

# Red River Valley Water Quality Assessment: Tile Drainage in Saline Soils



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Agricultural & Biosystems Engineering

**NDSU** EXTENSION  
SERVICE

# East Central #6

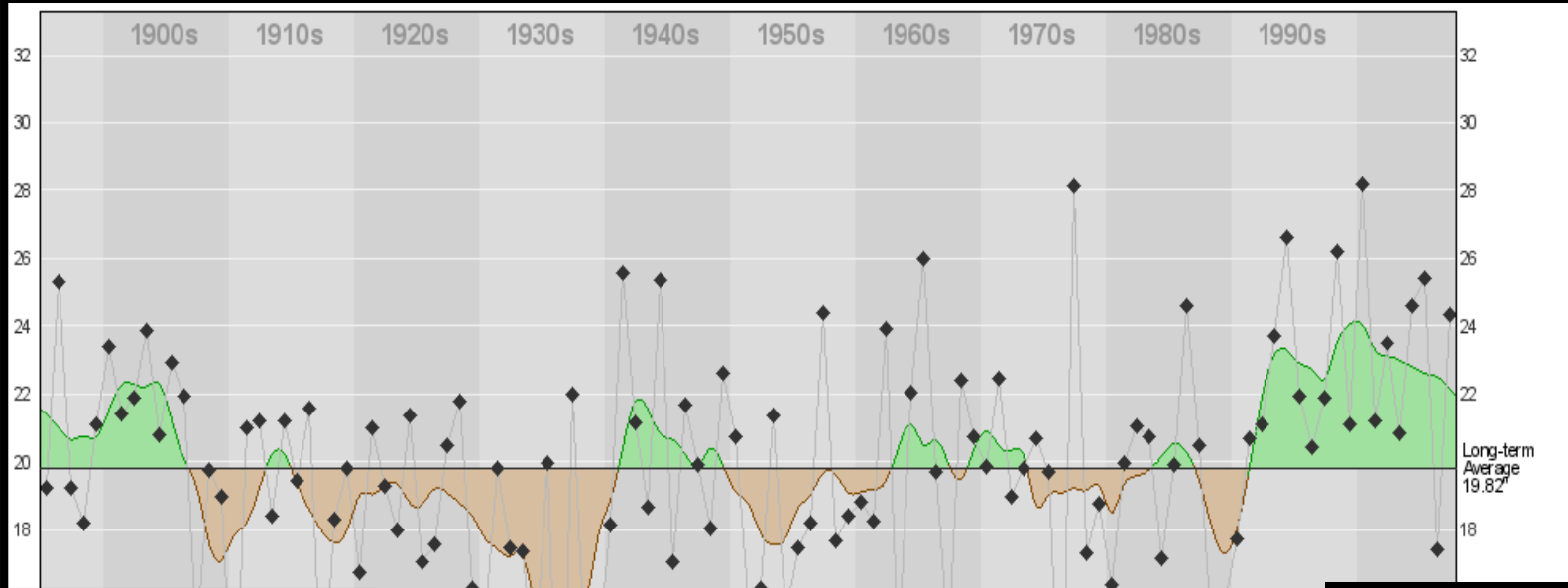


Image produced Jan 2008 at the Oklahoma Climate Center

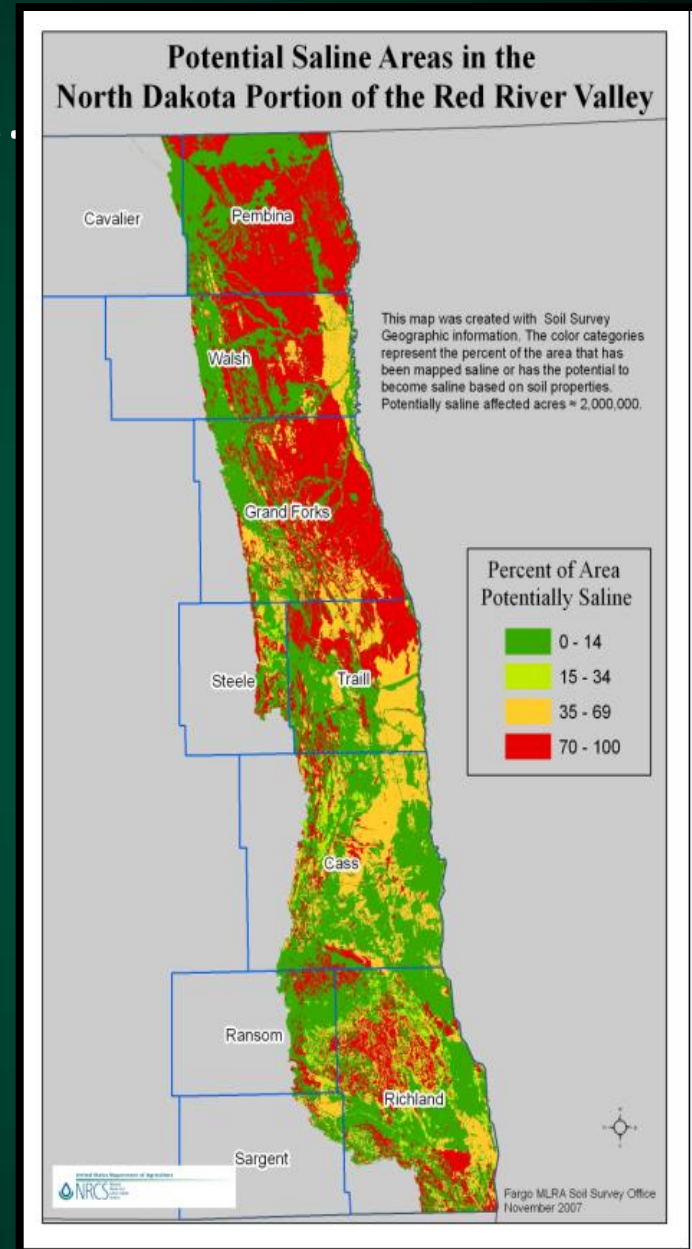
**Annual Precipitation History with 5-year Tendencies**  
 ND-CD6 (E. Central): 1895-2007

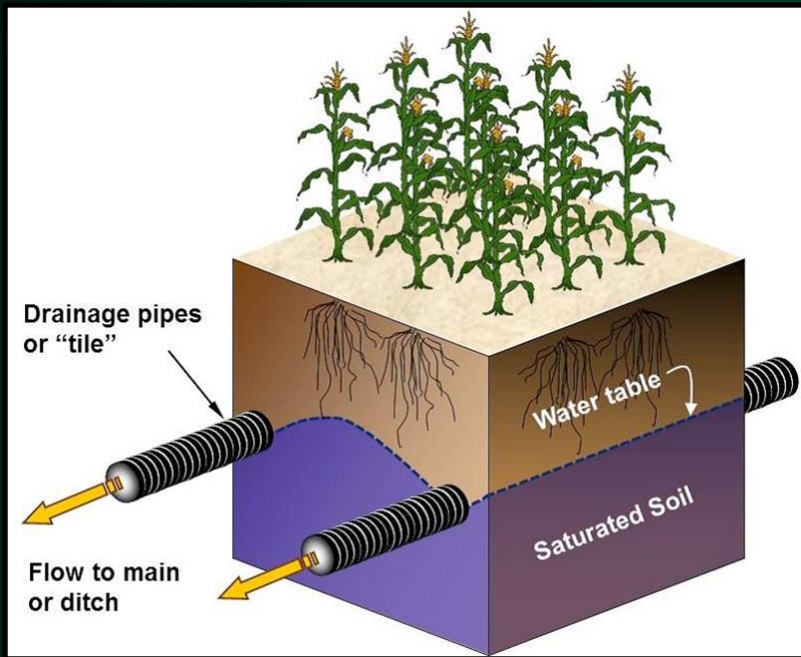
- Wetter historical periods
- Drier historical periods
- Individual Annual precipitation value

# Our unusual tiling situation....

- Increased salinity
  - Calcium carbonate
  - Magnesium sulfate
  - Sodium sulfate

Franzen 2007





# Farmer Response



**Commercial Tile Plow**



**Farmer owned plow**



**Free flowing tile outlet and a pumped outlet**



## Excess water

- surface removal
- subsurface removal



## Surface runoff

- increased nutrient and sediment loss

## Subsurface drainage

- decreases surface drainage
- reduces sediment losses by 16 to 65 %
- reduces phosphorus losses by up to 45%
- increased nitrates and other soluble constituents
- surface drains in a tiled field are a direct conduit to the tile

