Water Quality and Monitoring Choices

DRE Webinar Series – Webinar 3

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BEST PRACTICES FOR DEEP ROW ENTRENCHMENT (DRE) OF BIOSOLIDS USING HYBRID POPLAR TREES

Abstract

Deep row entrenchment (DRE) is a biosolids beneficial reuse system suited to strip mine reclamation that uses a one-time application of biosolids in wide and shallow trenches covered with overburden, and planted with hybrid poplar cuttings. The trees utilize the nitrogen and other nutrients over a five to seven year rotation and produce many environmental benefits (reduced erosion, improved water quality, woody biomass, and wildlife habitat). DRE solves many of the problems associated with surface application but it is not well understood by regulators, environmentalists, and others. This publication brings together the science and operational experience for DRE for the purpose of encouraging its proper application.

Images on right: Abandoned gravel mine with eroded drainage channels in southern Maryland prior to reclamation and deep row entrenchment (top) and same site after deep row entrenchment and growth of hybrid poplar trees (bottom).

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  - Porous media flow
  - Nitrogen & Phosphorus cycle
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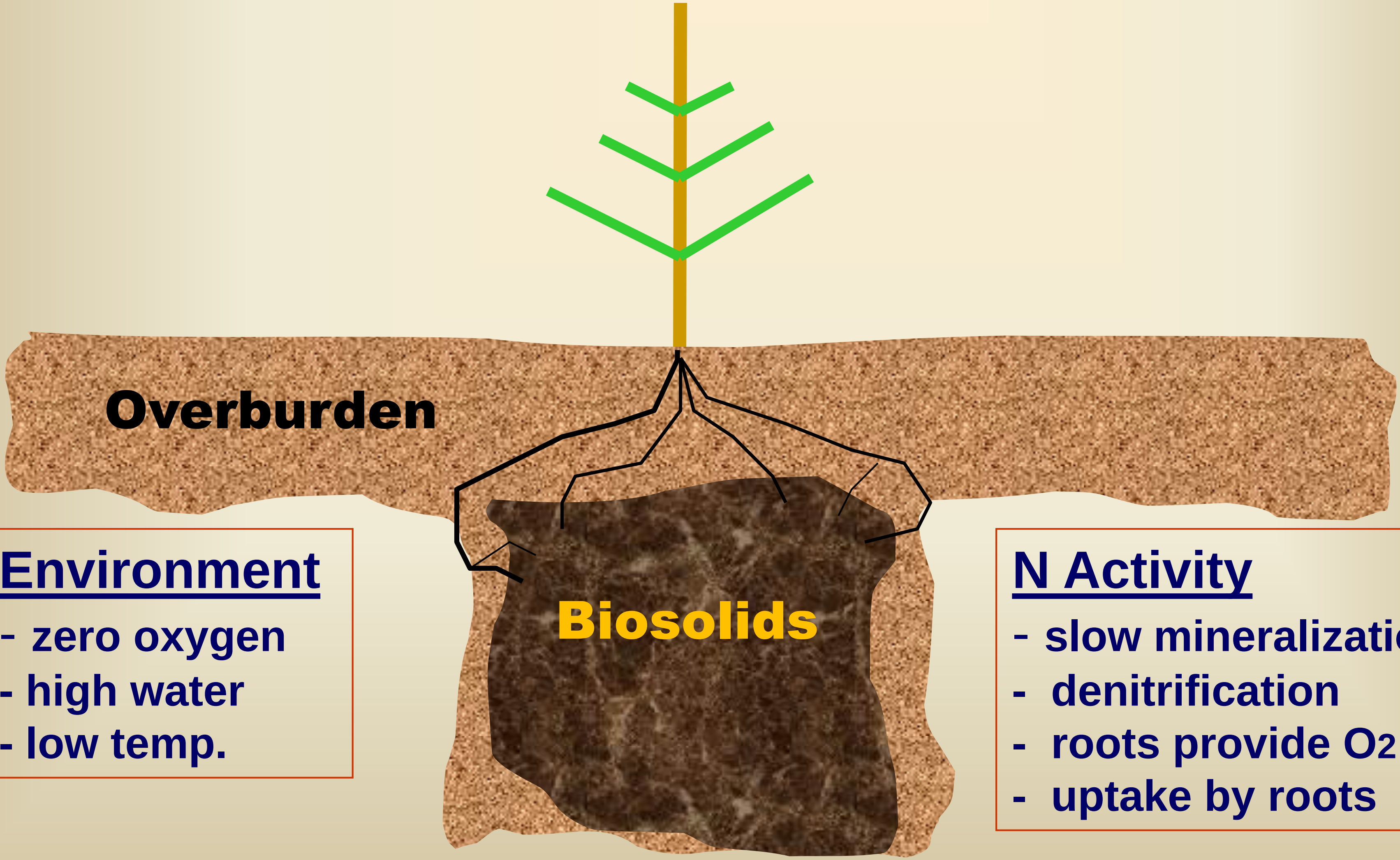
Environmental Benefits

- Wildlife habitat
- Carbon sequestration
- Increased infiltration/decreased storm runoff impact
- Extended life of landfills
- Reclaiming coal mine lands

N Dynamics in Deep-Row Application with Trees



Environment

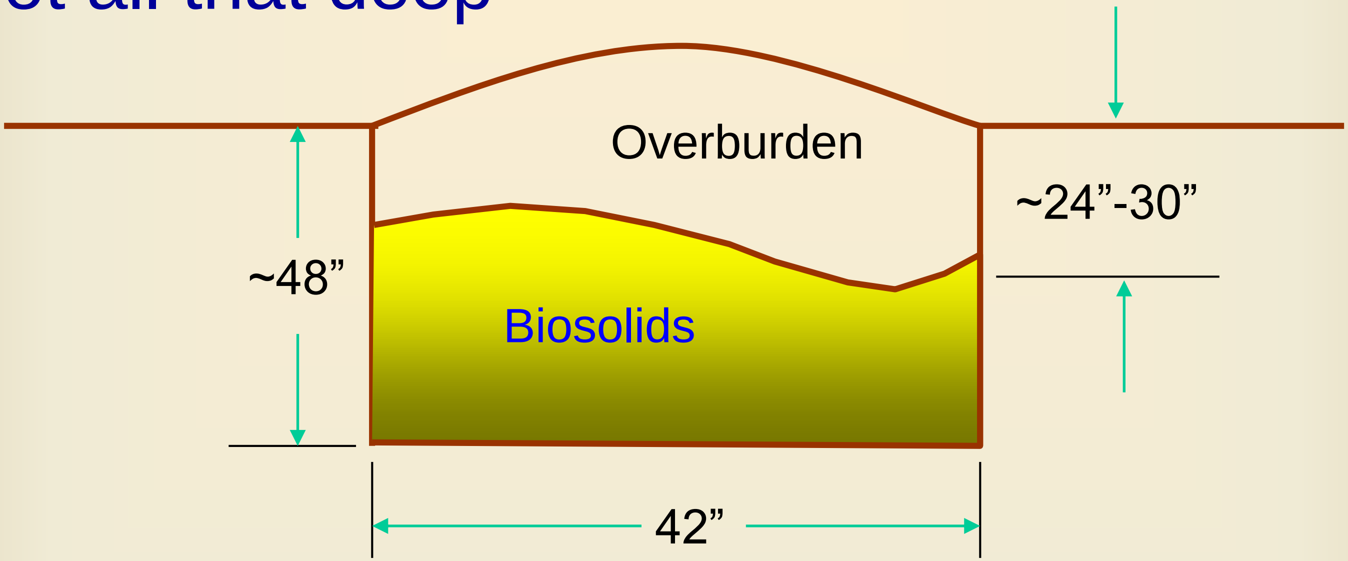
- zero oxygen
- high water
- low temp.

N Activity

- slow mineralization
- denitrification
- roots provide O_2
- uptake by roots

Deep Row Entrenchment

- Not all that deep



- High nitrogen appkication
  - Corn~175-200 lbs N/acre
  - DRE~172-345 dry tons biosolids/acre
    - About 3400 lbs N for each 1% N in biosolids
    - About 4,000-15,000 lbs N/acre

Why so much?

- Bottom Line is there is a lot of nitrogen moving
- See upcoming budget
- As trees grow, nitrogen demand increases
- Denitrification is very difficult to measure and estimates range widely
- Assumptions:
  - New trees require 55 lbs N/ac, 6 year old trees require 540 lbs N/ac
  - Denitrification is about 40% (39.6) of available N/year

Nitrogen budget DRE 172 dry tons/ac

units are lbs N/ac

Year	Starting N	Crop Uptake	Denitrification	Remaining N
1	14132.0	55	5596.3	8480.7
2	8480.7	152	3358.4	4970.4
3	4970.4	249	1968.3	2753.1
4	2753.1	346	1090.2	1316.9
5	1316.9	443	521.5	352.4
6	352.4	540	139.5	-327.2

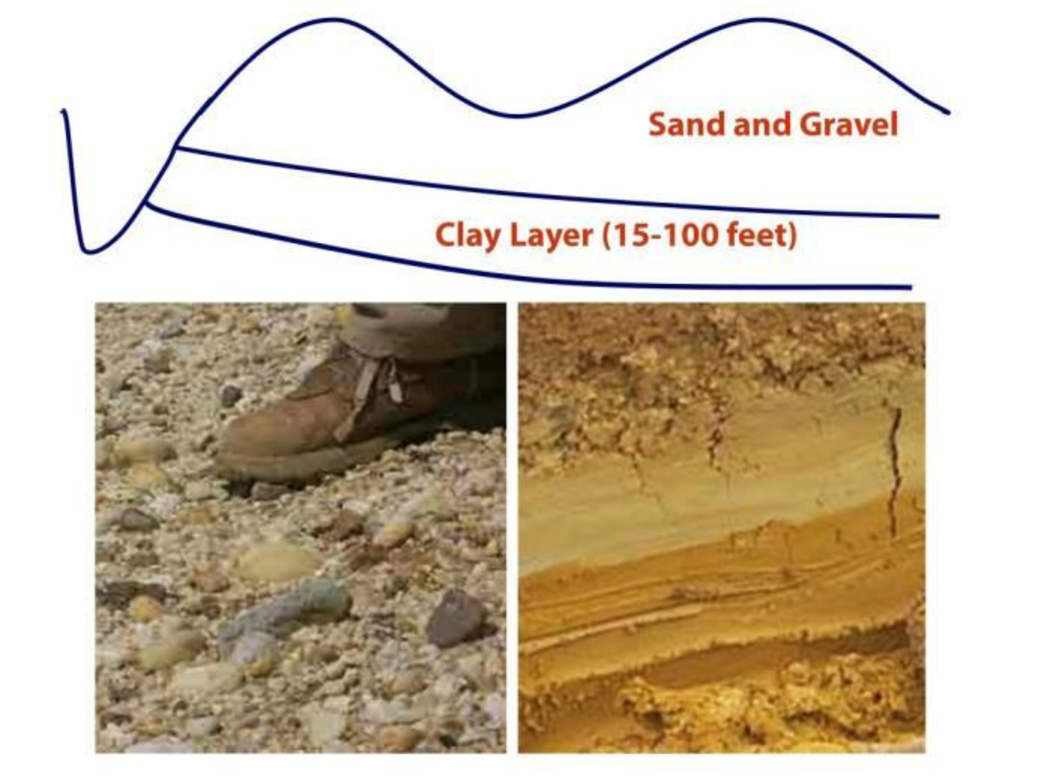
Crop uptake increases as trees grow
Denitrification is 39.6% of available N

