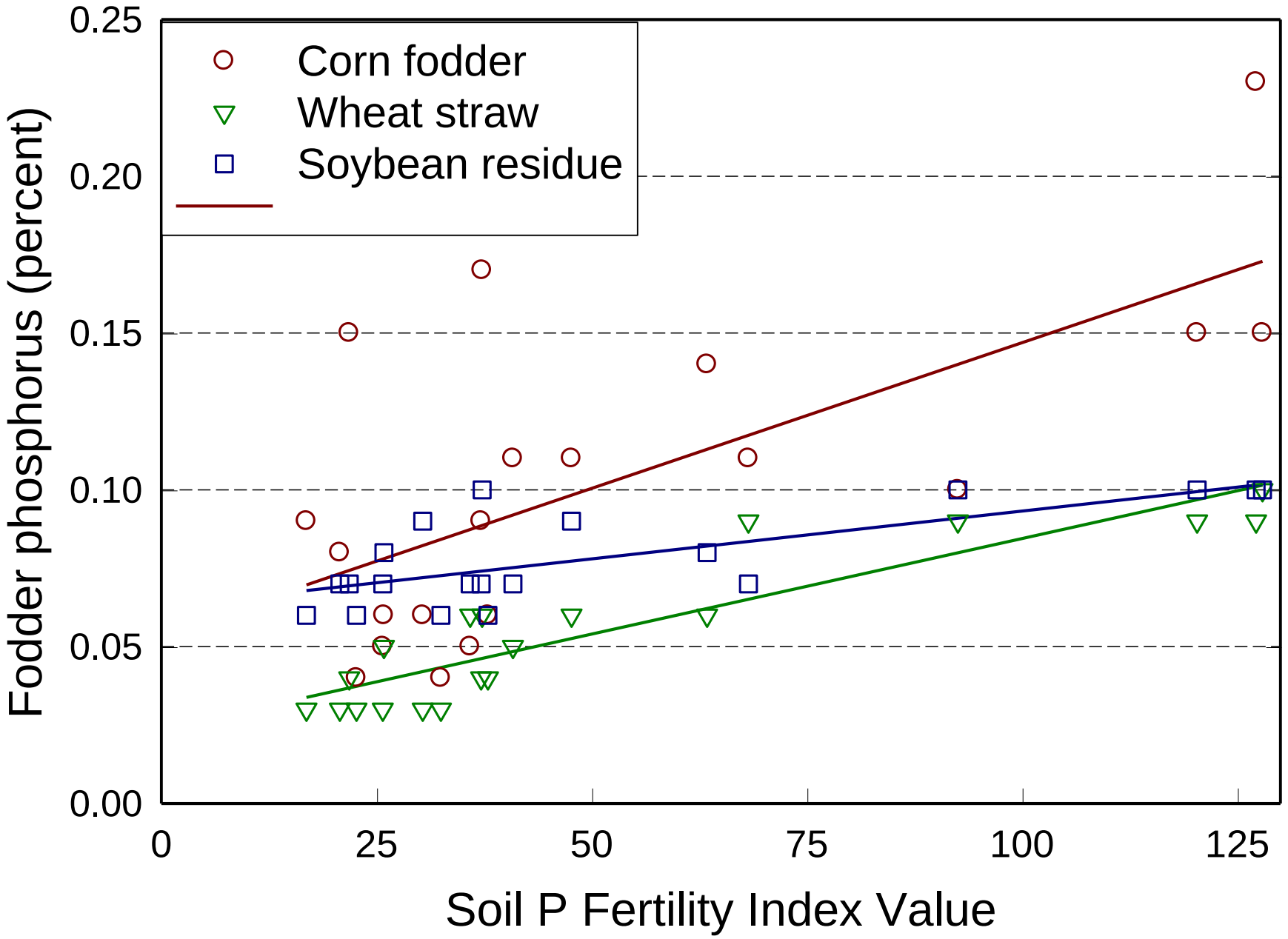

Average monthly runoff P (mg/L)
0
1
2
3
4
5
6
7
8
Tilled Dissolved P
Tilled Total P
No-till Dissolved P
No-till Total P
ONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMA
1997
1998
1999
2000
2001
2002

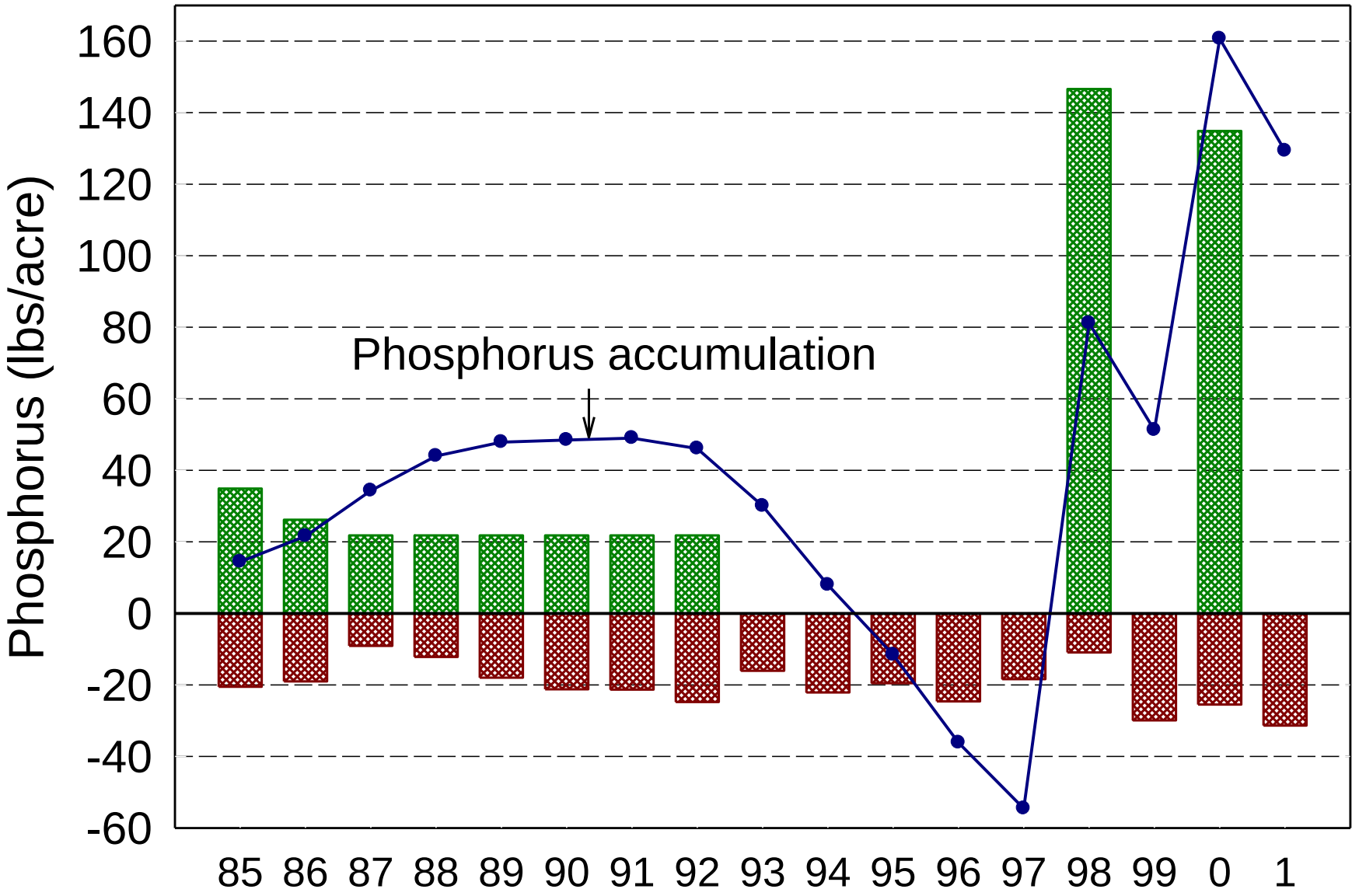

Average monthly runoff P (kg/ha)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Tilled dissolved P
Tilled particulate P
No-till dissolved P
No-till particulate P
M
J
J
A
S
O
N
D
J
F
M
A
1998/2000/2002

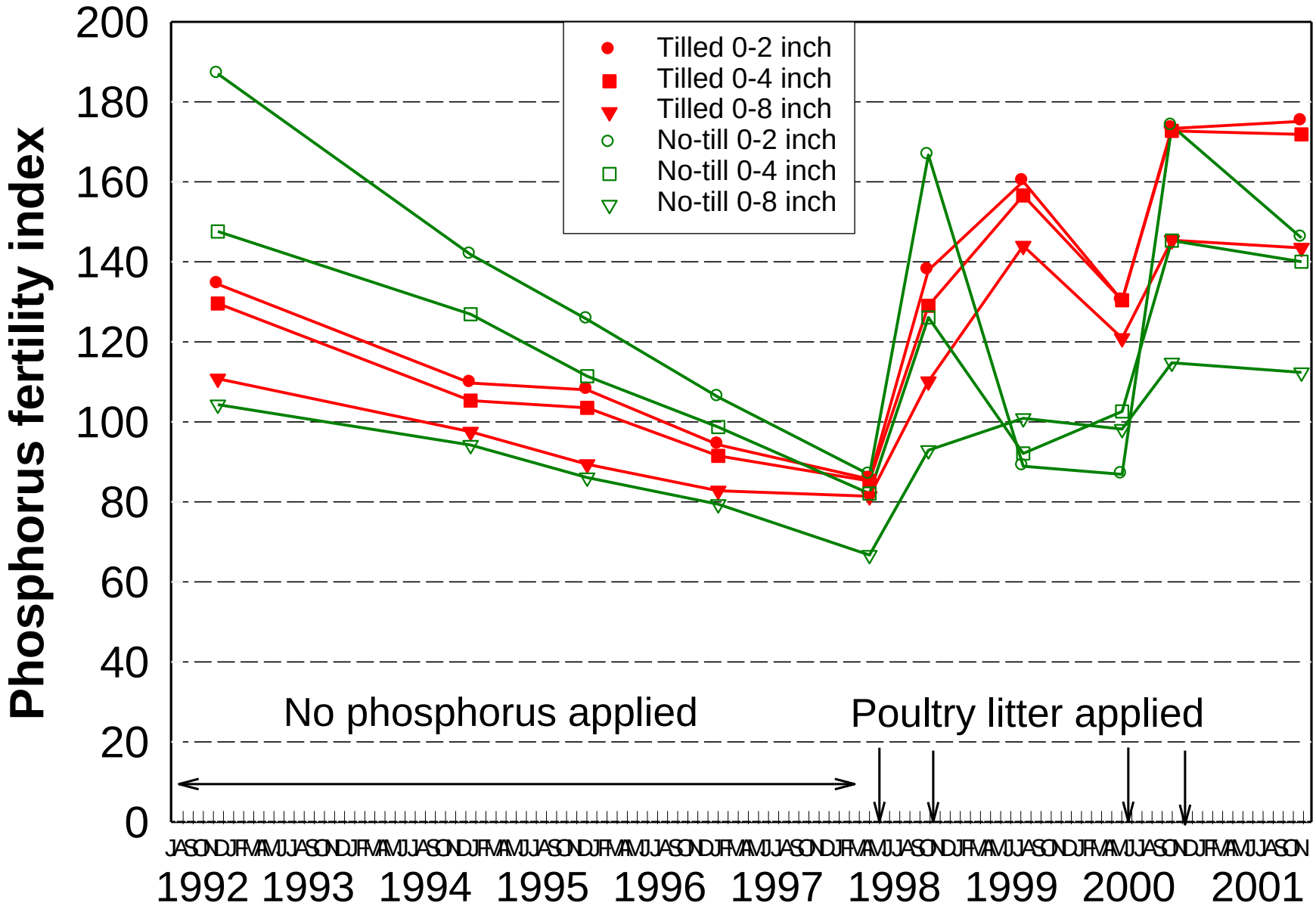
How P applications are managed is crucial to controlling P losses in surface runoff, independent of soil P levels.

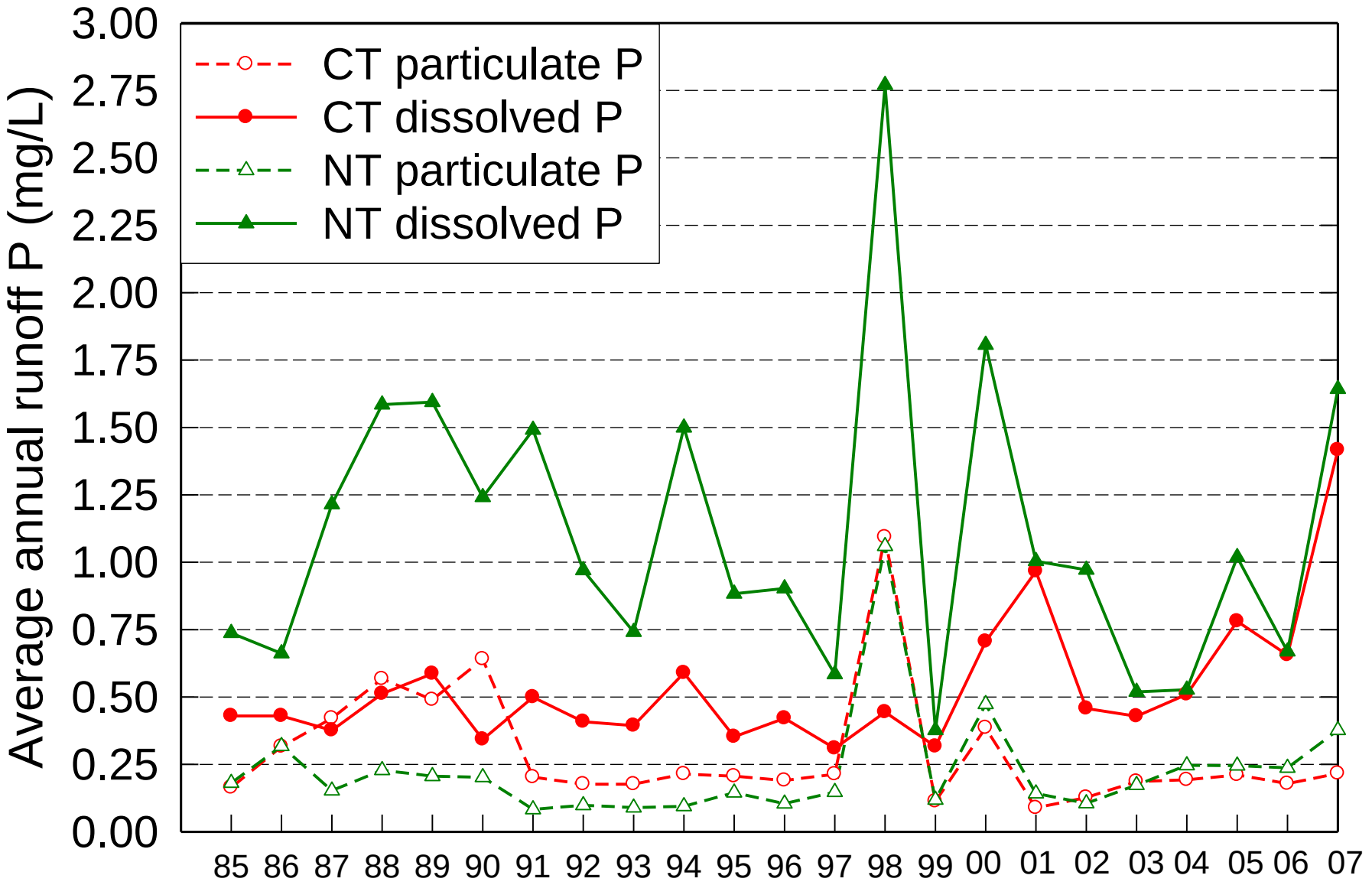
What about the long-term issues with soil P?