Zucker and Brown (eds.) 1998

# Overview of Project

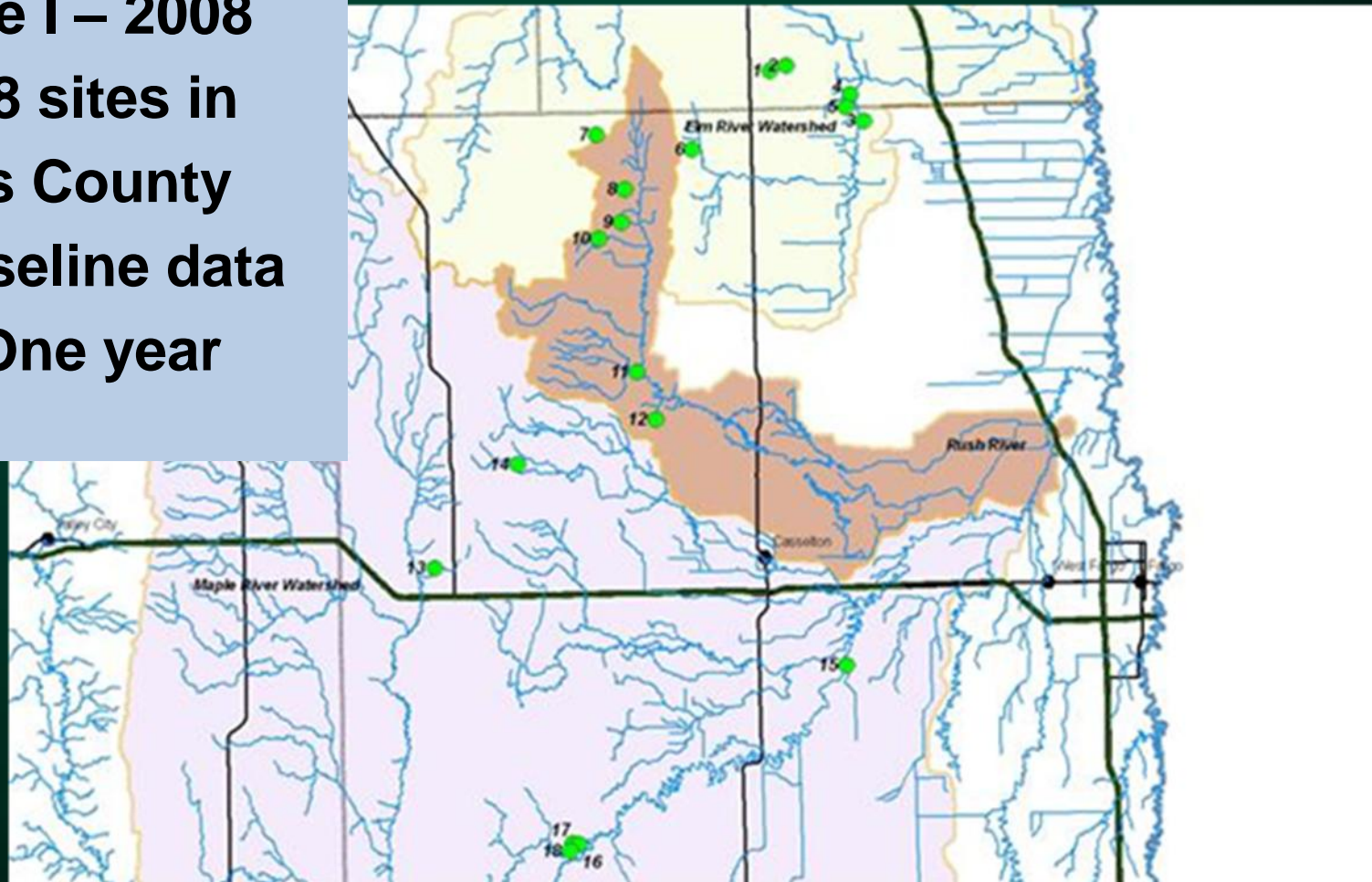
**Phase I – 2008**

**18 sites in**

**Cass County**

**Baseline data**

**One year**





# Overview of Project

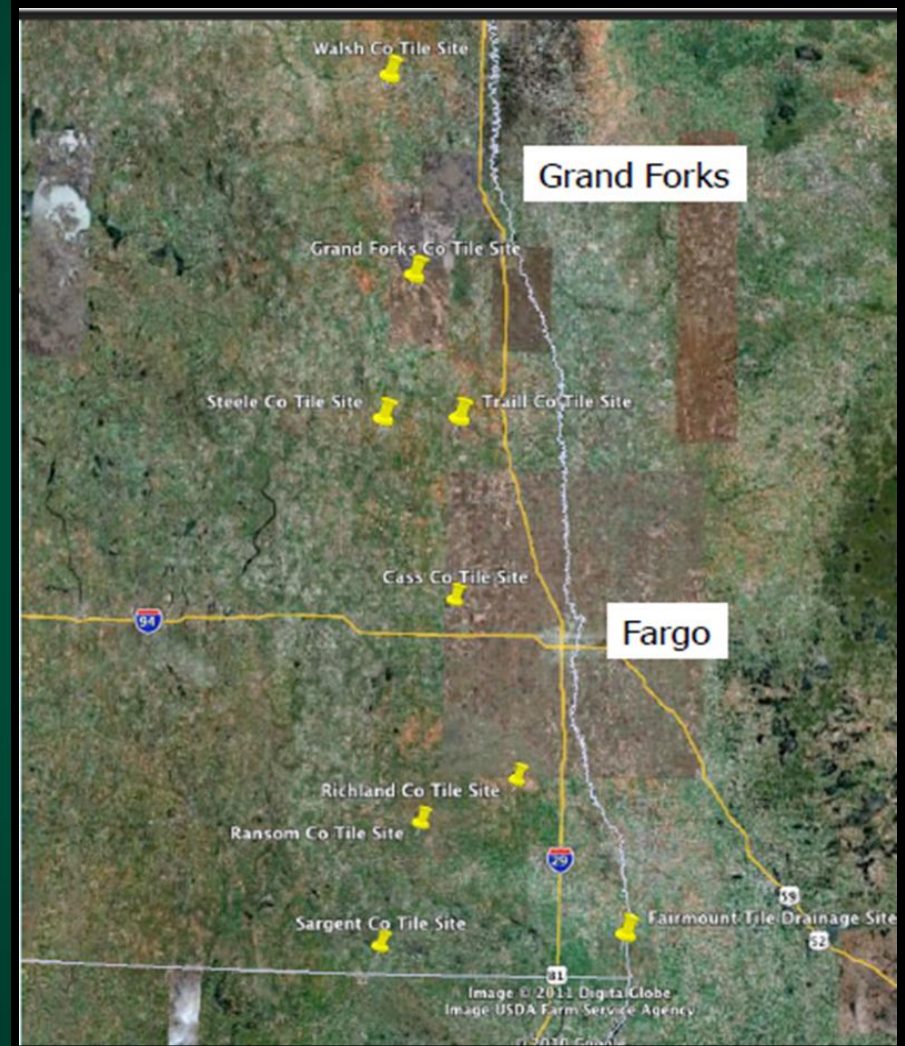
**Phase II**

**8 counties**

**Saline soils**

**Water quality &  
quantity**

**Samples from  
tiled surface,  
outlet,  
comparable  
untiled surface, &  
downstream**



# What Matters?

National  
Drinking Water  
Standards

North Dakota  
Department of Health

**Primary  
Standards**

**Secondary  
Standards**

**Standards  
of Quality  
for Waters  
of the  
State**

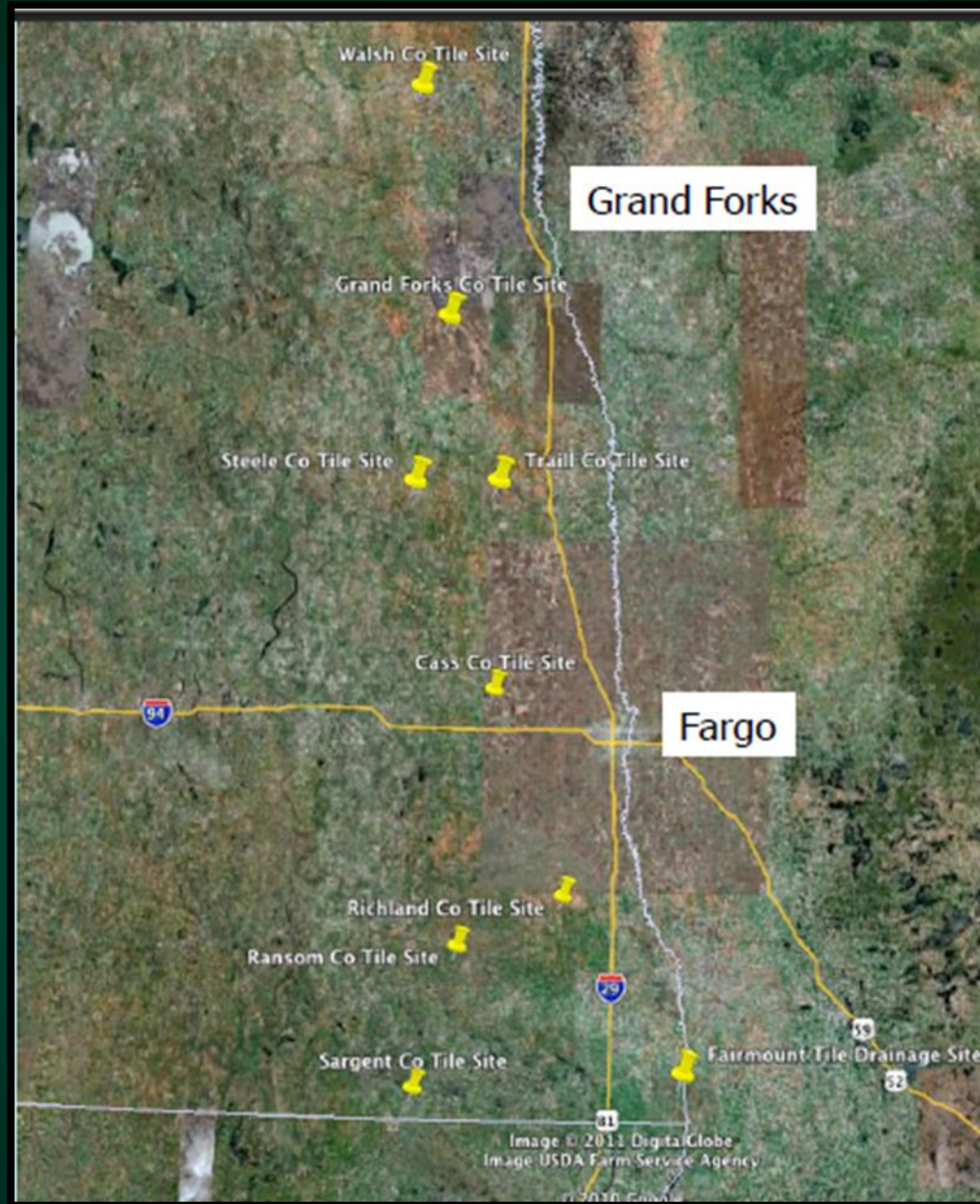
**Aquatic  
Standards**



# P h a s e I

| Parameter                    | Stds. of State | Other Studies of surface water | EPA's Drinking Water Std. |
|------------------------------|----------------|--------------------------------|---------------------------|
| pH                           | ↓              | ↓                              |                           |
| P (phosphorus)               | ↓              | ↓                              |                           |
| SO4 (sulfate)                | ↑              | ↑                              | ↑                         |
| Ba (barium)                  | ↑              |                                |                           |
| TDS (total dissolved solids) |                |                                | ↑                         |
| NO3(N) (nitrate nitrogen)    | ↑              |                                | ↑                         |
| Mg (magnesium)               | ↑              |                                |                           |
| Na (sodium)                  |                |                                |                           |
| Cl (chloride)                | ↓              |                                | 2↑ 16↓                    |
| EC (elec. cond)              |                |                                |                           |
| Al (aluminum)                | 9 of 248 ↑     |                                | ↓                         |
| Se (selenium)                | 8 sites ↓ 10 ↑ |                                |                           |

# Phase II



# Richland County



Downstream  
From Sheyenne  
Grasslands



| Parameter                    | Aquatics        | Primary Drinking H2O | Secondary Drinking H2O | Stds of Qual for Waters of the State |
|------------------------------|-----------------|----------------------|------------------------|--------------------------------------|
| Cu (copper)                  | 30.5 ug/l       |                      |                        |                                      |
| P (phosphorus)               |                 |                      |                        | 1.0mg/l                              |
| SO4 (sulfate)                |                 |                      | 250 mg/l               | 450 -750 mg/l                        |
| Zn (zinc)                    | 388 ug/l        |                      | 5 mg/l or 5000ug/l     |                                      |