Monitoring

- Geology
- Porous media flow
- Nitrogen and Phosphorus cycles
- Tools
  - Lysimeters
  - Interceptor drains
  - Wells

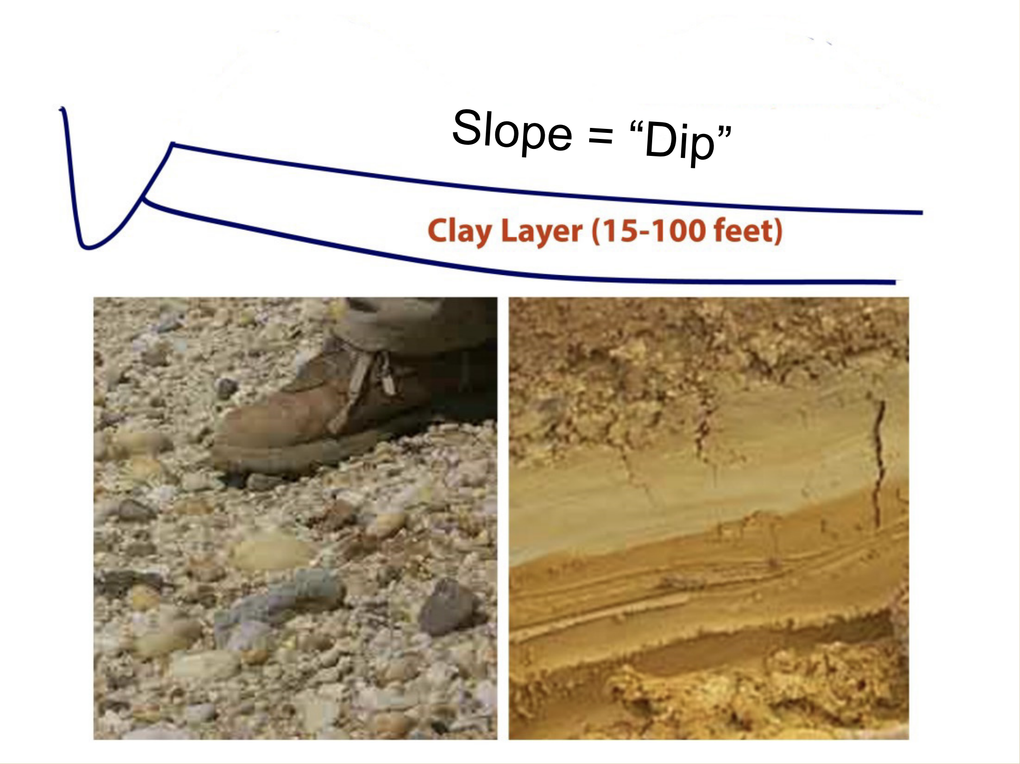
Monitoring - Geology

- What is below your feet?



Monitoring - Geology

- What is below your feet?



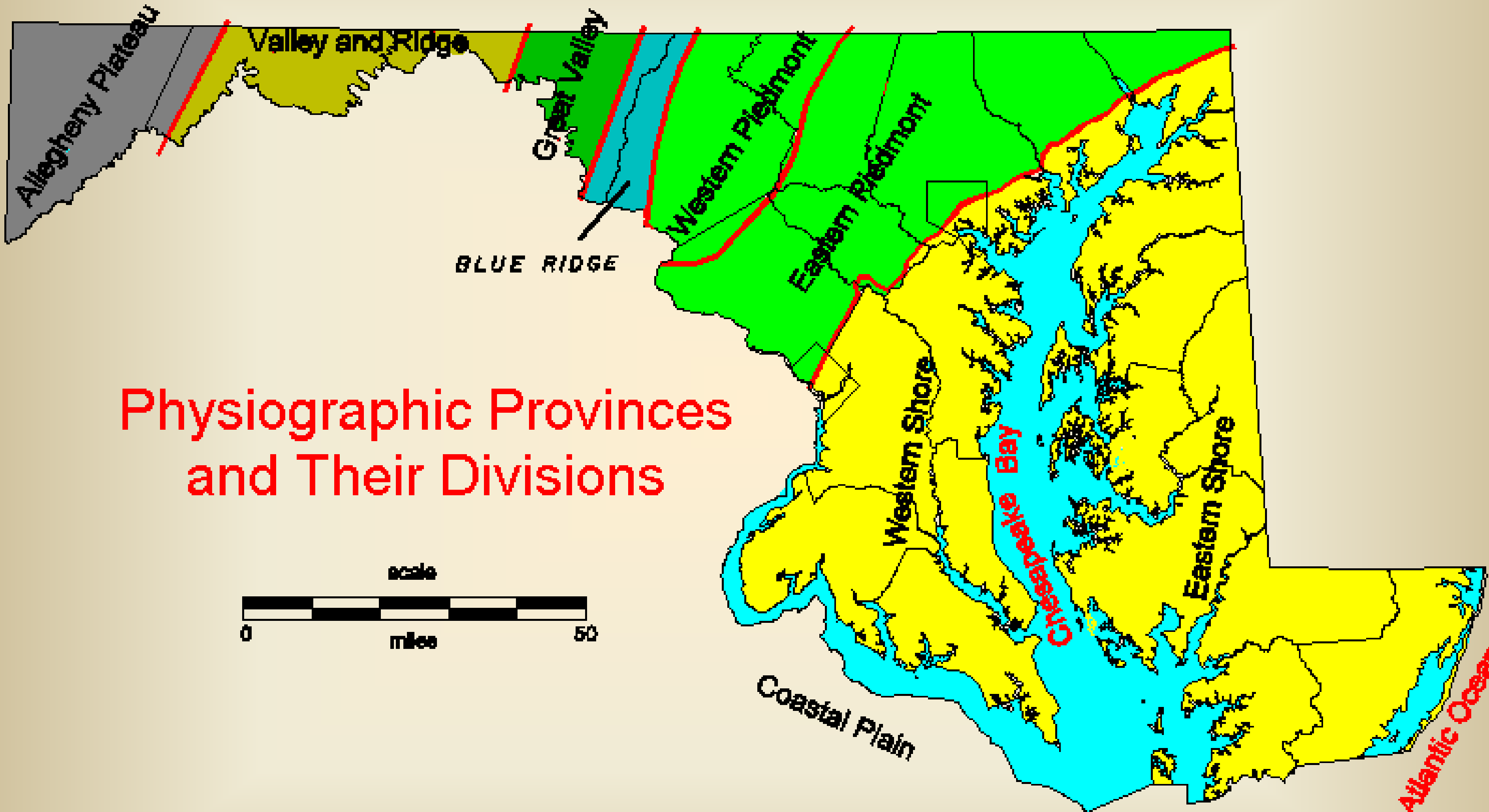
Geology Information Sources

- USGS
- MGS – Your state geologic survey

Tompkins, M.D. 1983. *Prince Georges County Ground-Water Information: Well Records, Chemical-Quality Data, Pumpage, Appropriation Data, Observation Well Records, and Well Logs*. Maryland Geological Survey Water Resources Basic Data Report No.13. pp160.

Wilson, J.M. and W.B. Fleck. 1990. Geology and Hydrologic Assessment of Coastal Plain Aquifers in the Waldorf Area, Charles County, Maryland. Maryland Geological Survey, Report of Investigation No. 53. Baltimore, MD. pp138.

Physiographic Provinces and Their Divisions



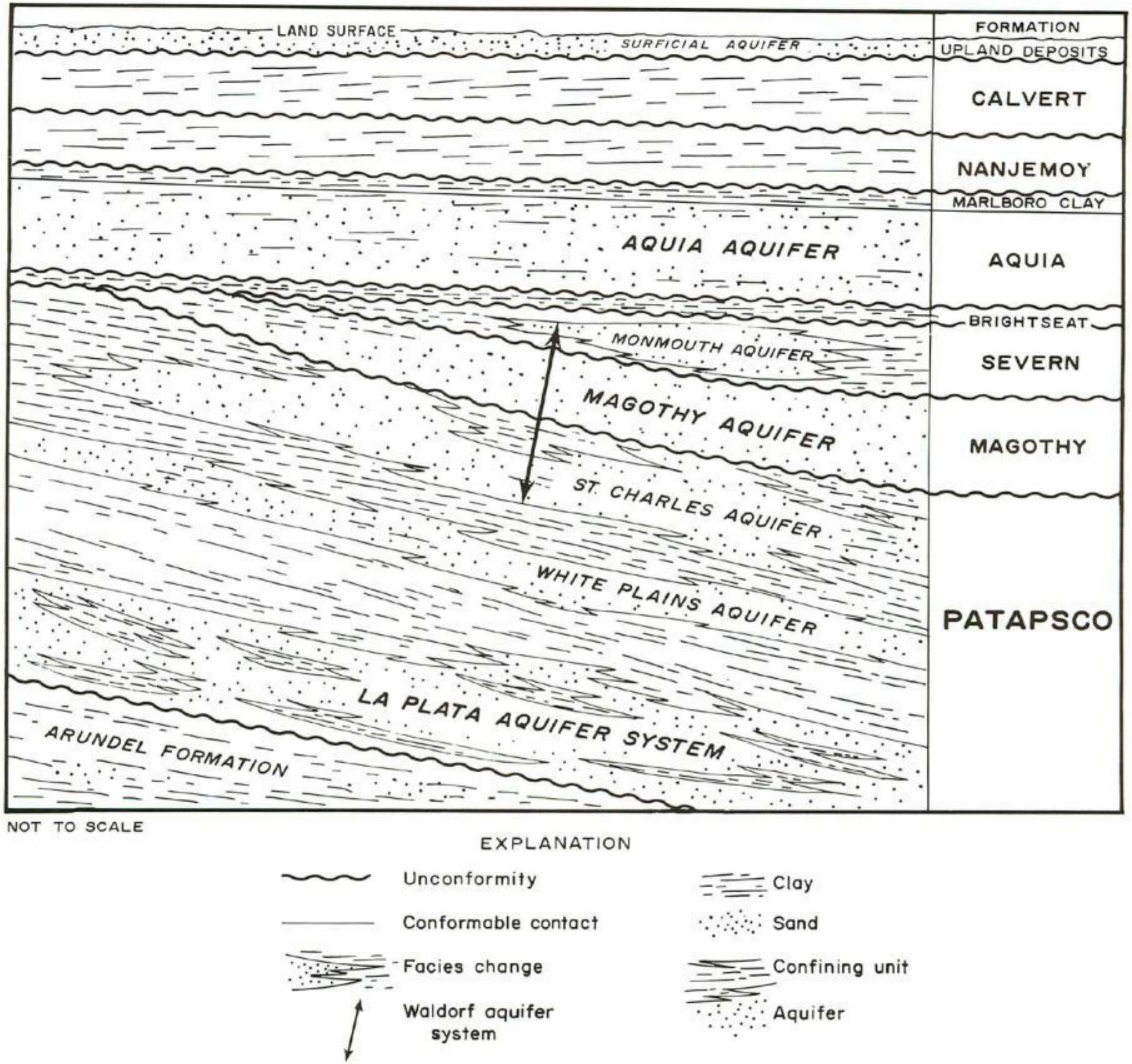


Figure 8.—Examples of the stratigraphic relations among the formations, aquifers, and confining units that overlie the Arundel Formation in north-central Charles County.

