Lake Red Rock Update

# Delta Water Quality and Geomorphology

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**Iowa Geological Survey**

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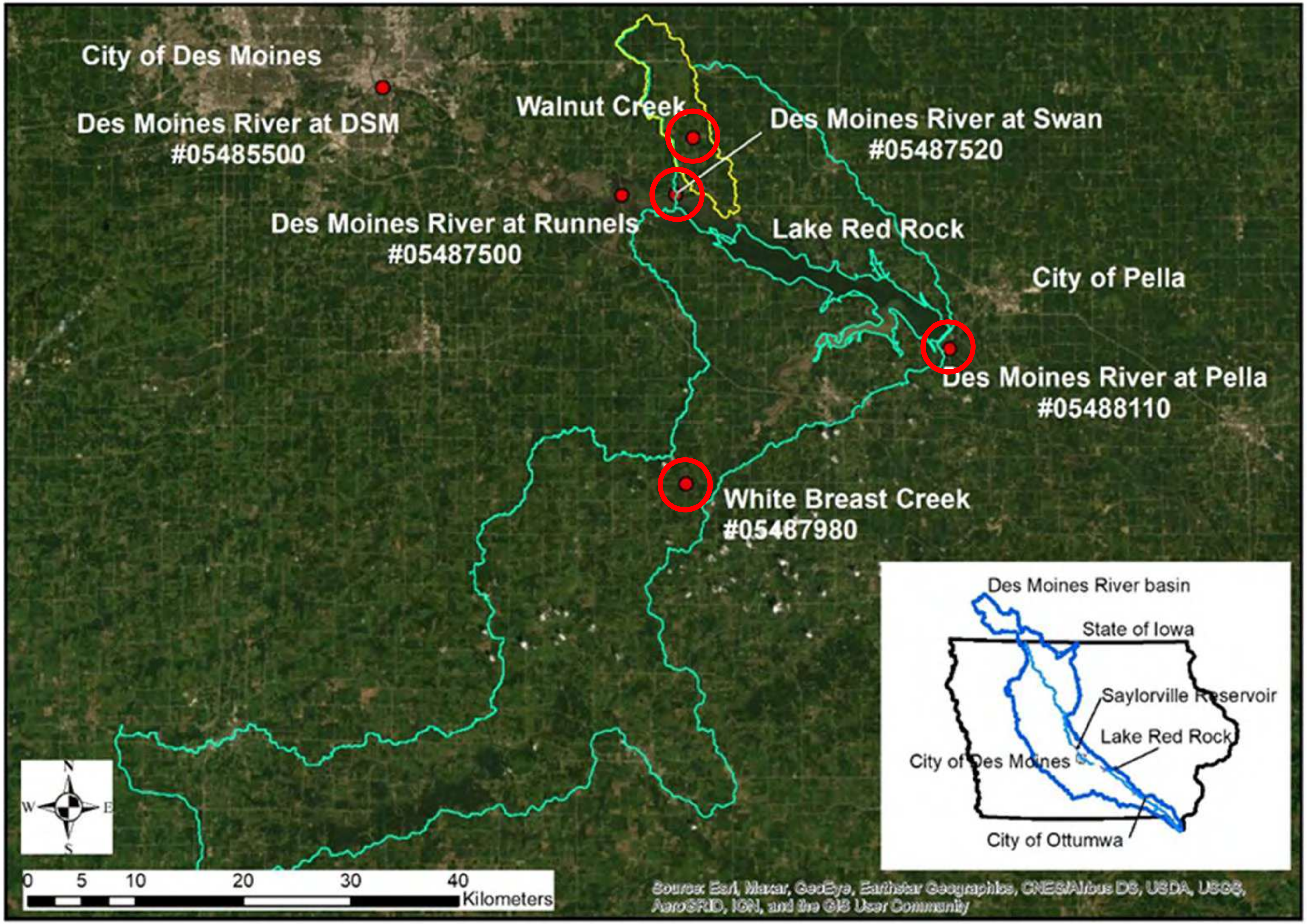
# Goals for IGS project

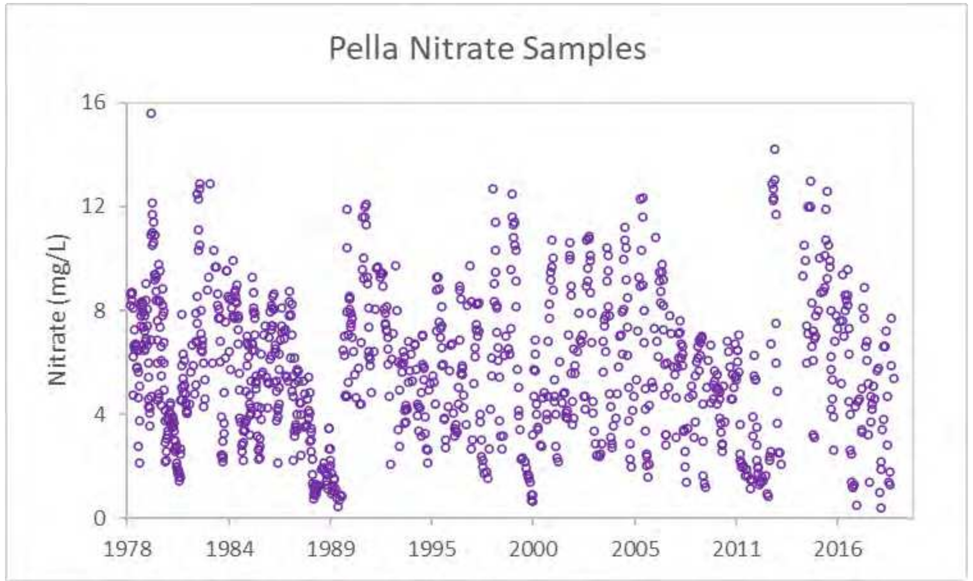
- Evaluate historical water quality data available for Red Rock to quantity the reduction of N concentrations and loads
- Conduct a literature review of N loss in reservoirs
- Evaluate delta sedimentology
- Measure N loss in delta sediments
- Evaluate potential for reservoir stage management to reduce N concentrations in the reservoir
- Conduct boat surveys of water quality conditions in the delta


City of Des Moines
Des Moines River at DSM
#05485500
Walnut Creek
Des Moines River at Swan
#05487520
Des Moines River at Runnels
#05487500
Lake Red Rock
City of Pella
Des Moines River at Pella
#05488110
White Breast Creek
#05487980
Des Moines River basin
State of Iowa
Saylorville Reservoir
Lake Red Rock
City of Des Moines
City of Ottumwa
N
S
E
W
0 5 10 20 30 40
Kilometers

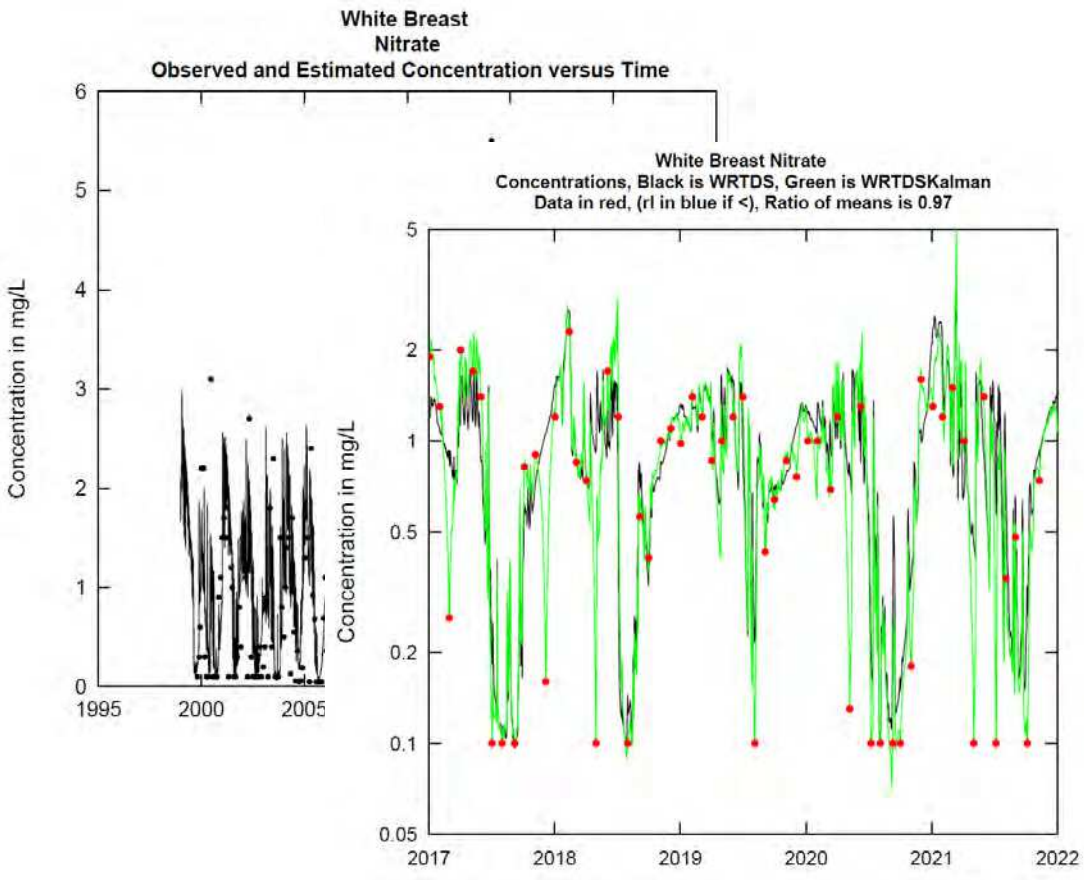
# These 4 sites had excellent historical nitrate datasets

- There has been a mix of sampling schedule organizations and schedule
- Nitrate datasets stretching back to 1978 are quite rare!

| Site | Start Date | End Date | n |
|---|---|---|---|
| Walnut | 10/1/1995 | 12/31/2020 | 5387 |
| White Breast | 1/1/1999 | 12/31/2021 | 260 |
| Swan | 1/1/1978 | 12/31/2019 | 1029 |
| Pella | 1/1/1978 | 12/31/2019 | 1059 |



# We modeled daily nitrate concentrations at each site

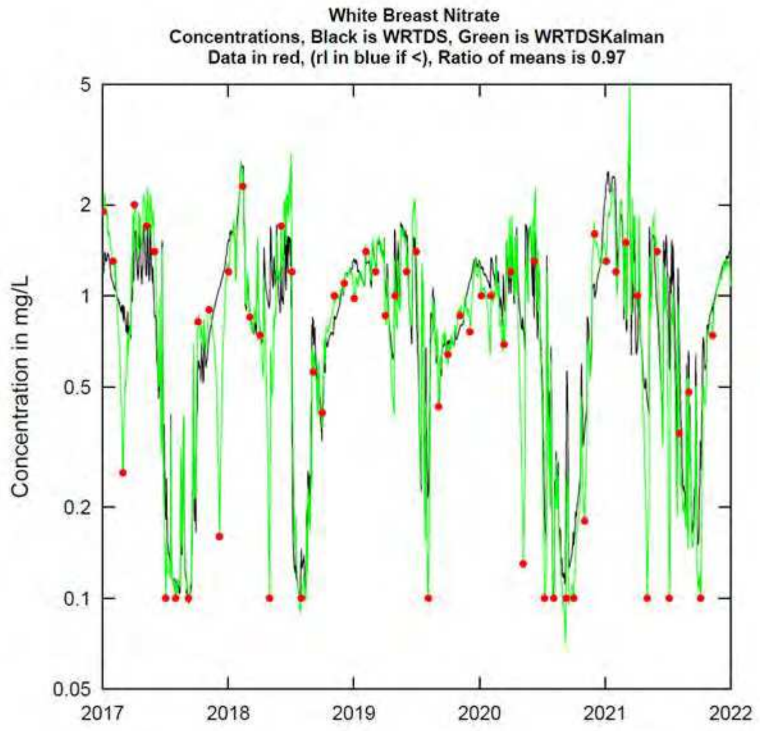



→ These models **predict nitrate concentrations** on days without measurements

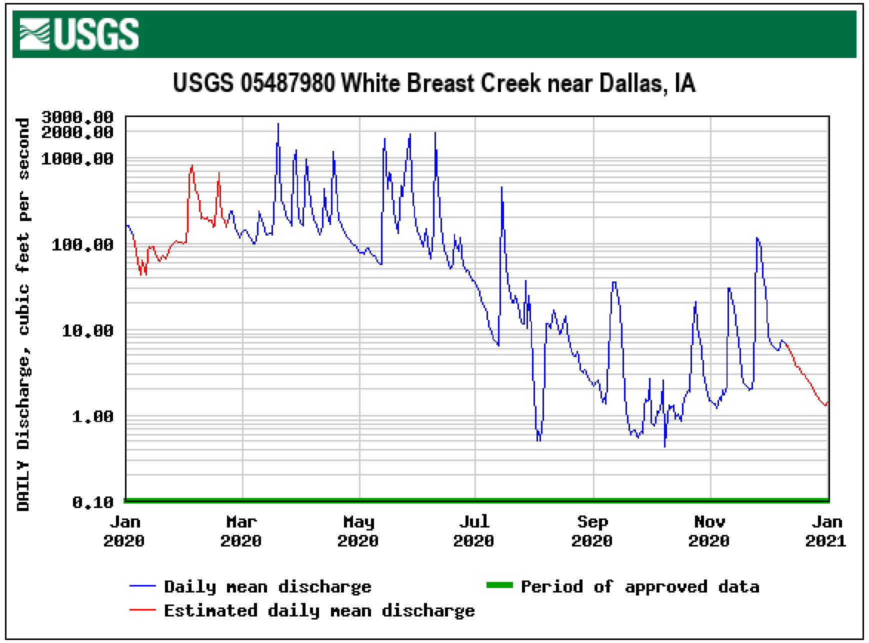
→ WRTDSK models account for:

- Flow conditions
- Time of the year
- Temporal trends
- Actual measurements

# With the modeled nitrate concentrations and USGS streamflow values, we calculated loads




Modeled Nitrate Concentrations



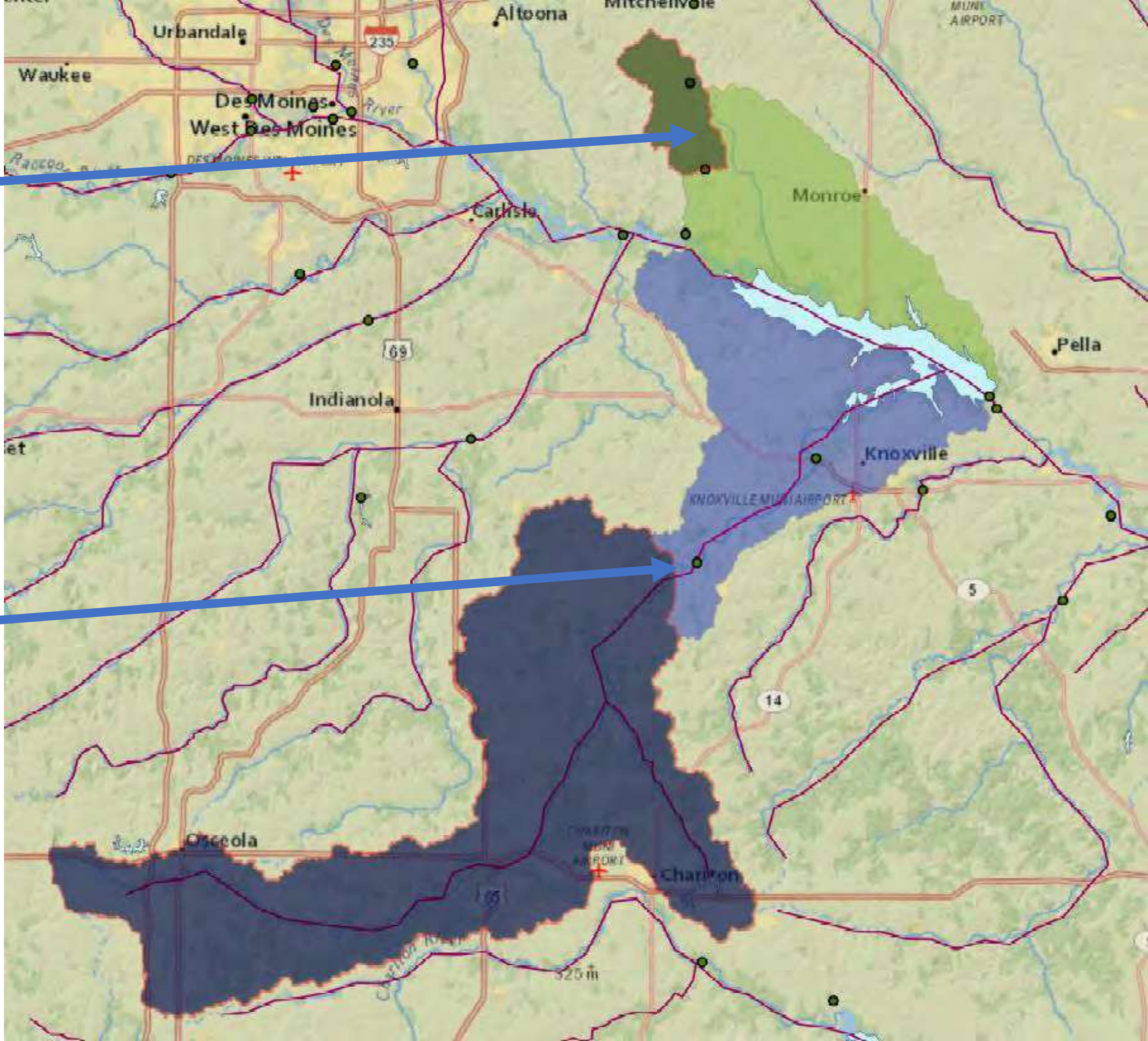

USGS Measured Streamflow

$$\frac{North}{Walnut} = \frac{118.9mi^2}{20.1mi^2} = 5.91$$

We delineated the tributary areas to the North and South of Red Rock

$$\frac{South}{White\ Breast} = \frac{466.4\ mi^2}{333\ mi^2} = 1.4$$

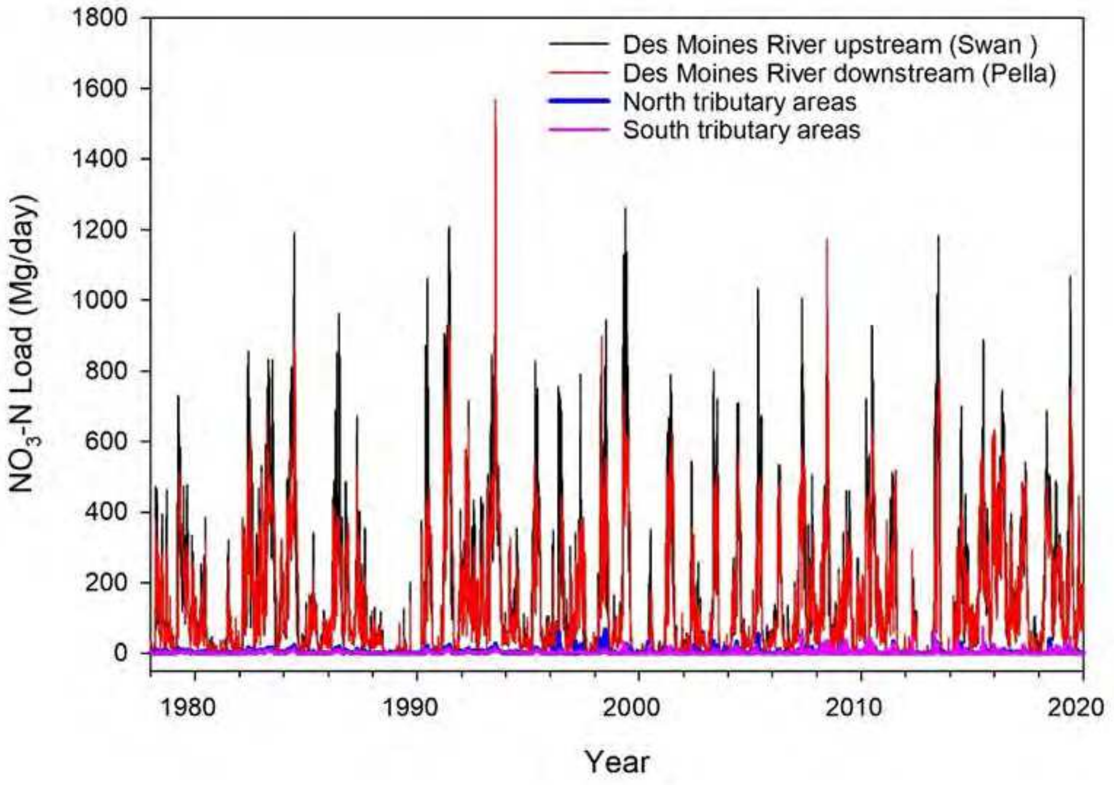
**We scaled up the loads to account for all North and South tributaries**



# The North and South nitrate loads are very minor

- Most nitrate flux occurs at Swan and Pella
- North is about 2% of upstream load
- South is about 1.2% of upstream load

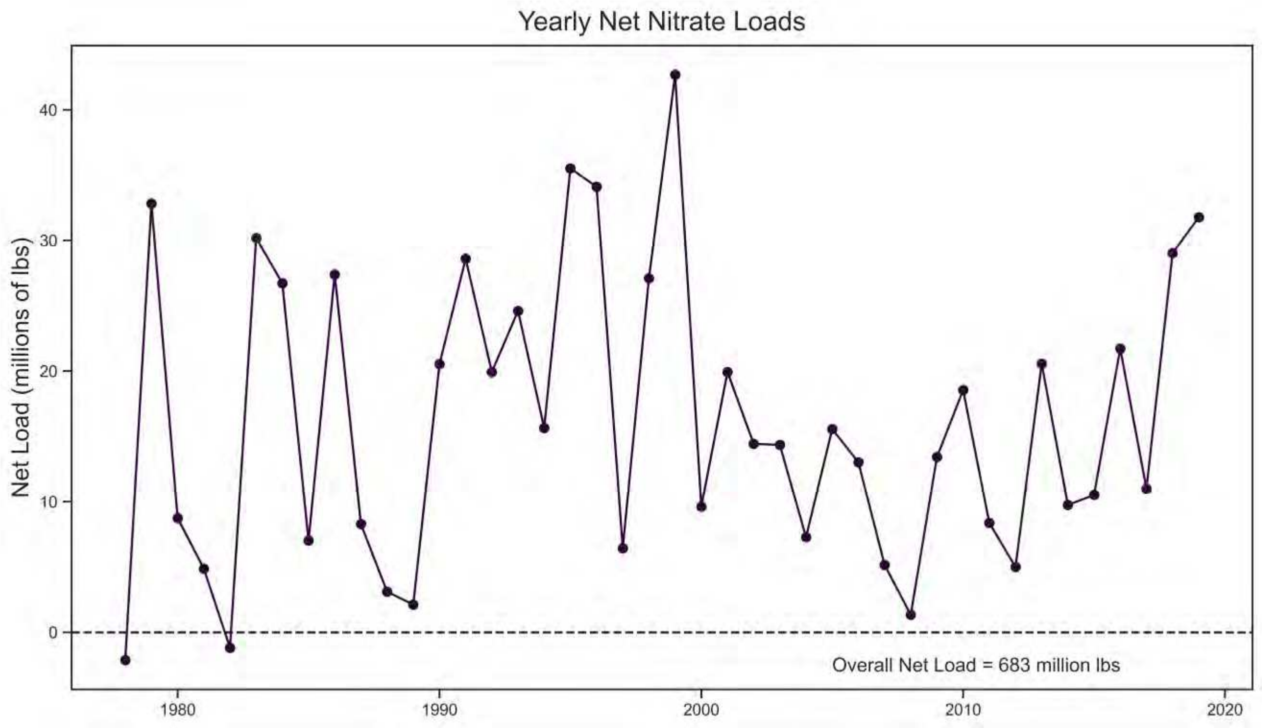
**Daily Nitrate Loads**



# Red Rock often has nitrate surpluses due to nitrate loss within the lake

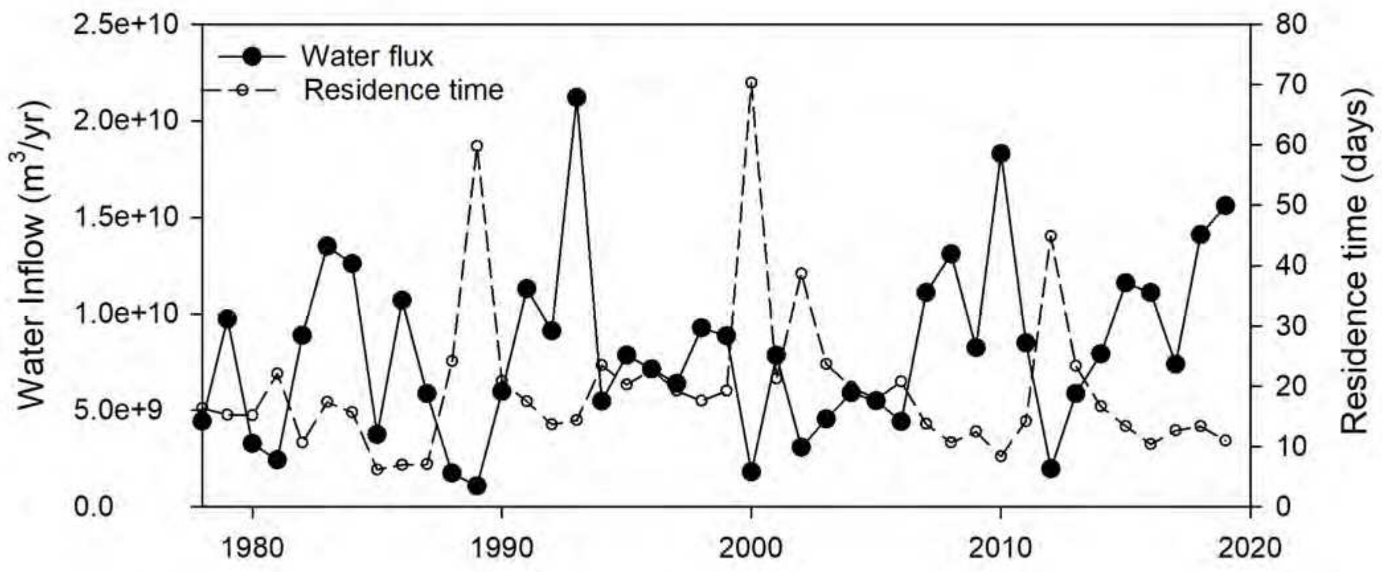
$$Net\ Nitrate = [Swan + North + South] - Pella$$

