Strengths and Weaknesses of Water Quality Monitoring Techniques

Little Bear River Basin

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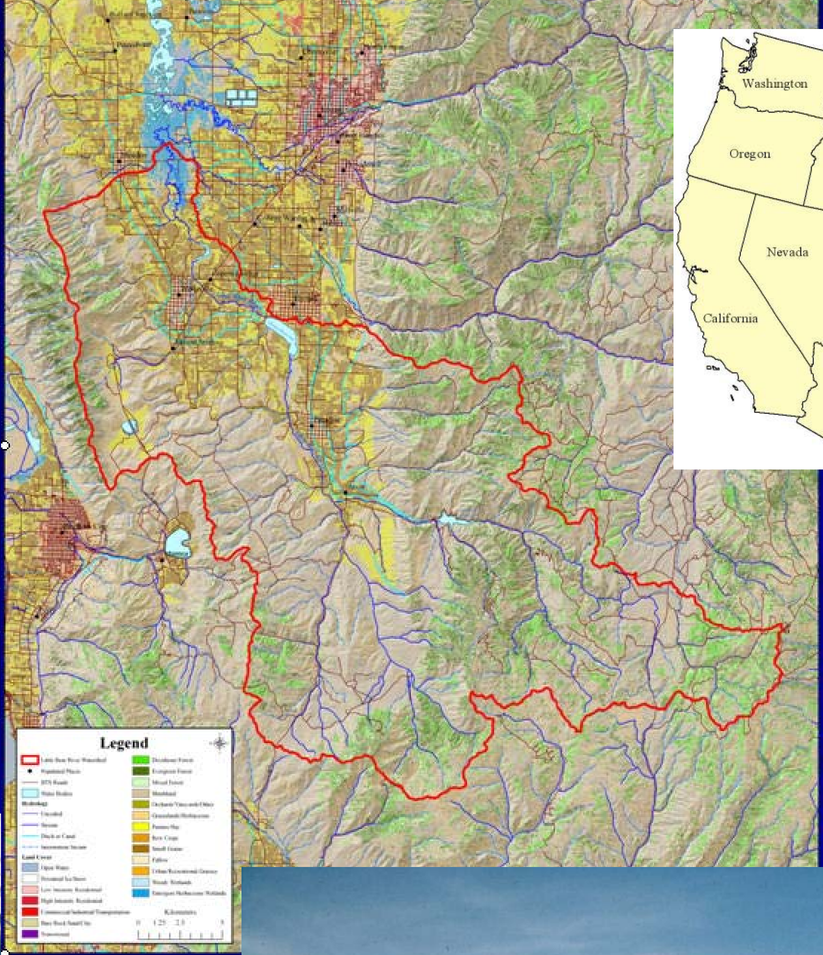
USDA CSREES Conservation Effectiveness Assessment Project

Objectives

- Determine if past implementations of agricultural BMPs resulted in improved water quality in the Little Bear River

- Investigate changes in practices from producer perspective: How persistant are behavioral changes. Do behaviors change over the long term, how effective are outreach / education efforts…

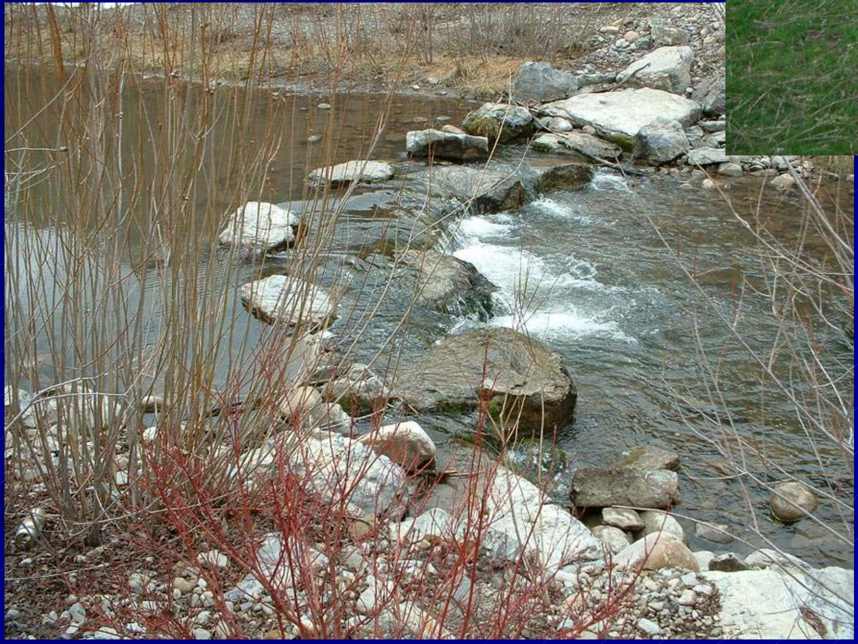
- **Critically examine the strengths and weaknesses of different water quality monitoring approaches, particularly wrt identifying changes at a watershed scale.**