The Calvert is a light to medium, olive gray to olive green, micaceous, clayey silt. The thickness of the Calvert in the Waldorf area is about 90 to 100 ft. The formation is the basal unit of the Chesapeake Group and it represents deposition in a marine shelf environment (Gibson, 1982).

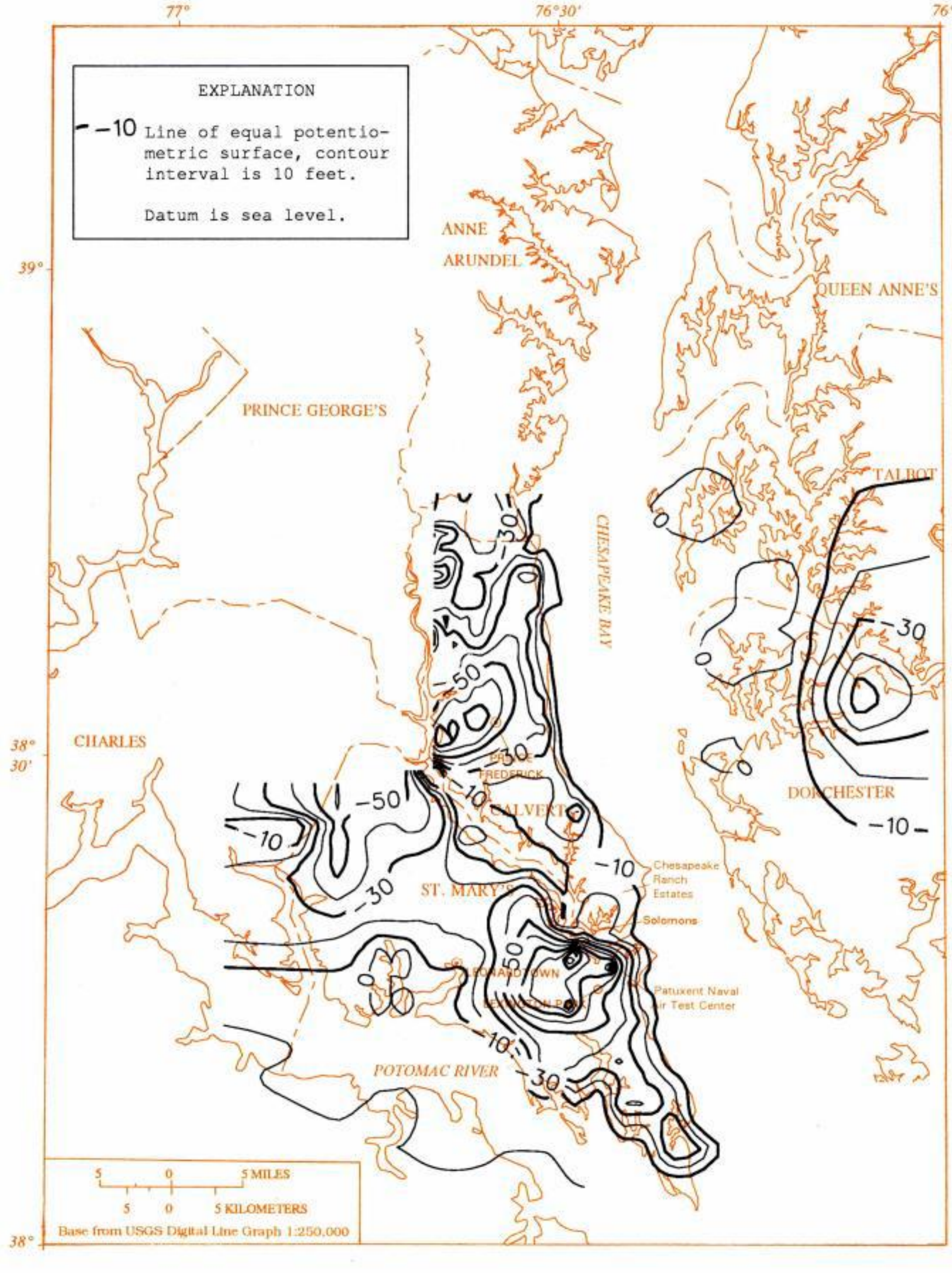


Figure 38. Simulated 2020 potentiometric surface of the Piney Point-Nanjemoy aquifer based on County Water Plans scenario.

Monitoring - Porous Media Flow

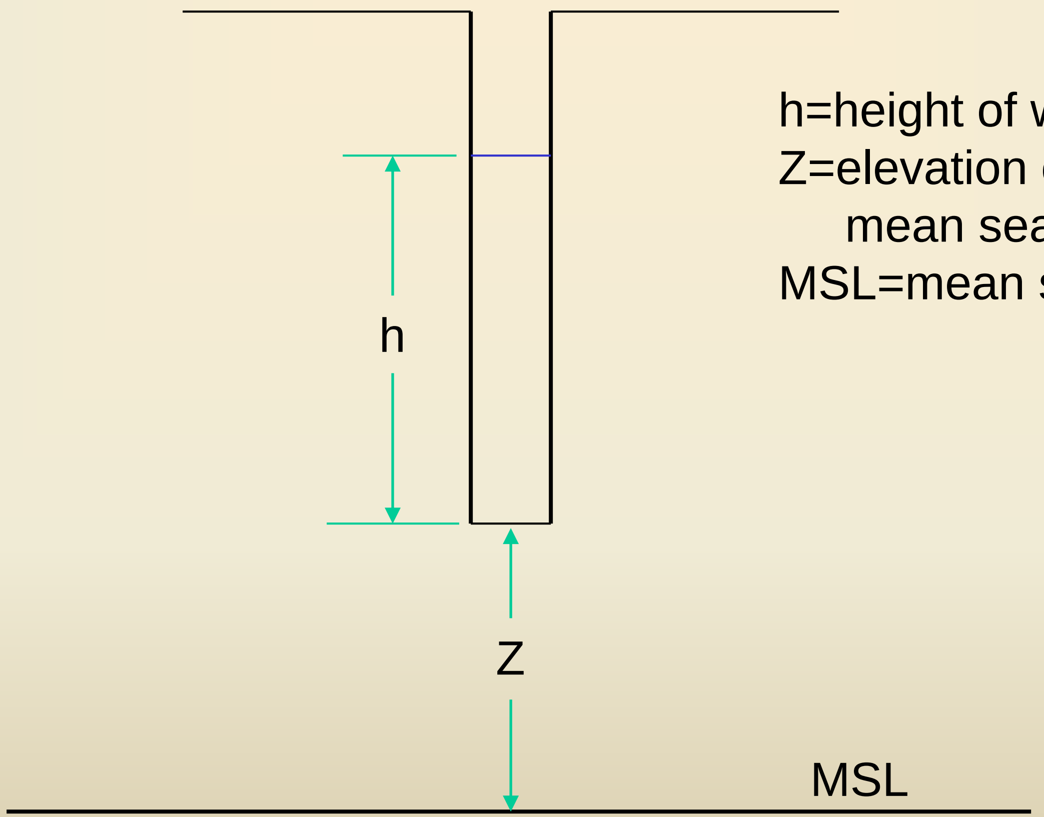
- Porous media flow is how anything in the biosolids will leave the biosolids and move to the monitoring device
- Saturated flow – pores are completely* filled
  - Darcy’s law describes flow
- Unsaturated flow – pore space is occupied by water, air, or both and changes with moisture content
  - Richard’s equation describes flow

Hydraulic Head

- Water potential is made up of elevation, pneumatic pressure, water pressure, osmotic pressure and thermal potential. If the media is saturated, there is no capillary effect on water pressure. If the temperature is fairly consistent throughout the porous media, then there is no thermal potential. Typically, there is no pneumatic (air) pressure imposed on ground water flow. That leaves the height of the column of water and the elevation. Together, those two elements make up hydraulic head.

Hydraulic Head Picture

$$H=h+Z$$



h=height of water in well
Z=elevation of well above mean sea level
MSL=mean sea level

Gradient

- Differences in hydraulic head cause water to move from one place to another. That is, water flows from locations of high hydraulic head to locations of lower hydraulic head. The gradient is the change in hydraulic head per length of flowpath. Maps of hydraulic head (Figure below) can be used to determine the direction of groundwater flow on a regional basis.