- We aggregated loads for each year and calculated net nitrate



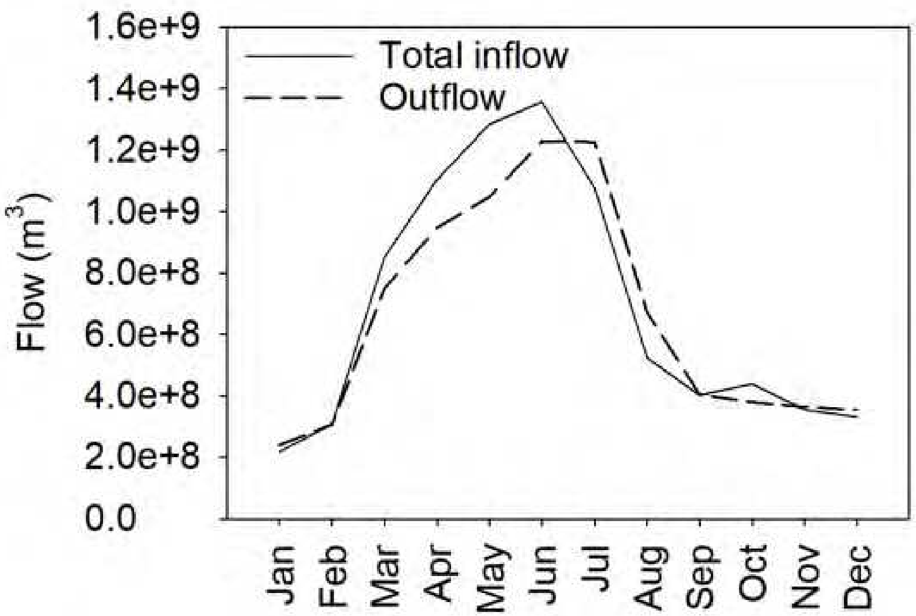
# Annual residences times varied between 6 to 70 days (average of 20 days)

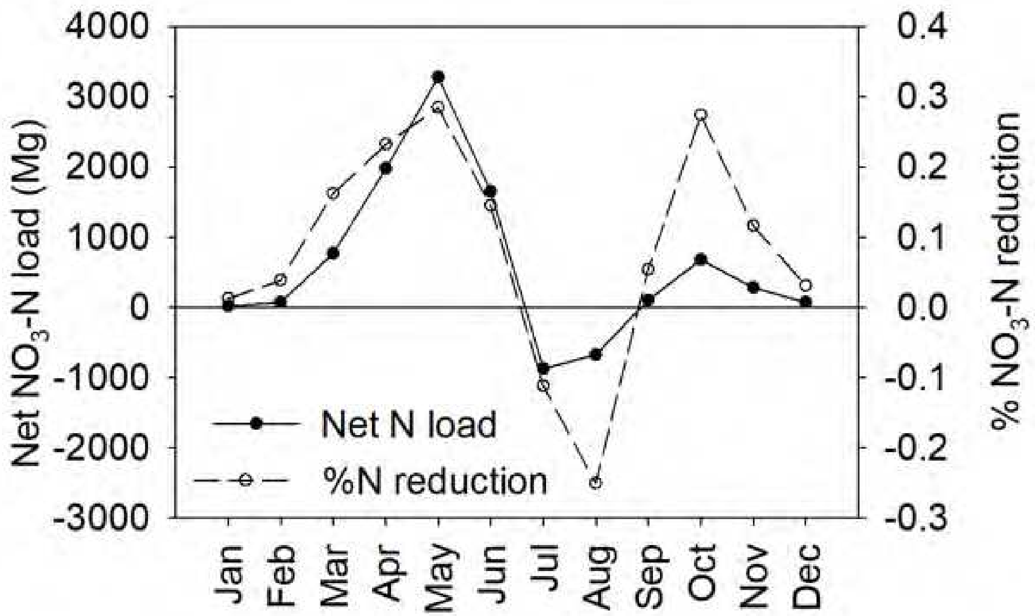
- *Residence time*: the average amount of time water spends in Lake Red Rock
- Generally, drier years have longer residence times



# Most nitrate loss occurs in the spring/early summer

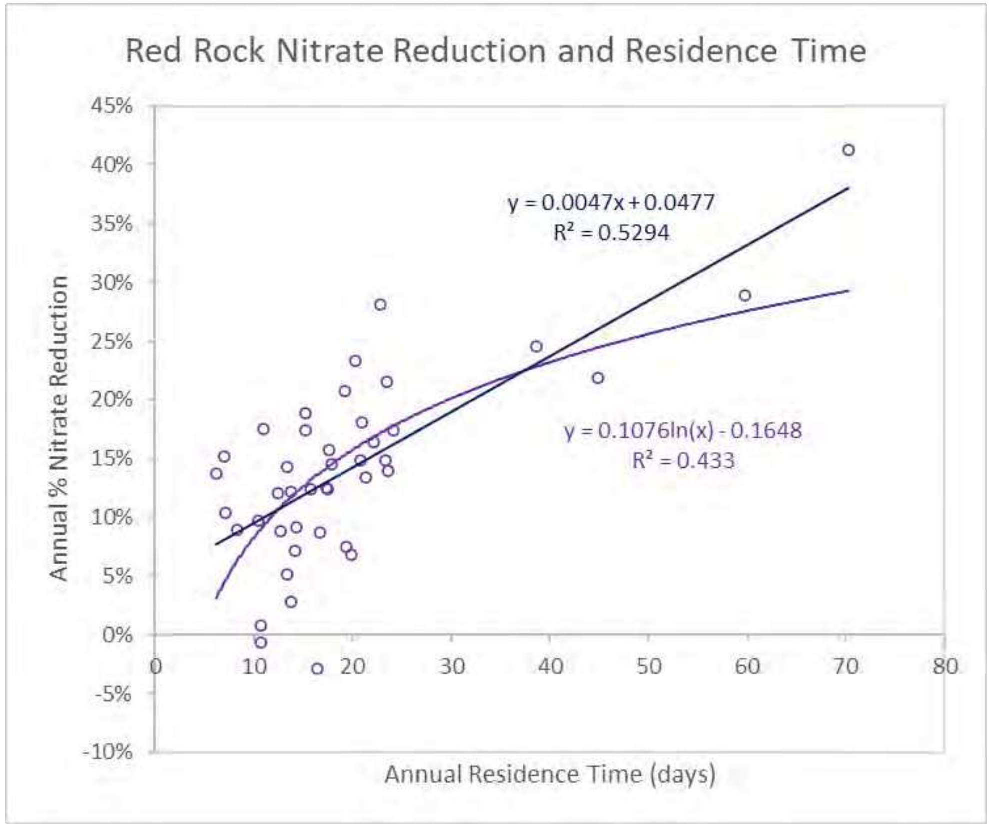
→ More nitrate enters red rock in the spring than leaves it in the late summer/fall



# Higher residences times lead to greater nitrate loss

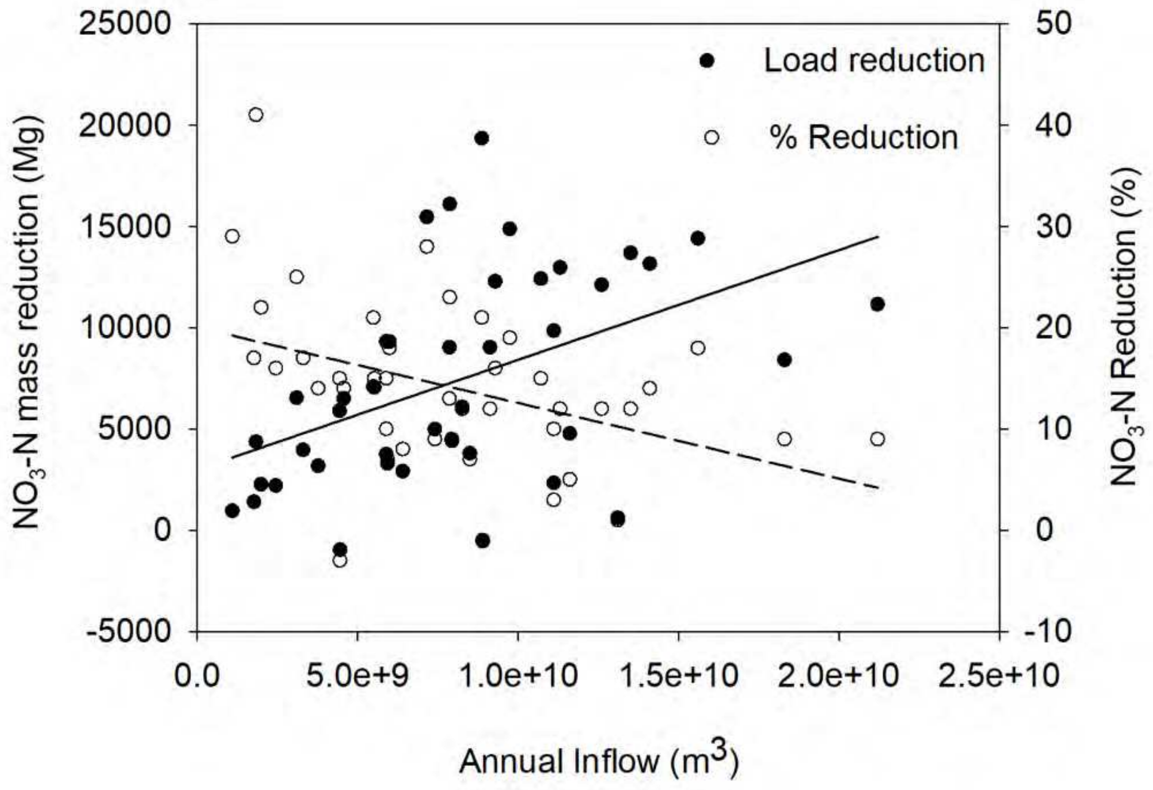
- An extra day of residence time removes an additional **0.5% of nitrate mass** approximately
- This is a common trend observed among flood-control reservoirs



# The inflow to Red Rock can affect how much nitrate is removed

→ In wet years, a higher mass of nitrate is removed because more nitrate enters the lake

→ But a smaller percentage of the nitrate is removed, as the residence time is lower during wet years



# For example:

→ *In a wet year*: 100,000 Mg enters Red Rock

- **10,000** gets removed, which is **10%** of the load

→ *In a dry year*: 30,000 Mg enters Red Rock

- **6,000** gets removed, which is **20%** of the load

→ The difference in % removal is due to drier years typically having longer residence times