| TDS (total dissolved solids) |                 |                      | 500mg/l                |                                      |
| NO3(N) (nitrate nitrogen)    |                 | 10 mg/l              |                        |                                      |
| Mg (magnesium)               |                 |                      |                        |                                      |
| Na (sodium)                  |                 |                      |                        |                                      |
| Cl (chloride)                |                 |                      | 250 mg/l               | 250 mg/l                             |
| EC (elec. cond)              |                 |                      |                        |                                      |
| Al (aluminum)                | 750 ug/l        |                      |                        |                                      |
| Se (selenium)                | 20 ug/l (acute) |                      |                        | 12                                   |

| Parameter                    | Aquatics        | Primary Drinking H2O | Secondary Drinking H2O | Stds of Qual for Waters of the State |
|------------------------------|-----------------|----------------------|------------------------|--------------------------------------|
| Cu (copper)                  | 30.5 ug/l       |                      |                        |                                      |
| P (phosphorus)               |                 |                      |                        | 1.0 mg/l                             |
| SO4 (sulfate)                |                 |                      | 250 mg/l               | 450 – 750 mg/l                       |
| Zn (zinc)                    | 388 ug/l        |                      | 5 mg/l or 5000 ug/l    |                                      |
| TDS (total dissolved solids) |                 |                      | 500mg/l                |                                      |
| NO3(N) (nitrate nitrogen)    |                 | 10 mg/l              |                        |                                      |
| Mg (magnesium)               |                 |                      |                        |                                      |
| Na (sodium)                  |                 |                      |                        |                                      |
| Cl (chloride)                |                 |                      | 250 mg/l               | 250 mg/l                             |
| EC (elec. cond)              |                 |                      |                        |                                      |
| Al (aluminum)                | 750 ug/l        |                      |                        |                                      |
| Se (selenium)                | 20 ug/l (acute) |                      |                        |                                      |

**Average – 7,953 mg/l**  
**High – 9,250 mg/l**  
**Low – 4,430 mg/l**

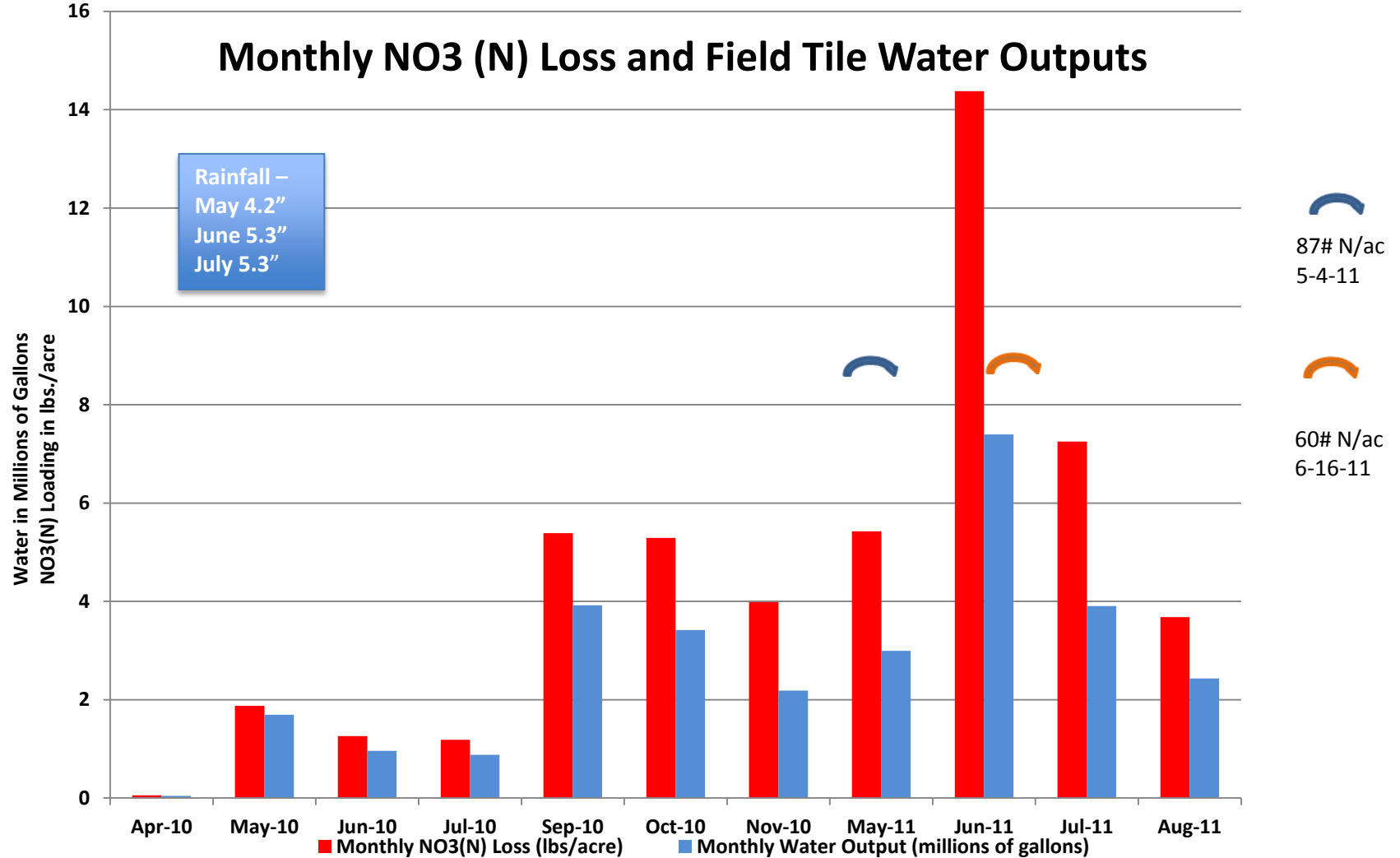
**Average – 30 mg/l**  
**High – 37 mg/l**  
**Low – 23 mg/l**