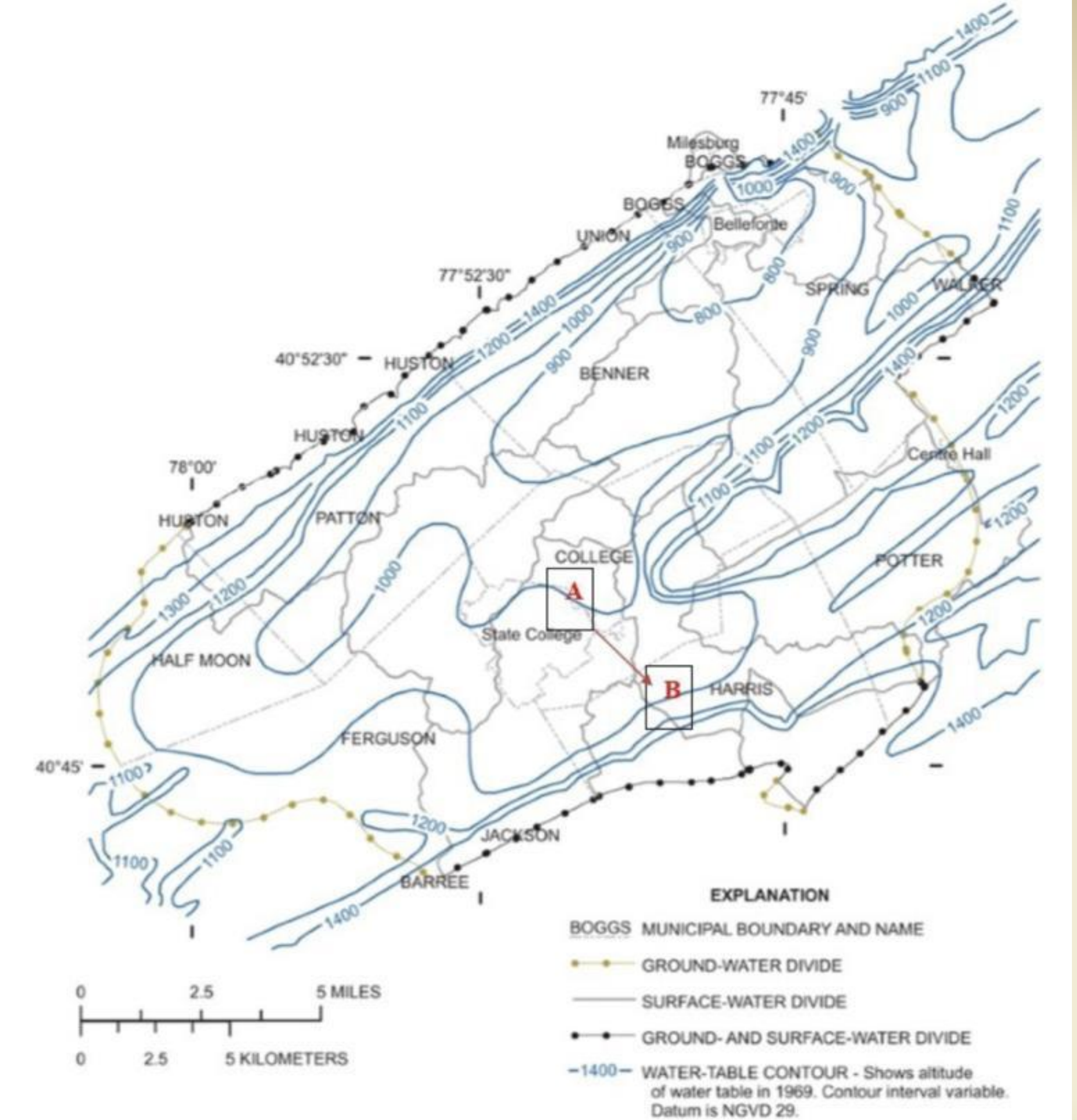
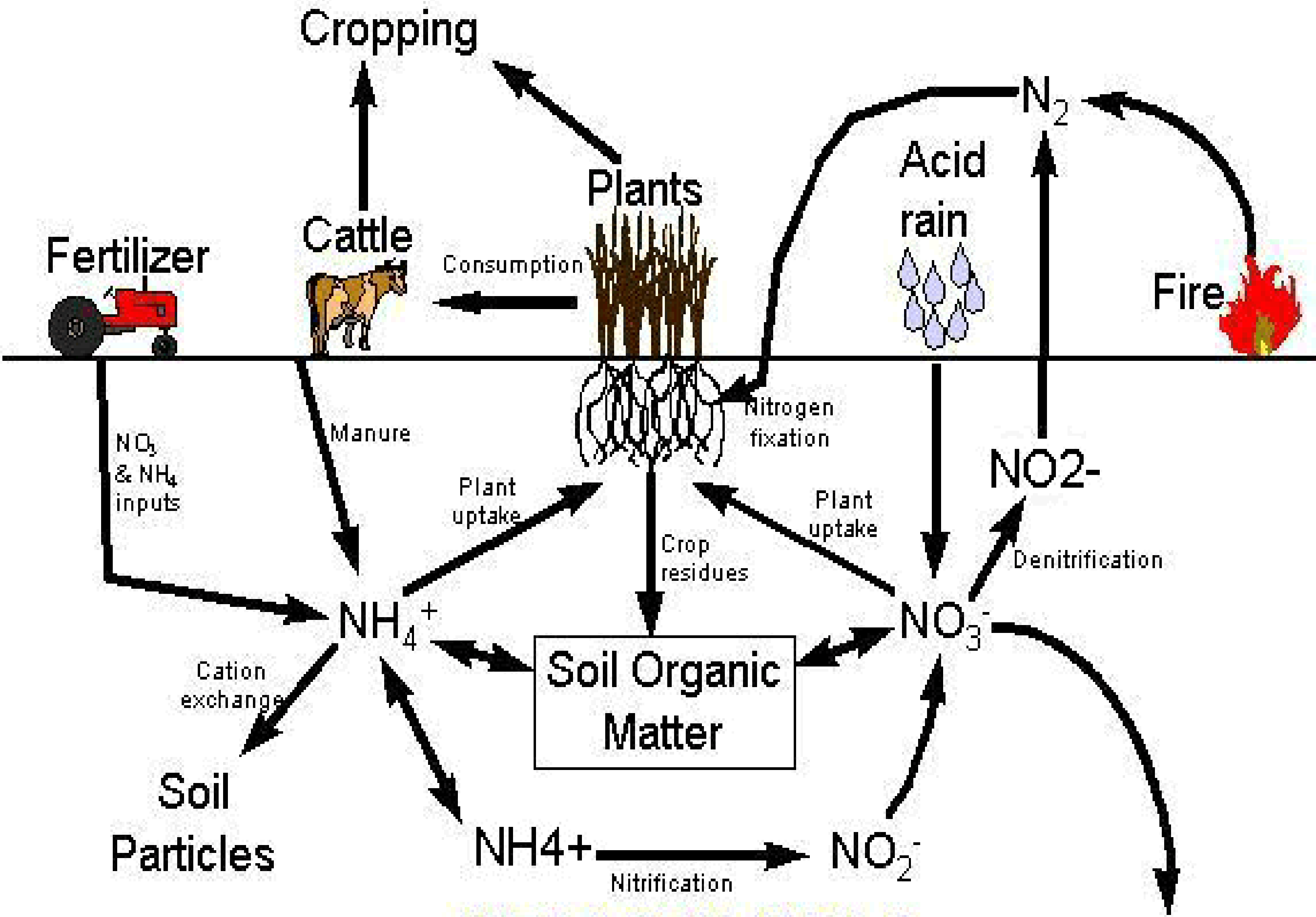


Figure 8. Potentiometric surface map of the Spring Creek Groundwater Basin ca 1969. (www.e-education.psu.edu)

Vadose Zone

- The soil zone just below the surface is seldom saturated. It controls the rate of aquifer recharge.
- Flow rates and chemical reactions in the vadose zone also control whether, where, and how fast contaminants enter groundwater supplies.
- DRE trenches are installed in the vadose zone and monitoring for the fate and transport of constituents in the biosoids is indicative of processes that occur in the vadose zone.



NITROGEN CYCLE

Nitrogen Fates

- Mineralization
- Nitrification
- Amonification
- Denitrification
- Volatilization

Mineralization

- Nitrogen changes from organic materials, such as biosolids, manure or plant materials to an inorganic form of nitrogen that plants can use.
- Mineralization generates ammonia, NH3. The NH3 in the soil then reacts with water to form ammonium, NH4. This ammonium is held in the soils.
- Mineralization is done by microbes.

Nitrification

- Ammonia in the soils is converted into nitrite, NO_2^-, and then into nitrate, NO_3^-.
- Microbes perform these two conversions
- These microbes require oxygen.

What happens to the NO_3 and NH_4?

- Both nitrate and ammonium can be taken up by plants.
- NO_3 can leach easily, NH_4 not so much.
- NO_3 and NH_4 can be consumed by microbes.

Immobilization

- Soil microorganisms pull nitrogen from the soil when the residues of decomposing plants do not contain enough nitrogen. When microorganisms take in ammonium ($NH4+$) and nitrate ($NO3-$), these forms of nitrogen are no longer available to the plants and may cause nitrogen deficiency.

Denitrification

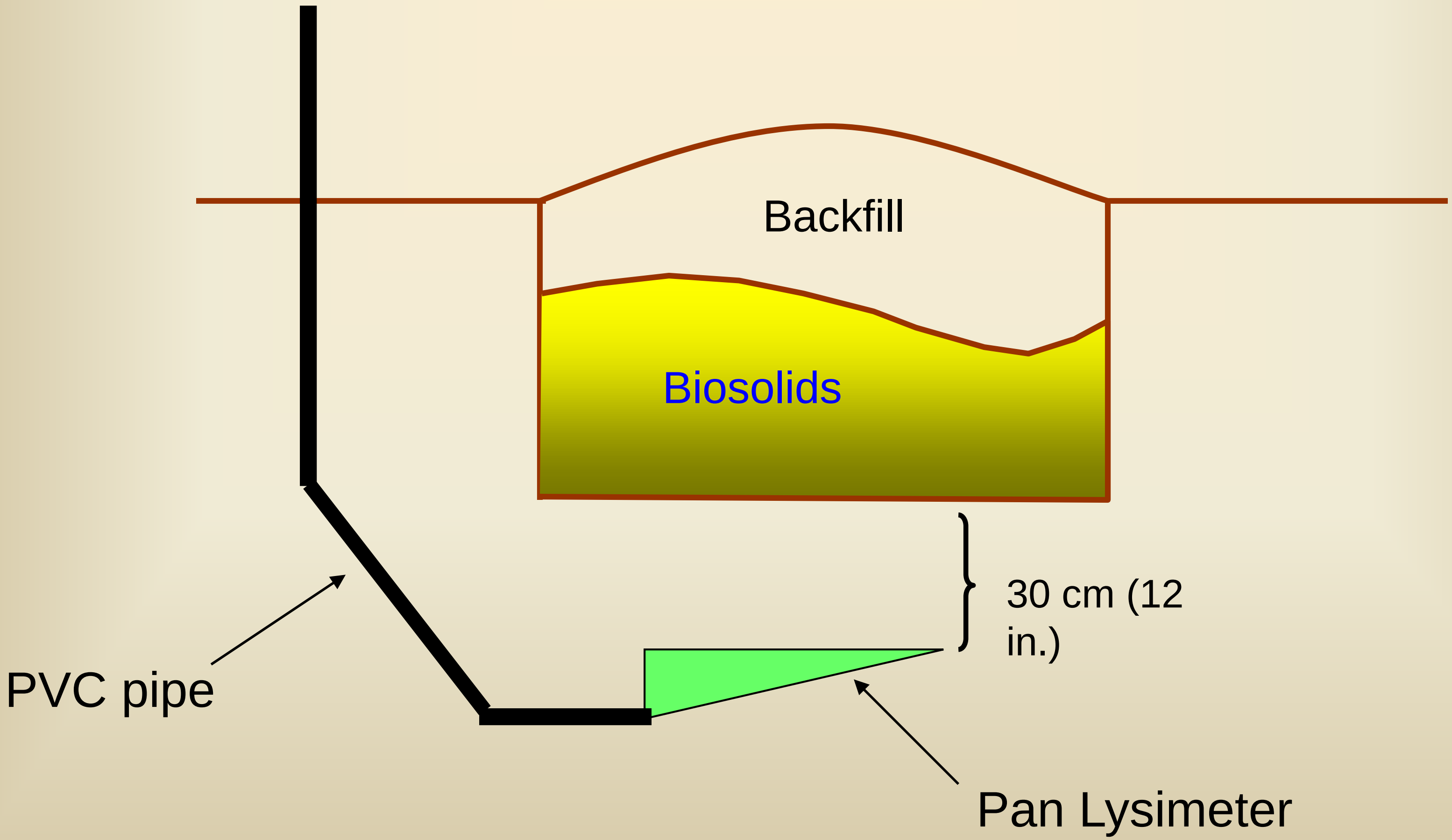
- Nitrogen returns to the air as nitrate is converted to atmospheric nitrogen (N2) by bacteria.
- Anaerobic microbes are involved
- These microbes require carbon to function.