0.04
0.03
0.02
0.01
0.00
Solution ortho-phosphate (mg/L)
0
20
40
60
80
100
120
Plant available soil phosphorus (mg/kg)
Optimum
Excessive


Corn fodder
Wheat straw
Soybean residue
Fodder phosphorus (percent)
0.25
0.20
0.15
0.10
0.05
0.00
0
25
50
75
100
125
Soil P Fertility Index Value


Phosphorus (lbs/acre)
160
140
120
100
80
60
40
20
0
-20
-40
-60
Phosphorus accumulation
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
0
1

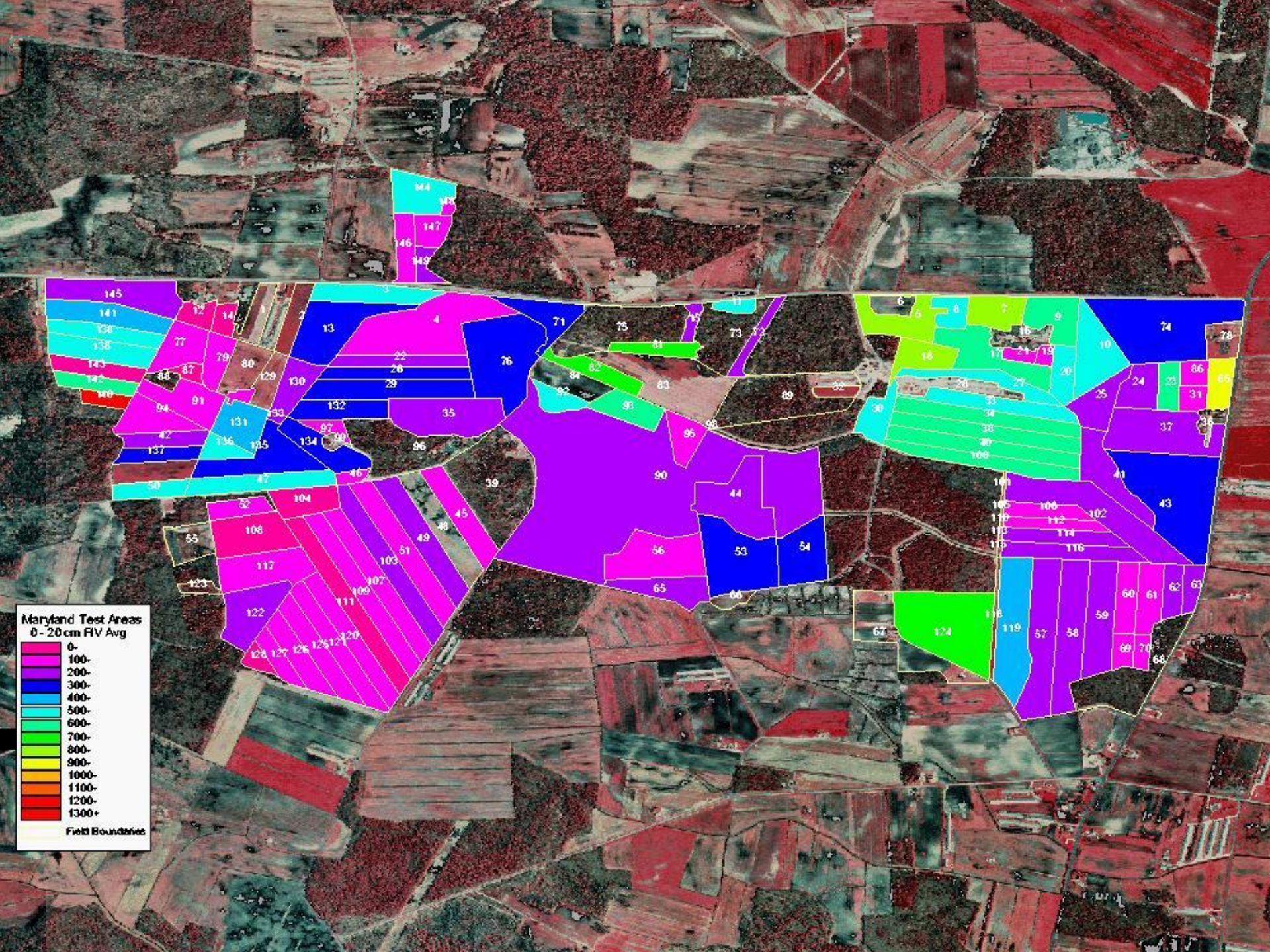

Phosphorus fertility index
200
180
160
140
120
100
80
60
40
20
0
Tilled 0-2 inch
Tilled 0-4 inch
Tilled 0-8 inch
No-till 0-2 inch
No-till 0-4 inch
No-till 0-8 inch
No phosphorus applied
Poultry litter applied
JASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASON
1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

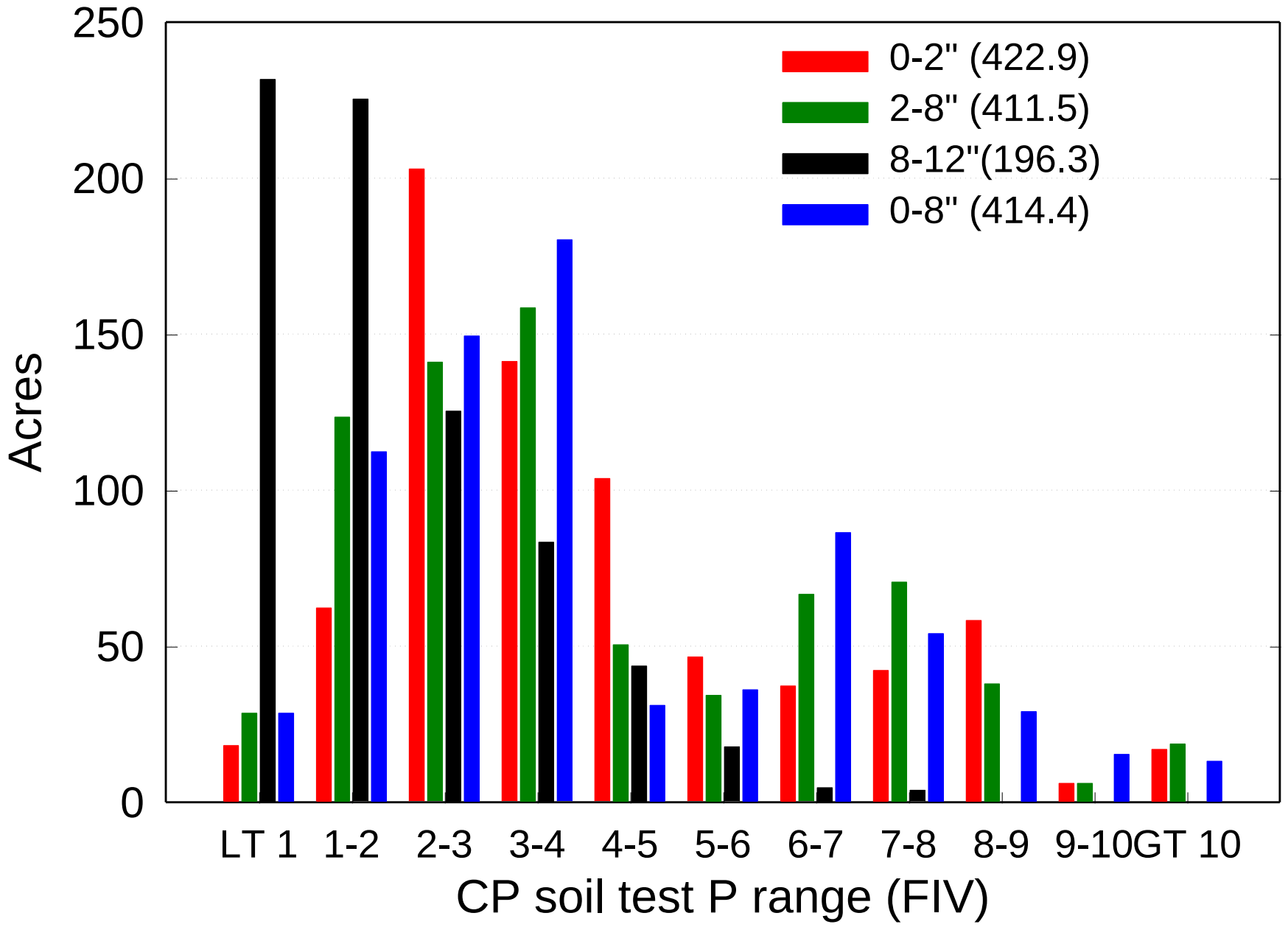

Average annual runoff P (mg/L)
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
CT particulate P
CT dissolved P
NT particulate P
NT dissolved P
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07

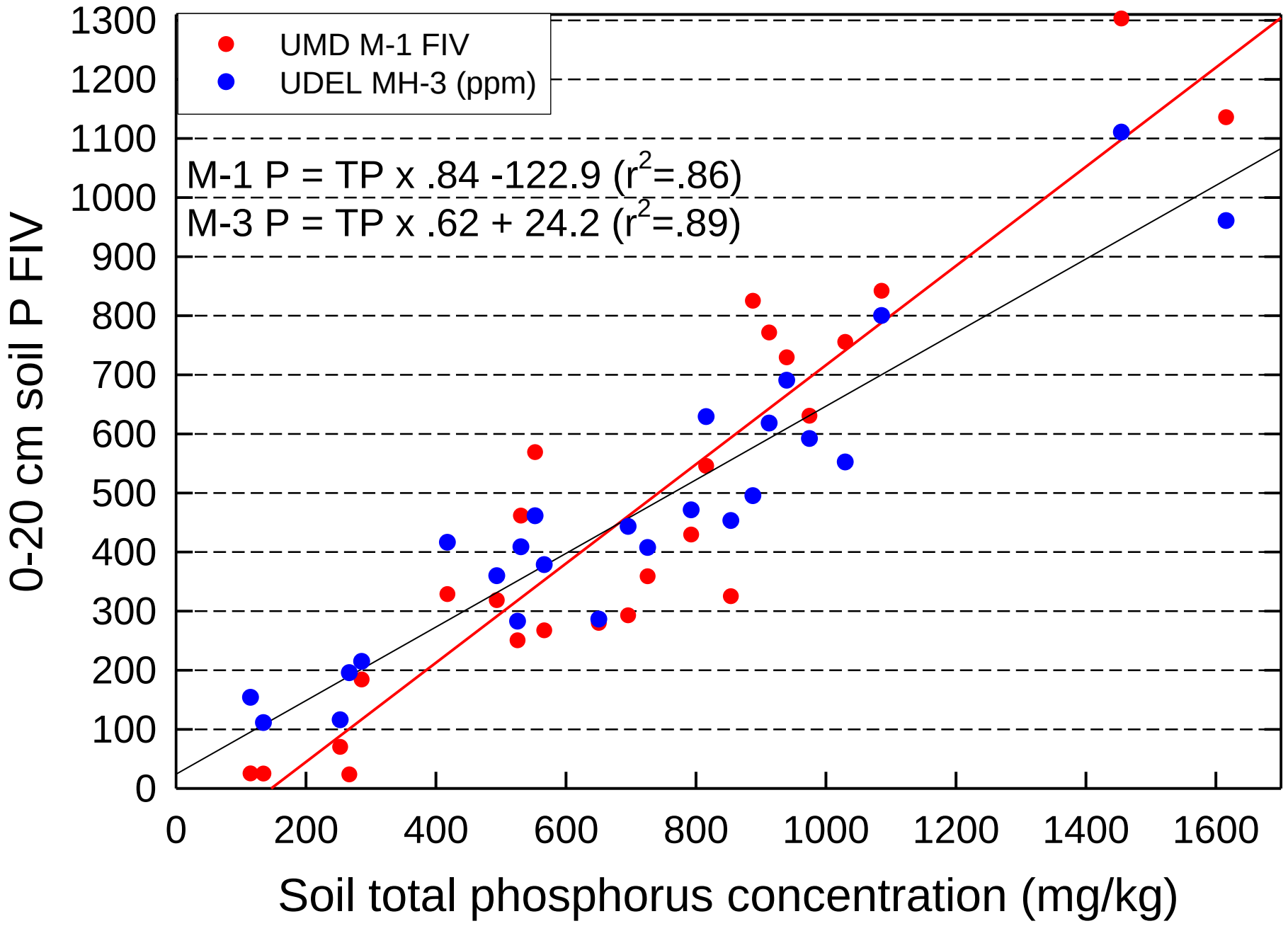
Pocomoke River Watershed

- 4 million lbs poultry litter P/year
- 100,000 acres cropland
- 40 lbs P/acre/year applied
- 20 lbs P/acre/year removed in harvested grain

Since the effort started to reduce nonpoint source nutrient loads in Maryland, the quantity of P stored in cropland in the Pocomoke River drainage basin increased by approximately 25 million pounds.

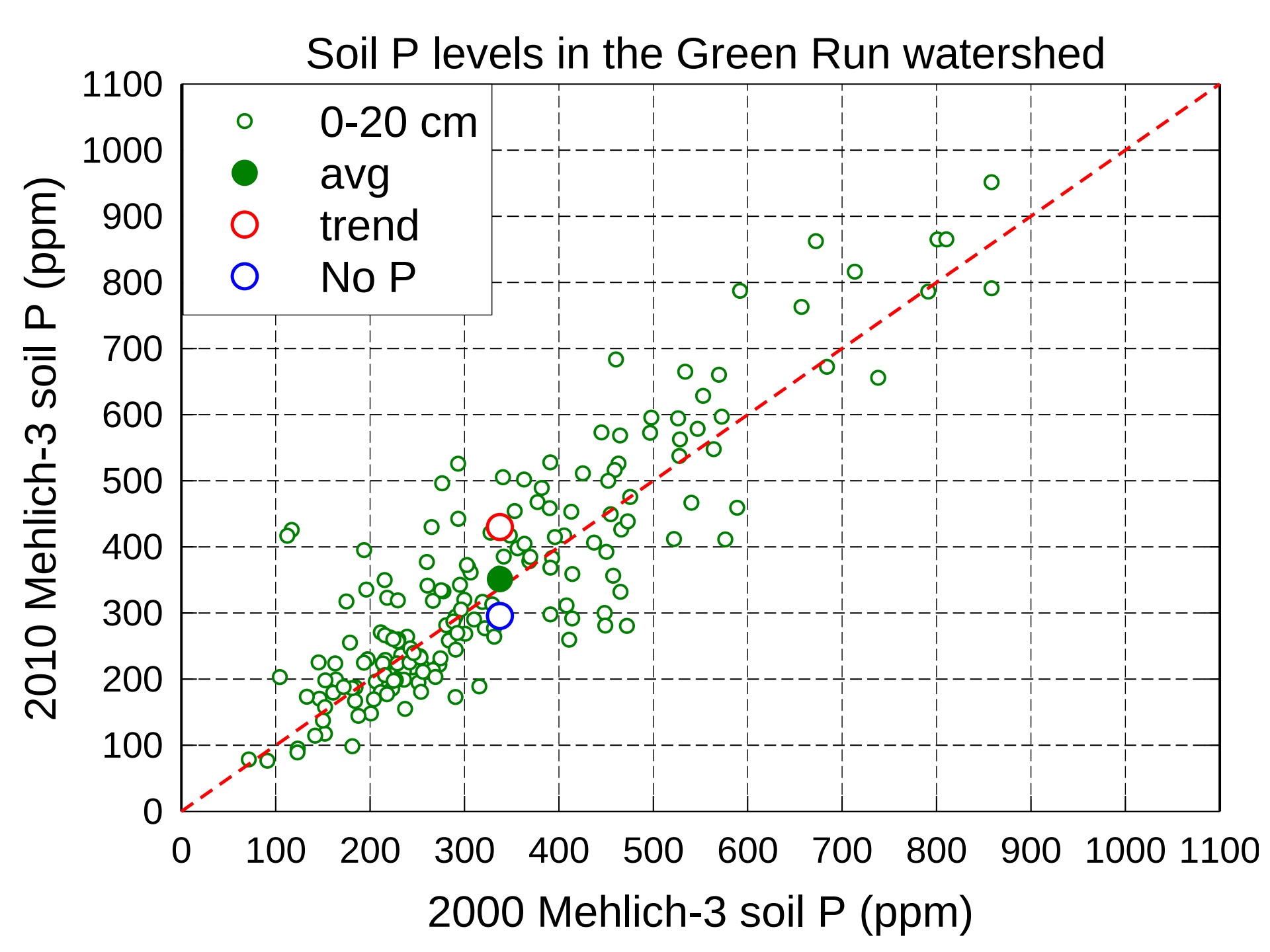

Maryland Test Areas
0 - 20 cm FIV Avg
0-
100-
200-
300-
400-
500-
600-
700-
800-
900-
1000-
1100-
1200-
1300+
Field Boundaries


250
200
150
100
50
0
Acres
0-2" (422.9)
2-8" (411.5)
8-12"(196.3)
0-8" (414.4)
LT 1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
GT 10
CP soil test P range (FIV)