Legend
Kilometers


Washington
Montana
Oregon
Idaho
Wyoming
Nevada
Utah
Colorado
California
Arizona
New Mexico

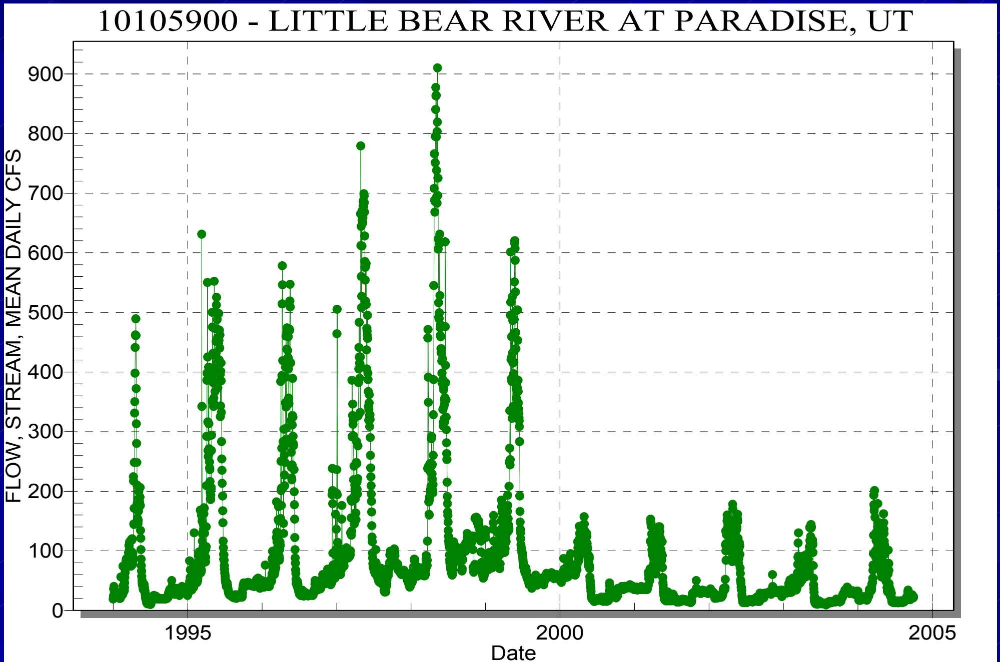




Little Bear River at Mendon Road - Utah DWQ 4905000 (1994-2004)		
	Number of Observations	
Year	Flow (cfs)	Total Phosphorus (mg/L)
1994	11	13
1995	10	13
1996	10	13
1997	11	4
1998	6	10
1999	7	10
2000	6	5
2001	4	7
2002	2	8
2003	4	8
2004	1	8