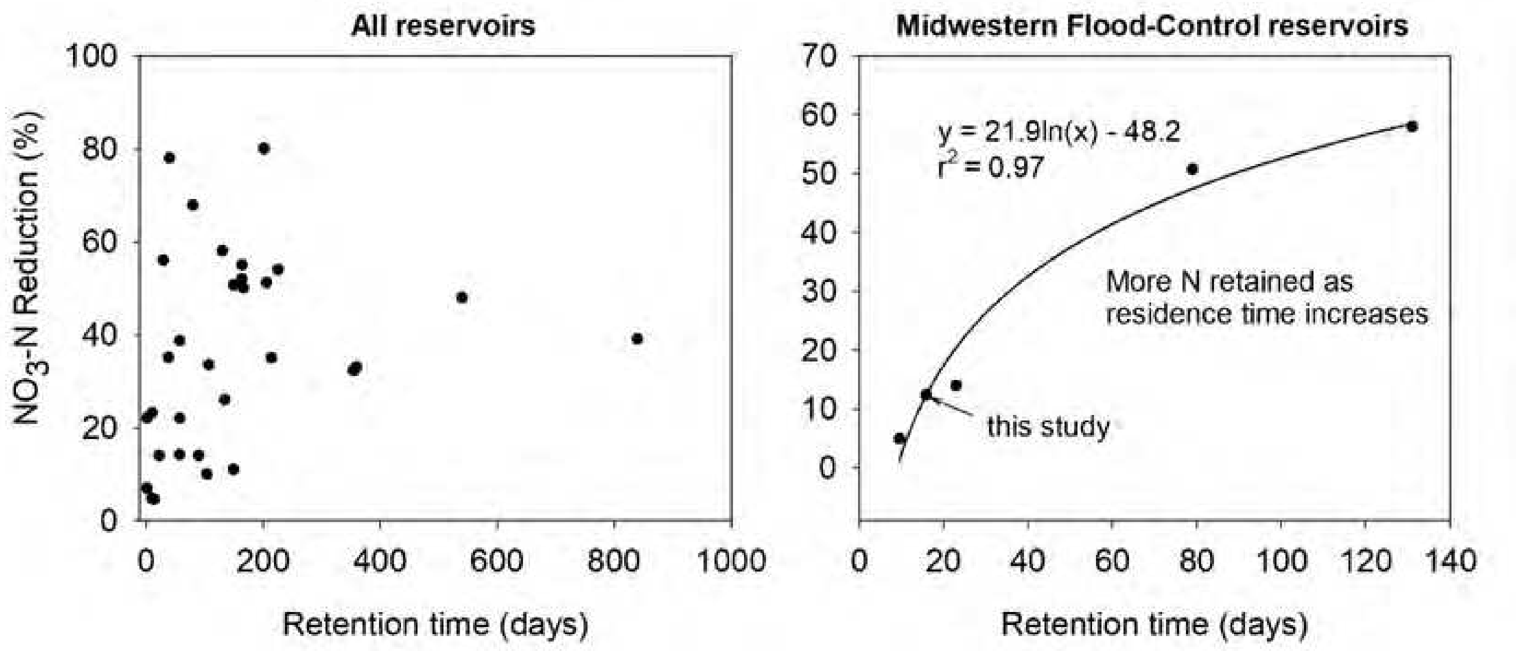
# Literature Review

| Locale | No. studied | Reservoir size (km2) | Depth (m) | Residence time (days) | % N retained | Citation |
|---|---|---|---|---|---|---|
| USA, IA | 1 | 24.1 | 3.8 | 9.6 | 4.9 | Stenback et al., 2014 |
| USA, IL | 1 | 44 | 5.2 | 131 | 58 | David et al., 2006 |
| USA, IL | 1 | 105 | 3.4 | | 50.7 | Shaughnessy et al., 2019 |
| USA, WI | 17 | 3.6-28.9 | 2.4-28.1 | 5-354.8 | -7.4-67.9 | Powers et al., 2015 |
| USA, AR | 3 | 0.34-0.60 | 3 | 164-202 | 52-80 | Grantz et al., 2014 |
| USA, KS | 6 | 13.8-63.6 | 1.8-7.6 | 30-840 | 11-56 | Cunha et al., 2014 |
| USA, MN | 1 | 102.7 | 5.4 | 23 | 14 | Mauer et al., 1995 |
| France | 3 | 21-48 | 7.2-8.9 | 135-226 | 26-54 | Garnier et al., 1999 |
| U.K. | 1 | 0.18 | 7 | 104 | 10 | Edokpa et al, 2016 |
| Poland | 2 | 1.2-22 | 3.3-25 | 2-215 | 22-35 | Tomaszek and Koszelnik, 2003 |
| India | 1 | 375 | | | 96 | Gupta et al., 2021 |

Globally, where $NO_3$-N load reductions in reservoirs have been measured, effects have varied across landscapes, regions and countries

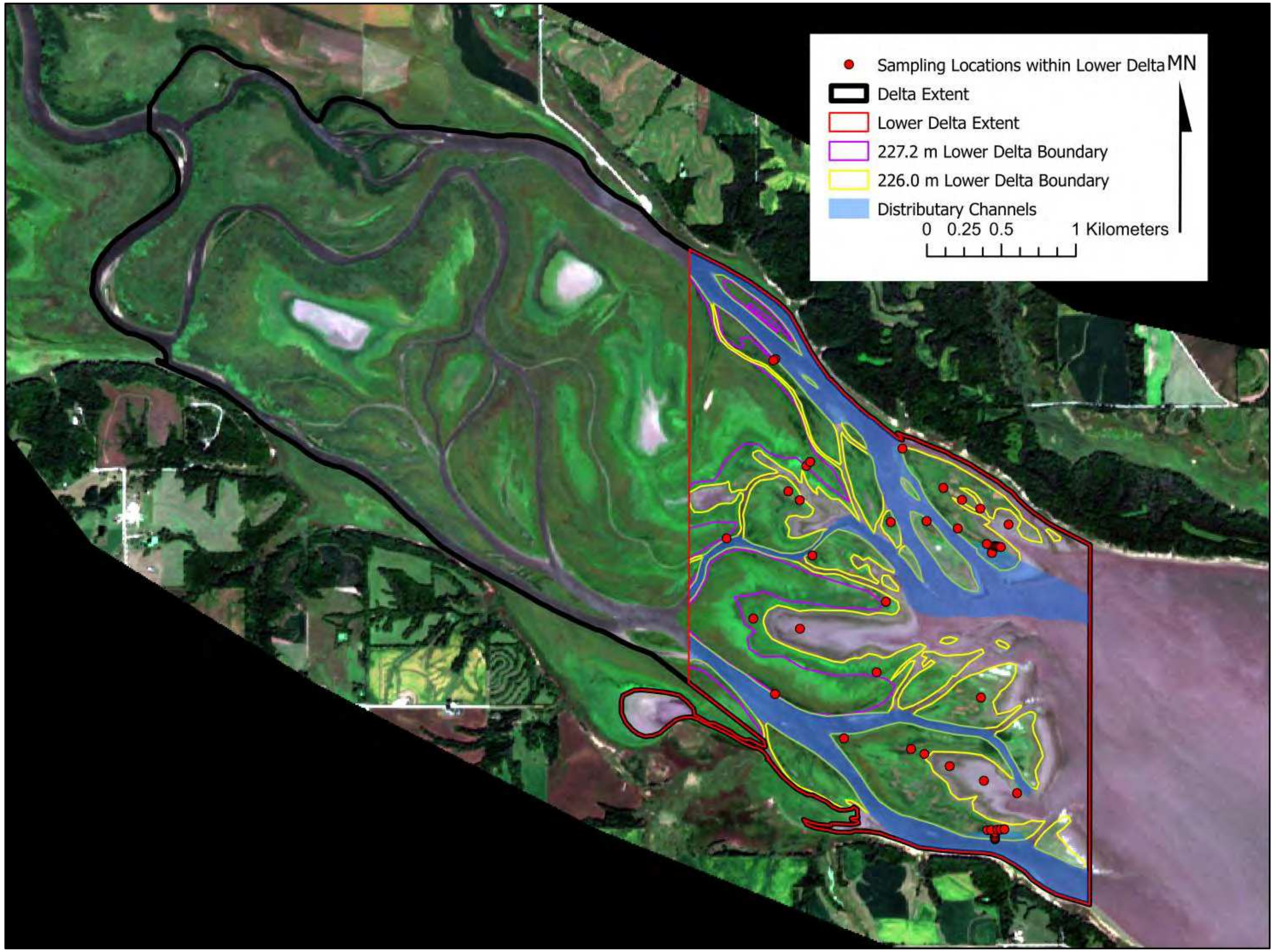
# Relation of N Reductions to Residence Time

→ No relation at global scale but clear relation for Midwestern flood control reservoirs

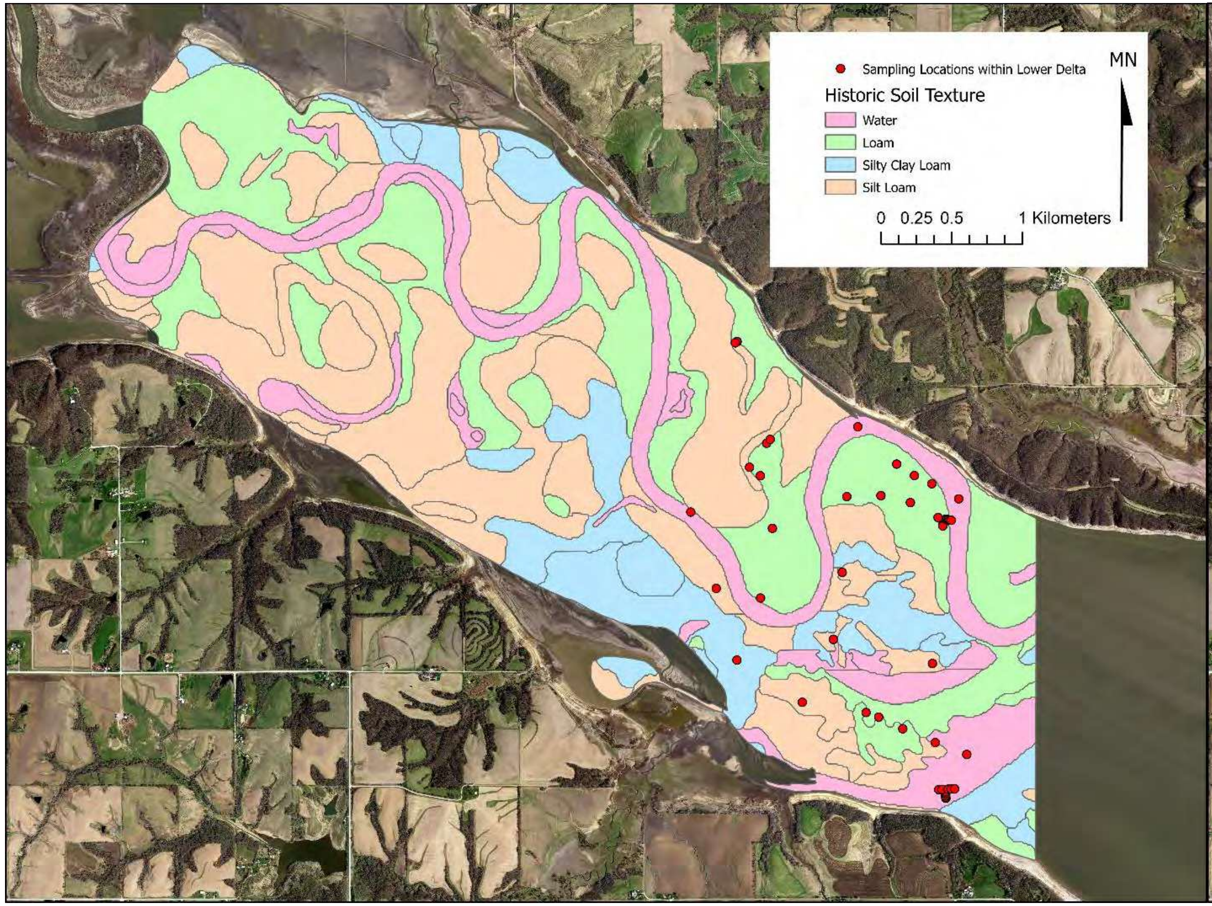


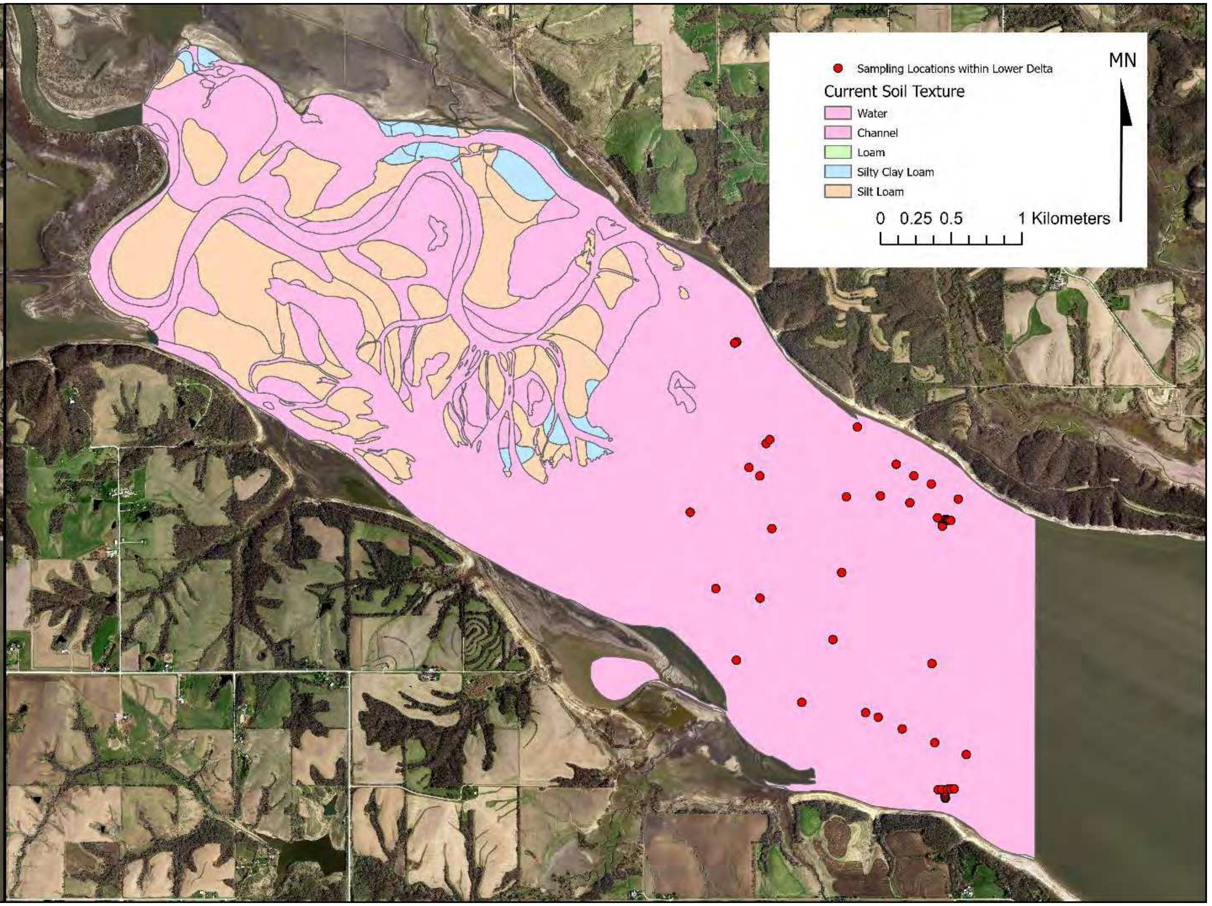
# Des Moines River Delta Extent

- Lower Delta elevations range from 741.59 to 745.50 ft
- Lower Delta is the most "active"
- Split into Plain and Distributary Channel