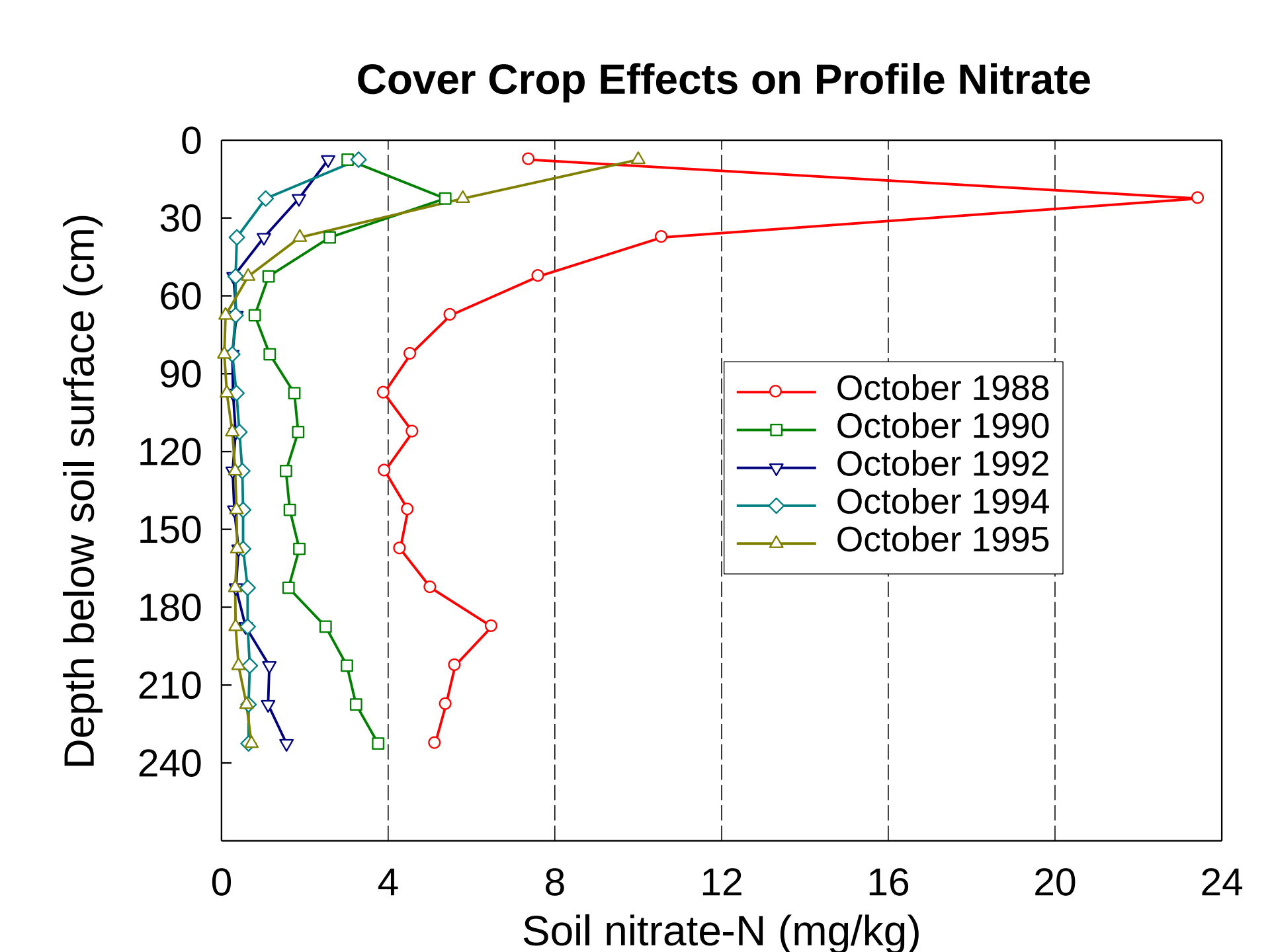

UMD M-1 FIV
UDEL MH-3 (ppm)
M-1 P = TP x .84 -122.9 (r2=.86)
M-3 P = TP x .62 + 24.2 (r2=.89)
0-20 cm soil P FIV
Soil total phosphorus concentration (mg/kg)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
0
200
400
600
800
1000
1200
1400
1600

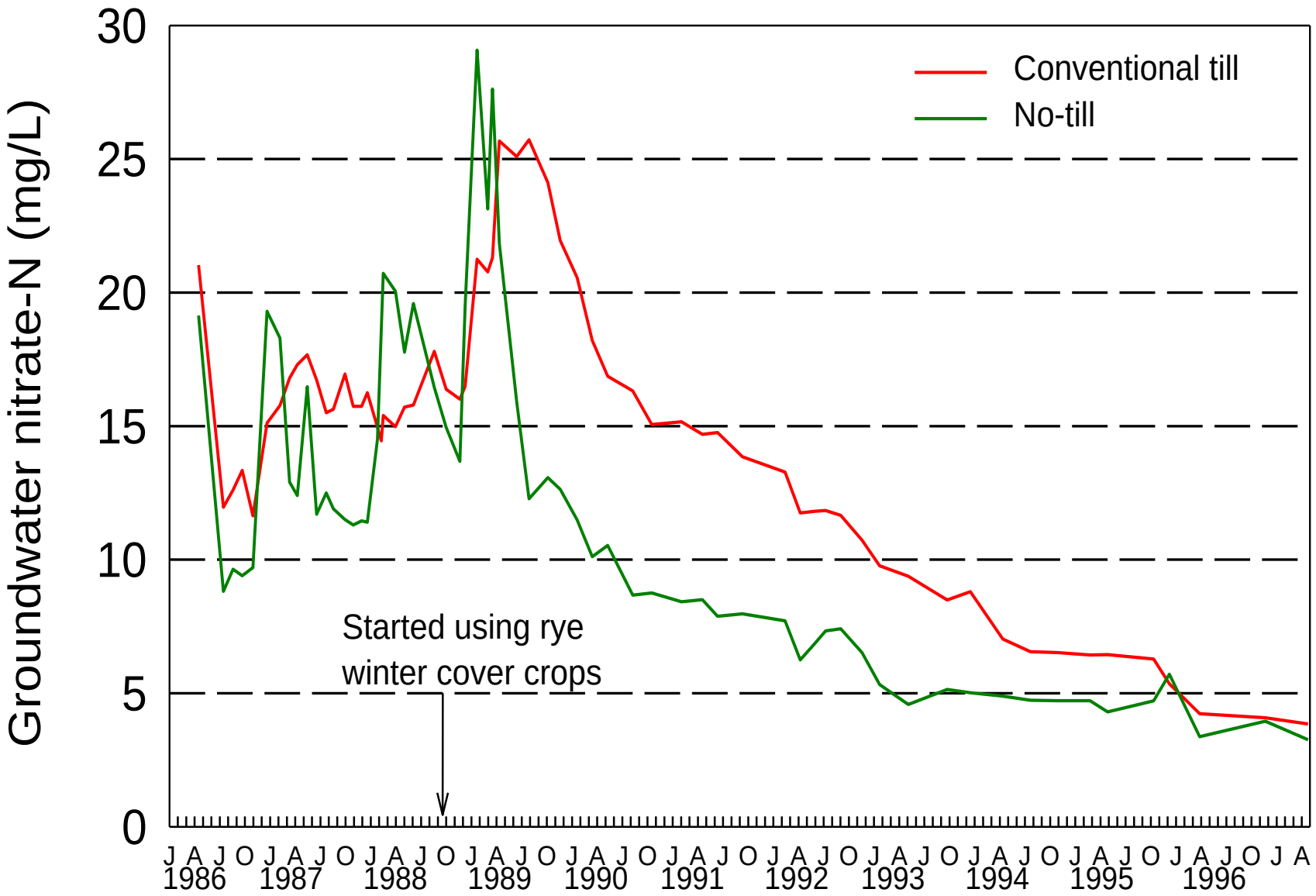
After assumptions, the math is simple!

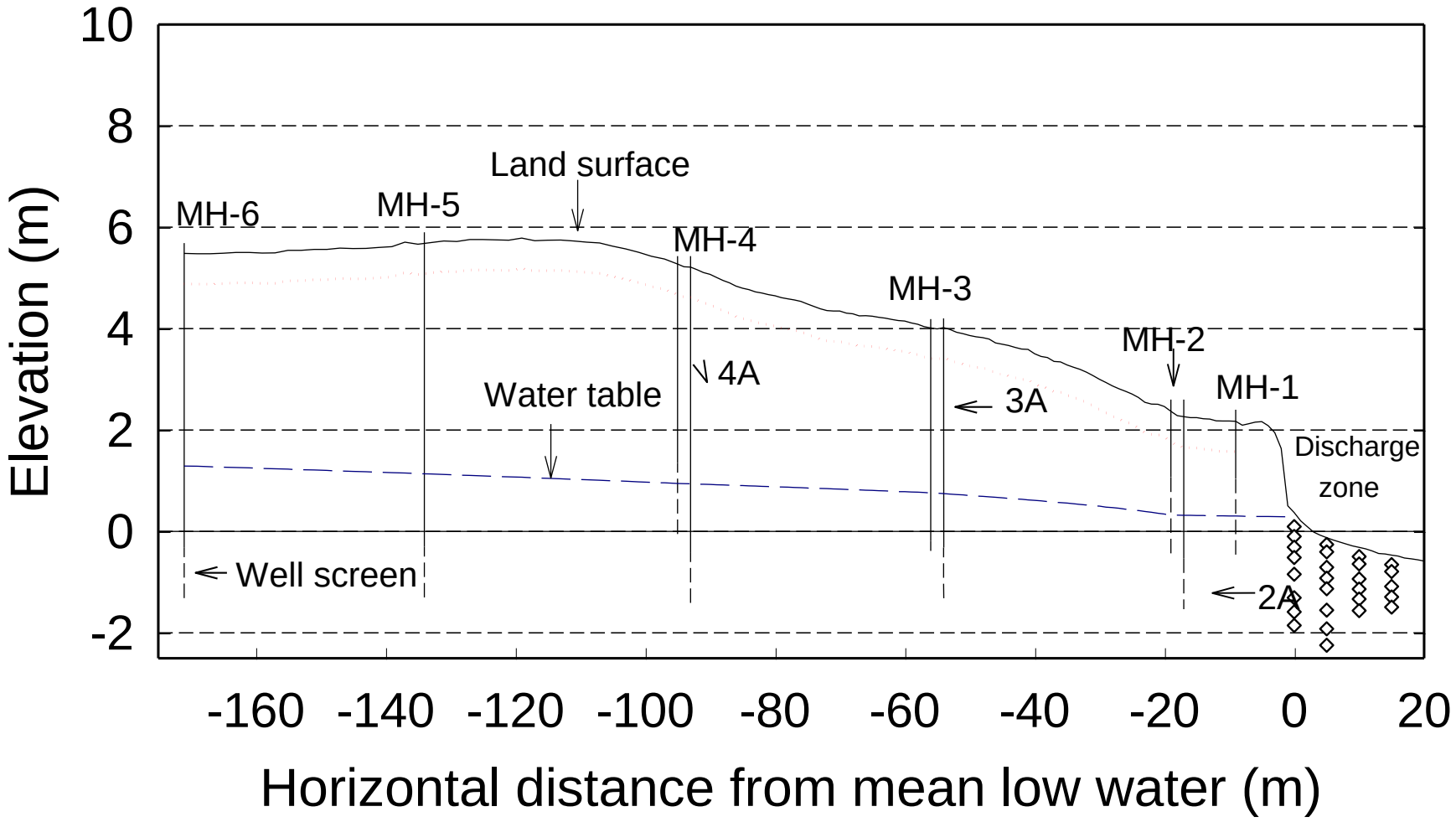
From 1960-2000 P was being added to cropland in Green Run watershed at a rate of ~ 40 kg/ha/yr, increasing M-3 P ~ 9 units/yr. 2000-2010 average crop harvests in Wicomico County removed ~ 20 kg P/ha, which will reduce M-3 P ~ 4-5 units/year.

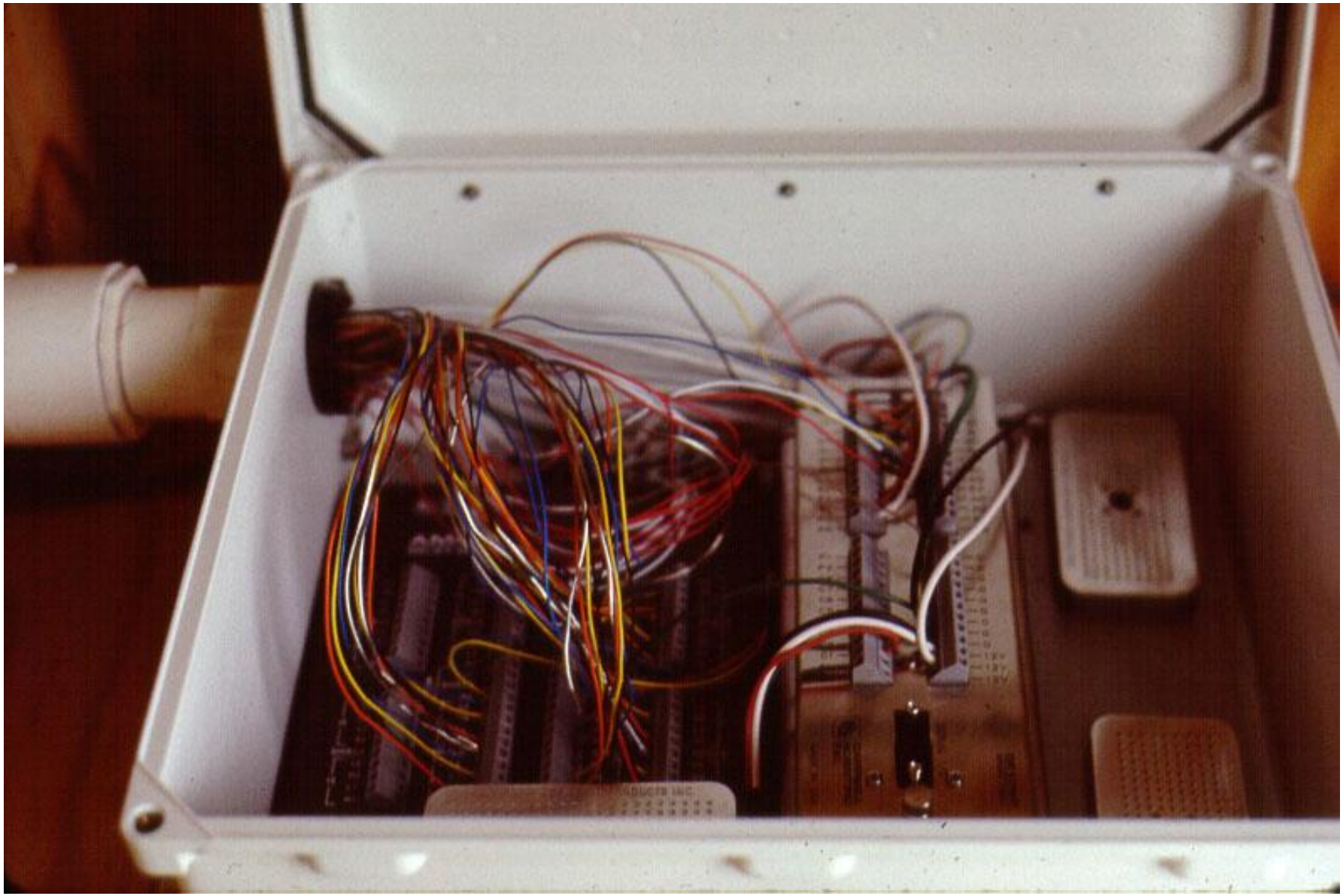

Soil P levels in the Green Run watershed
0-20 cm
avg
trend
No P
2010 Mehlich-3 soil P (ppm)
2000 Mehlich-3 soil P (ppm)
0
100
200
300
400
500
600
700
800
900
1000
1100

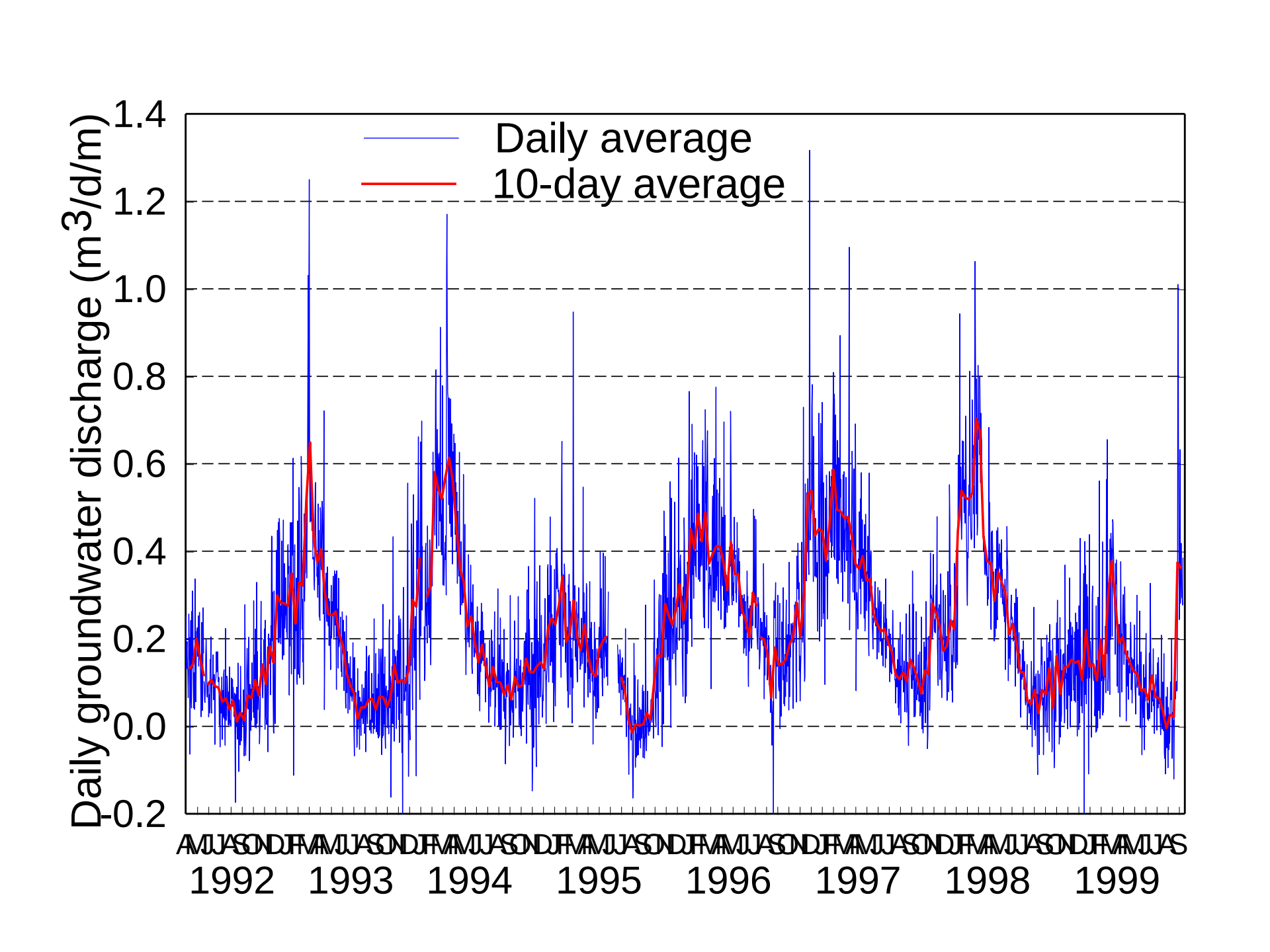
Achieving significant reductions in N losses from cropland will require reductions in nitrate leaching rates. The key to reducing nitrate leaching rates is reducing soil nitrate availability during periods of groundwater recharge.