All samples below the standards

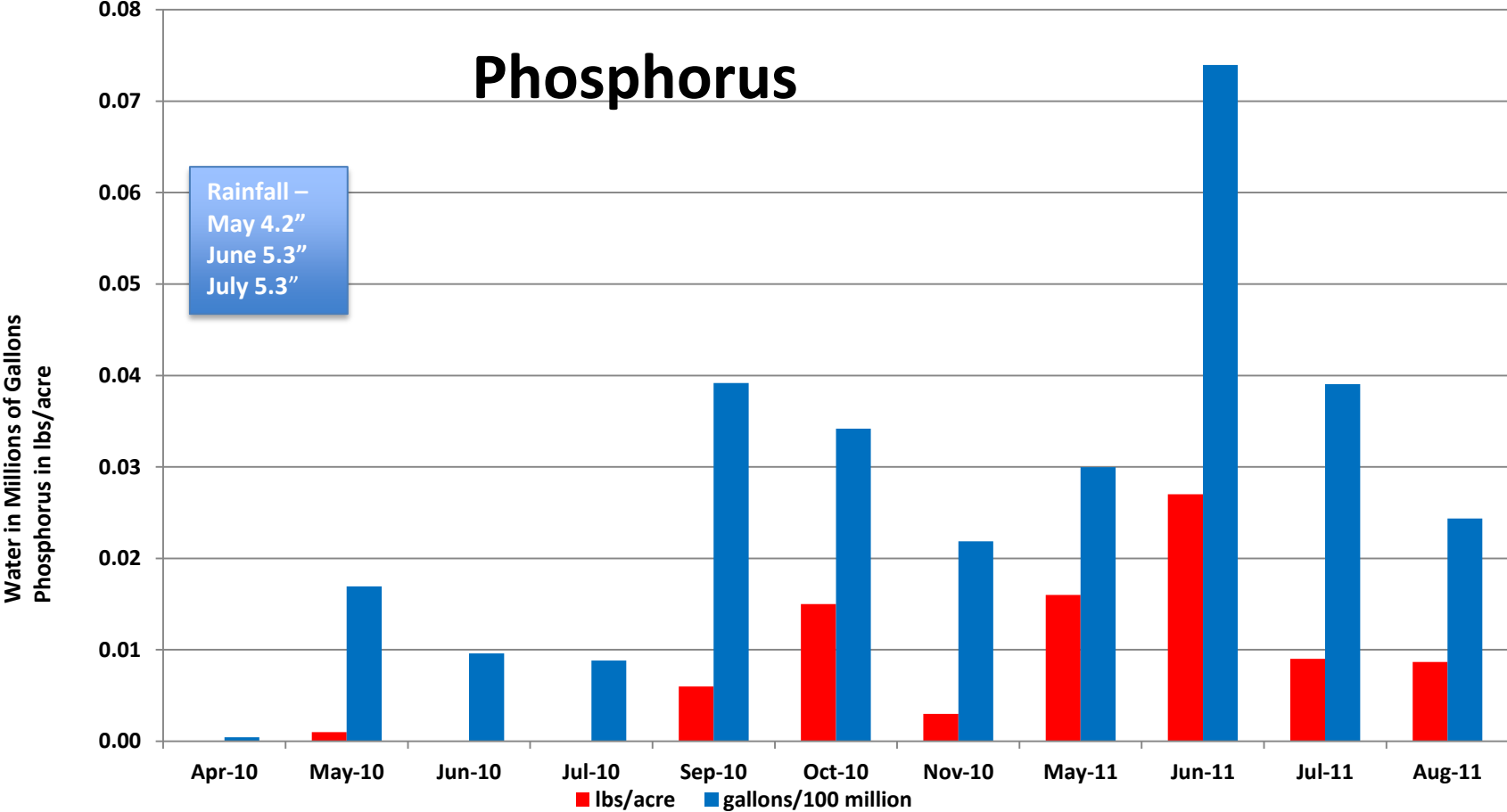
| Parameter                    | Aquatics        | Primary Drinking H2O   | Secondary Drinking H2O | Stds of Qual for Waters of the State              |
|------------------------------|-----------------|--|------------------------|---|
| Cu (copper)                  | 30.5 ug/l       | <b>No detects</b>  |                        |   |
| P (phosphorus)               |                 |  | 1.0 mg/l               |   |
| SO4 (sulfate)                |                 |  | 250 mg/l               | 450-750 mg/l                                      |
| Zn (zinc)                    | 388 ug/l        |  | 5 mg/l or 5000 ug/l    |   |
| TDS (total dissolved solids) |                 |  | 500mg/l                |   |
| NO3(N) (nitrate nitrogen)    |                 | 10 mg/l  |                        |   |
| Mg (magnesium)               |                 | <b>No detect from tile but high in 4 of 19 up and downstream samples</b> |                        |   |
| Na (sodium)                  |                 |  |                        |   |
| Cl (chloride)                |                 |  | 250 mg/l               | 250 mg/l  |
| EC (elec. cond)              |                 |  |                        |   |
| Al (aluminum)                | 750 ug/l        |  |                        | <b>17 of 19 samples were over the acute level</b> |
| Se (selenium)                | 20 ug/l (acute) |  |                        |   |



# Monthly NO3 (N) Loss and Field Tile Water Outputs



# Phosphorus



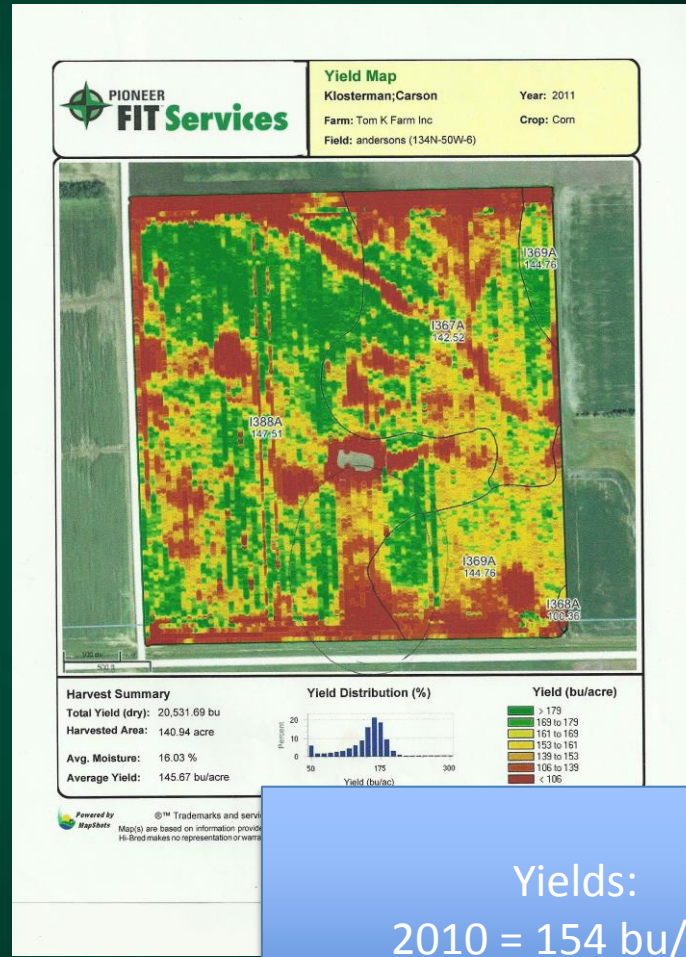
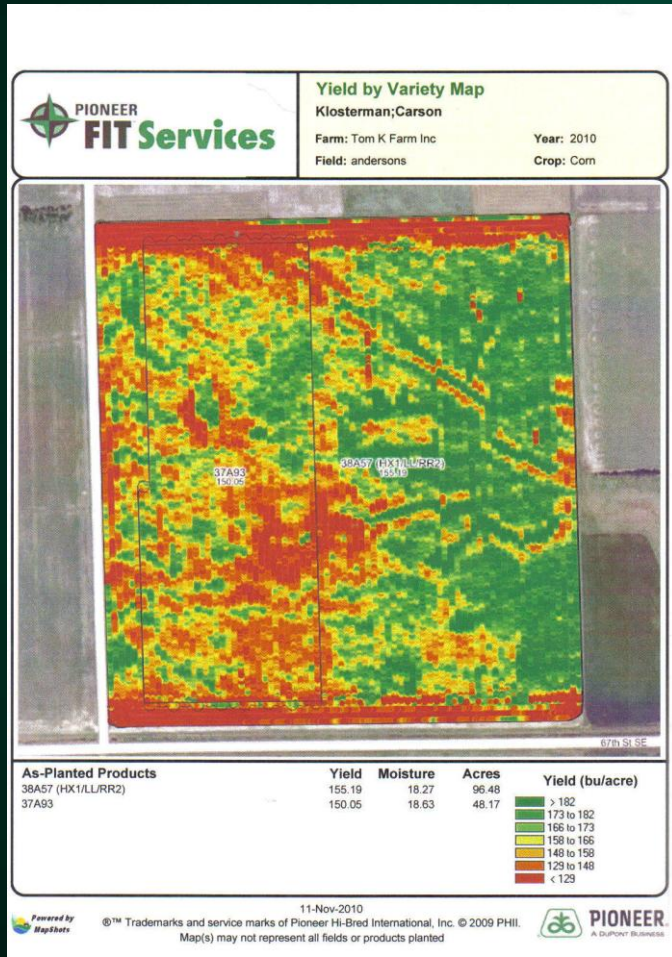
Richland County  
142 acres installed in 2007

Beardon silty clay loam, saline soil  
East side more saline affected



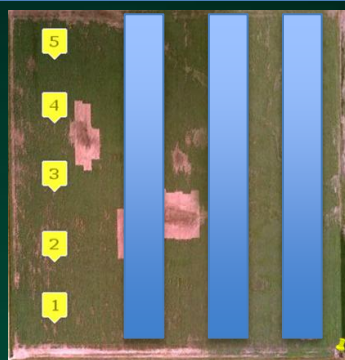


# 2010 and 2011 Yield Maps



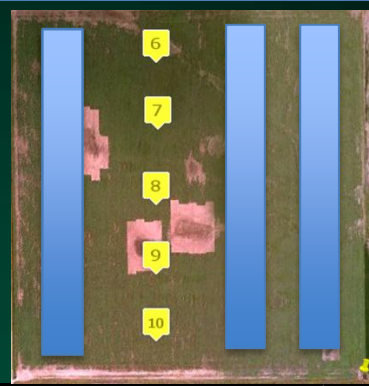
Yields:  
 2010 = 154 bu/acre  
 2011 = 146 bu/acre