Monitoring Tools - Lysimeters

- Pan Lysimeters aka Zero Tension Lysimeters

Pan Lysimeter Placement

1 pan per subplot x 30 subplots = 30 pan lysimeters



Installing lysimeters pans

Lysimeter plan inserted below filled trench with access tube

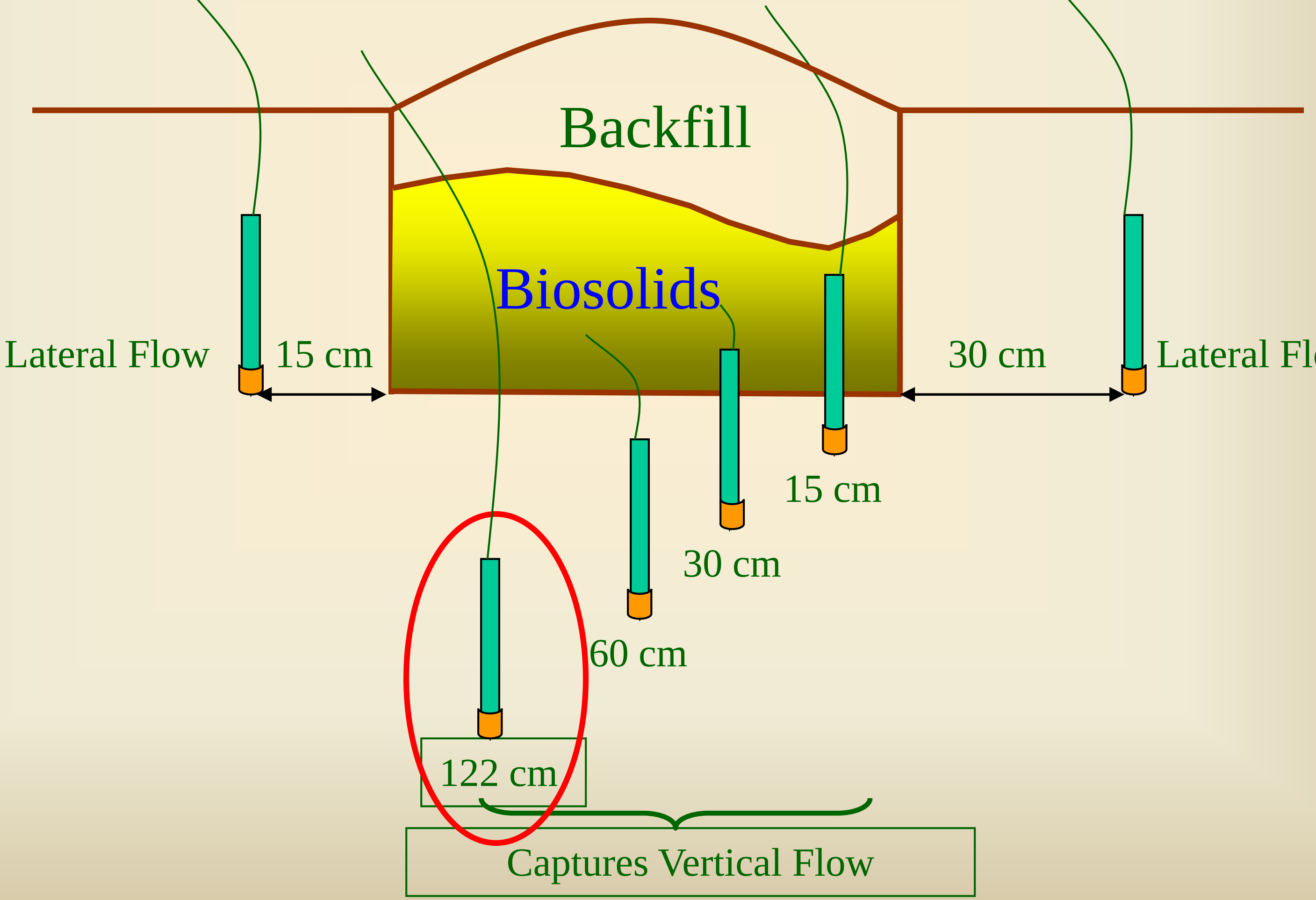
Monitoring Tools - Lysimeters

- Suction Lysimeters

Suction Lysimeter Layout

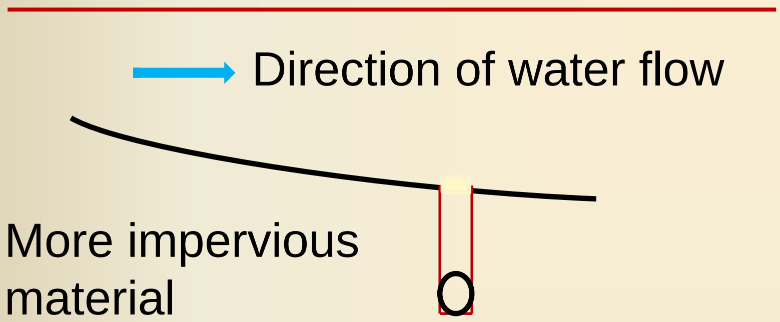
Current Conditions: 5 per subplot = 150 suction lysimeters

Proposed Conditions: Add vertical flow lysimeter at 122 cm




B

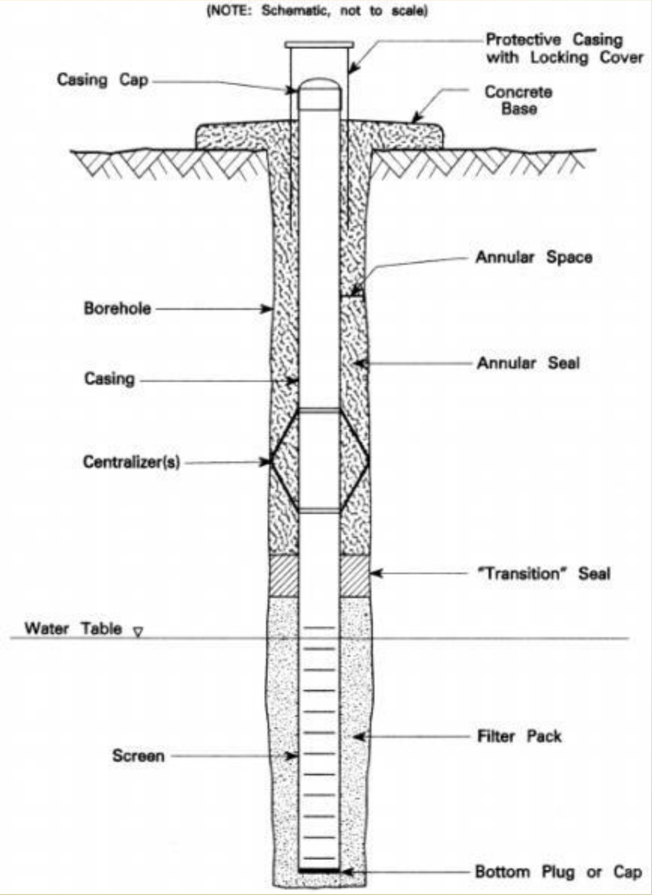

Monitoring Tools – Interceptor Drain Lines



Media can be porous media or broken rock spoil
Used in drainage experiments on coastal plains
Used on mine spoil in Kentucky, but installed before spoil was deposited

Monitoring Tools - Wells

- Porous Media



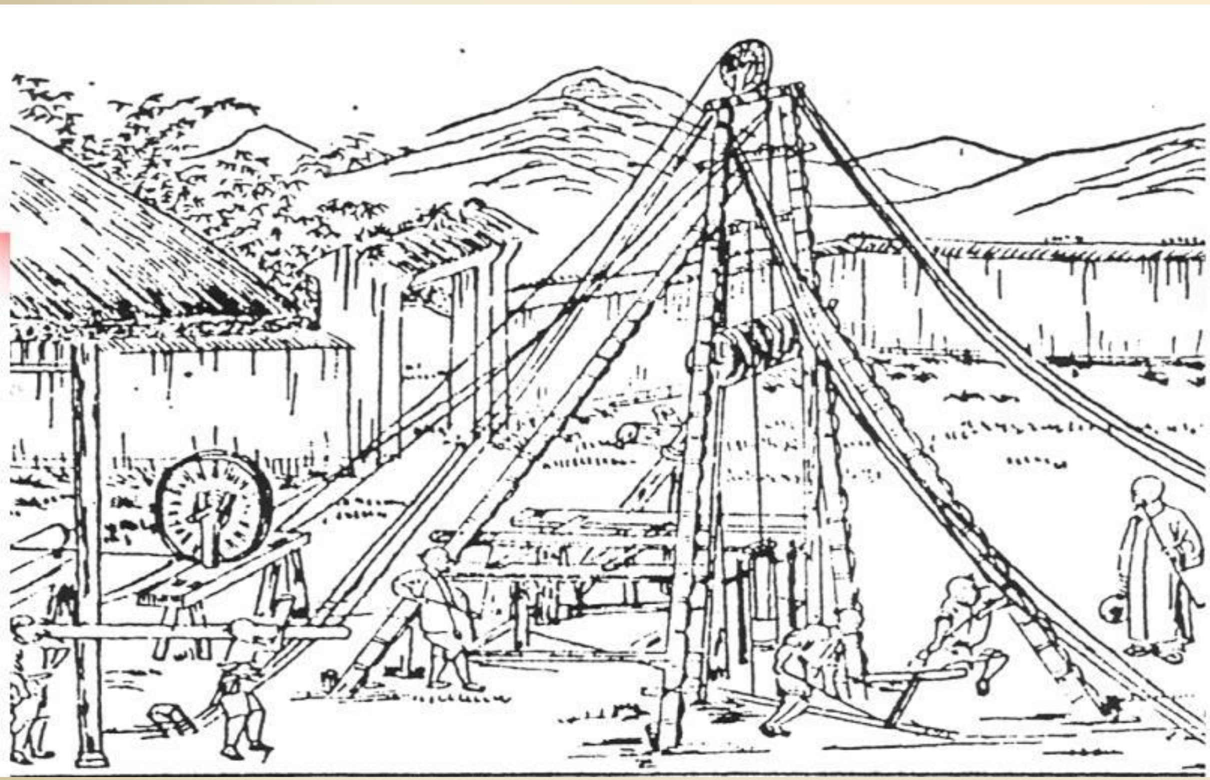
Monitoring Tools - Wells

- Broken Rock Spoil

percussion method of drilling, cable tool, churn drills, sputter, or pounders it’s sometimes referred to, is one of the oldest cutting actions utilized in the drilling industry.