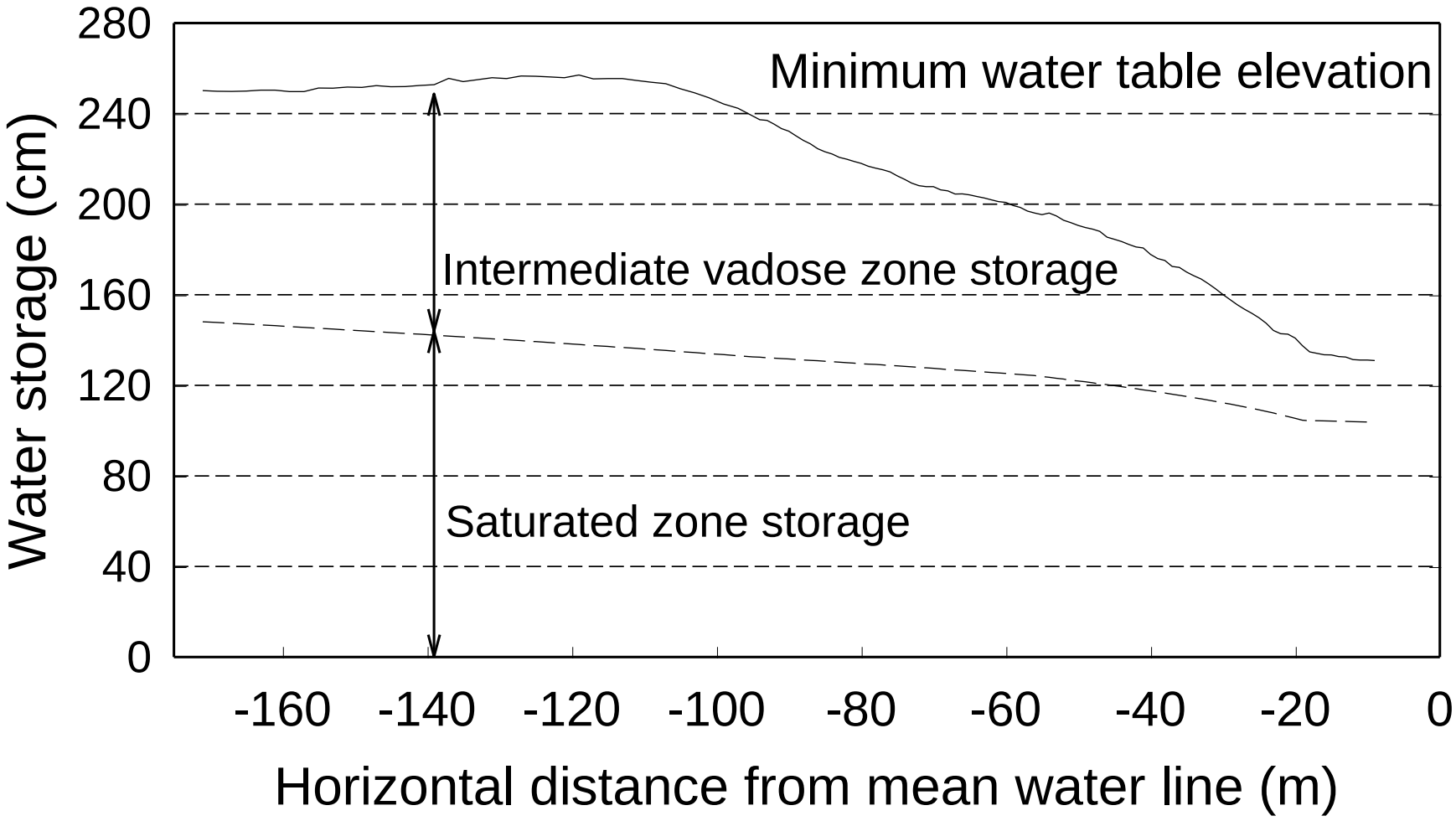

Cover Crop Effects on Profile Nitrate
Depth below soil surface (cm)
0
30
60
90
120
150
180
210
240
0
4
8
12
16
20
24
Soil nitrate-N (mg/kg)
October 1988
October 1990
October 1992
October 1994
October 1995

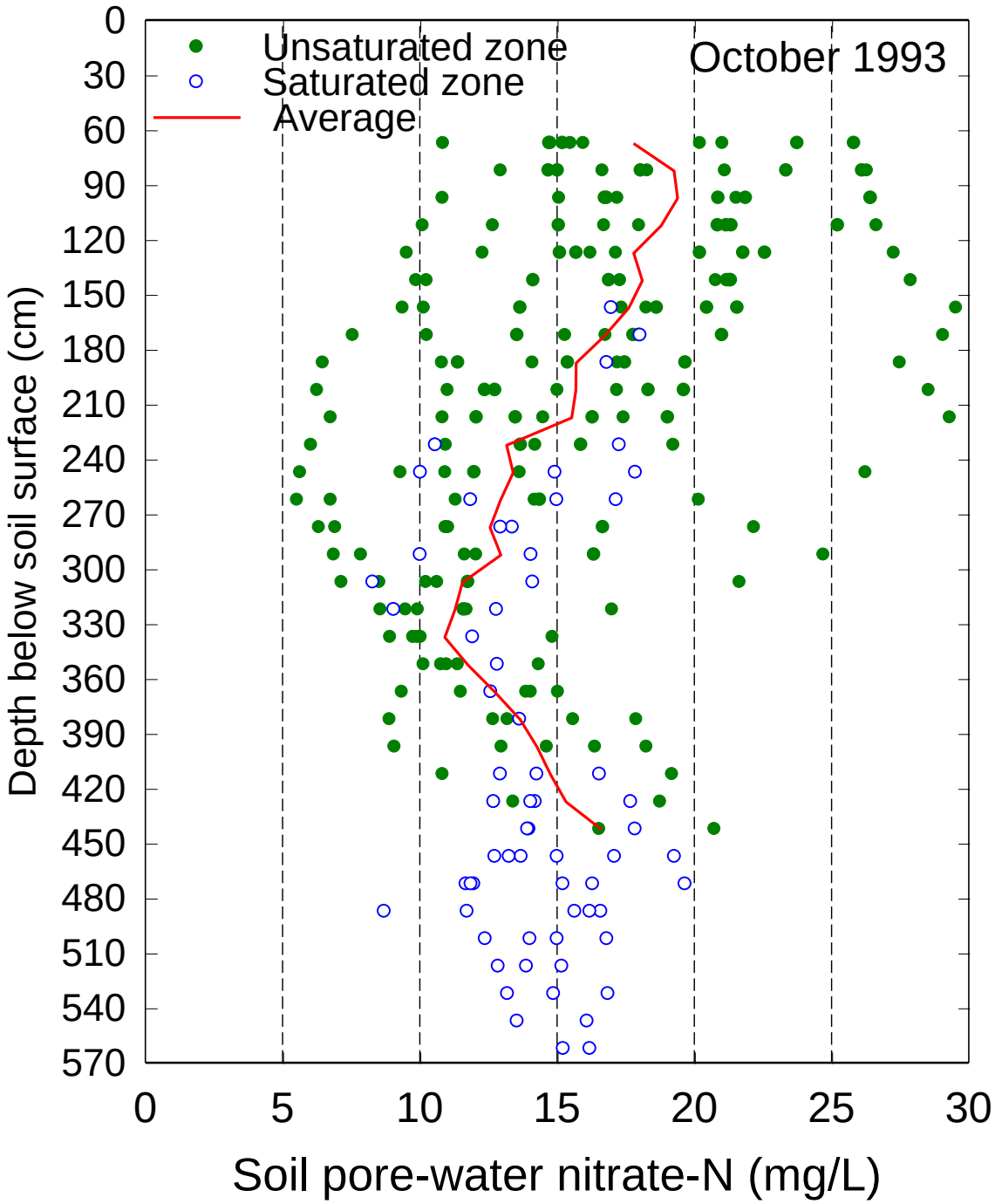

Groundwater nitrate-N (mg/L)
30
25
20
15
10
5
0
Conventional till
No-till
Started using rye
winter cover crops
J A J O J A J O J A J O J A J O J A J O J A J O J A J O J A J O J A J O J A J O J A J O J A J O J A J O J A
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996

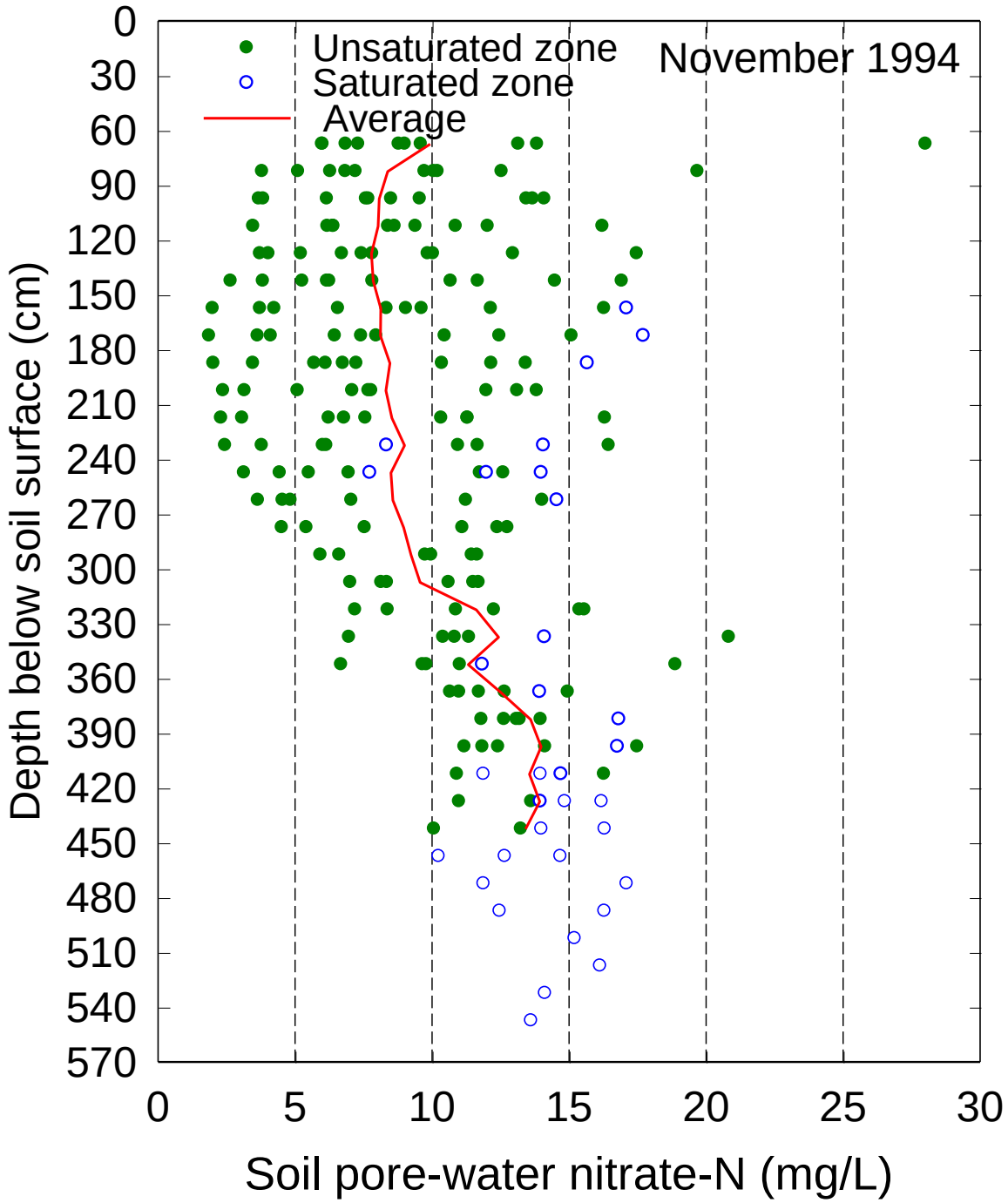

10
8
6
4
2
0
-2
Elevation (m)
Land surface
MH-6
MH-5
MH-4
MH-3
MH-2
MH-1
4A
3A
2A
Water table
Discharge
zone
Well screen
-160
-140
-120
-100
-80
-60
-40
-20
0
20
Horizontal distance from mean low water (m)