# 1-5



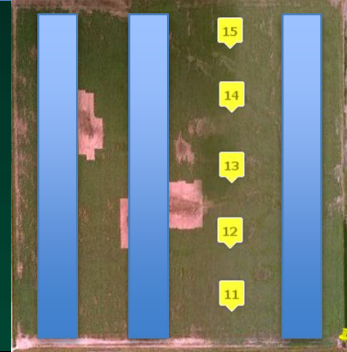
| Richland Co site | Depth | EC 2010 | EC 2011 | K 2010 | K 2011 | Ca 2010 | Ca 2011 | Mg 2010 | Mg 2011 | Na 2010 | Na 2011 | Cl 2010 | Cl 2011 | S 2010 | S 2011 | N 2010 | N 2011 | P 2010 | P 2011 | decreased or the same = |
|------------------|-------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|--------|--------|--------|-------------------------|
| #1               | 1_6   | 2.3     | 2.5     | 150.0  | 214.0  | 7061.6  | 8630.4  | 1211.6  | 1400.0  | 256.2   | 342.0   | 10.7    | 16.9    | 317.0  | 317.0  | 14.0   | 23.0   | 14.0   | 15.0   |                         |
|                  | 6_12  | 2.6     | 3.0     | 135.0  | 154.0  | 3084.8  | 1091.2  | 1271.1  | 1660.0  | 567.0   | 621.0   | 17.8    | 6.3     | 317.0  | 354.0  | 37.0   | 21.0   | 3.0    | 2.0    |                         |
|                  | 12_18 | 2.1     | 1.9     | 135.0  | 190.0  | 1999.6  | 6150.4  | 1159.6  | 1380.0  | 831.6   | 702.0   | 11.9    | 4.2     | 354.0  | 354.0  | 18.0   | 17.0   | 1.0    | 1.0    |                         |
|                  | 18_24 | 2.3     | 2.4     | 115.0  | 184.0  | 2638.8  | 7638.4  | 936.6   | 1120.0  | 726.6   | 738.0   | 16.6    | 7.0     | 354.0  | 354.0  | 7.0    | 14.0   | 1.0    | 1.0    |                         |
| #2               | 0_6   | 2.2     | 2.4     | 200.0  | 224.0  | 4192.4  | 16070.4 | 817.7   | 1400.0  | 126.0   | 189.0   | 15.5    | 10.7    | 271.0  | 317.0  | 8.0    | 6.0    | 19.0   | 13.0   |                         |
|                  | 6_12  | 1.7     | 2.3     | 115.0  | 132.0  | 11477.0 | 27379.2 | 794.6   | 1100.0  | 117.6   | 198.0   | 10.4    | 12.8    | 317.0  | 354.0  | 13.0   | 3.0    | 13.0   | 2.0    |                         |
|                  | 12_18 | 2.4     | 2.5     | 100.0  | 144.0  | 13379.9 | 32636.8 | 817.7   | 1020.0  | 340.2   | 315.0   | 15.9    | 4.7     | 354.0  | 354.0  | 15.0   | 3.0    | 2.0    | 0.0    |                         |
|                  | 18_24 | 2.4     | 2.5     | 140.0  | 160.0  | 3452.1  | 39084.8 | 683.9   | 980.0   | 424.2   | 351.0   | 2.1     | 2.1     | 354.0  | 354.0  | 3.0    | 6.0    | 2.0    | 0.0    |                         |
| #3               | 0_6   | 2.0     | 2.3     | 130.0  | 248.0  | 5277.6  | 9424.0  | 929.2   | 1420.0  | 296.1   | 279.0   | 10.9    | 10.9    | 271.0  | 317.0  | 11.0   | 14.0   | 18.0   | 8.0    |                         |
|                  | 6_12  | 2.3     | 2.6     | 192.0  | 130.0  | 20924.7 | 21228.8 | 115.0   | 1360.0  | 281.4   | 414.0   | 8.8     | 8.8     | 317.0  | 354.0  | 11.0   | 17.0   | 3.0    | 1.0    |                         |
|                  | 12_18 | 2.5     | 2.8     | 100.0  | 162.0  | 10258.0 | 21328.0 | 914.3   | 1280.0  | 529.2   | 675.0   | 14.6    | 7.2     | 354.0  | 354.0  | 8.0    | 22.0   | 1.0    | 1.0    |                         |
|                  | 18_24 | 3.1     | 2.8     | 130.0  | 160.0  | 13900.3 | 10614.4 | 1115.0  | 1240.0  | 663.6   | 666.0   | 7.5     | 7.5     | 354.0  | 354.0  | 16.0   | 27.0   | 1.0    | 0.0    |                         |
| #4               | 0_6   | 2.4     | 2.3     | 180.0  | 212.0  | 8771.3  | 10515.2 | 1085.3  | 1340.0  | 319.2   | 207.0   | 16.4    | 14.4    | 291.0  | 317.0  | 15.0   | 18.0   | 17.0   | 13.0   |                         |
|                  | 6_12  | 2.0     | 2.4     | 91.0   | 128.0  | 22337.1 | 23708.8 | 728.5   | 1280.0  | 264.6   | 360.0   | 11.9    | 10.5    | 317.0  | 354.0  | 18.0   | 24.0   | 3.0    | 4.0    |                         |
|                  | 12_18 | 2.5     | 2.4     | 77.0   | 118.0  | 15944.4 | 12995.2 | 832.5   | 1040.0  | 604.8   | 468.0   | 14.8    | 7.0     | 354.0  | 354.0  | 21.0   | 25.0   | 1.0    | 1.0    |                         |
|                  | 18_24 | 2.1     | 1.7     | 120.0  | 106.0  | 1509.0  | 6844.8  | 988.6   | 980.0   | 924.0   | 531.0   | 21.5    | 6.8     | 354.0  | 317.0  | 29.0   | 26.0   | 1.0    | 0.0    |                         |
| #5               | 0_6   | 2.1     | 2.4     | 116.0  | 174.0  | 7544.8  | 13292.8 | 1233.9  | 1360.0  | 289.2   | 243.0   | 16.7    | 10.9    | 317.0  | 317.0  | 27.0   | 23.0   | 12.0   | 7.0    |                         |
|                  | 6_12  | 1.9     | 2.4     | 98.0   | 116.0  | 8994.3  | 10515.2 | 973.8   | 1380.0  | 268.8   | 243.0   | 13.9    | 4.2     | 354.0  | 317.0  | 24.0   | 21.0   | 3.0    | 2.0    |                         |
|                  | 12_18 | 1.3     | 1.1     | 106.0  | 128.0  | 1442.1  | 1289.6  | 951.5   | 1220.0  | 361.4   | 459.0   | 16.2    | 5.1     | 317.0  | 291.0  | 22.0   | 20.0   | 1.0    | 1.0    |                         |
|                  | 18_24 | 1.2     | 1.0     | 105.0  | 116.0  | 669.0   | 1686.4  | 297.3   | 1080.0  | 567.0   | 414.0   | 5.4     | 5.4     | 317.0  | 317.0  | 17.0   | 19.0   | 1.0    | 1.0    |                         |