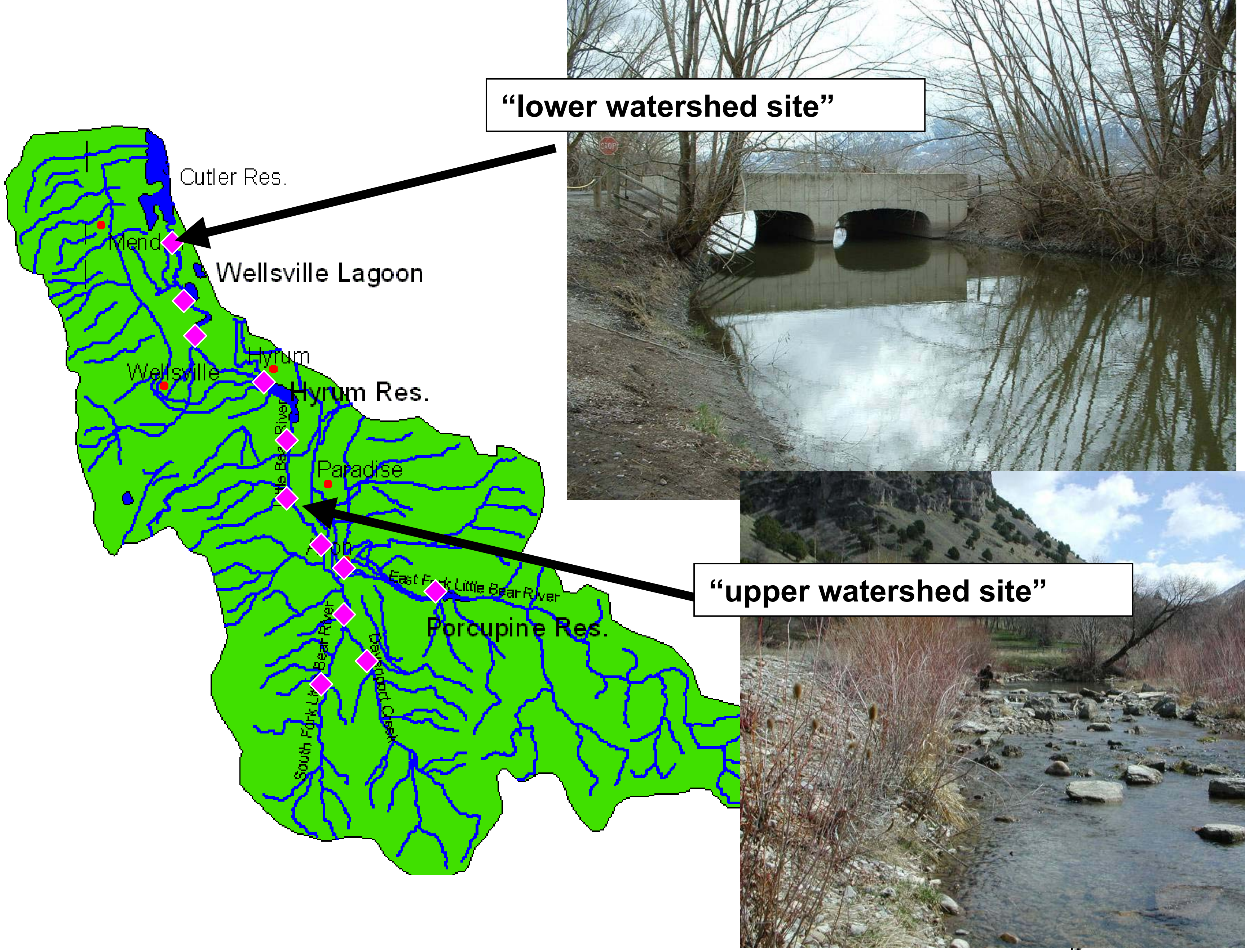
Existing Little Bear River monitoring program:
Grab samples at 2-8 sites/year



High frequency flow and turbidity data used..