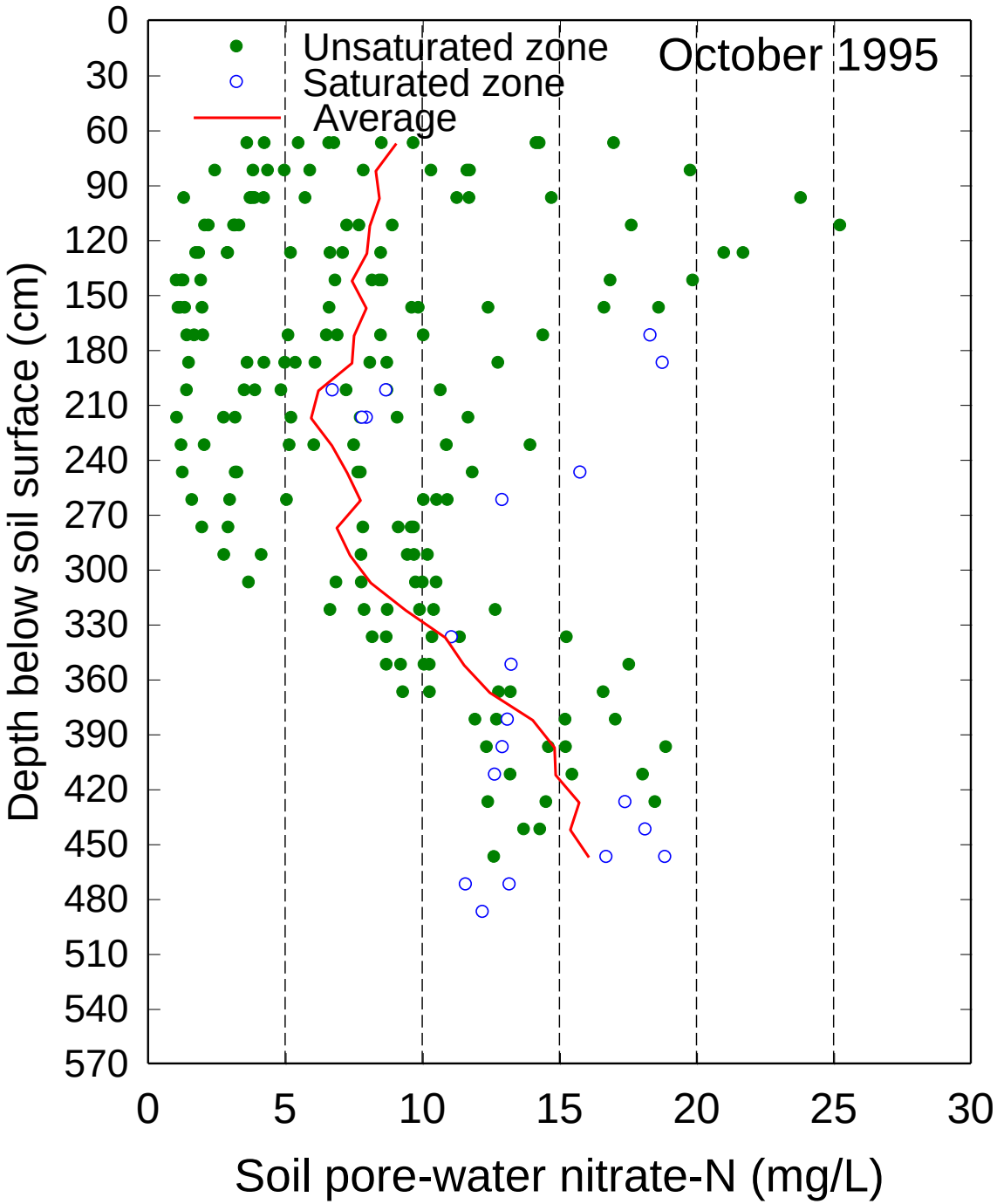


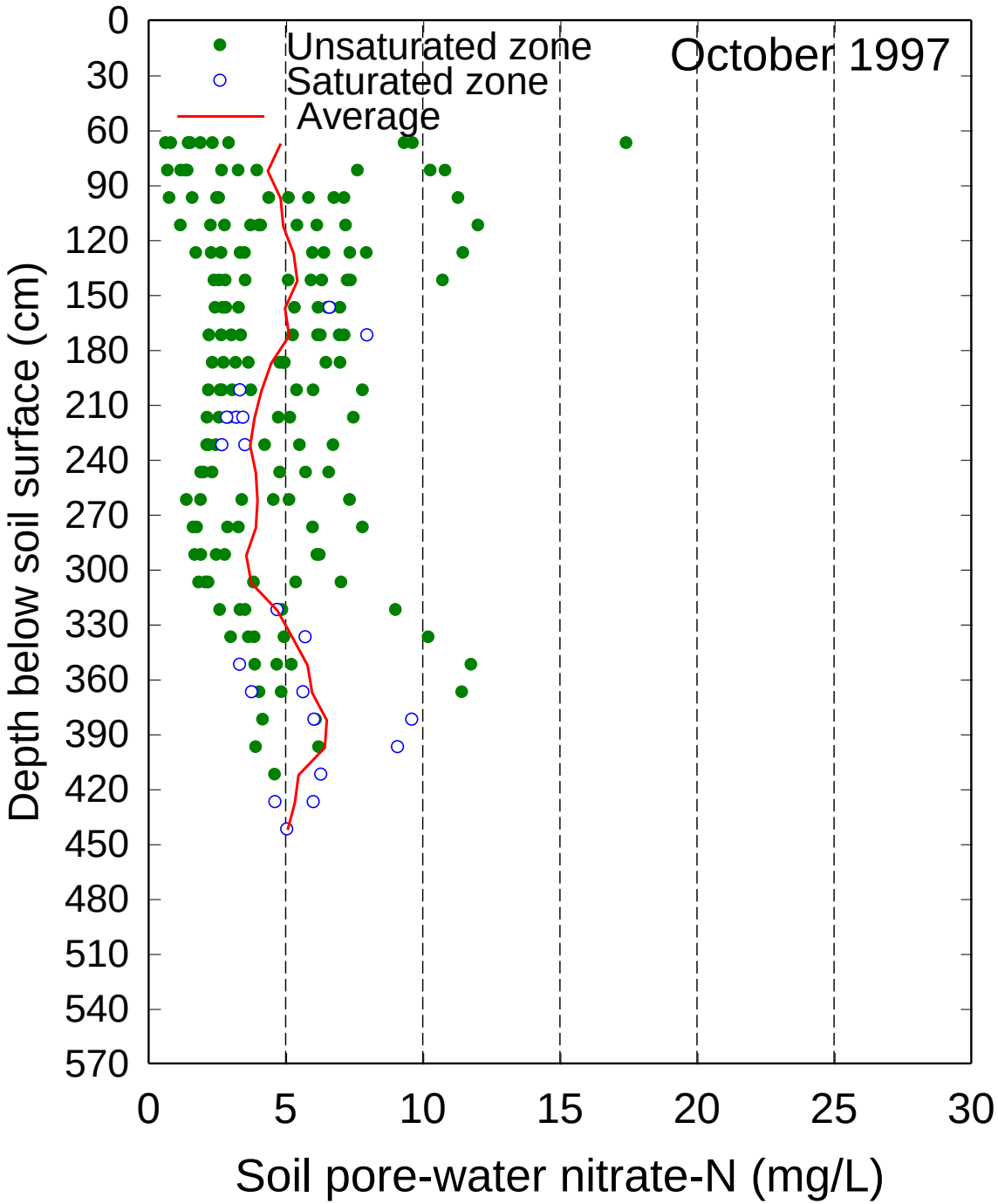

Daily average
10-day average
Daily groundwater discharge (m3/d/m)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
AMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJAS
1992
1993
1994
1995
1996
1997
1998
1999

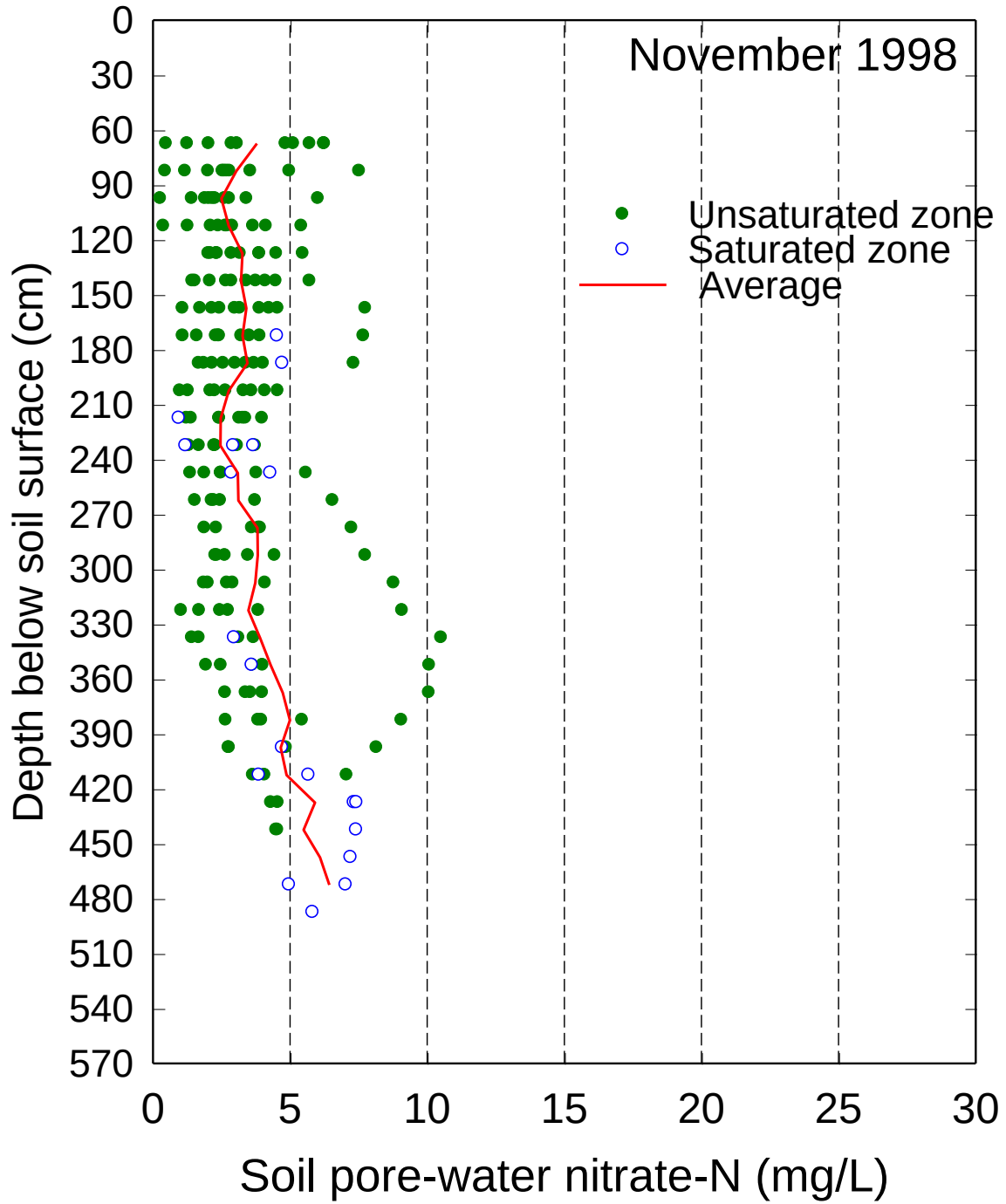

Minimum water table elevation
Intermediate vadose zone storage
Saturated zone storage
Water storage (cm)
280
240
200
160
120
80
40
0
-160
-140
-120
-100
-80
-60
-40
-20
0
Horizontal distance from mean water line (m)

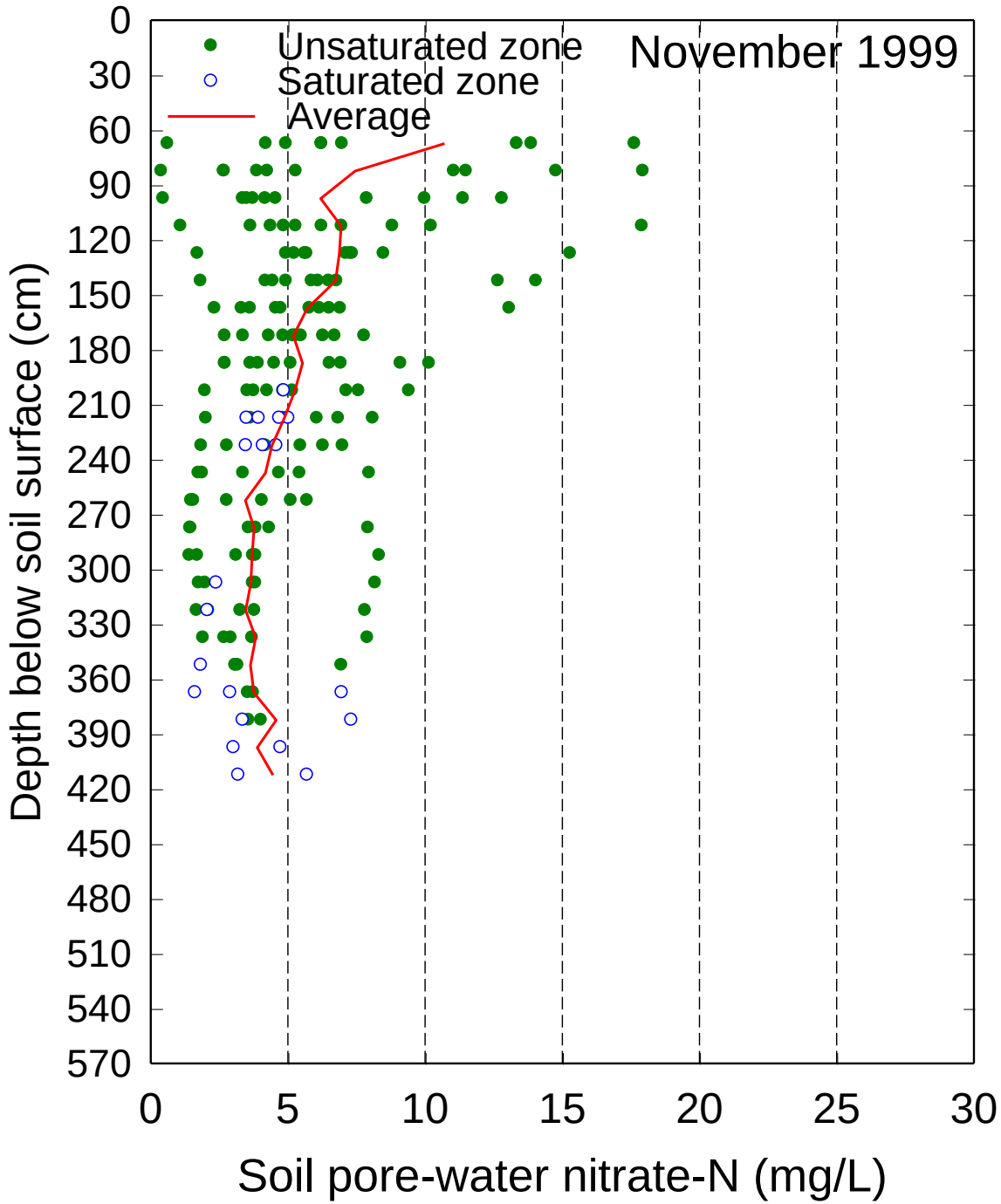

Unsaturated zone
Saturated zone
Average
October 1993
Depth below soil surface (cm)
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
0
5
10
15
20
25
30
Soil pore-water nitrate-N (mg/L)

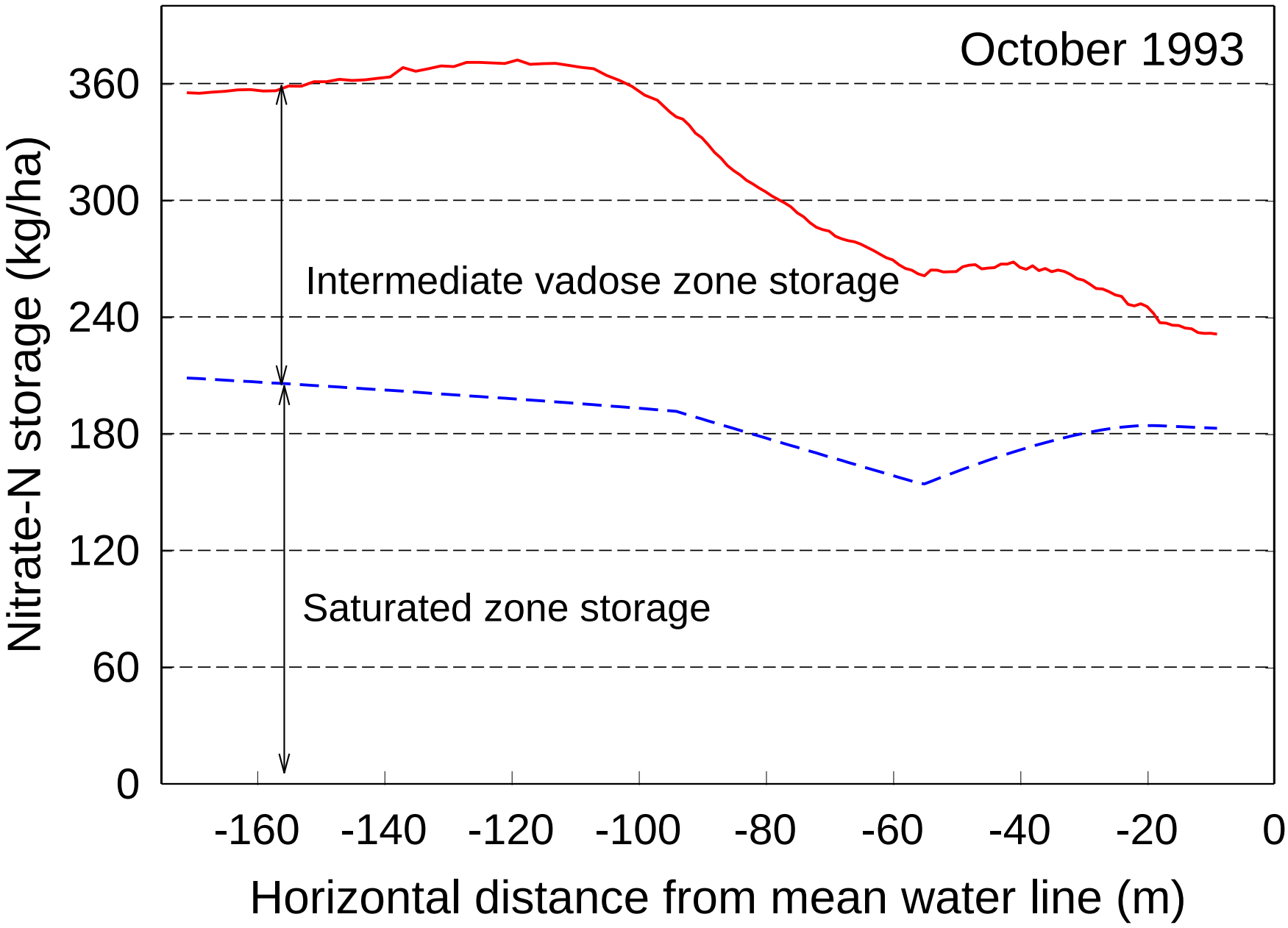

Unsaturated zone
Saturated zone
Average
November 1994
Depth below soil surface (cm)
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
0
5
10
15
20
25
30
Soil pore-water nitrate-N (mg/L)