# Des Moines River Delta Soil Maps



# Lower Delta Plain Samples


# Lower Delta Distributary Channel Samples

# Landscape Position Comparisons

| Landscape Position | Sand | C Silt | F Silt | T Silt | Clay | TC | TN | Bulk Density |
|---|---|---|---|---|---|---|---|---|
| | % | % | % | % | % | % | % | g/cm$^3$ |
| **Distributary Channel** | 46±22 | 27±11 | 12±8 | 39±17 | 15±5 | 0.98±0.47 | 0.07±0.03 | |
| **Plain** | 34±22 | 32±10 | 17±9 | 49±17 | 17±6 | 1.23±0.44 | 0.08±0.03 | |
| **Surface Distributary Channel** | 42±9 | 33±7 | 10±8 | 43±6 | 15±2 | 0.99±0.31 | 0.07±0.02 | 1.20±0.06 |
| **Surface Plain** | 24±12 | 37±6 | 20±7 | 57±9 | 19±4 | 1.36±0.26 | 0.09±0.02 | 1.49±0.08 |

# Vertical Sediment Distribution

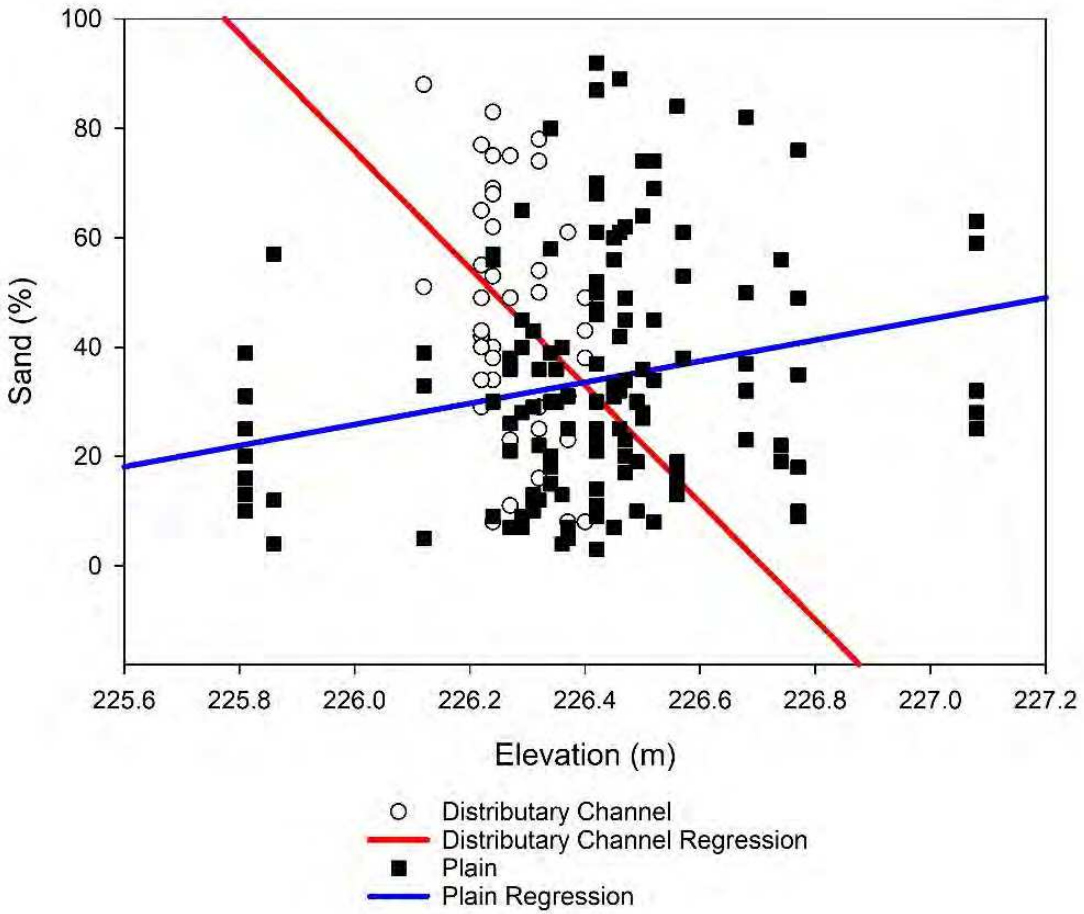
| Depth | Sand | C Silt | F Silt | T Silt | Clay | TN | TC |
|---|---|---|---|---|---|---|---|
| cm | % | % | % | % | % | % | % |
| | Distributary Channel | | | | | | |
| 20 | 39±3B | 33±3A | 13±1AB | 46±3A | 16±1AB | 0.07±0.02AB | 1.09±0.31AB |
| 40 | 45±12B | 31±8A | 9±8B | 40±9A | 15±3AB | 0.07±0.02AB | 0.89±0.27B |
| 60 | 67±11A | 16±6B | 7±3B | 23±8B | 10±3B | 0.05±0.02B | 0.66±0.32B |
| 80 | 41±18B | 33±11A | 11±4AB | 44±15A | 14±2AB | 0.09±0.03A | 1.46±0.89A |
| 100 | 39±19B | 31±10A | 15±7AB | 45±16A | 16±4AB | 0.08±0.02A | 1.02±0.23AB |
| 122 | 39±36B | 26±15AB | 19±12A | 44±26A | 17±10A | 0.09±0.04A | 1.02±0.47AB |
| | Plain | | | | | | |
| 20 | 26±15AB | 39±9A | 18±10AB | 56±12A | 18±3AB | 0.10±0.01A | 1.40±0.28AB |
| 40 | 32±17AB | 34±9AB | 17±8AB | 52±15AB | 17±6AB | 0.09±0.03AB | 1.37±0.40A |
| 60 | 40±22A | 30±10BC | 14±7B | 44±16B | 15±6B | 0.07±0.03B | 1.11±0.45B |
| 80 | 38±23AB | 30±9BC | 16±10AB | 45±17AB | 17±7AB | 0.08±0.03AB | 1.17±0.51AB |
| 100 | 28±21B | 34±10ABC | 20±9A | 54±18A | 18±6AB | 0.09±0.02A | 1.27±0.39AB |
| 122 | 33±26AB | 28±11C | 19±10A | 48±19AB | 19±7A | 0.09±0.04AB | 1.19±0.47AB |

# Big Picture Sediment and Carbon Storage in the lower delta

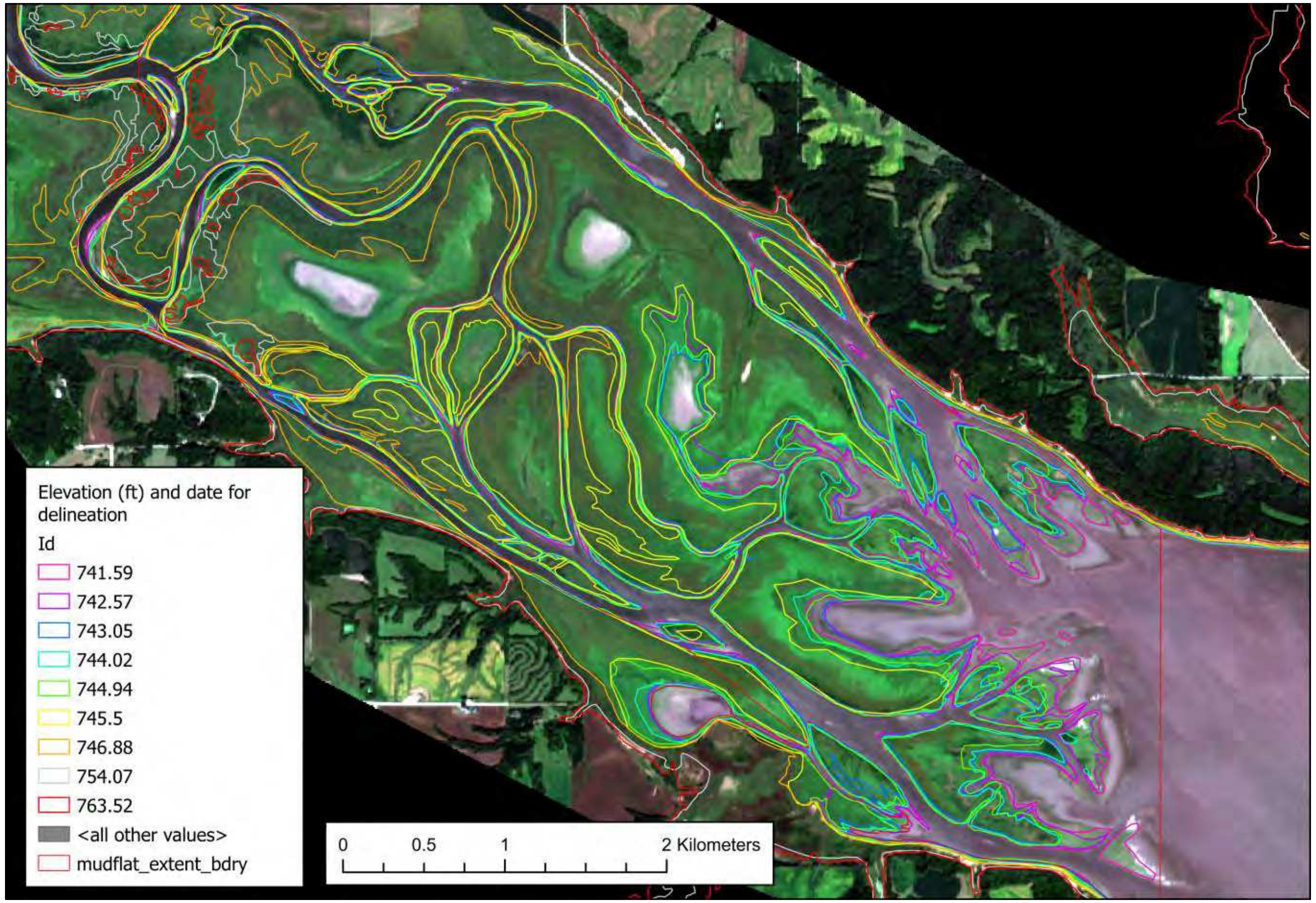
- → In the top 4 ft that we sampled
  - 15.1 million tons of sediment
  - 186,000 tons of total organic carbon
  - 8% of eroded soil since 1992
- → In the entire 30 ft deep deposit
  - 110 million tons of sediment
  - 1.1 million tons of total organic carbon
  - 60% of eroded soil since 1992