# 6-10



| Richland Co site | Depth | EC 2010 | EC 2011 | K 2010 | K 2011 | Ca 2010 | Ca 2011 | Mg 2010 | Mg 2011 | Na 2010 | Na 2011 | Cl 2010 | Cl 2011 | S 2010 | S 2011 | N 2010 | N 2011 | P 2010 | P 2011 | decreased or the same= |
|------------------|-------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|--------|--------|--------|------------------------|
| #6               | 0_6   | 1.6     | 1.1     | 135.0  | 182.0  | 6704.8  | 8630.4  | 669.0   | 800.0   | 130.2   | 108.0   | 26.8    | 19.5    | 218.0  | 254.0  | 22.0   | 18.0   | 5.0    | 7.0    |                        |
|                  | 6_12  | 1.8     | 1.6     | 70.0   | 106.0  | 7909.0  | 9721.6  | 817.7   | 820.0   | 33.8    | 180.0   | 27.9    | 6.8     | 291.0  | 291.0  | 20.0   | 10.0   | 1.0    | 3.0    |                        |
|                  | 12_18 | 1.0     | 1.4     | 77.0   | 78.0   | 6125.0  | 8233.6  | 832.5   | 860.0   | 478.8   | 207.0   | 32.6    | 7.7     | 291.0  | 271.0  | 9.0    | 9.0    | 1.0    | 1.0    |                        |
|                  | 18_24 | 0.8     | 0.8     | 69.0   | 102.0  | 2661.1  | 3174.4  | 639.3   | 920.0   | 512.8   | 270.0   | 21.3    | 5.1     | 291.0  | 271.0  | 9.0    | 12.0   | 0.0    | 0.0    |                        |
| #7               | 0_6   | 1.4     | 1.9     | 97.0   | 138.0  | 6407.5  | 9424.0  | 787.9   | 980.0   | 197.4   | 279.0   | 16.4    | 21.5    | 240.0  | 291.0  | 16.0   | 33.0   | 5.0    | 1.0    |                        |
|                  | 6_12  | x       | 1.0     | 54.0   | 102.0  | 7091.4  | 5852.8  | 906.9   | 800.0   | 36.2    | 549.0   | 20.3    | 13.0    | 291.0  | 291.0  | 32.0   | 24.0   | 1.0    | 6.0    |                        |
|                  | 12_18 | 1.3     | 1.0     | 58.0   | 78.0   | 5991.2  | 6944.0  | 743.3   | 940.0   | 55.4    | 324.0   | 25.0    | 13.2    | 291.0  | 291.0  | 42.0   | 32.0   | 0.6    | 1.0    |                        |
|                  | 18_24 | 1.1     | 2.1     | 57.0   | 92.0   | 5188.4  | 7638.4  | 624.4   | 1040.0  | 663.6   | 405.0   | 27.0    | 14.4    | 317.0  | 317.0  | 20.0   | 39.0   | 2.0    | 1.0    |                        |
| #8               | 0_6   | 1.7     | 2.1     | 107.0  | 152.0  | 6452.1  | 8432.0  | 862.3   | 1080.0  | 445.2   | 351.0   | 19.4    | 36.8    | 254.0  | 291.0  | 11.0   | 13.0   | 5.0    | 6.0    |                        |
|                  | 6_12  | 1.8     | 2.1     | 78.0   | 114.0  | 16368.1 | 9027.0  | 832.5   | 1140.0  | 779.6   | 405.0   | 17.3    | 11.8    | 177.0  | 291.0  | 9.0    | 11.0   | 9.0    | 3.0    |                        |
|                  | 12_18 | 1.8     | 2.0     | 70.0   | 108.0  | 14138.1 | 7142.4  | 698.7   | 980.0   | 504.0   | 441.0   | 16.4    | 12.3    | 317.0  | 291.0  | 8.0    | 11.0   | 7.0    | 2.0    |                        |
|                  | 18_24 | 1.6     | 1.6     | 66.0   | 118.0  | 2542.2  | 2182.4  | 713.6   | 1000.0  | 585.8   | 522.0   | 16.2    | 7.7     | 317.0  | 317.0  | 8.0    | 12.0   | 1.0    | 1.0    |                        |
| #9               | 0_6   | 1.7     | 2.2     | 175.0  | 244.0  | 6883.2  | 8729.6  | 847.4   | 1180.0  | 273.0   | 369.0   | 26.7    | 28.7    | 254.0  | 317.0  | 29.0   | 13.0   | 11.0   | 12.0   |                        |
|                  | 6_12  | 1.9     | 2.6     | 85.0   | 158.0  | 7894.2  | 13491.2 | 758.2   | 1260.0  | 340.2   | 486.0   | 10.6    | 18.1    | 291.0  | 317.0  | 20.0   | 14.0   | 3.0    | 3.0    |                        |
|                  | 12_18 | 1.9     | 2.3     | 89.0   | 156.0  | 6868.4  | 28272.0 | 802.8   | 960.0   | 466.2   | 603.0   | 11.3    | 10.2    | 317.0  | 354.0  | 35.0   | 13.0   | 1.0    | 1.0    |                        |
|                  | 18_24 | 2.4     | 2.8     | 100.0  | 140.0  | 27428.9 | 29264.0 | 728.5   | 980.0   | 806.4   | 837.0   | 19.4    | 5.8     | 354.0  | 354.0  | 36.0   | 18.0   | 0.4    | 0.0    |                        |
| #10              | 0_6   | 1.3     | 1.2     | 220.0  | 200.0  | 6481.8  | 7142.4  | 966.3   | 1100.0  | 268.8   | 162.0   | 14.6    | 18.8    | 146.0  | 228.0  | na     | 12.0   | 12.0   | 4.0    |                        |
|                  | 6_12  | 2.0     | 2.1     | 131.0  | 206.0  | 8741.6  | 11507.2 | 1040.7  | 1240.0  | 346.6   | 243.0   | 14.6    | 4.2     | 254.0  | 291.0  | na     | 7.0    | 2.0    | 1.0    |                        |
|                  | 12_18 | 2.4     | 2.0     | 143.0  | 162.0  | 17750.7 | 21824.0 | 996.1   | 1100.0  | 407.4   | 279.0   | 18.0    | 1.7     | 317.0  | 317.0  | 18.0   | 5.0    | 1.0    | 1.0    |                        |
|                  | 18_24 | 2.3     | 2.1     | 97.0   | 136.0  | 14004.3 | 26288.0 | 787.9   | 980.0   | 487.3   | 297.0   | 10.1    | 2.4     | 317.0  | 354.0  | 17.0   | 5.0    | 1.0    | 0.0    |                        |