A method of drilling whereby an impact tool or bit, suspended in the well from a steel cable, is dropped repeatedly on the bottom of the hole to crush the rock.

Cable Tool or Percussion Drilling



Permits

- In Maryland, because of the high loading rate, MDE can write many monitoring requirements into the permits.
- Well data is easier for permitting agencies to evaluate because they are familiar with it (as compared to lysimeters).
- MDE will work with you, but they won't tell you where to put a well. You must propose the monitoring plan and they will approve or deny it.

Permits

- ERCO permits included some metals, total N, total P, NH3, NO3, Na, Mg, Cu and others.
- Foliar leaf nutrient content.
- Biosolids pack sampling for nutrients.

Results

- Sandy soil
- Clay Soil

Sandy Soil

- A mineral sands (ilmenite and zircon) mine reclamation site in Dinwiddie County in Virginia was instrumented with pan lysimeters.
- Both anaerobically digested (AD) and lime stabilized (LS) DRE biosolids and inorganic N fertilizer were compared.

Ammonia Leachate

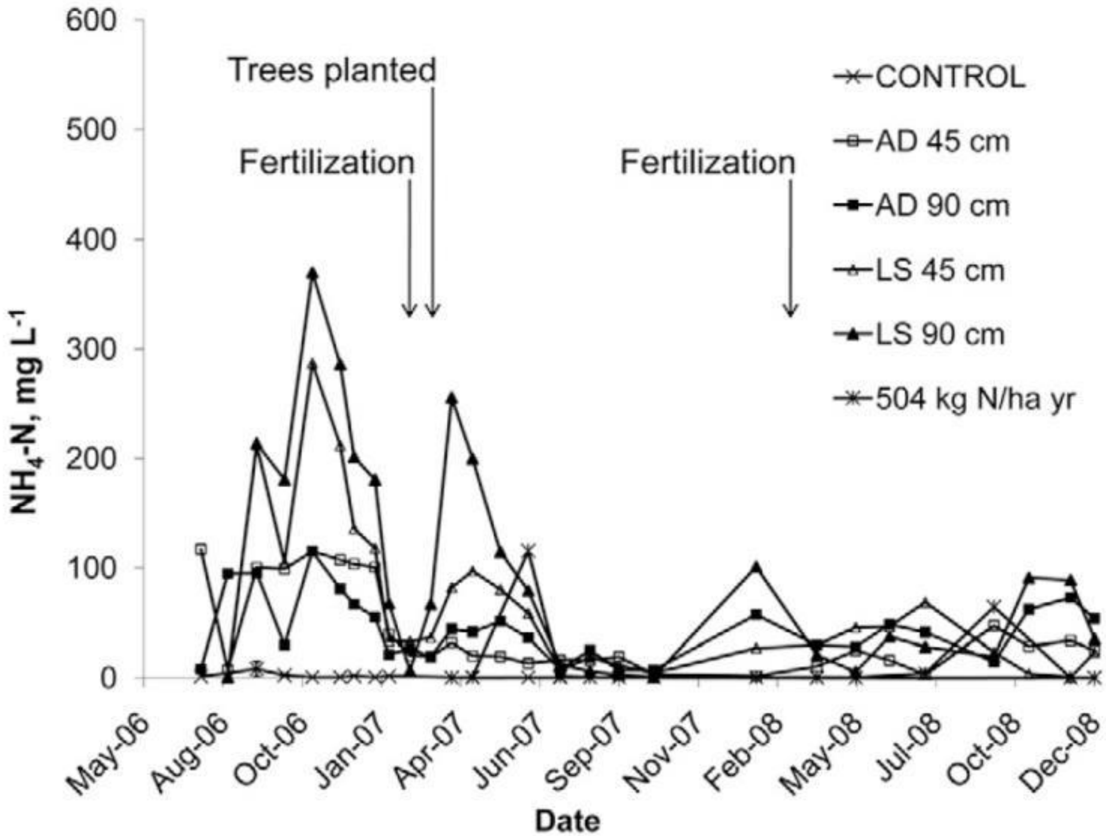


Fig. 1. Concentrations of NH_4–N in leachate collected by zero tension lysimeters from the deep-row incorporation biosolids and conventional fertilizer treatments through the study period (July 2006–December 2008). AD, anaerobically digested; LS, lime-stabilized.

Organic N Leachate

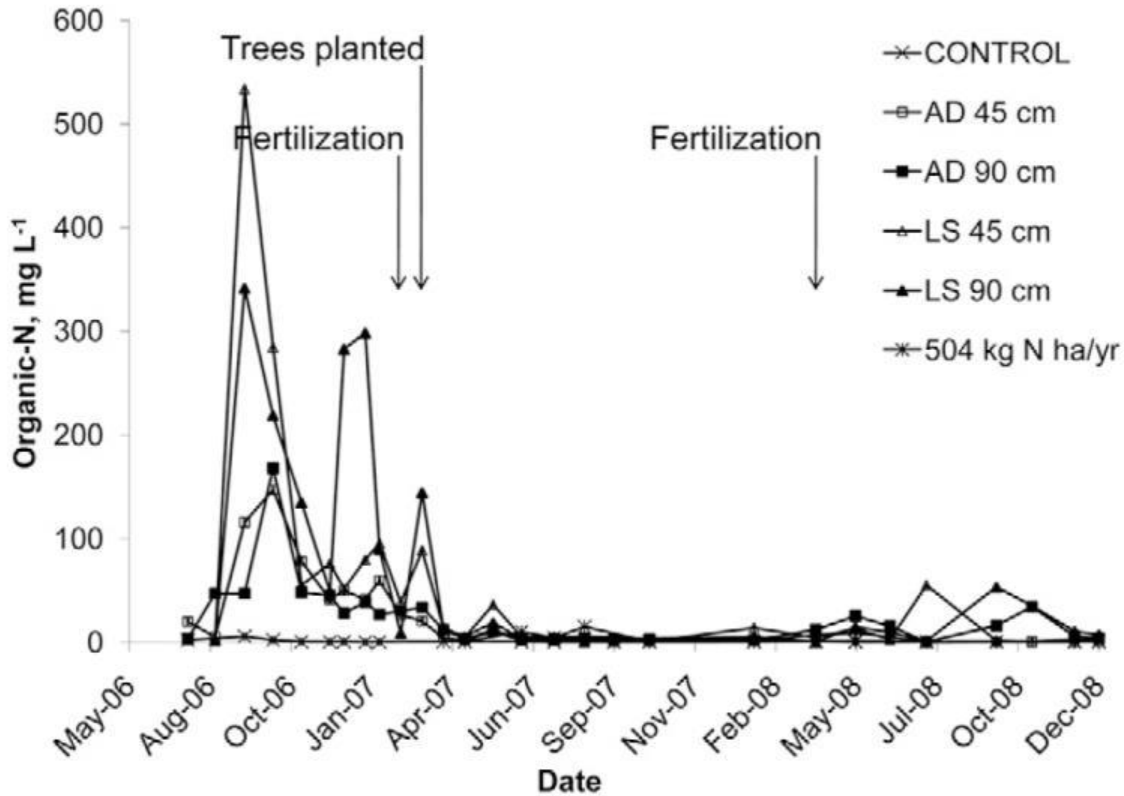


Fig. 2. Concentrations of organic N in leachate collected by zero tension lysimeters from the deep-row incorporation biosolids and conventional fertilizer treatments through the study period (July 2006–December 2008). AD, anaerobically digested; LS, lime-stabilized.

Nitrate Leachate

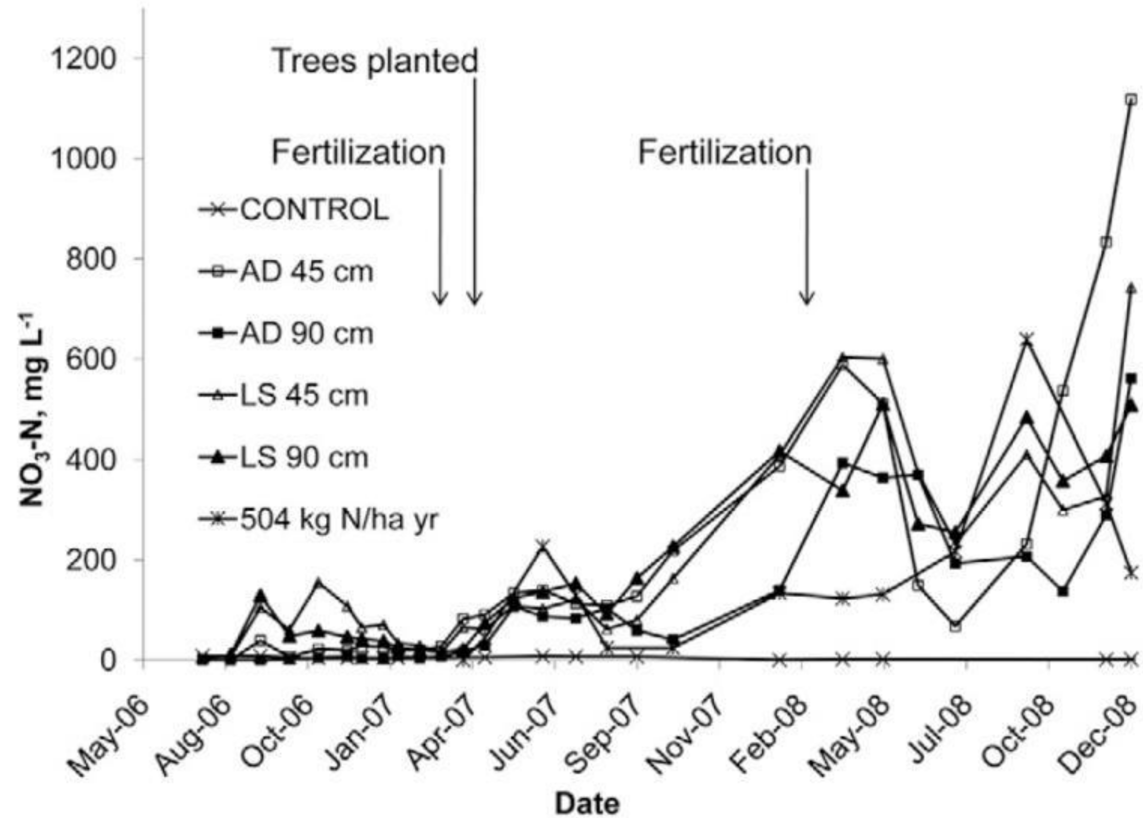


Fig. 3. Concentrations of NO_3–N in leachate collected by zero tension lysimeters from the deep-row incorporation biosolids and conventional fertilizer treatments through the study period (July 2006–December 2008). AD, anaerobically digested; LS, lime-stabilized.