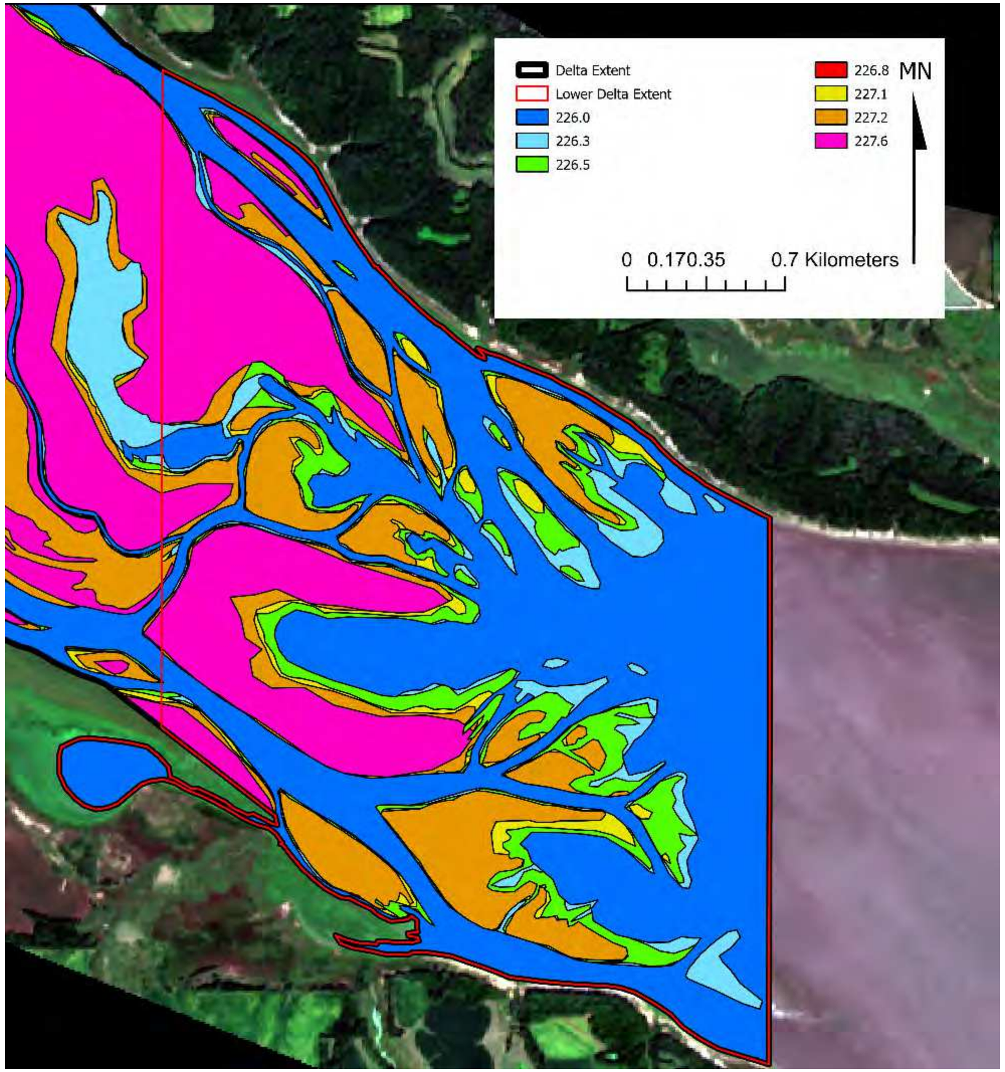
# Sand and Elevation Relationships

- Sand increases with elevation in the Plain but decreases with elevation in the Distributary Channel



# Inundation Contours



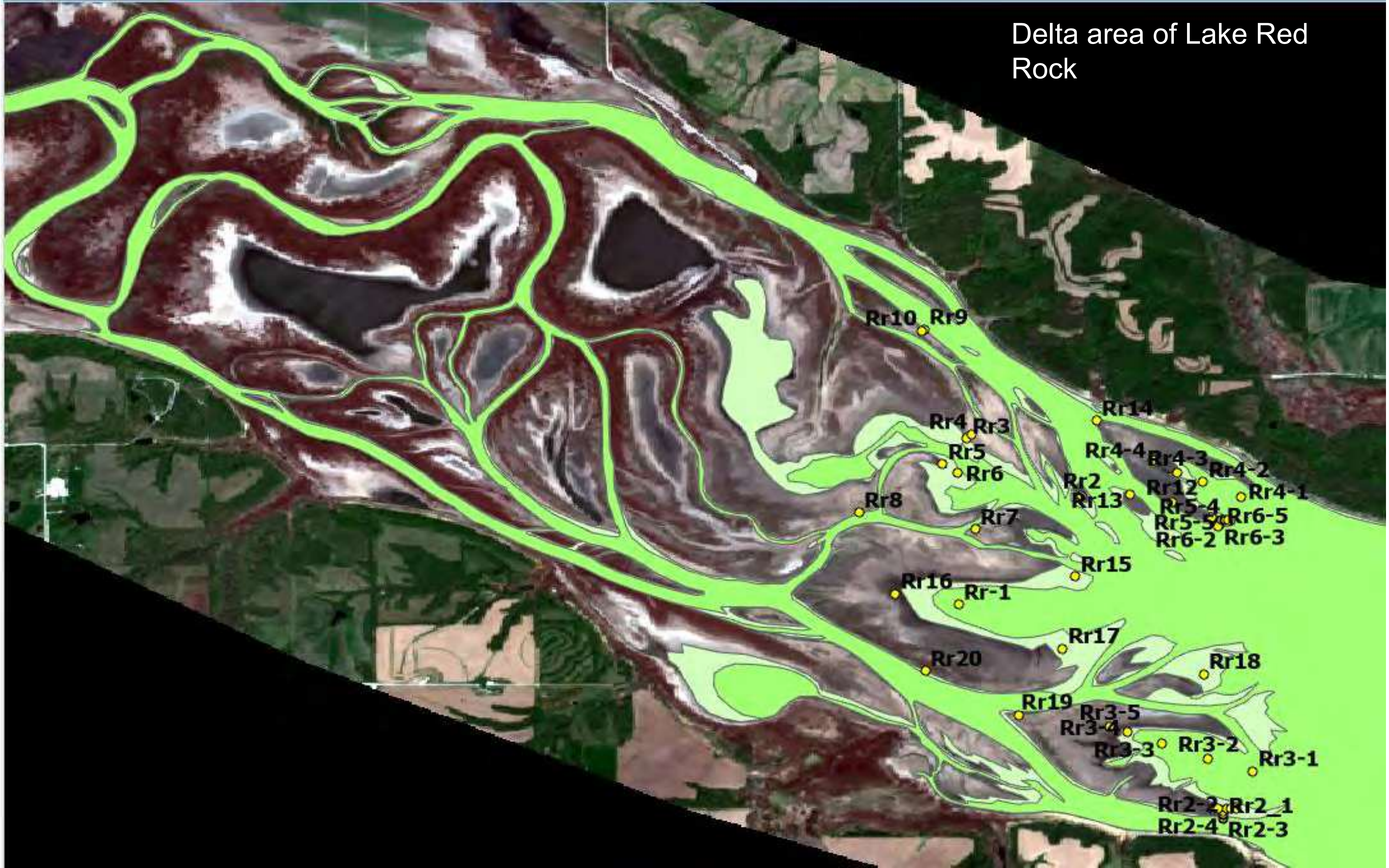
# Inundation/Elevation Relationships for the Lower Delta

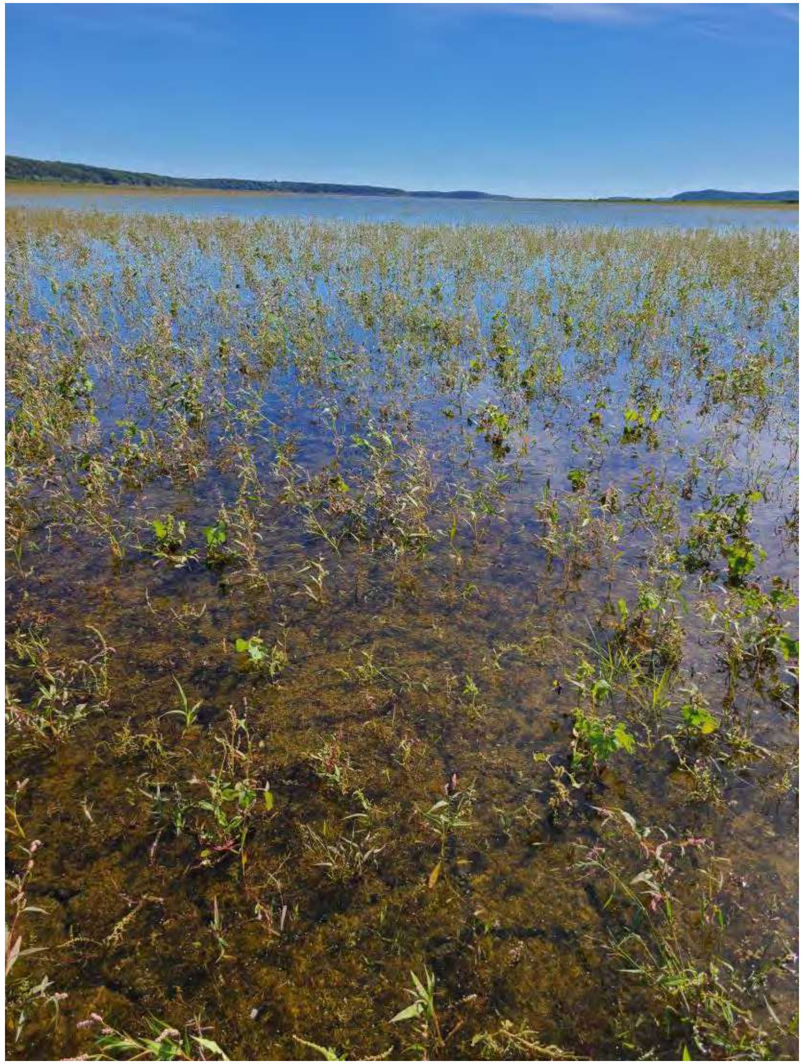
| Date | Elevation | Elevation | Inundation Area | Inundation | relative area increase |
|---|---|---|---|---|---|
| | m | ft | ha | % | % |
| 9/8/2021 | 226.0 | 741.59 | 370 | 49.0 | |
| 5/1/2021 | 226.3 | 742.57 | 399 | 52.8 | 7.8 |
| 4/26/2021 | 226.5 | 743.05 | 451 | 59.7 | 13.0 |
| 10/18/2021 | 226.8 | 744.02 | 467 | 61.9 | 3.5 |
| 12/2/2020 | 227.1 | 744.94 | 477 | 63.2 | 2.1 |
| 3/2/2021 | 227.2 | 745.5 | 612 | 81.1 | 28.3 |
| 12/4/2015 | 227.6 | 746.88 | 746 | 98.8 | 21.9 |
| 12/8/2018 | 229.8 | 754.07 | 746 | 98.8 | 0.0 |
| 5/22/2019 | 232.7 | 763.52 | 746 | 98.8 | 0.0 |

# N Loss Measurements (ISU led)

- Subcontract to Tom Isenhart at NREM, Iowa State University
- Soil cores were collected by Jen Merryman from 51 locations in the exposed delta or in areas of shallow water inundation within the mud flat delta.
- Locations corresponded with samples collected for assessment of soil physical characteristics.
- Cores were collected on September 15 and 29, 2022
- Laboratory tests at Iowa State University