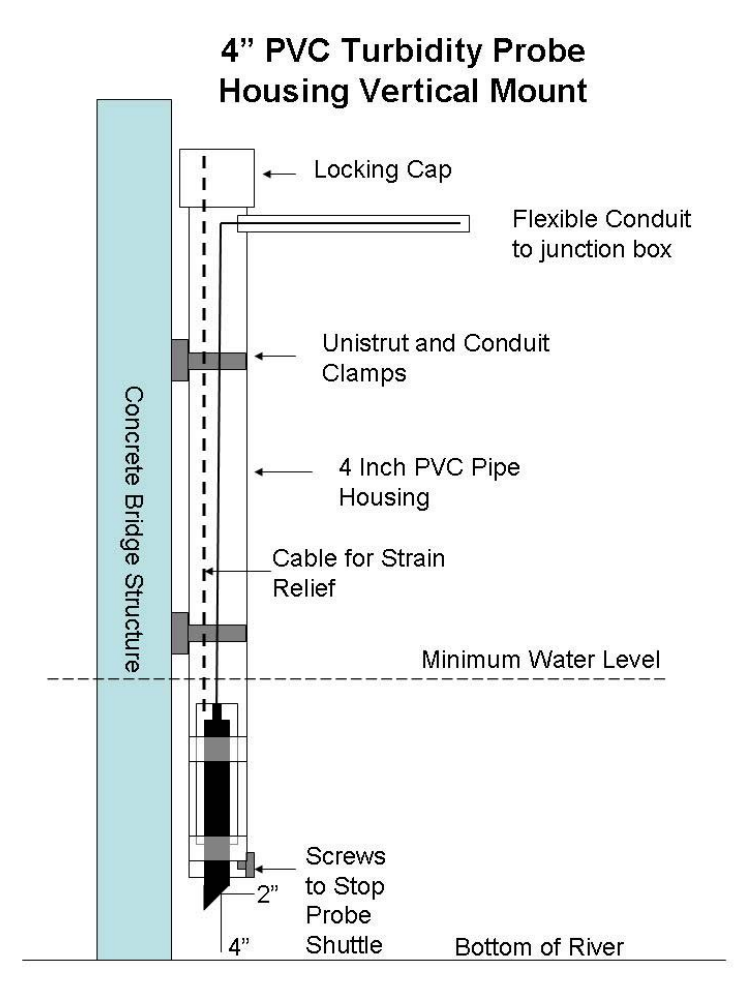
- to determine concentrations and loads (TSS and TP)

- To characterize:
  - Variabiity over time
    - Sampling frequency
    - Timing of sampling
  - Variability between sites
  - Contribution of storm events and major runoff events



"lower watershed site"
"upper watershed site"
Cutler Res.
Wellsville Lagoon
Hyrum
Wellsville
Hyrum Res.
Paradise
East Fork Little Bear River
Porcupine Res.