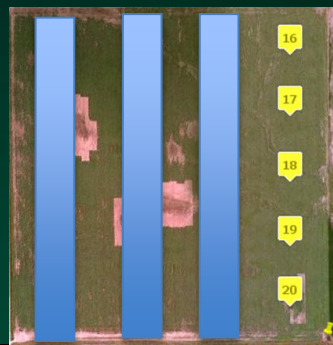
# 11-15



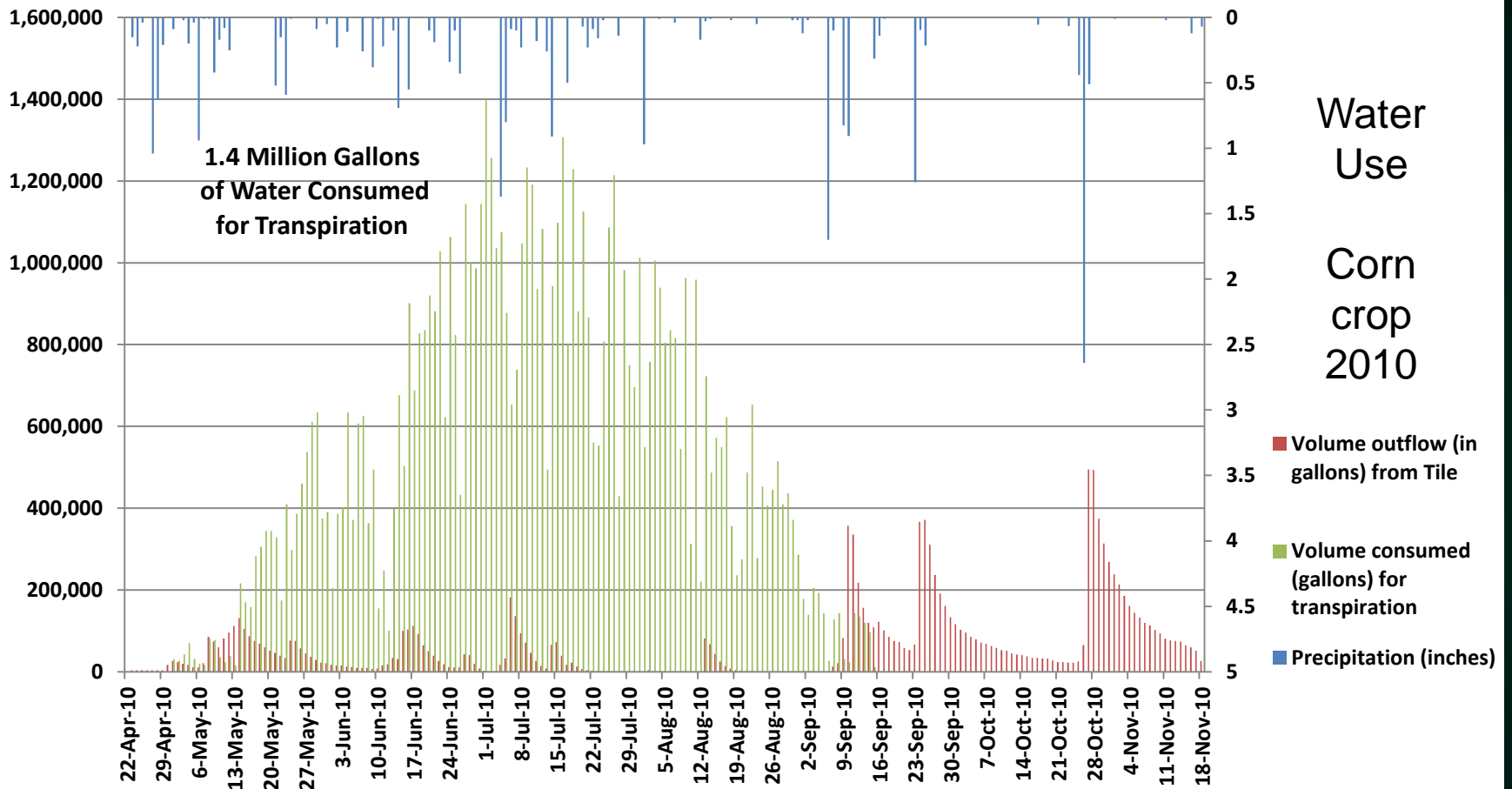
| Richland Co site | Depth | EC 2010 | EC 2011 | K 2010 | K 2011 | Ca 2010 | Ca 2011 | Mg 2010 | Mg 2011 | Na 2010 | Na 2011 | Cl 2010 | Cl 2011 | S 2010 | S 2011 | N 2010 | N 2011 | P 2010 | P 2011 | decreased or the same = |
|------------------|-------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|--------|--------|--------|-------------------------|
| #11              | 0_6   | 1.1     | 0.5     | 125.0  | 166.0  | 6511.6  | 5456.0  | 639.3   | 520.0   | 201.2   | 60.8    | 11.6    | 6.8     | 172.0  | 61.0   | na     | 11.0   | 3.0    | 4.0    |                         |
|                  | 6_12  | 1.6     | 0.5     | 115.0  | 98.0   | 7938.8  | 3174.4  | 713.6   | 360.0   | 483.0   | 51.2    | 9.0     | 4.3     | 271.0  | 88.0   | 13.0   | 5.0    | 1.0    | 2.0    |                         |
|                  | 12_18 | 2.1     | 0.4     | 88.0   | 110.0  | 8206.4  | 2480.0  | 743.3   | 400.0   | 340.2   | 52.4    | 13.6    | 4.7     | 291.0  | 43.0   | 14.0   | 5.0    | 0.8    | 1.0    |                         |
|                  | 18_24 | 2.2     | 0.4     | 68.0   | 88.0   | 1843.5  | 2281.6  | 579.8   | 400.0   | 369.6   | 62.2    | 12.9    | 3.8     | 317.0  | 76.0   | 14.0   | 5.0    | 0.6    | 1.0    |                         |
| #12              | 0_6   | 2.8     | 3.2     | 188.0  | 241.0  | 9455.2  | 11408.0 | 1278.5  | 1720.0  | 441.0   | 324.0   | 13.6    | 12.1    | 317.0  | 354.0  | na     | 13.0   | 22.0   | 19.0   |                         |
|                  | 6_12  | 2.9     | 3.5     | 100.0  | 180.0  | 28246.5 | 10614.4 | 1085.3  | 1820.0  | 4783.0  | 315.0   | 17.4    | 16.1    | 317.0  | 354.0  | 12.0   | 17.0   | 5.0    | 3.0    |                         |
|                  | 12_18 | 2.3     | 3.3     | 125.0  | 158.0  | 8072.6  | 8928.0  | 1204.2  | 1560.0  | 630.0   | 261.0   | 14.3    | 16.3    | 317.0  | 354.0  | 31.0   | 30.0   | 2.0    | 1.0    |                         |
|                  | 18_24 | 2.4     | 3.2     | 112.0  | 130.0  | 6779.2  | 8035.2  | 1278.5  | 1360.0  | 756.0   | 171.0   | 21.0    | 11.7    | 354.0  | 354.0  | 47.0   | 36.0   | 1.0    | 1.0    |                         |
| #13              | 0_6   | 2.7     | 2.1     | 225.0  | 284.0  | 7834.7  | 9225.6  | 1129.9  | 1100.0  | 495.7   | 162.0   | 18.2    | 6.1     | 291.0  | 317.0  | 9.0    | 10.0   | 10.0   | 8.0    |                         |
|                  | 6_12  | 2.2     | 2.0     | 148.0  | 194.0  | 13870.5 | 21129.6 | 1352.9  | 1040.0  | 747.6   | 135.0   | 17.6    | 5.9     | 317.0  | 317.0  | 36.0   | 7.0    | 3.0    | 3.0    |                         |
|                  | 12_18 | 2.0     | 1.9     | 116.0  | 106.0  | 18553.5 | 26486.4 | 1159.5  | 740.0   | 761.2   | 126.0   | 11.2    | 4.7     | 354.0  | 354.0  | 29.0   | 6.0    | 1.0    | 0.0    |                         |
|                  | 18_24 | 2.2     | 1.9     | 80.0   | 64.0   | 27072.1 | 41465.6 | 787.9   | 640.0   | 810.6   | 207.0   | 14.8    | 0.6     | 354.0  | 354.0  | 17.0   | 10.0   | 0.0    | 0.0    |                         |
| #14              | 0_6   | 1.9     | 1.3     | 218.0  | 350.0  | 7790.1  | 8332.8  | 1025.8  | 1060.0  | 676.2   | 261.0   | 12.9    | 12.1    | 254.0  | 228.0  | 4.0    | 11.0   | 7.0    | 15.0   |                         |
|                  | 6_12  | 2.1     | 2.0     | 103.0  | 130.0  | 13647.8 | 12896.0 | 936.6   | 1140.0  | 287.8   | 153.0   | 17.7    | 3.6     | 317.0  | 317.0  | 51.0   | 5.0    | 2.0    | 2.0    |                         |
|                  | 12_18 | 1.7     | 2.1     | 105.0  | 126.0  | 16680.4 | 10217.6 | 951.5   | 1140.0  | 373.0   | 225.0   | 19.2    | 0.1     | 317.0  | 317.0  | 49.0   | 5.0    | 1.0    | 2.0    |                         |
|                  | 18_24 | 2.5     | 2.1     | 99.0   | 96.0   | 2555.7  | 13987.2 | 906.9   | 940.0   | 512.0   | 243.0   | 14.8    | 5.0     | 354.0  | 317.0  | na     | 4.0    | 0.1    | 1.0    |                         |
| #15              | 0_6   | 1.7     | 0.8     | 202.0  | 268.0  | 7061.6  | 7936.0  | 1100.1  | 1080.0  | 281.7   | 180.0   | 25.4    | 17.9    | 228.0  | 166.0  | 21.0   | 15.0   | 4.0    | 10.0   |                         |
|                  | 6_12  | 2.2     | 2.2     | 159.0  | 154.0  | 6838.6  | 9622.4  | 1471.8  | 1220.0  | 470.4   | 252.0   | 21.5    | 8.0     | 317.0  | 291.0  | 40.0   | 9.0    | 2.0    | 3.0    |                         |
|                  | 12_18 | 2.5     | 2.3     | 152.0  | 158.0  | 7225.2  | 10217.6 | 1442.0  | 1460.0  | 581.0   | 306.0   | 17.3    | 1.5     | 317.0  | 317.0  | 20.0   | 5.0    | 1.0    | 1.0    |                         |
|                  | 18_24 | 2.5     | 2.4     | 147.0  | 148.0  | 14707.1 | 22915.2 | 1263.7  | 1340.0  | 646.8   | 387.0   | 14.8    | 2.7     | 354.0  | 354.0  | na     | 7.0    | 0.1    | 1.0    |                         |



# 16-20

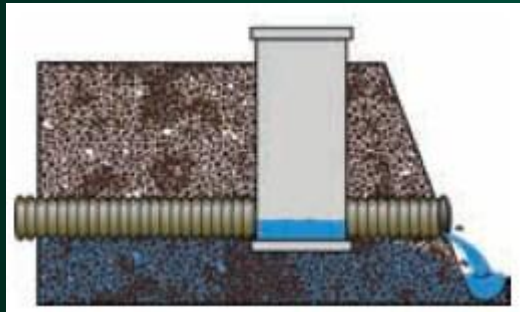


| Richland Co site | Depth | EC 2010 | EC 2011 | K 2010 | K 2011 | Ca 2010 | Ca 2011 | Mg 2010 | Mg 2011 | Na 2010 | Na 2011 | Cl 2010 | Cl 2011 | S 2010 | S 2011 | N 2010 | N 2011 | P 2010 | P 2011 | decreased or the same = |
|------------------|-------|---------|---------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|--------|--------|--------|--------|--------|--------|-------------------------|
| #16              | 0_6   | 1.2     | 1.0     | 250.0  | 262.0  | 6660.2  | 7638.4  | 1263.7  | 940.0   | 231.0   | 111.2   | 22.4    | 12.4    | 208.0  | 129.0  | 20.0   | 16.0   | 6.0    | 6.0    |                         |
|                  | 6_12  | 2.4     | 1.6     | 178.0  | 136.0  | 7373.8  | 7638.4  | 1263.7  | 1060.0  | 315.0   | 153.0   | 17.8    | 2.4     | 291.0  | 271.0  | 16.0   | 6.0    | 6.0    | 1.0    |                         |
|                  | 12_18 | 2.3     | 2.1     | 152.0  | 116.0  | 9505.0  | 10515.2 | 1397.5  | 1120.0  | 495.6   | 153.0   | 15.0    | 5.0     | 317.0  | 317.0  | 20.0   | 5.0    | 5.0    | 1.0    |                         |
|                  | 18_24 | 2.4     | 2.2     | 129.0  | 96.0   | 8622.6  | 16070.4 | 1620.3  | 960.0   | 655.2   | 144.0   | 18.3    | 7.7     | 317.0  | 354.0  | 25.0   | 6.0    | 6.0    | 0.0    |                         |
| #17              | 0_6   | 0.8     | 2.0     | 261.0  | 240.0  | 5887.2  | 7340.8  | 1382.6  | 1180.0  | 130.2   | 162.0   | 12.7    | 13.5    | 92.0   | 271.0  | 12.0   | 20.0   | 20.0   | 9.0    |                         |
|                  | 6_12  | 1.6     | 2.1     | 137.0  | 140.0  | 12963.7 | 8729.6  | 1070.4  | 1120.0  | 130.2   | 252.0   | 13.6    | 11.9    | 271.0  | 317.0  | 22.0   | 11.0   | 11.0   | 2.0    |                         |
|                  | 12_18 | 1.8     | 2.3     | 126.0  | 144.0  | 14628.7 | 12300.8 | 966.3   | 1060.0  | 205.8   | 315.0   | 21.3    | 11.2    | 317.0  | 317.0  | 34.0   | 14.0   | 14.0   | 1.0    |                         |
|                  | 18_24 | 2.2     | 2.4     | 277.0  | 98.0   | 9826.8  | 12102.4 | 1025.8  | 1060.0  | 268.8   | 369.0   | 21.0    | 6.4     | 317.0  | 317.0  | 52.0   | 14.0   | 14.0   | 1.0    |                         |
| #18              | 0_6   | 0.6     | 0.8     | 269.0  | 298.0  | 6764.3  | 7340.8  | 862.3   | 940.0   | 54.6    | 108.0   | 16.6    | 23.2    | 27.0   | 95.0   | 13.0   | 14.0   | 14.0   | 9.0    |                         |
|                  | 6_12  | 0.5     | 1.1     | 269.0  | 150.0  | 5719.7  | 7440.0  | 906.9   | 1060.0  | 113.4   | 153.0   | 7.5     | 0.6     | 43.0   | 240.0  | 9.0    | 8.0    | 8.0    | 2.0    |                         |
|                  | 12_18 | 0.6     | 2.0     | 333.0  | 126.0  | 6645.4  | 10019.2 | 802.8   | 880.0   | 92.4    | 225.0   | 8.8     | 0.8     | 85.0   | 291.0  | 9.0    | 5.0    | 5.0    | 1.0    |                         |
|                  | 18_24 | 0.9     | 1.9     | 259.0  | 86.0   | 6779.2  | 17360.0 | 683.9   | 640.0   | 117.6   | 288.0   | 2.0     | 2.0     | 185.0  | 317.0  | 9.0    | 5.0    | 5.0    | 0.0    |                         |
| #19              | 0_6   | 1.4     | 2.2     | 307.0  | 324.0  | 4891.1  | 7142.4  | 966.3   | 1240.0  | 180.7   | 405.0   | 13.7    | 13.0    | 200.0  | 291.0  | 17.0   | 25.0   | 25.0   | 25.0   |                         |
|                  | 6_12  | 2.2     | 2.7     | 300.0  | 136.0  | 7388.7  | 9225.6  | 1546.1  | 1360.0  | 323.4   | 450.0   | 11.1    | 8.7     | 291.0  | 317.0  | 16.0   | 31.0   | 31.0   | 3.0    |                         |
|                  | 12_18 | 2.2     | 2.6     | 280.0  | 116.0  | 5247.9  | 12499.2 | 1486.1  | 1180.0  | 491.4   | 405.0   | 24.0    | 5.9     | 317.0  | 317.0  | 15.0   | 23.0   | 23.0   | 2.0    |                         |
|                  | 18_24 | 2.4     | 2.6     | 350.0  | 140.0  | 2899.0  | 16566.4 | 1248.8  | 1180.0  | 596.4   | 450.0   | 31.0    | 7.7     | 317.0  | 354.0  | 17.0   | 19.0   | 19.0   | 1.0    |                         |
| #20              | 0_6   | 1.4     | 1.2     | 350.0  | 296.0  | 6764.3  | 7836.8  | 1174.5  | 820.0   | 197.4   | 126.0   | 20.0    | 20.0    | 218.0  | 228.0  | 48.0   | 30.0   | 30.0   | 10.0   |                         |
|                  | 6_12  | 2.3     | 1.7     | 344.0  | 90.0   | 7072.6  | 13788.8 | 1442.1  | 780.0   | 277.2   | 135.0   | 23.2    | 9.8     | 317.0  | 271.0  | 83.0   | 26.0   | 26.0   | 2.0    |                         |
|                  | 12_18 | 2.3     | 1.8     | 301.0  | 86.0   | 8221.2  | 18649.6 | 1412.3  | 900.0   | 327.6   | 153.0   | 32.6    | 8.8     | 317.0  | 317.0  | 83.0   | 24.0   | 24.0   | 1.0    |                         |
|                  | 18_24 | 2.3     | 2.1     | 270.0  | 94.0   | 7641.4  | 25593.6 | 1531.3  | 980.0   | 504.1   | 198.0   | 34.7    | 13.5    | 317.0  | 354.0  | 44.0   | 32.0   | 32.0   | 1.0    |                         |