Delta area of Lake Red Rock






Phowler Series


R4.2

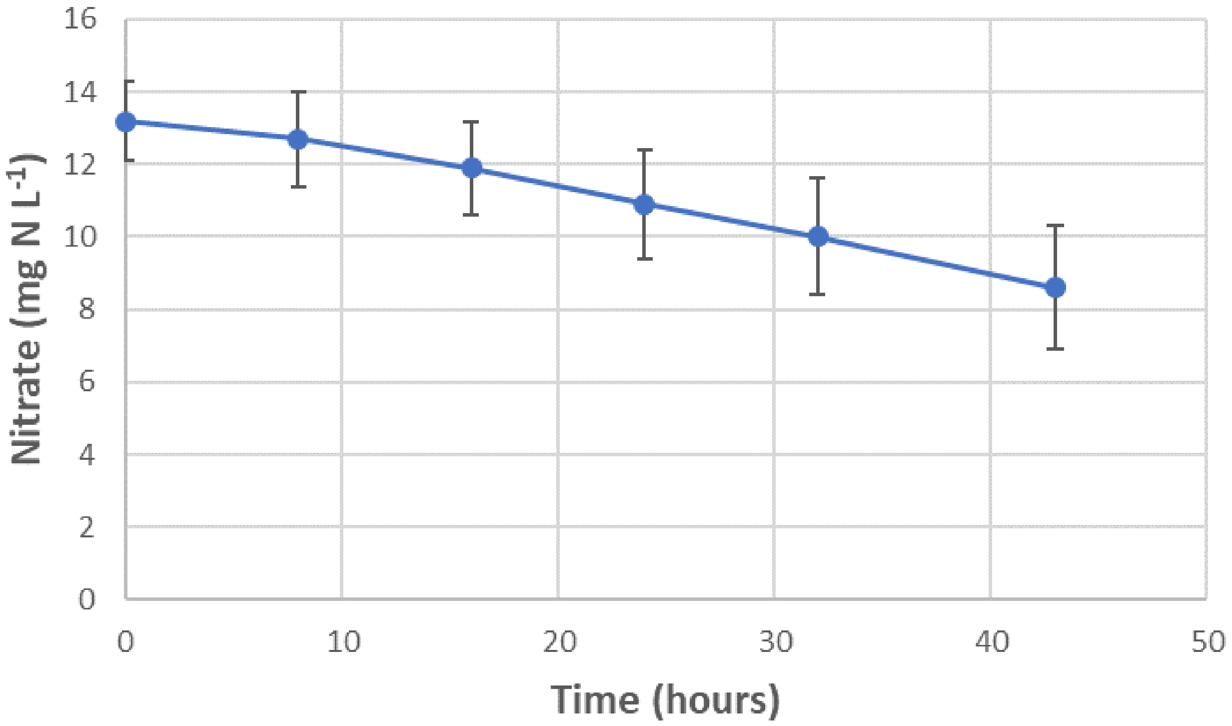
13
1-5
A5
A4
A3
A2

RR16
RR12
RR11
RR10
A5
A4
A3
A2

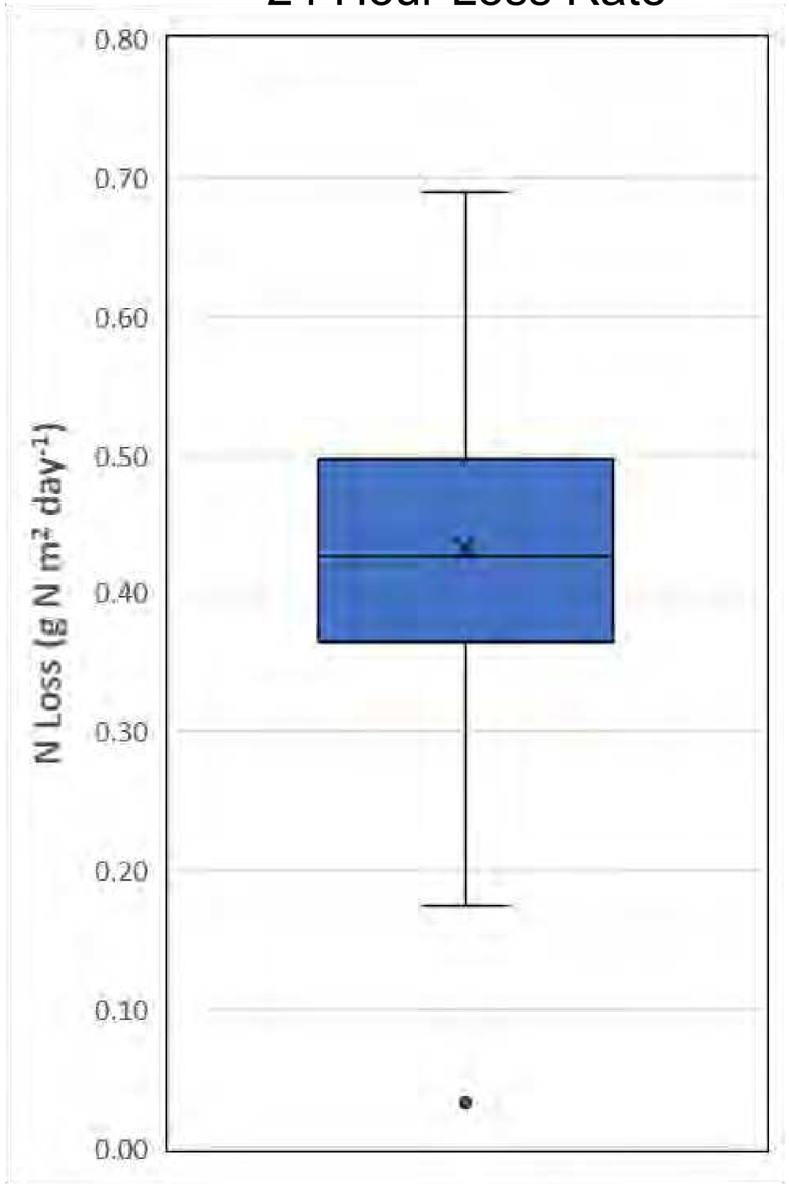
| Nitrate Loss (g N $m^{-2}$ $day^{-1}$) | |
|---|---|
| | 24 Hour |
| mean | 0.67 |
| s.d. | 0.21 |
| median | 0.66 |
| max | 1.23 |
| min | 0.08 |
| count | 52 |

- Range from 0.08 to 1.23
- Similar mean and median
- Seemingly normal distribution

Average Nitrate (mg N $L^{-1}$) of all samples over the first 43 hours.




24 Hour Loss Rate



# Implications for N load reductions

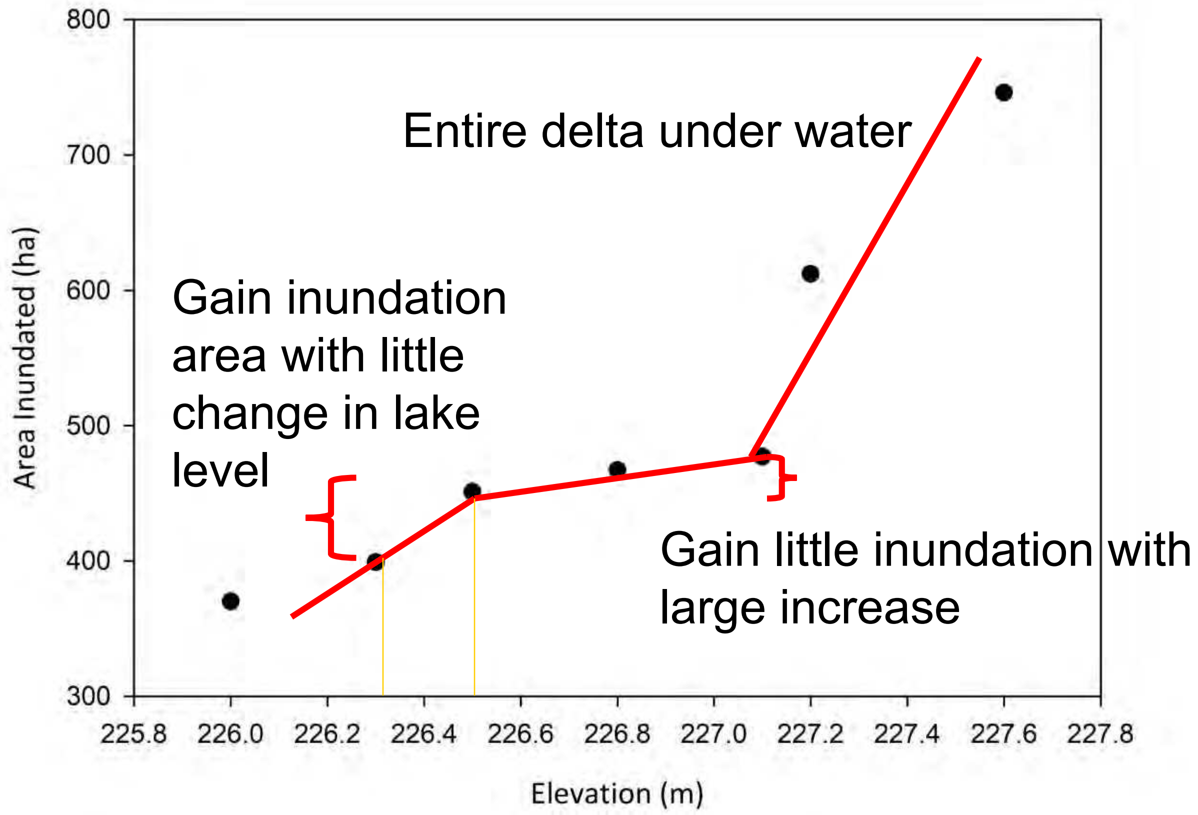
*Preliminary analysis*

| Date | Elevation | Elevation | Inundation Area | Inundation of entire delta | relative area increase | Lower Delta Nitrate Loss | Entire Delta Nitrate Loss | Lower Delta Portion of Total Nitrate Loss |
|---|---|---|---|---|---|---|---|---|
| | m | ft | ha | % | % | Mg/day | Mg/day | % |
| 9/8/2021 | 226.0 | 741.59 | 370 | 49.0 | | 2.5 | 3.6 | 70 |
| 5/1/2021 | 226.3 | 742.57 | 399 | 52.8 | 7.8 | 2.7 | 4.0 | 68 |
| 4/26/2021 | 226.5 | 743.05 | 451 | 59.7 | 13.0 | 3.0 | 4.3 | 71 |
| 10/18/2021 | 226.8 | 744.02 | 467 | 61.9 | 3.5 | 3.1 | 4.4 | 72 |
| 12/2/2020 | 227.1 | 744.94 | 477 | 63.2 | 2.1 | 3.2 | 4.4 | 73 |
| 3/2/2021 | 227.2 | 745.5 | 612 | 81.1 | 28.3 | 4.1 | 6.0 | 68 |
| 12/4/2015 | 227.6 | 746.88 | 746 | 98.8 | 21.9 | 5.0 | 10.3 | 48 |
| 12/8/2018 | 229.8 | 754.07 | 746 | 98.8 | 0.0 | 5.0 | 11.2 | 45 |
| 5/22/2019 | 232.7 | 763.52 | 746 | 98.8 | 0.0 | 5.0 | 11.4 | 44 |

Based on average N loss x inundation area

# Implications for reservoir management

***preliminary***




- Assume 3 Mg/day of N loss with lower delta inundation
- Drop in the bucket compared to long-term daily inflow N loads of 163 Mg than can exceed 1000 Mg
- Key point – will compare to seasonal loads or non-event periods

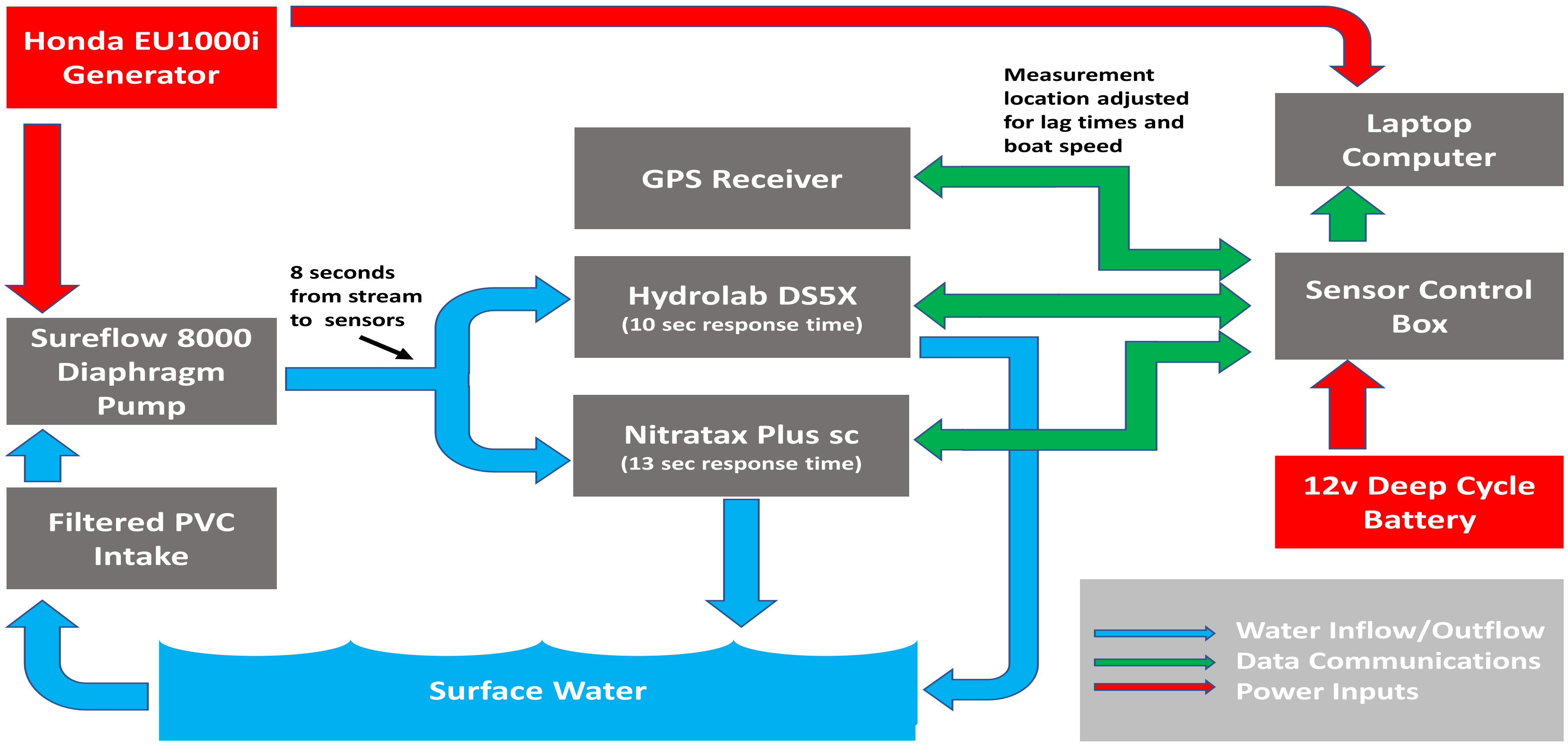
# Groundwater in the Lower Delta

- Bonus question…
- Installed five shallow wells using a hand auger
- Lower water yielding than anticipated – tough to sample
- NO3-N and dissolved oxygen much lower in delta groundwater than in adjacent surface water