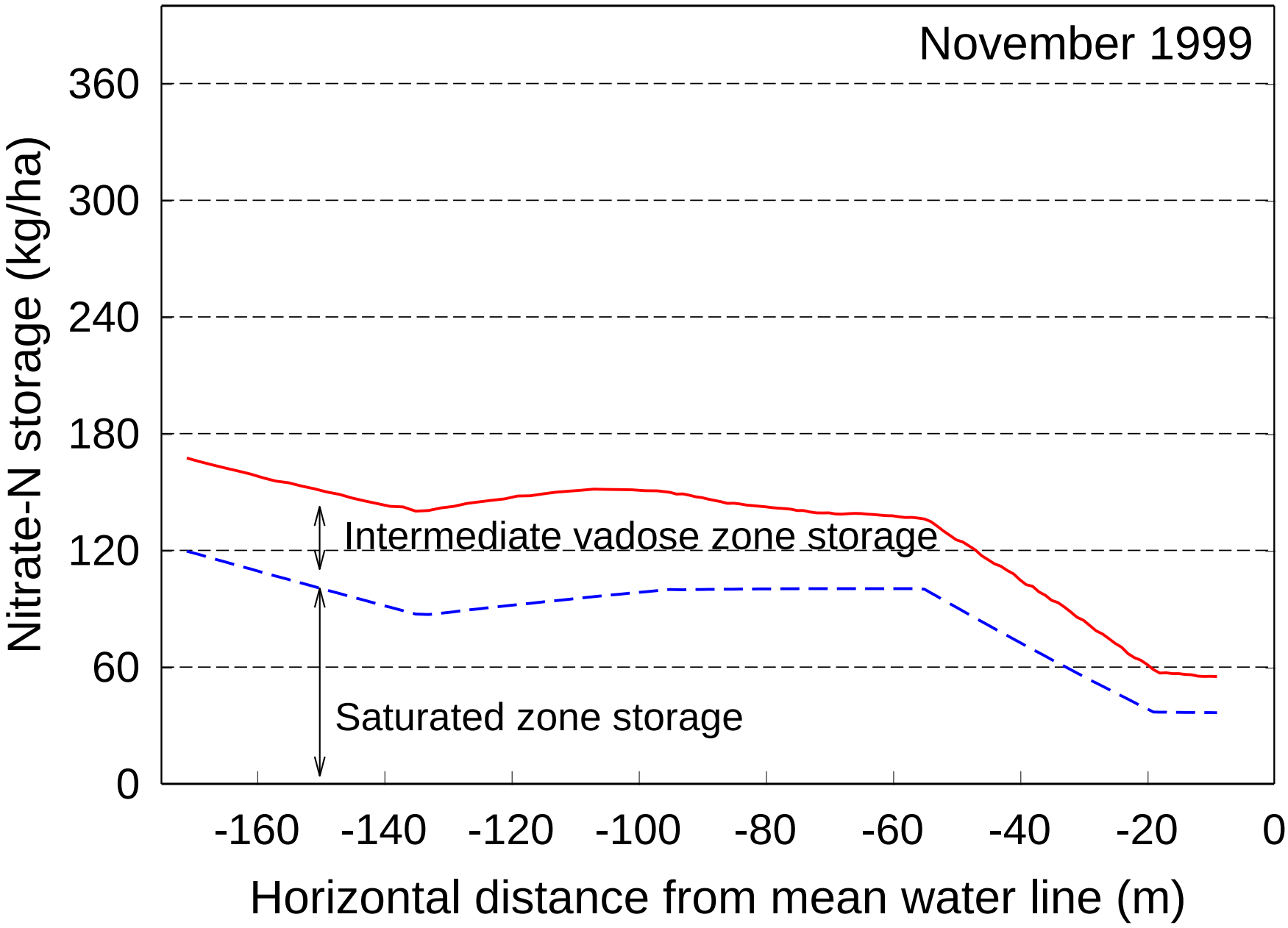

Unsaturated zone
Saturated zone
Average
October 1995
Depth below soil surface (cm)
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
0
5
10
15
20
25
30
Soil pore-water nitrate-N (mg/L)

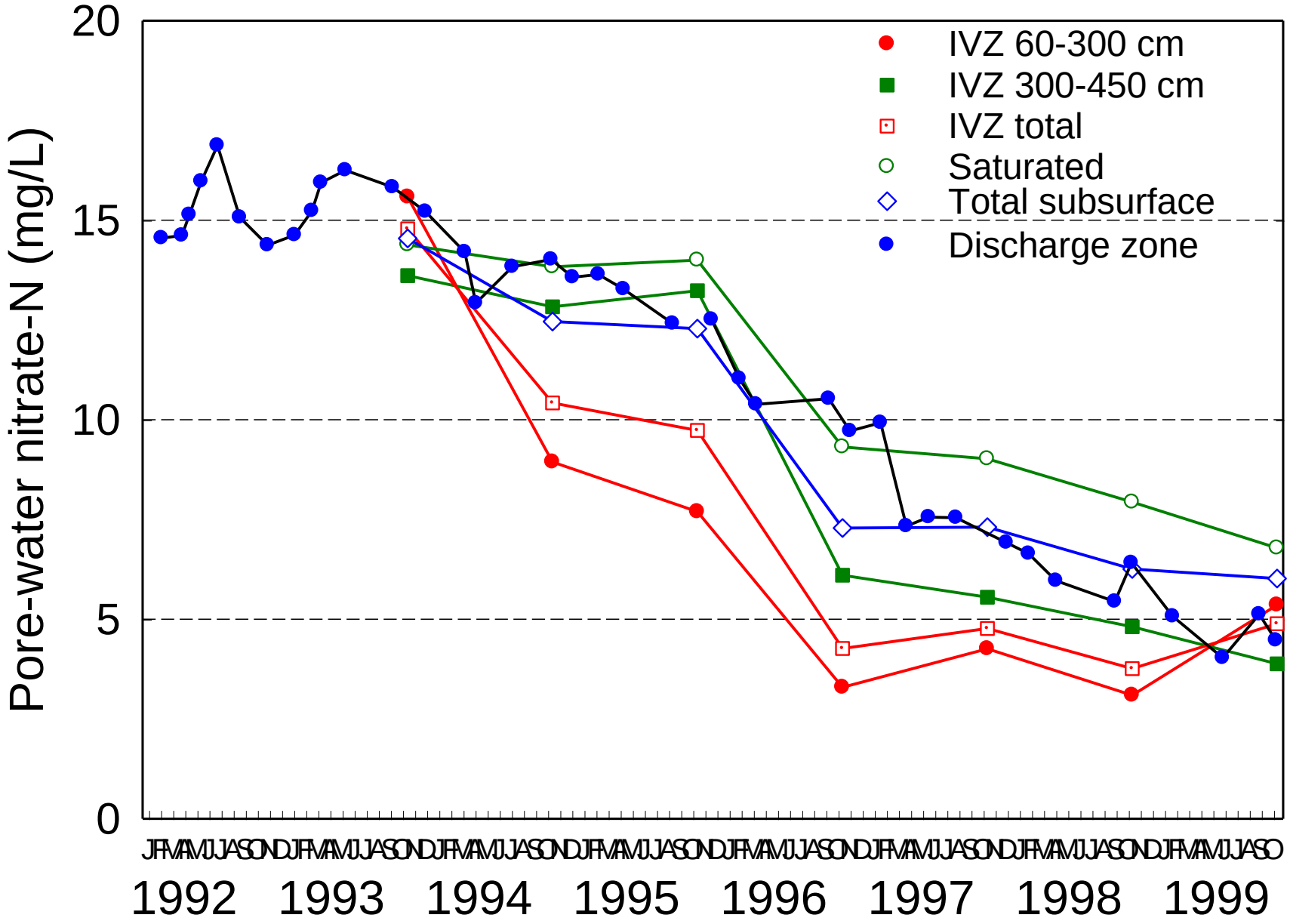

Unsaturated zone
Saturated zone
Average
October 1997
Depth below soil surface (cm)
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
0
5
10
15
20
25
30
Soil pore-water nitrate-N (mg/L)

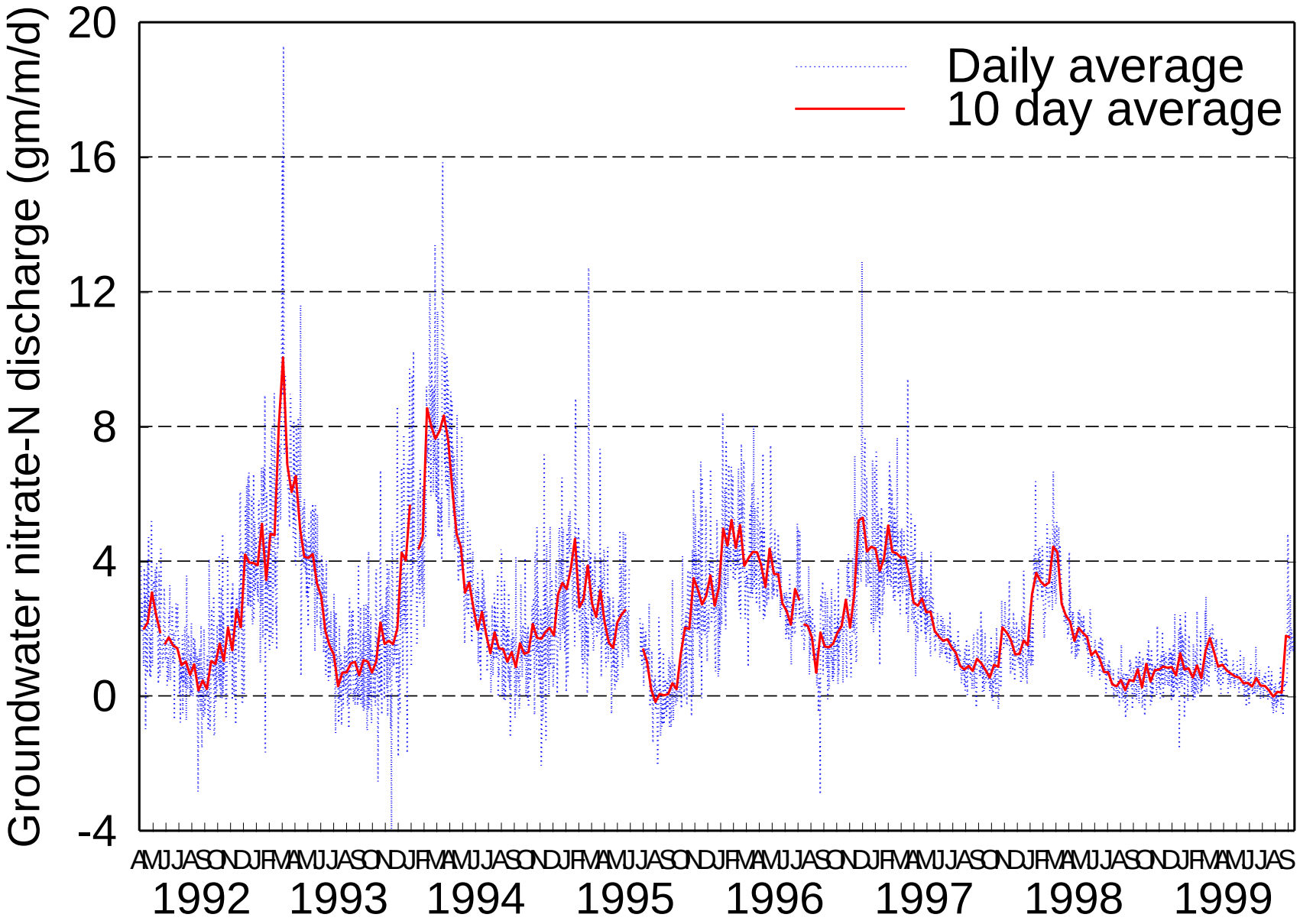

November 1998
Unsaturated zone
Saturated zone
Average
Depth below soil surface (cm)
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
0
5
10
15
20
25
30
Soil pore-water nitrate-N (mg/L)

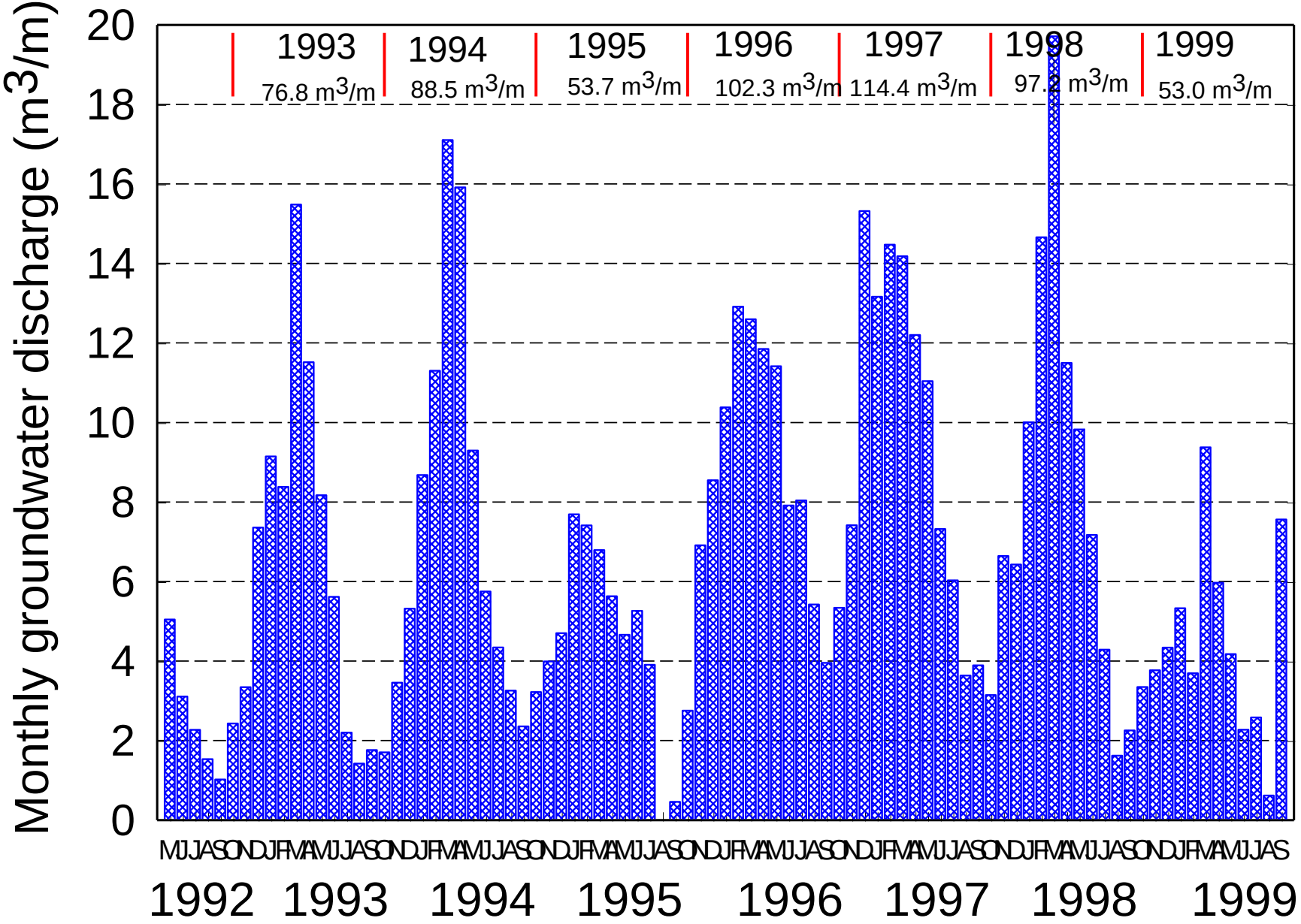

Unsaturated zone
Saturated zone
Average
November 1999
Depth below soil surface (cm)
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
0
5
10
15
20
25
30
Soil pore-water nitrate-N (mg/L)