Little Bear River Sampling Program Continuous Monitoring Equipment



Stage recording devices to estimate discharge

http://www.campbellsci.com

Turbidity sensors to monitor water quality

http://www.ftsinc.com/

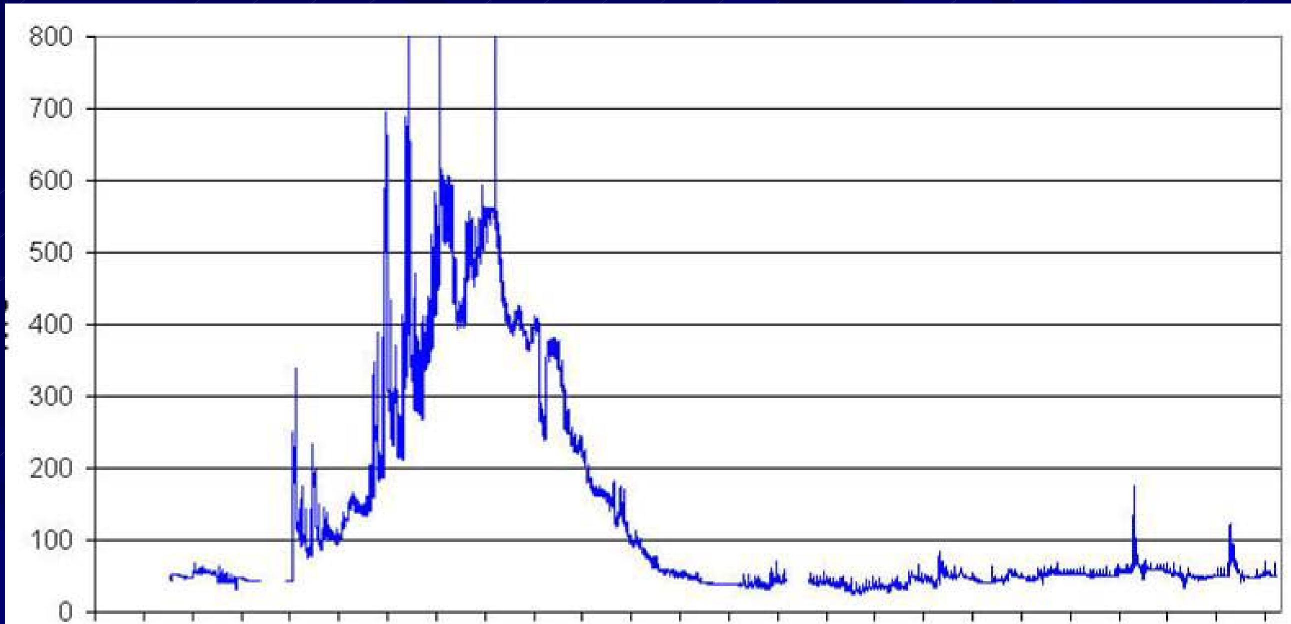
Dataloggers and telemetry equipment

http://www.campbellsci.com

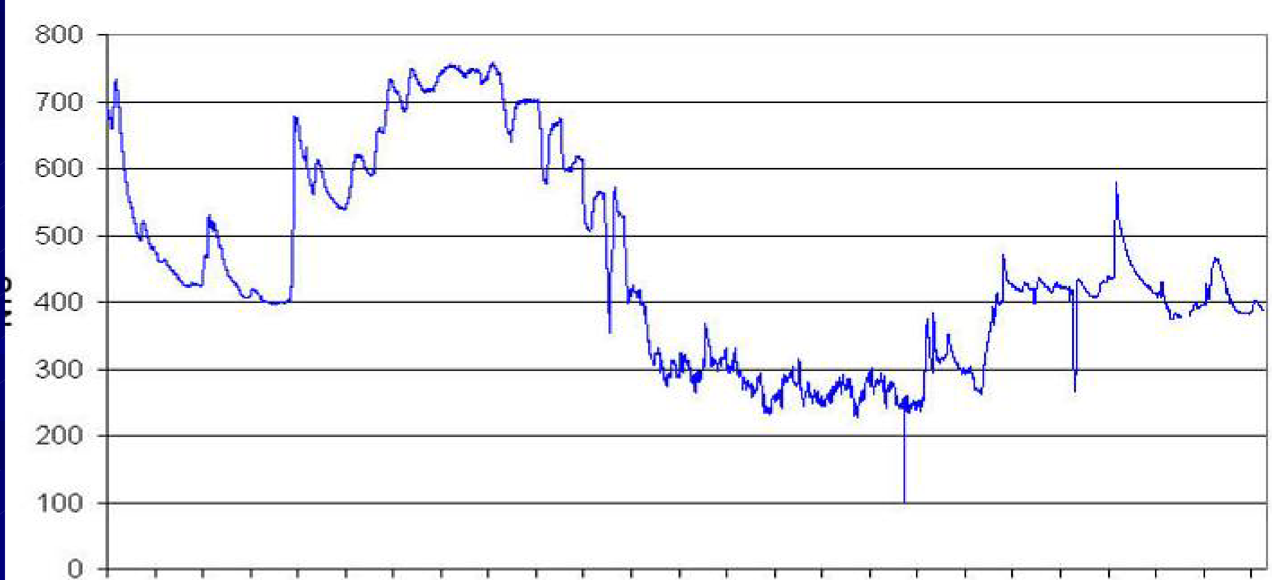
Additional monitoring:

- Automated sampling of storm events at two sites
- Ongoing monitoring program by Utah Division of Water Quality
- Periodic grab samples to establish Flow / TSS and TSS/TP relationship

Upper Site Flow (cfs)