# Keeping nutrients out of downstream water bodies

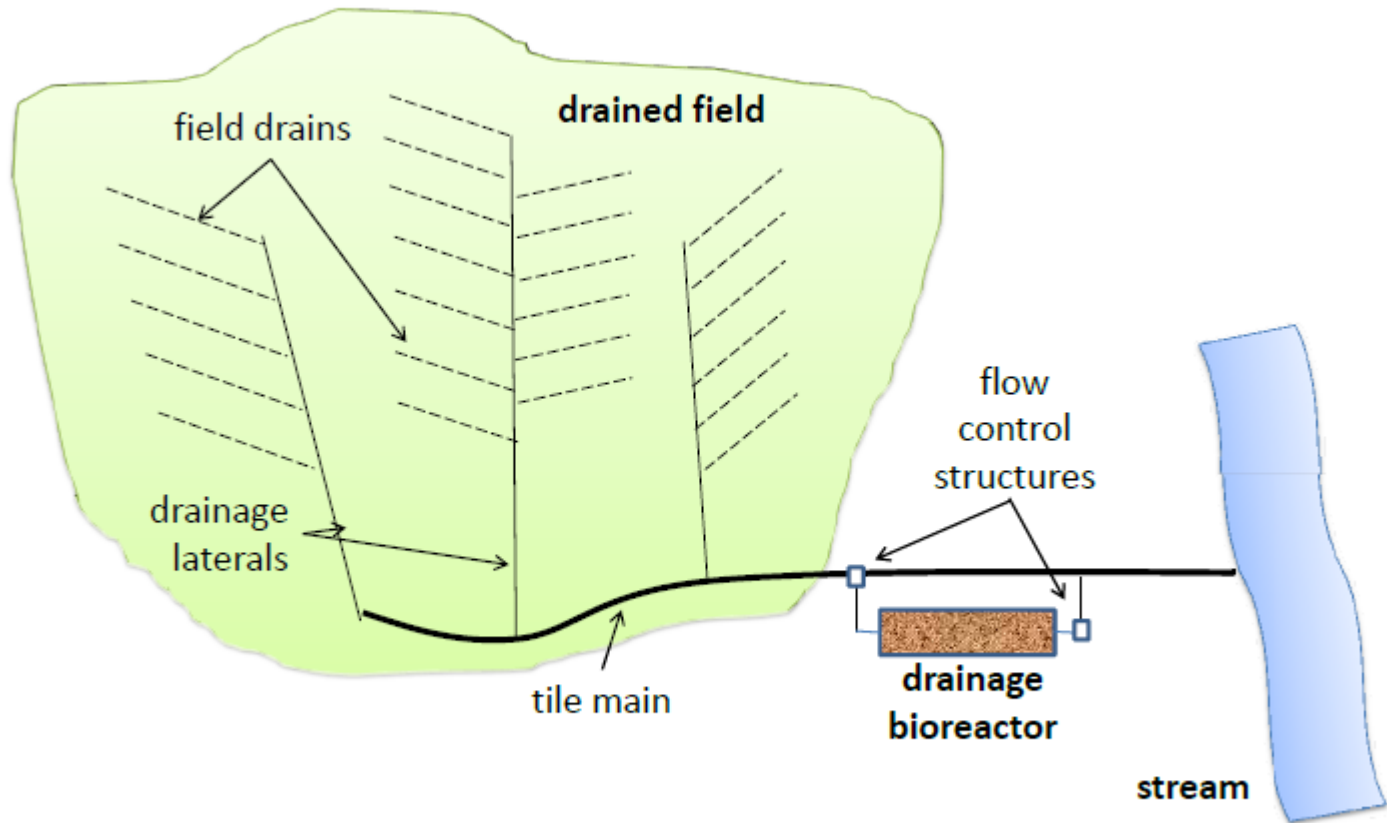
- Drainage Management



- Split Application of Fertilizer
- Wetlands

# Controlling nutrient loading

## In-Line Bioreactor



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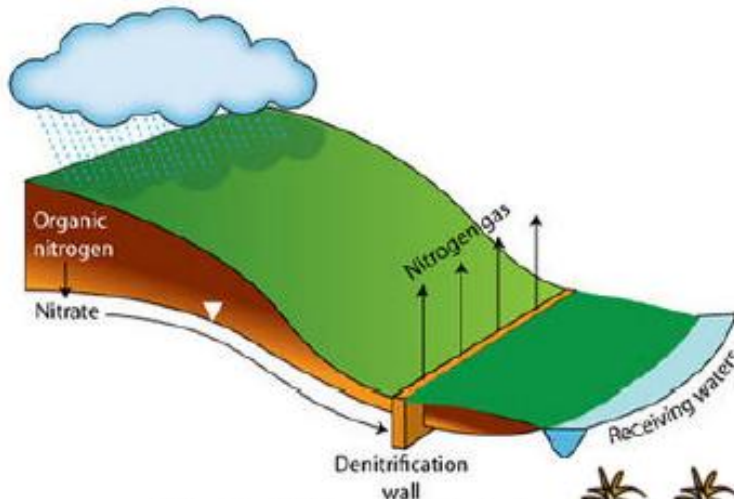


# Reactor Installation

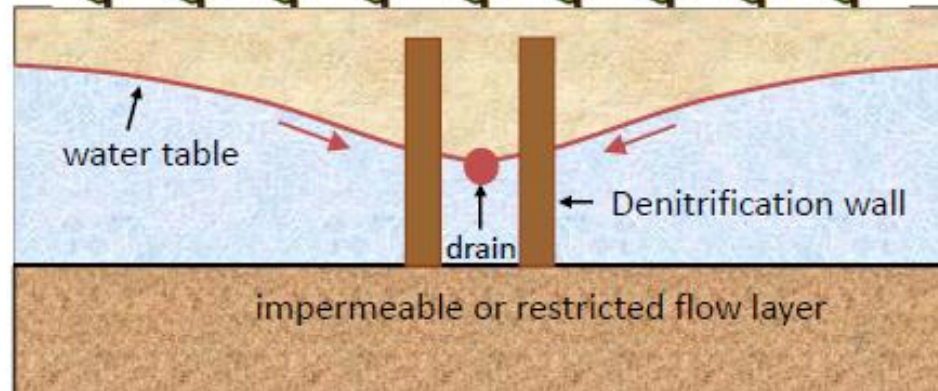


# Denitrification Wall

Denitrification walls intercept subsurface flow and use a carbon source such as sawdust or woodchips to remove nitrates by microbial denitrification.



University of Waikato, New Zealand



IOWA STATE UNIVERSITY

Question?

**NDSU** EXTENSION  
SERVICE