Results/Conclusions

- Total N lost over the course of 2 yr was 15.2 Mg ha^{-1} and 10.9 Mg ha^{-1} for LS and AD biosolids, respectively, which was roughly 50% of the N applied.
- Entrenchment of biosolids in coarse-textured media should not be used as a mined land reclamation technique because the anaerobic conditions required to limit mineralization and nitrifi cation cannot be maintained in such permeable soils

Importance of clay.

- Topsoil – some clay content, some sand OK
- Sub-soil – requires significant clay content. Some fine sand is OK.
- Below – prefer clay.
- Coarse sand will result in nitrogen pollution.

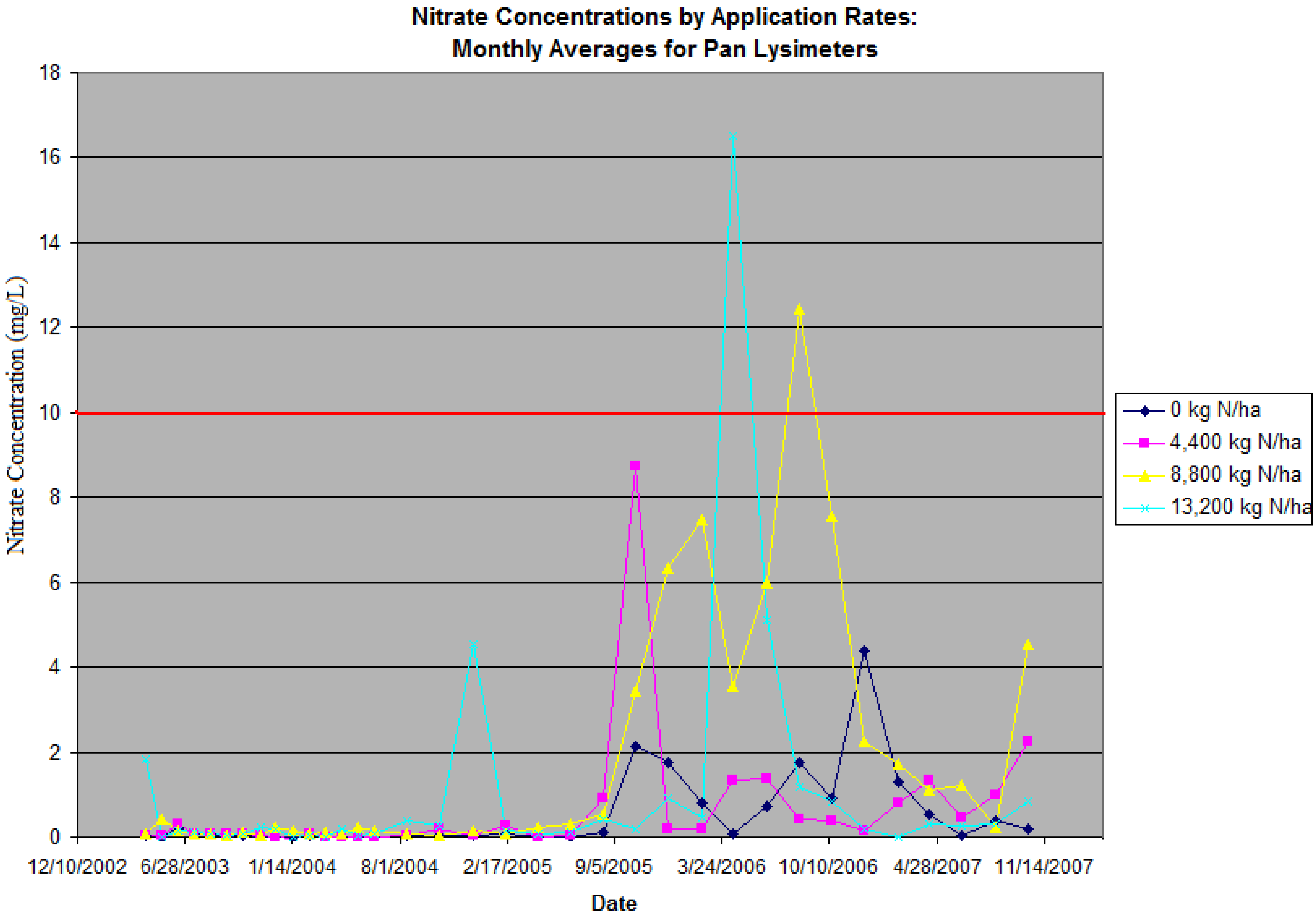
Clay Soil

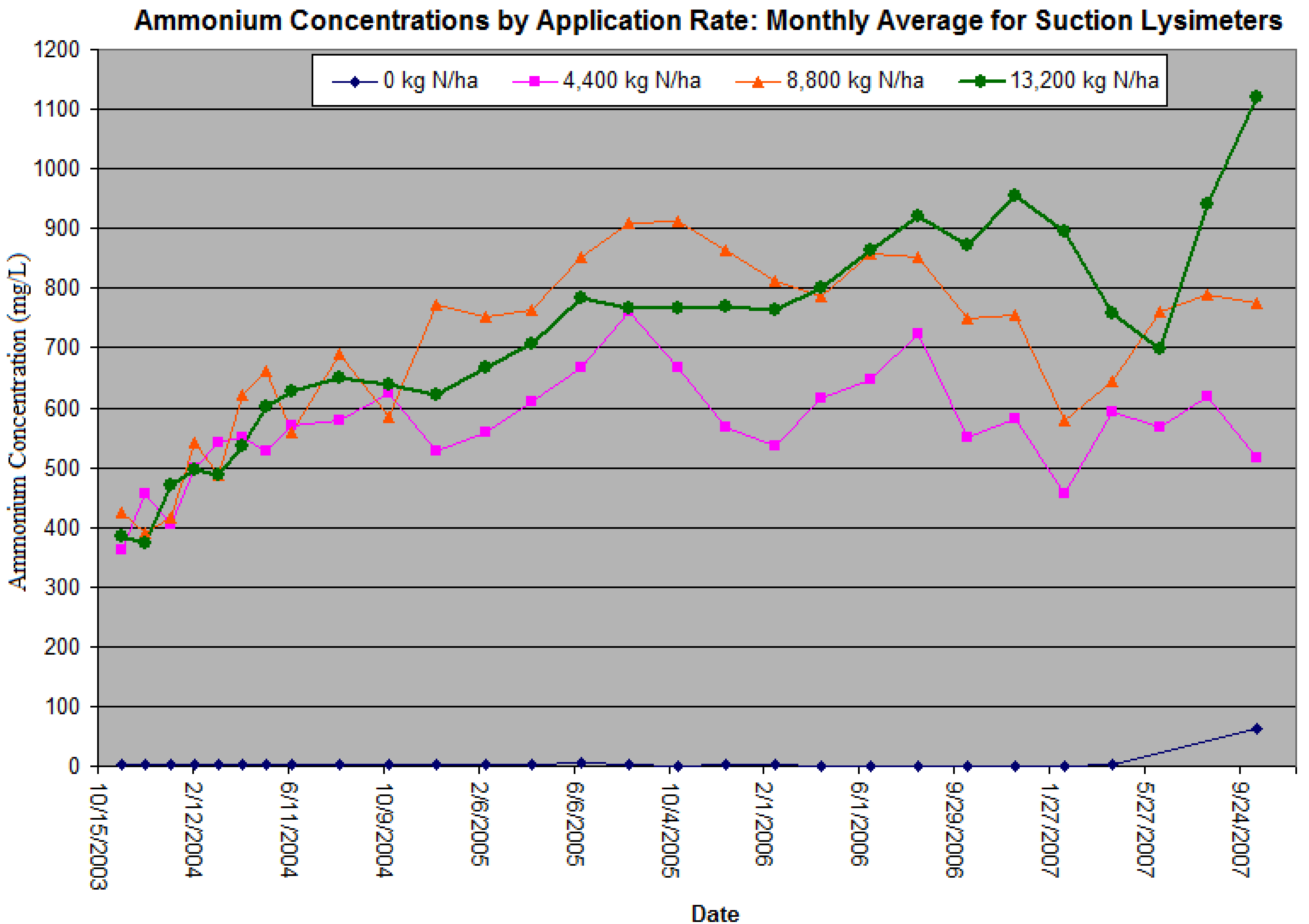
- A sand and gravel mine site in Prince Georges County, Md. was instrumented with pan lysimeters and suction lysimeters.
- Lime stabilized DRE biosolids was compared to no biosolids application and no trees.