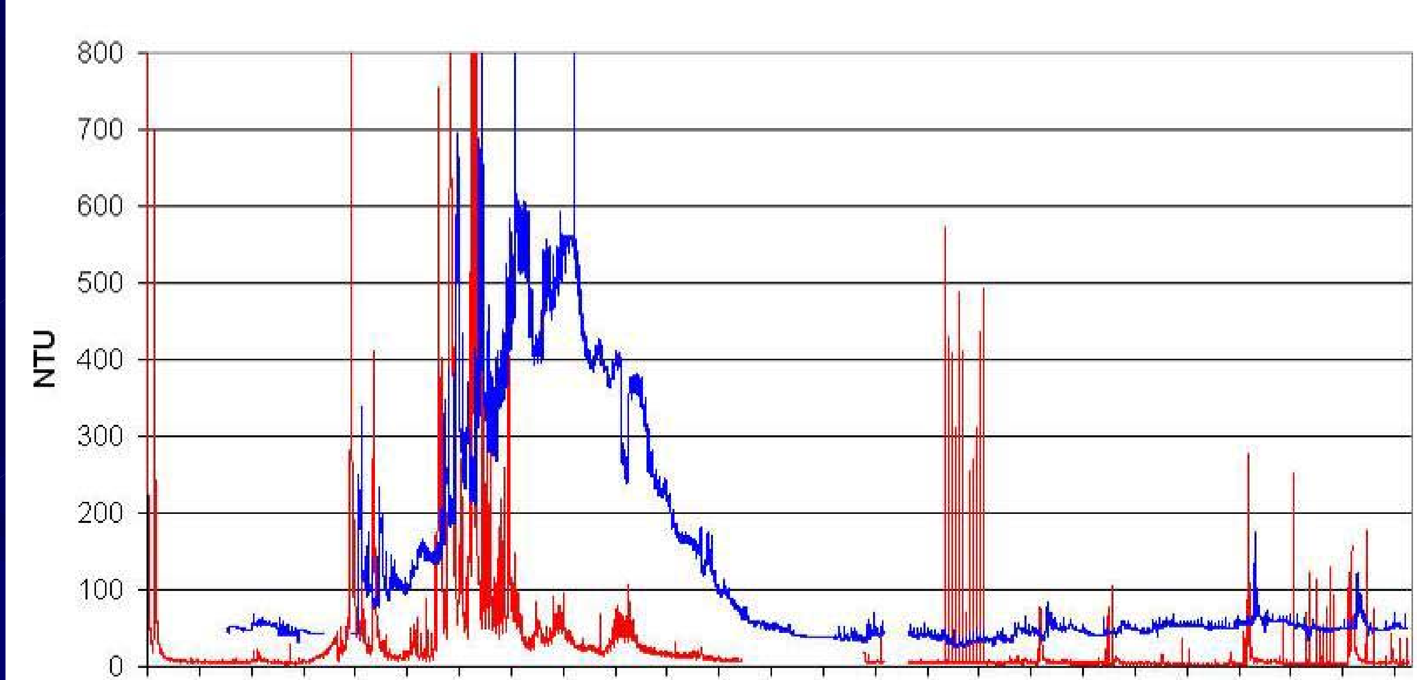


Lower Site Flow (cfs)