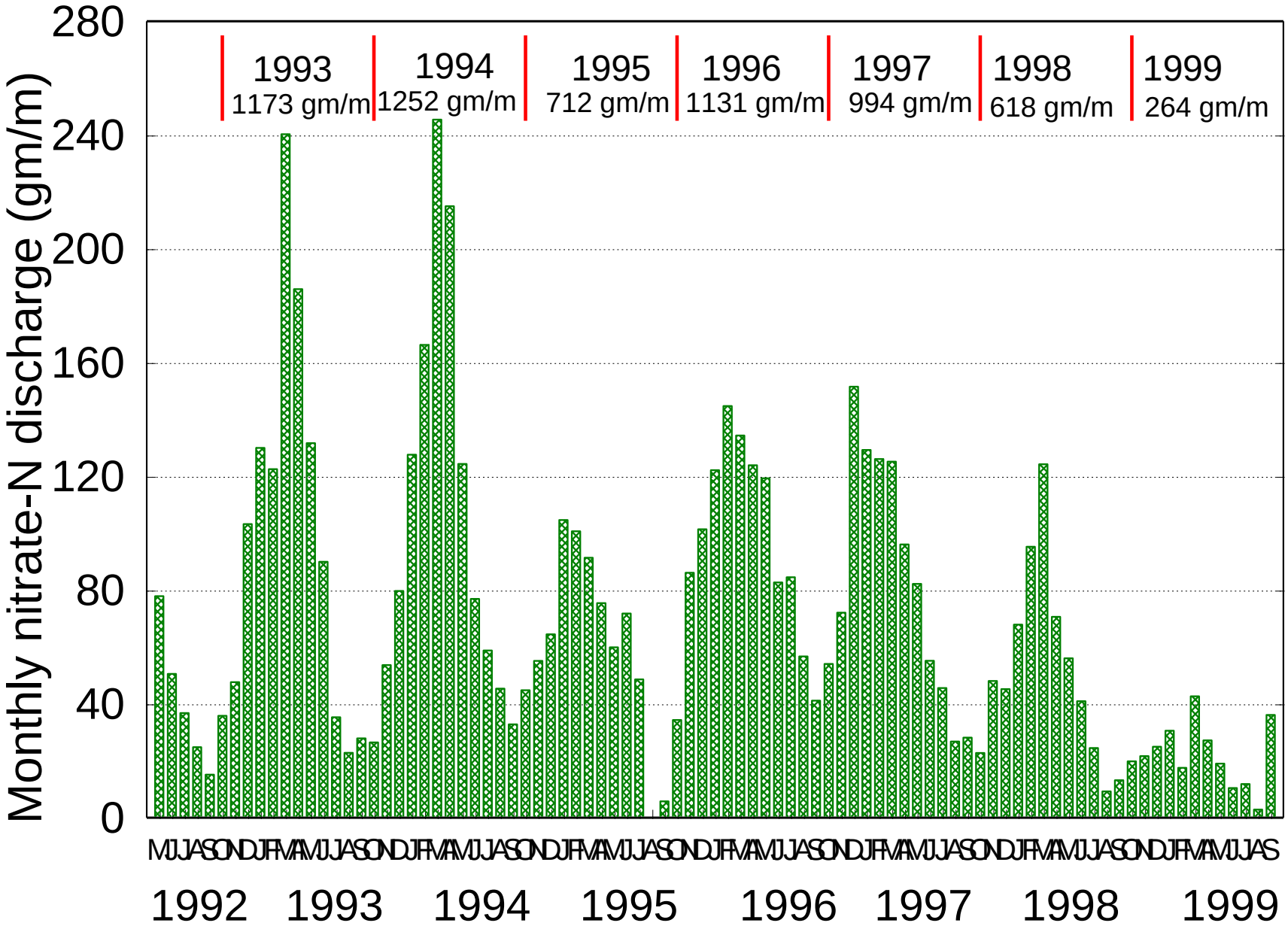

October 1993
Intermediate vadose zone storage
Saturated zone storage
Nitrate-N storage (kg/ha)
360
300
240
180
120
60
0
-160
-140
-120
-100
-80
-60
-40
-20
0
Horizontal distance from mean water line (m)

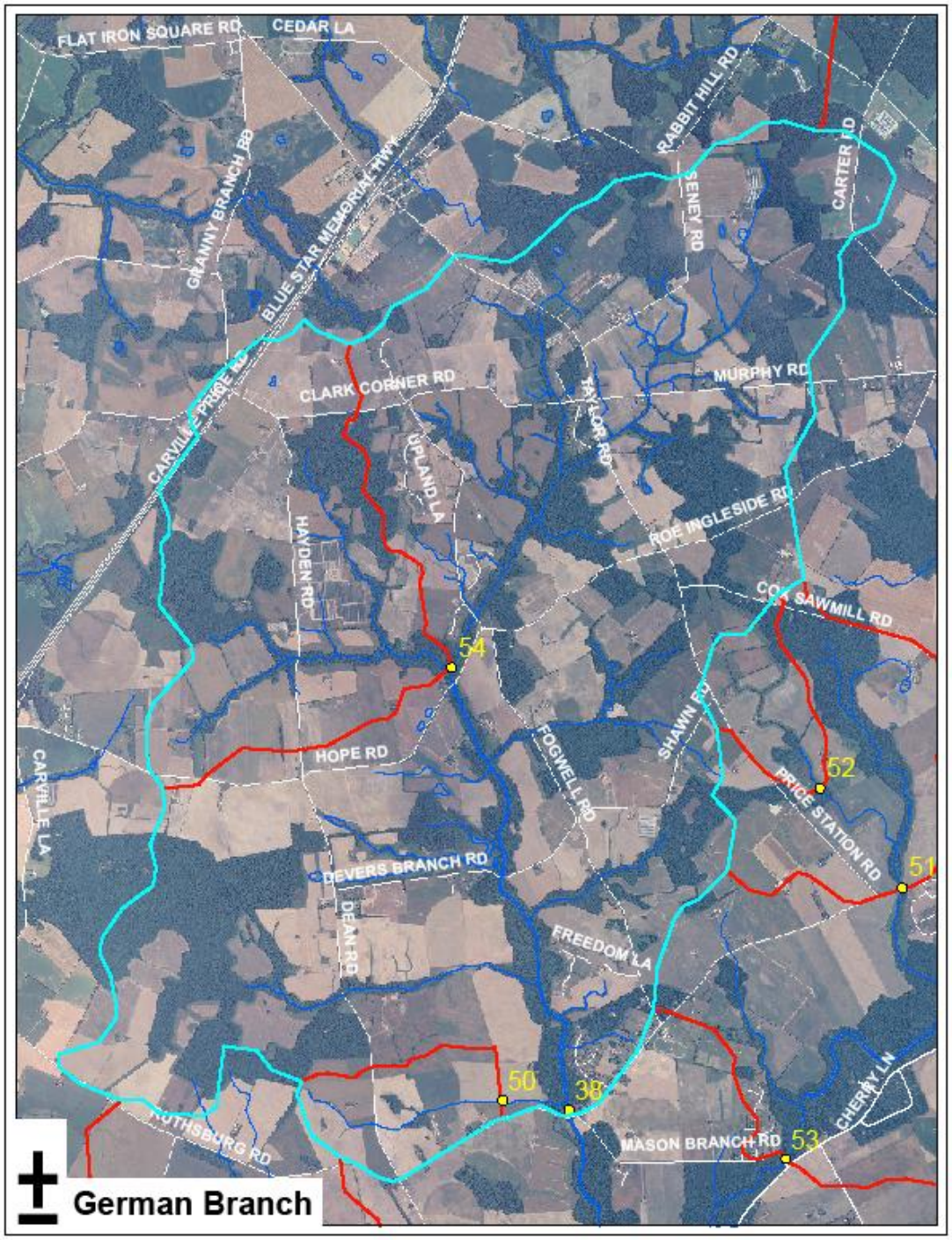

November 1999
Nitrate-N storage (kg/ha)
360
300
240
180
120
60
0
Intermediate vadose zone storage
Saturated zone storage
-160
-140
-120
-100
-80
-60
-40
-20
0
Horizontal distance from mean water line (m)

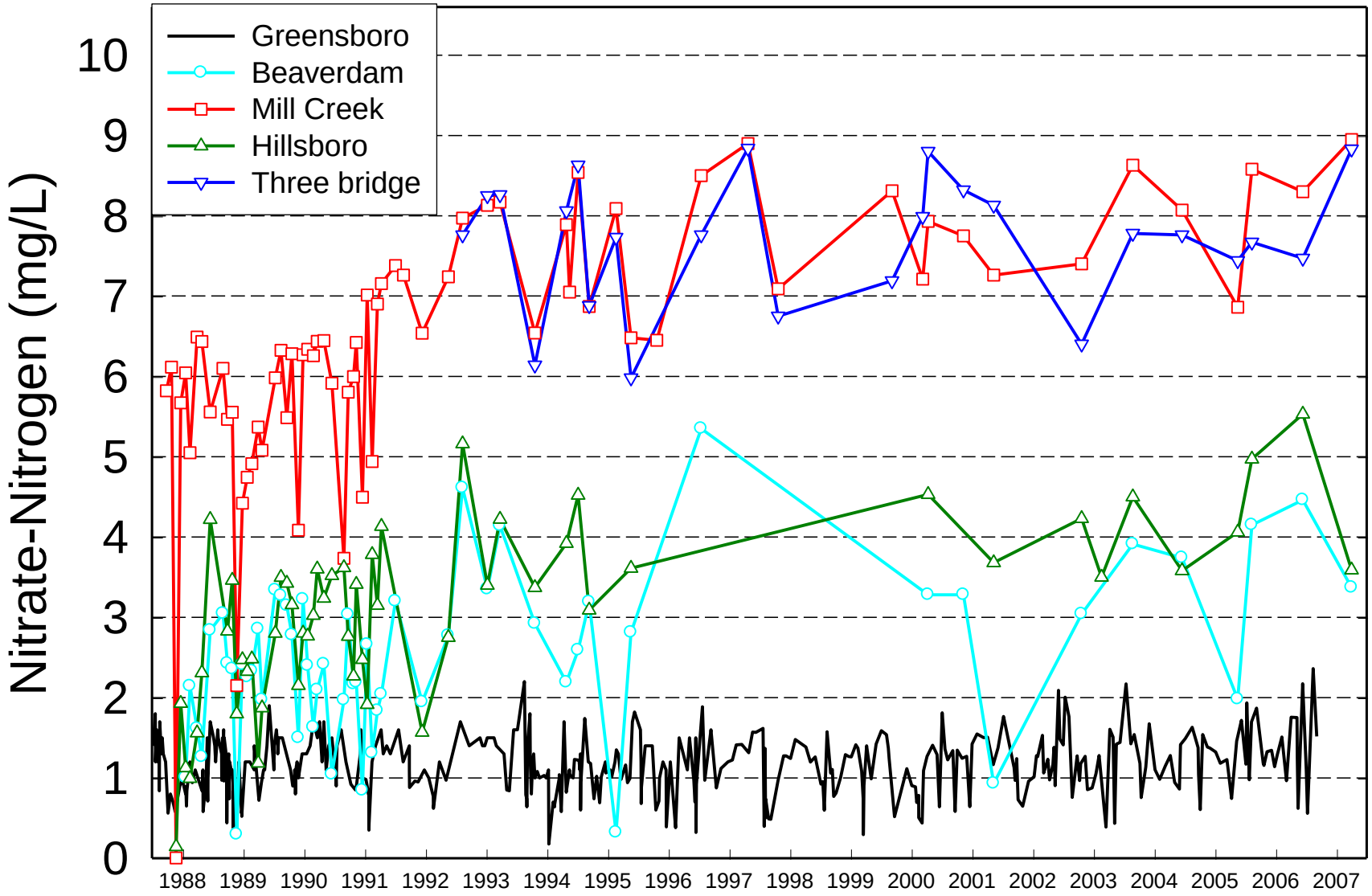

Pore-water nitrate-N (mg/L)
20
15
10
5
0
IVZ 60-300 cm
IVZ 300-450 cm
IVZ total
Saturated
Total subsurface
Discharge zone
JFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASO
1992
1993
1994
1995
1996
1997
1998
1999

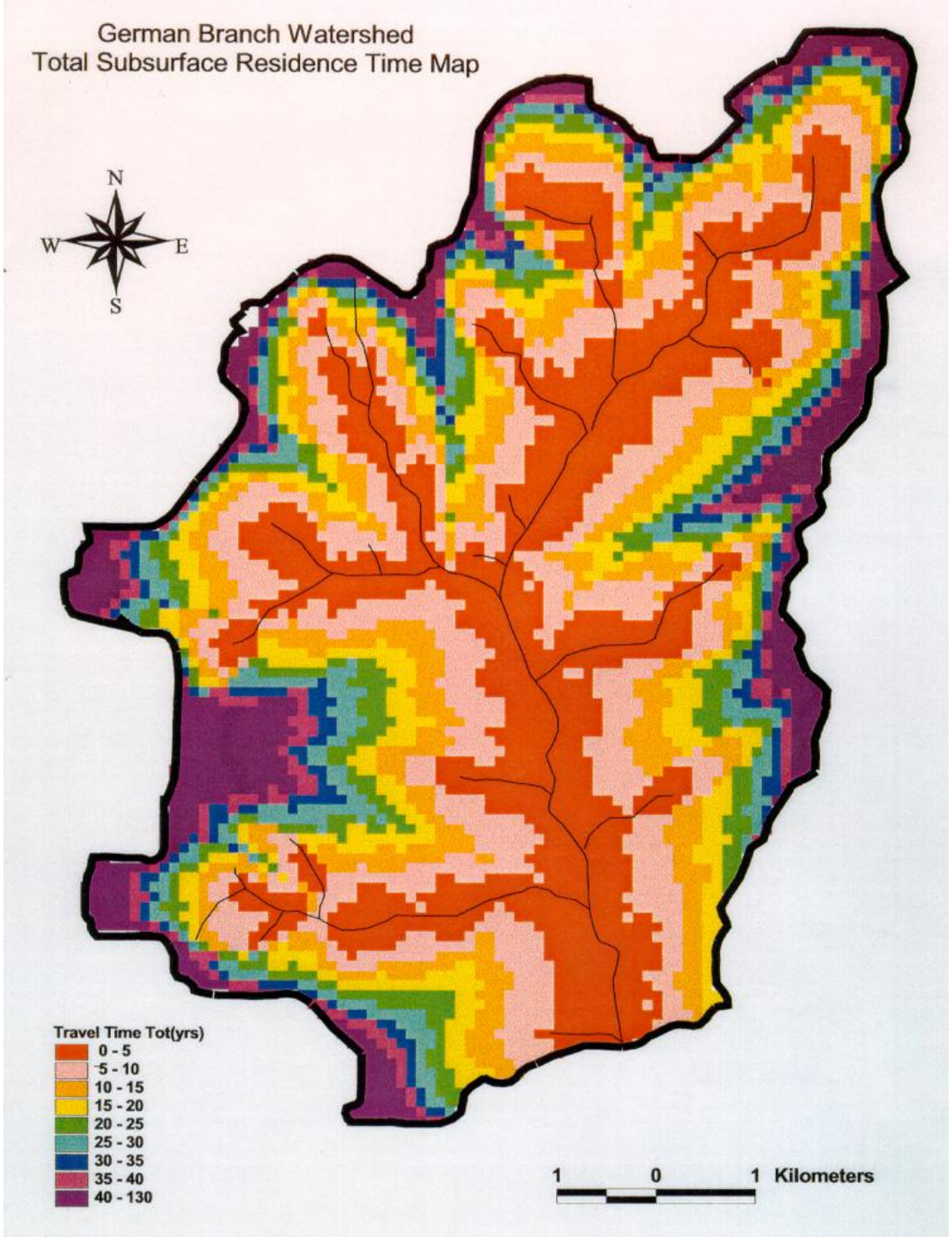

Groundwater nitrate-N discharge (gm/m/d)
20
16
12
8
4
0
-4
Daily average
10 day average
AMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJAS
1992
1993
1994
1995
1996
1997
1998
1999