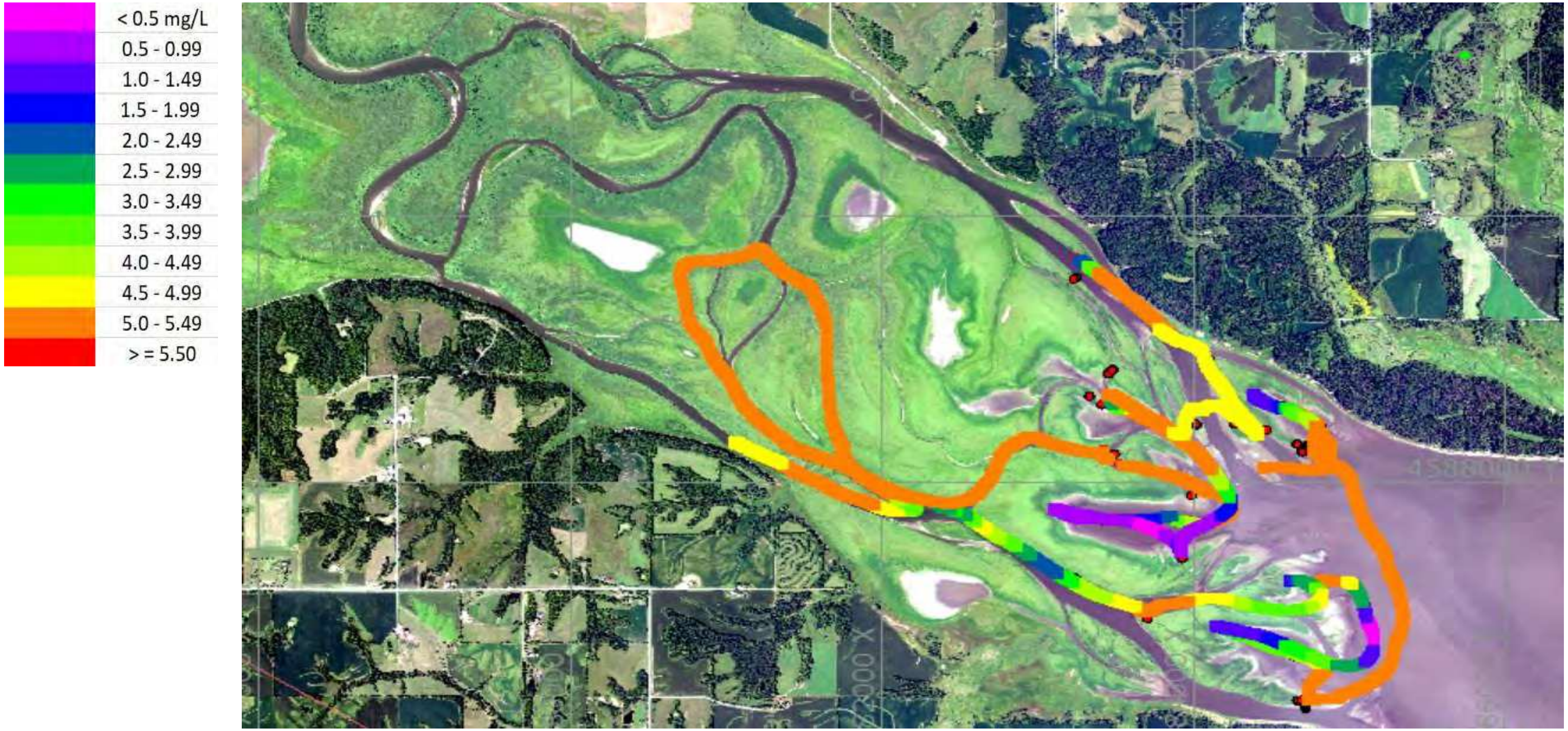
| Location | pH | Spec Cond (uS/m) | Diss Oxygen (mg/l) | NO3-N (mg/l) |
|---|---|---|---|---|
| Surface water | 9.5 | 675 | 13.4 | 2.3 |
| Groundwater | 7.4 | 1975 | 2.7 | 0.7 |

# Documenting NO3-N Concentration Reductions in the Red Rock Delta: Boat Surveys

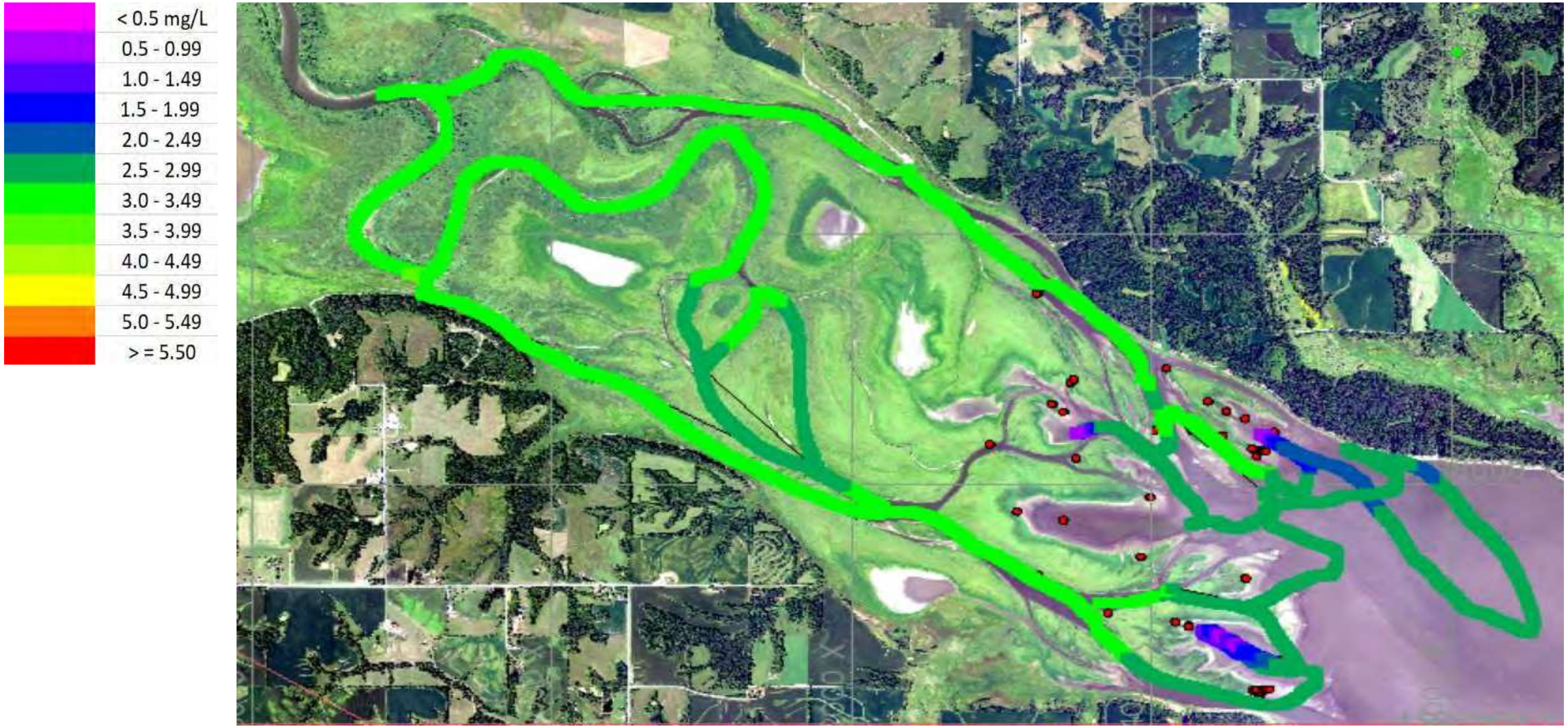
# Diagram of Boat Mounted Water Quality Monitoring System



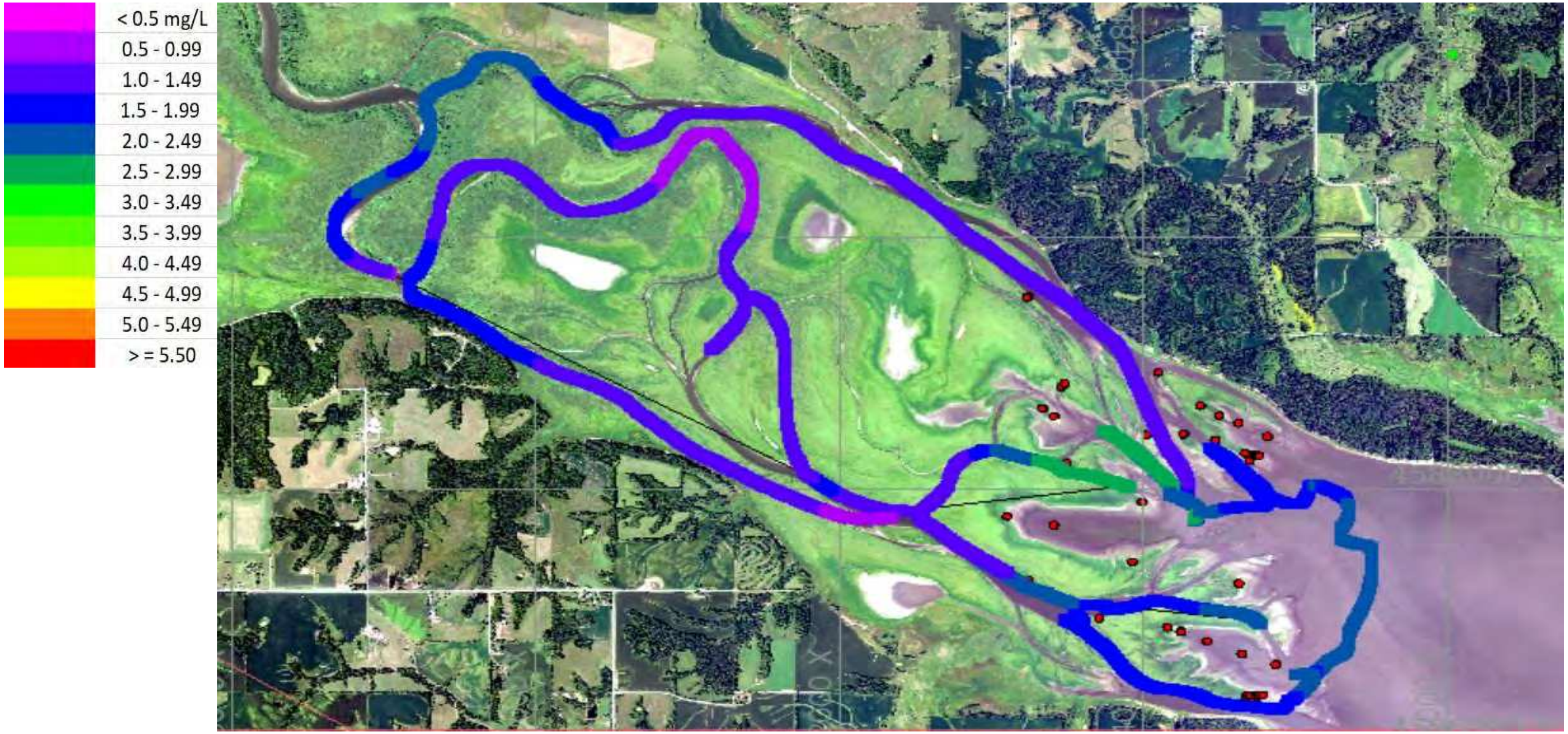
# Results of Nitrate Survey Conducted 7-19-2022 (mg/L NOx)



# Results of Nitrate Survey Conducted 7-28-2022 (mg/L NOx)



# Results of Nitrate Survey Conducted 9-14-2022 (mg/L NOx)



# Progress and deliverables

- Literature review and historical data analysis completed – manuscript submitted to Journal of Hydrology (accepted with revisions)
- Sedimentology – Data analysis, preparation of manuscript nearing completion
- N Loss measurements – completed
- Synthesis paper bringing together all Phase 1 components with reservoir operations – conceptualized and finished by March 31
- Boat surveys – Continue monthly through 2023, future funding?

# Future work

- Surface-groundwater interactions in the delta – quantify subsurface N processing in saturated sediments
- Redistribution of delta sediment including bank erosion
- Soil development in the delta? Rate?
- Phosphorus budget, other nutrients, minerals?