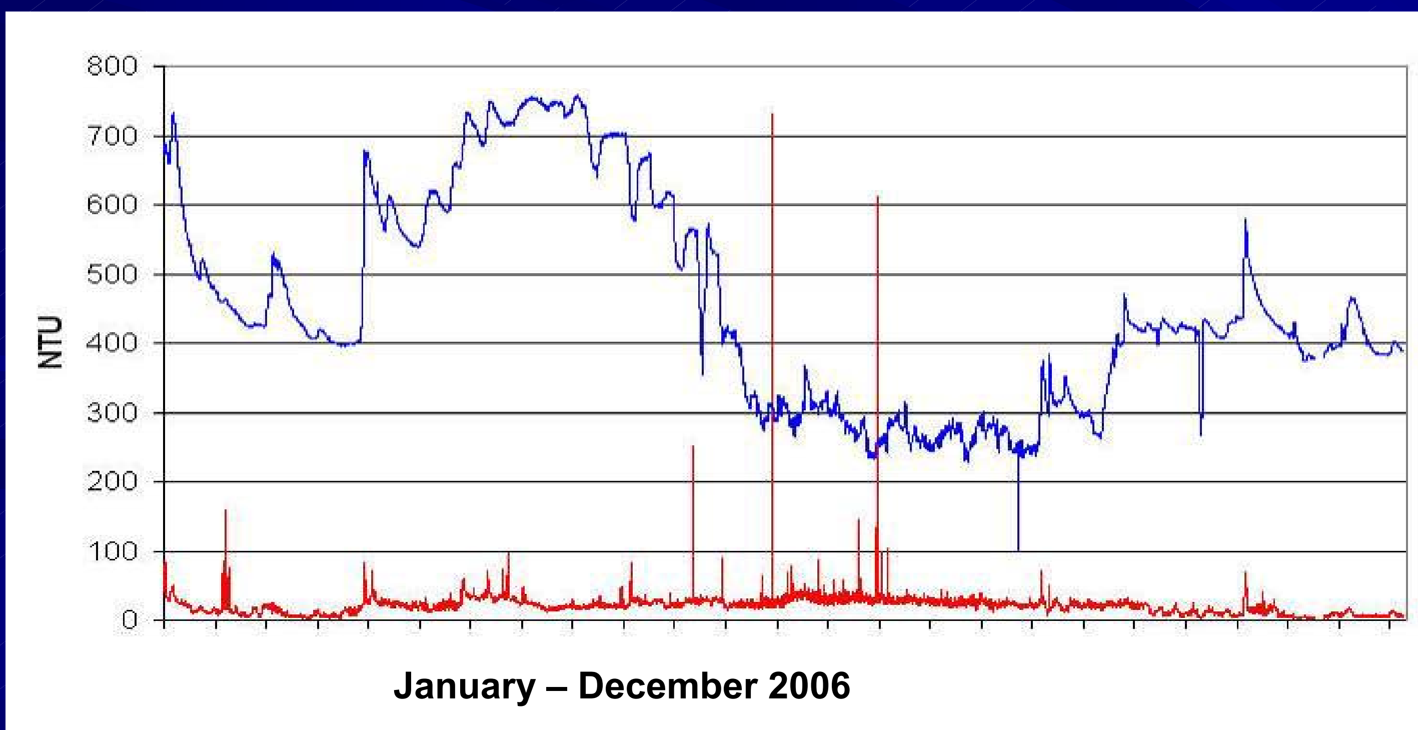


January – December 2006

Upper Site Flow (cfs) and turbidity