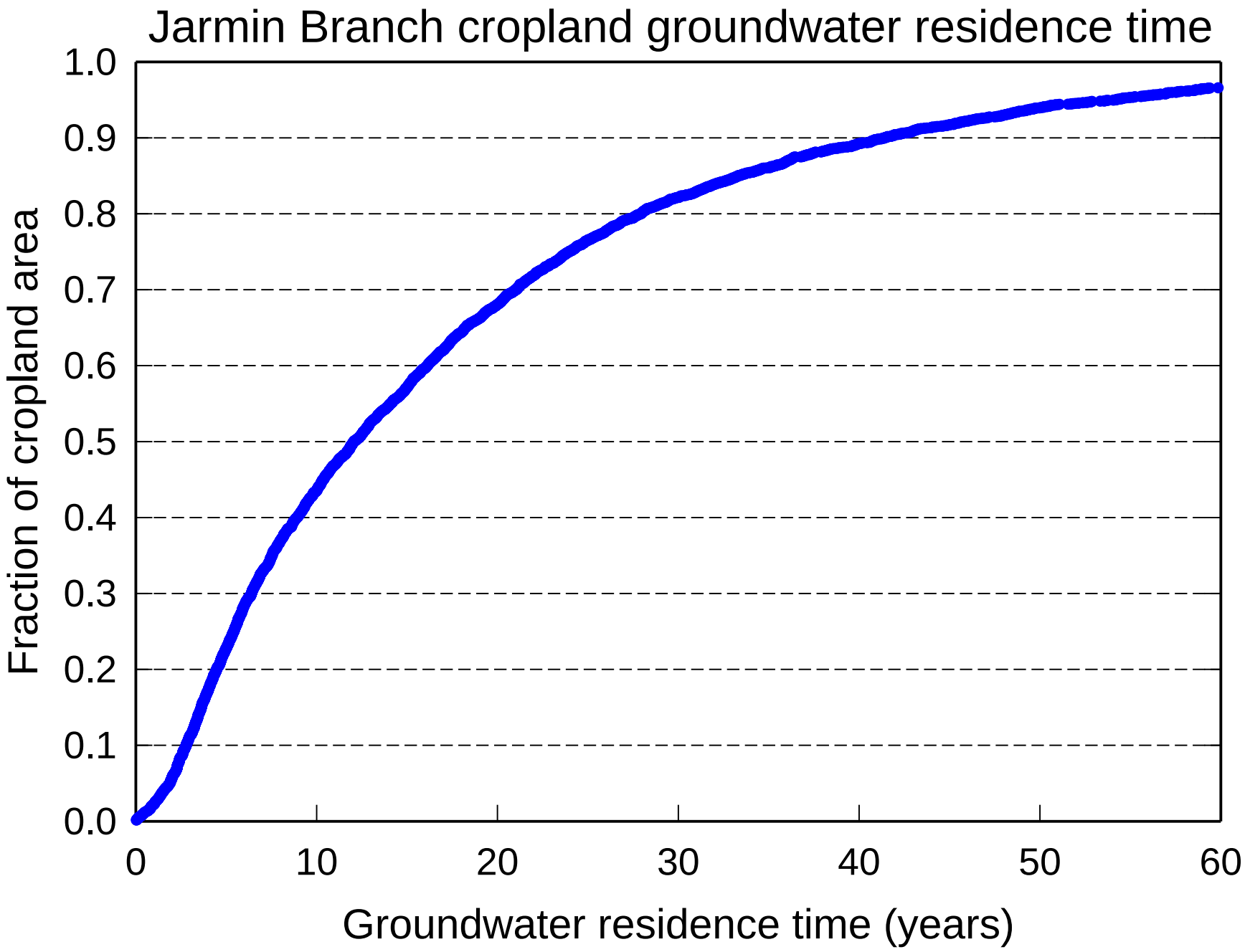

Monthly groundwater discharge (m3/m)
0
2
4
6
8
10
12
14
16
18
20
1993
76.8 m3/m
1994
88.5 m3/m
1995
53.7 m3/m
1996
102.3 m3/m
1997
114.4 m3/m
1998
97.2 m3/m
1999
53.0 m3/m
MJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJAS
1992
1993
1994
1995
1996
1997
1998
1999

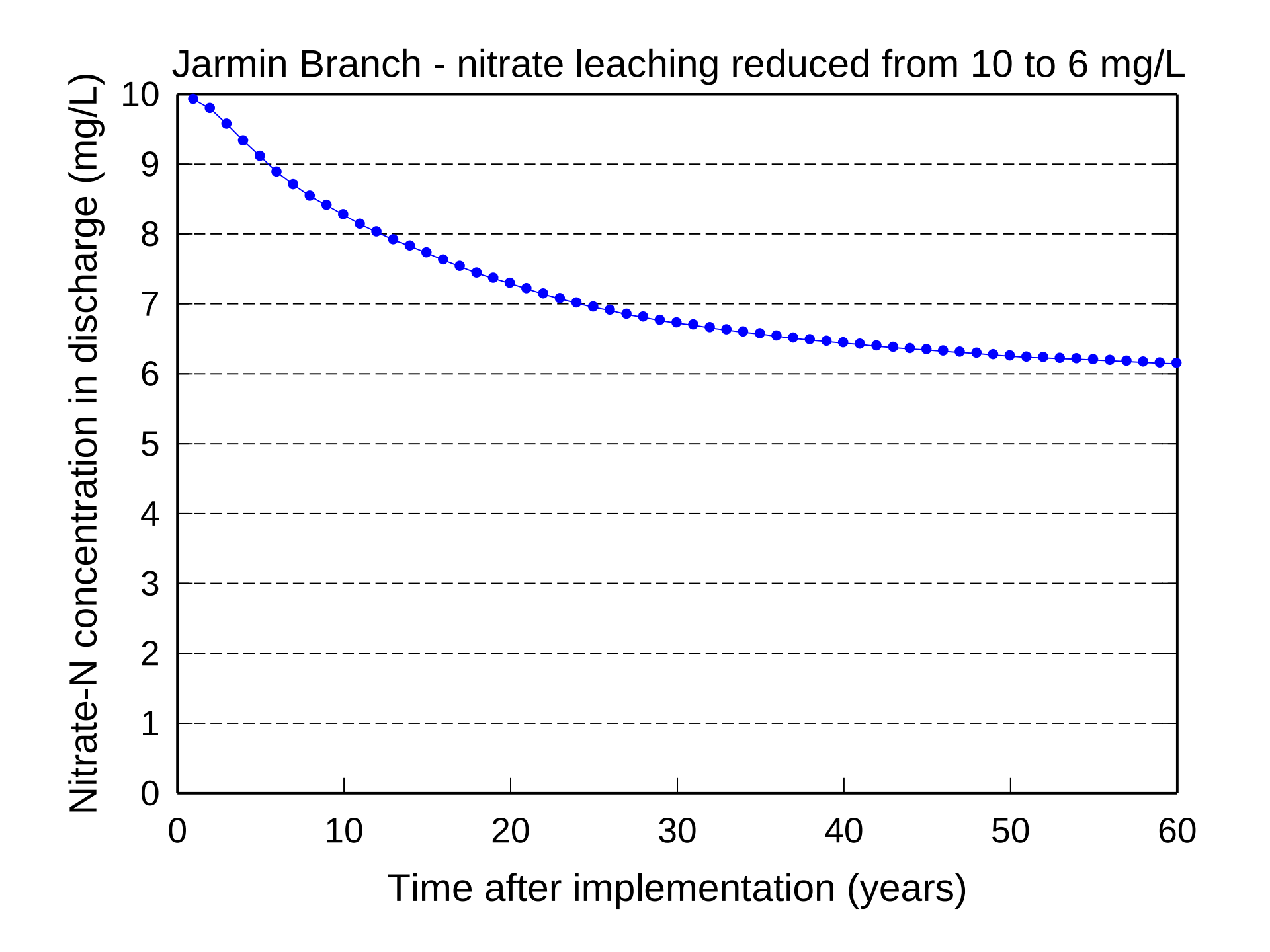

Monthly nitrate-N discharge (gm/m)
280
240
200
160
120
80
40
0
1993
1173 gm/m
1994
1252 gm/m
1995
712 gm/m
1996
1131 gm/m
1997
994 gm/m
1998
618 gm/m
1999
264 gm/m
MJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJAS
1992
1993
1994
1995
1996
1997
1998
1999


FLAT IRON SQUARE RD
CEDAR LA
GRANNY BRANCH RD
BLUE STAR MEMORIAL HWY
RABBIT HILL RD
SENEY RD
CARTER RD
CARVILLE PRICE RD
CLARK CORNER RD
TAYLOR RD
MURPHY RD
UPLAND LA
HAYDEN RD
ROE INGLESIDE RD
SAWMILL RD
54
HOPE RD
FOGWELL RD
SHAWN RD
52
PRICE STATION RD
CARVILLE LA
DEVERS BRANCH RD
DEAN RD
FREEDOM LA
50
38
CHERRY LN
RUTHSBURG RD
MASON BRANCH RD
53
German Branch


Greensboro
Beaverdam
Mill Creek
Hillsboro
Three bridge
Nitrate-Nitrogen (mg/L)
0
1
2
3
4
5
6
7
8
9
10
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007


German Branch Watershed
Total Subsurface Residence Time Map
N
W
E
S
Travel Time Tot(yrs)
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 130
1
0
1
Kilometers

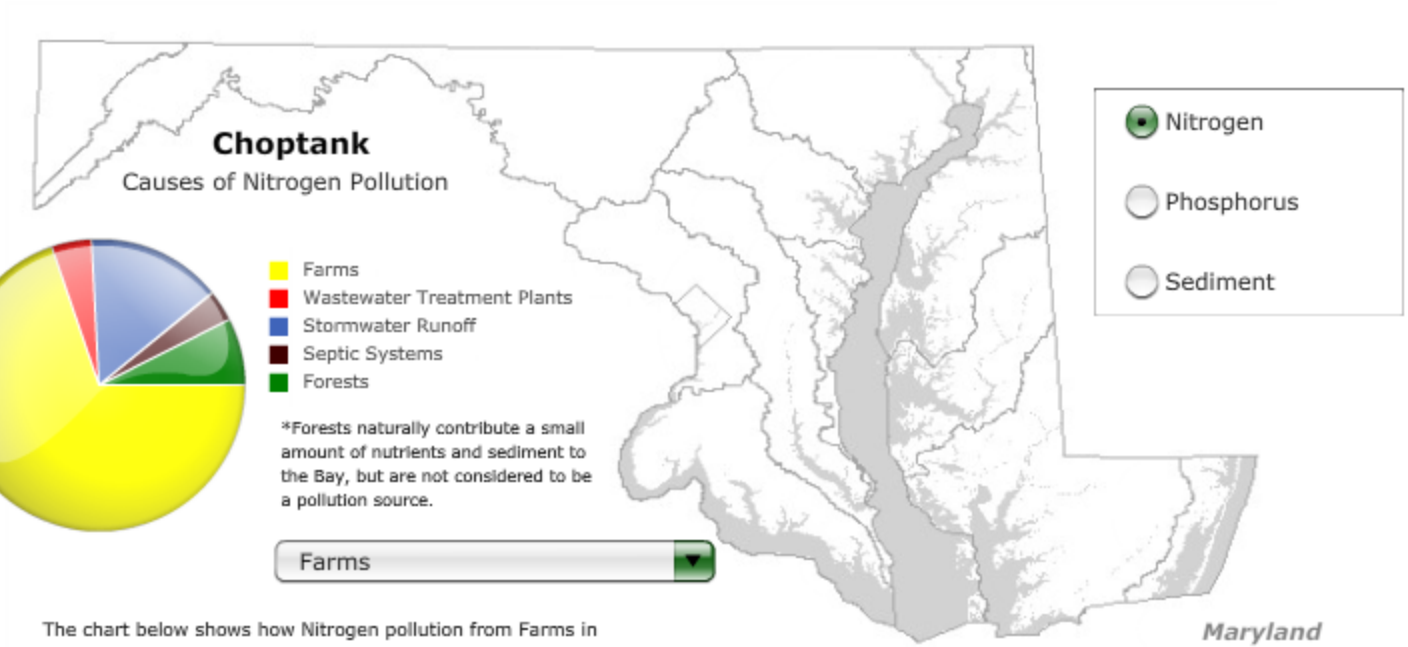

Jarmin Branch cropland groundwater residence time
Fraction of cropland area
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
Groundwater residence time (years)


Jarmin Branch - nitrate leaching reduced from 10 to 6 mg/L
Nitrate-N concentration in discharge (mg/L)
10
9
8
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
Time after implementation (years)

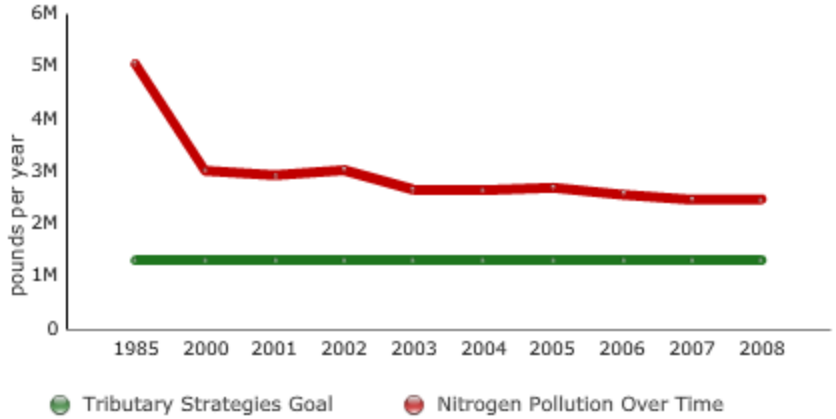
Summary – edge of field

- Erosion potential changed instantaneously with tillage and ~1-2 years with buffers.
- Nutrient application methods change potential for dissolved N and P losses immediately. ??
- Large soil P reservoirs take decades to draw down using crop removal. Predictable but need to know the starting point.
- Flow system characteristics and landscape position determine leaching to surface water lag times. Tidal interface fields 5-10 years, Choptank subwatershed average 15-20

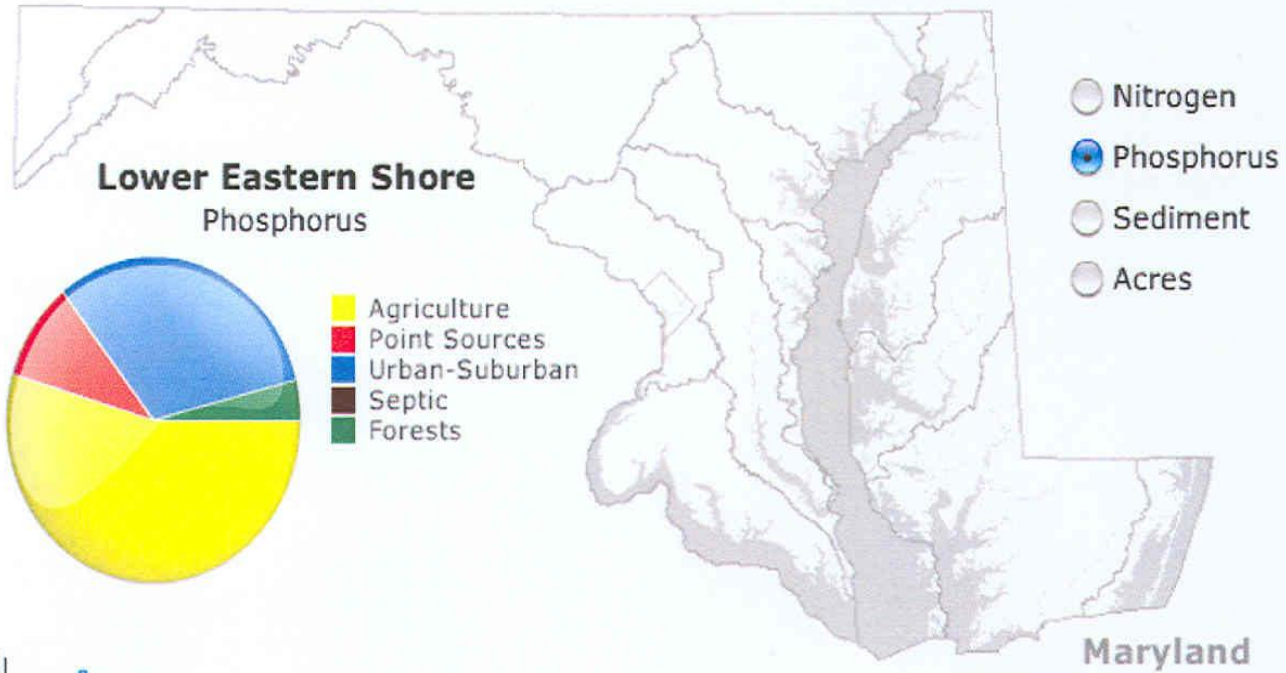
Causes of the Problems



The chart below shows how Nitrogen pollution from Farms in Choptank has changed over time.



Nitrogen pollution fuels the growth of algae, creating dense, harmful algae blooms that rob the Chesapeake Bay's aquatic life of needed sunlight and oxygen. Sources of nitrogen pollution include air pollution from vehicles, coal-burning power plants and industry; fertilizers from farmfields, lawns and golf courses; wastewater from industrial facilities, sewage treatment plants and septic systems; and animal manure from farms.



Phosphorus: The primary nutrients polluting the Chesapeake Bay are nitrogen and phosphorous. High amounts of these nutrients increase the growth of algae. Algae become so abundant that the color of the water turns brownish or greenish. Sunlight is blocked from reaching other plants. When the algae die and decompose, oxygen dissolved in the water is used. Often, so much oxygen is used by decomposing algae that fish and other animals must move to areas with more oxygen. Plants and animals that cannot move may die.