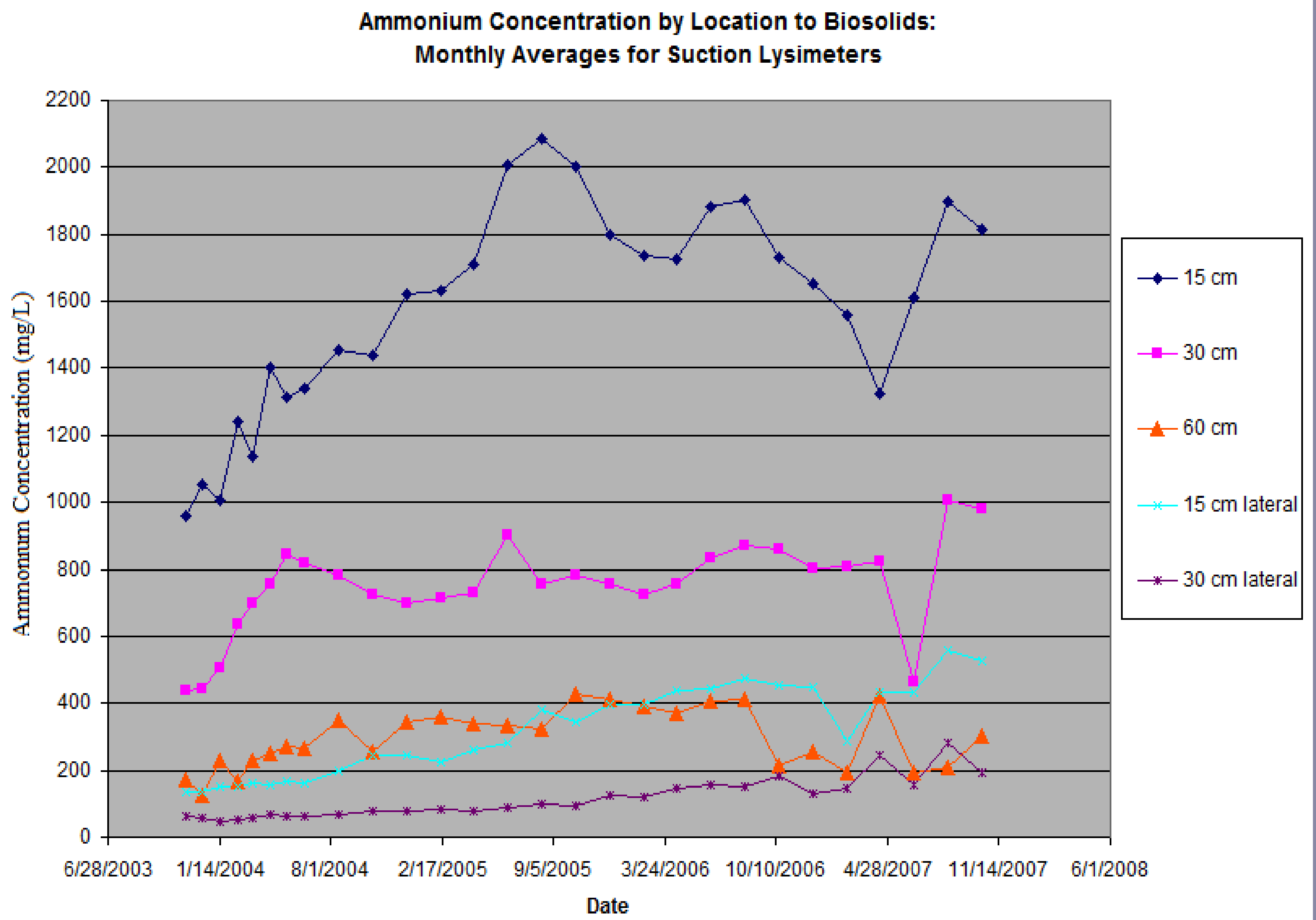
Application Rate for Different Tree Density Treatments – 3 acre site

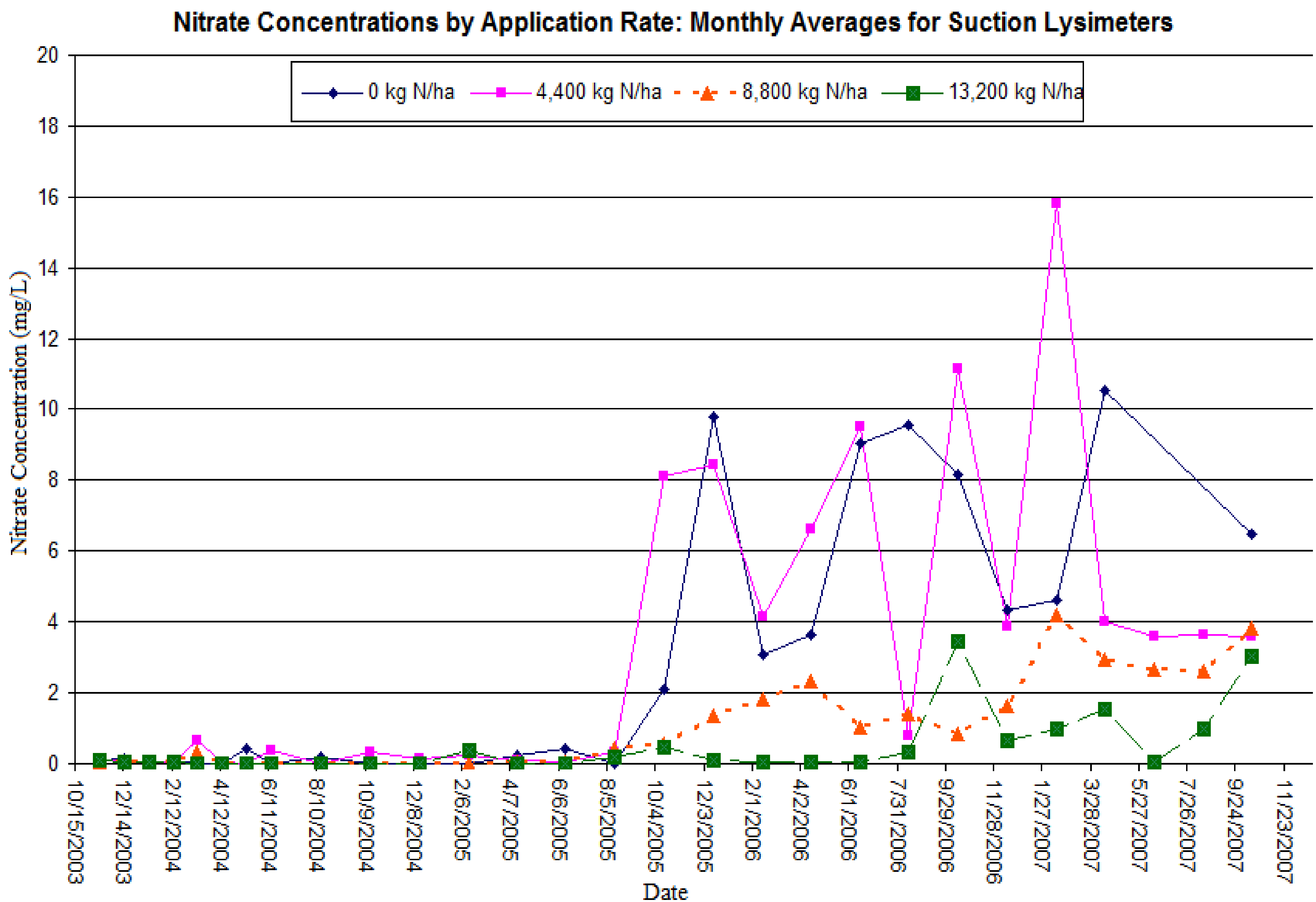
(0, 290, & 430 trees /acre)

Application Rate	Inches of Biosolids	Total Depth of Deep Row	Dry (Wet) Tons per Acre
4,000	12.5	24	172 (688)
8,000	25	37	345 (1,380)
12,000	37.5	49	517 (2,068)


Nitrate Concentrations by Application Rates:
Monthly Averages for Pan Lysimeters
Nitrate Concentration (mg/L)
0
2
4
6
8
10
12
14
16
18
12/10/2002
6/28/2003
1/14/2004
8/1/2004
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
11/14/2007
Date
0 kg N/ha
4,400 kg N/ha
8,800 kg N/ha
13,200 kg N/ha


Ammonium Concentrations by Application Rate: Monthly Average for Suction Lysimeters
0 kg N/ha
4,400 kg N/ha
8,800 kg N/ha
13,200 kg N/ha
Ammonium Concentration (mg/L)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
10/15/2003
2/12/2004
6/11/2004
10/9/2004
2/6/2005
6/6/2005
10/4/2005
2/1/2006
6/1/2006
9/29/2006
1/27/2007
5/27/2007
9/24/2007
Date


Ammonium Concentration by Location to Biosolids:
Monthly Averages for Suction Lysimeters
Ammonium Concentration (mg/L)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
6/28/2003
1/14/2004
8/1/2004
2/17/2005
9/5/2005
3/24/2006
10/10/2006
4/28/2007
11/14/2007
6/1/2008
Date
15 cm
30 cm
60 cm
15 cm lateral
30 cm lateral



Nitrate Concentrations by Application Rate: Monthly Averages for Suction Lysimeters
0 kg N/ha
4,400 kg N/ha
8,800 kg N/ha
13,200 kg N/ha
Nitrate Concentration (mg/L)
20
18
16
14
12
10
8
6
4
2
0
10/15/2003
12/14/2003
2/12/2004
4/12/2004
6/11/2004
8/10/2004
10/9/2004
12/8/2004
2/6/2005
4/7/2005
6/6/2005
8/5/2005
10/4/2005
12/3/2005
2/1/2006
4/2/2006
6/1/2006
7/31/2006
9/29/2006
11/28/2006
1/27/2007
3/28/2007
5/27/2007
7/26/2007
9/24/2007
11/23/2007
Date

Perspective

Nitrate in Corn

- No fertilizer: 3-10 mg N/L
- Commercial corn: 18-30 mg N/L
- Corn-Soybean 2 yr rotation: 23 mg N/L
- Corn-Soybean 2 yr rotation, cover crops, split applications: 110-12 mg N/L

Nitrate in Corn

- No fertilizer: 3-10 mg N/L
- Commercial corn: 18-30 mg N/L
- Corn-Soybean 2 yr rotation: 23 mg N/L
- Corn-Soybean 2 yr rotation, cover crops, split applications: 10-12 mg N/L

Nitrate in Deep Row Trees

- March ‘03 - June ‘05: 0-1 mg N/L
- June ‘05 - April ‘06: 1-10 mg N/L
- April ‘06 - Nov ‘06: slightly less

Conclusions

- For the first three years, zero nitrate left the deep-row tree system.
- Ammonium was immediately released into the soil surrounding the biosolids.
- Ammonium concentrations decrease dramatically with distance from the biosolids, falling from 2100 mg N/L at 15 cm (6 in.) from the biosolids to 400 mg N/L at 60 cm (24 in.) from the biosolids.
- After three years, nitrate ranges between 15 and 36 mg/L with the exception of two data points in the winter of 2008-2009.
- Overall, nitrate concentrations are lower than those found beneath corn crops while utilizing a great deal higher application of nitrogen

Questions?

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