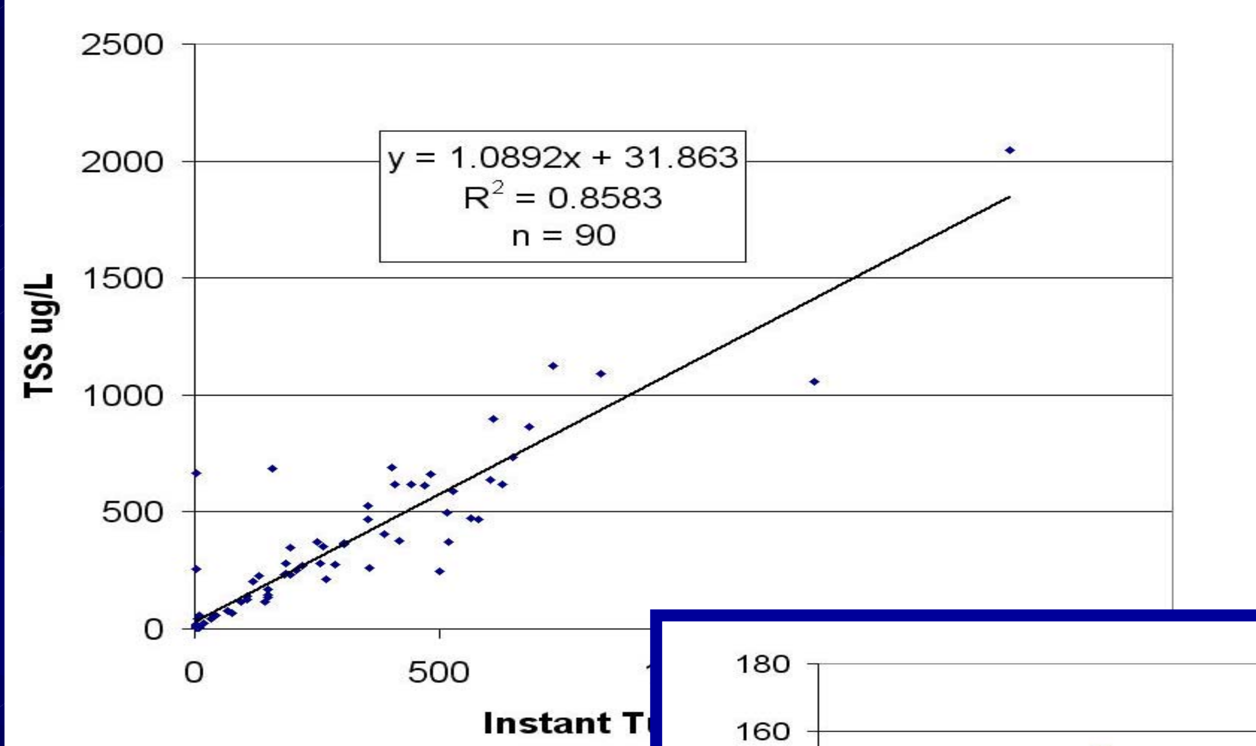


Lower Site Flow (cfs) and turbidity



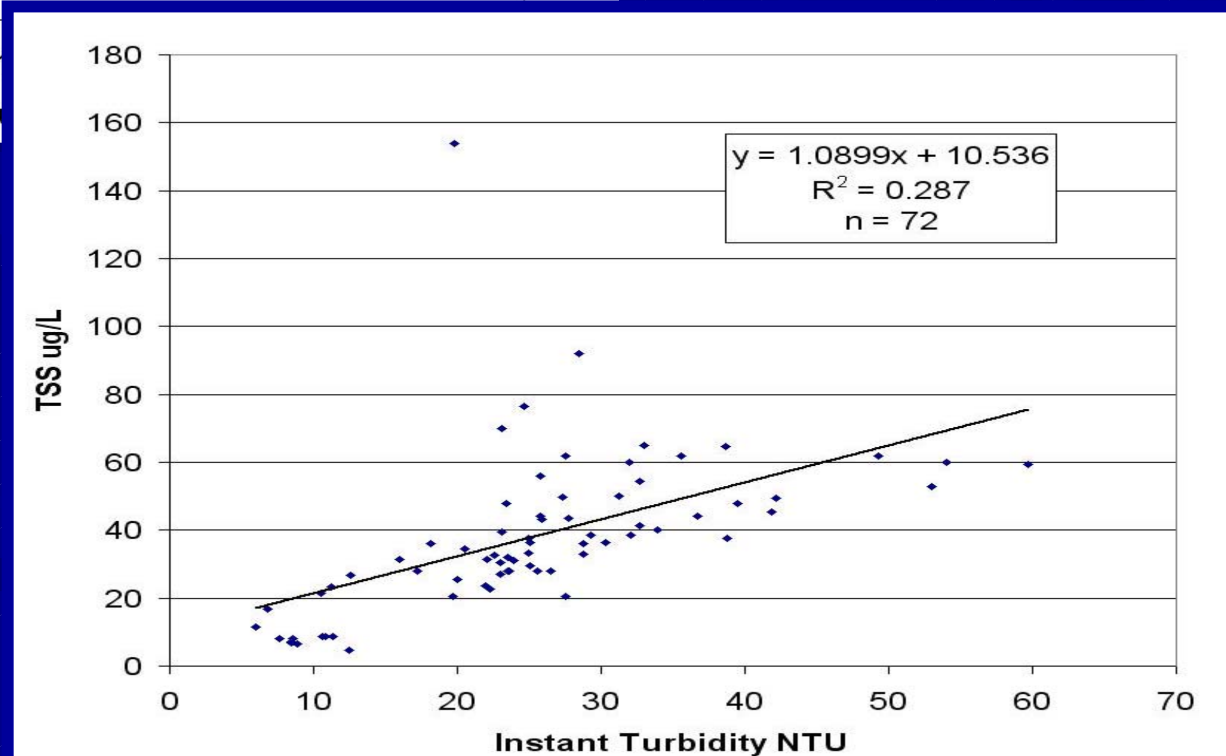
Upper Site

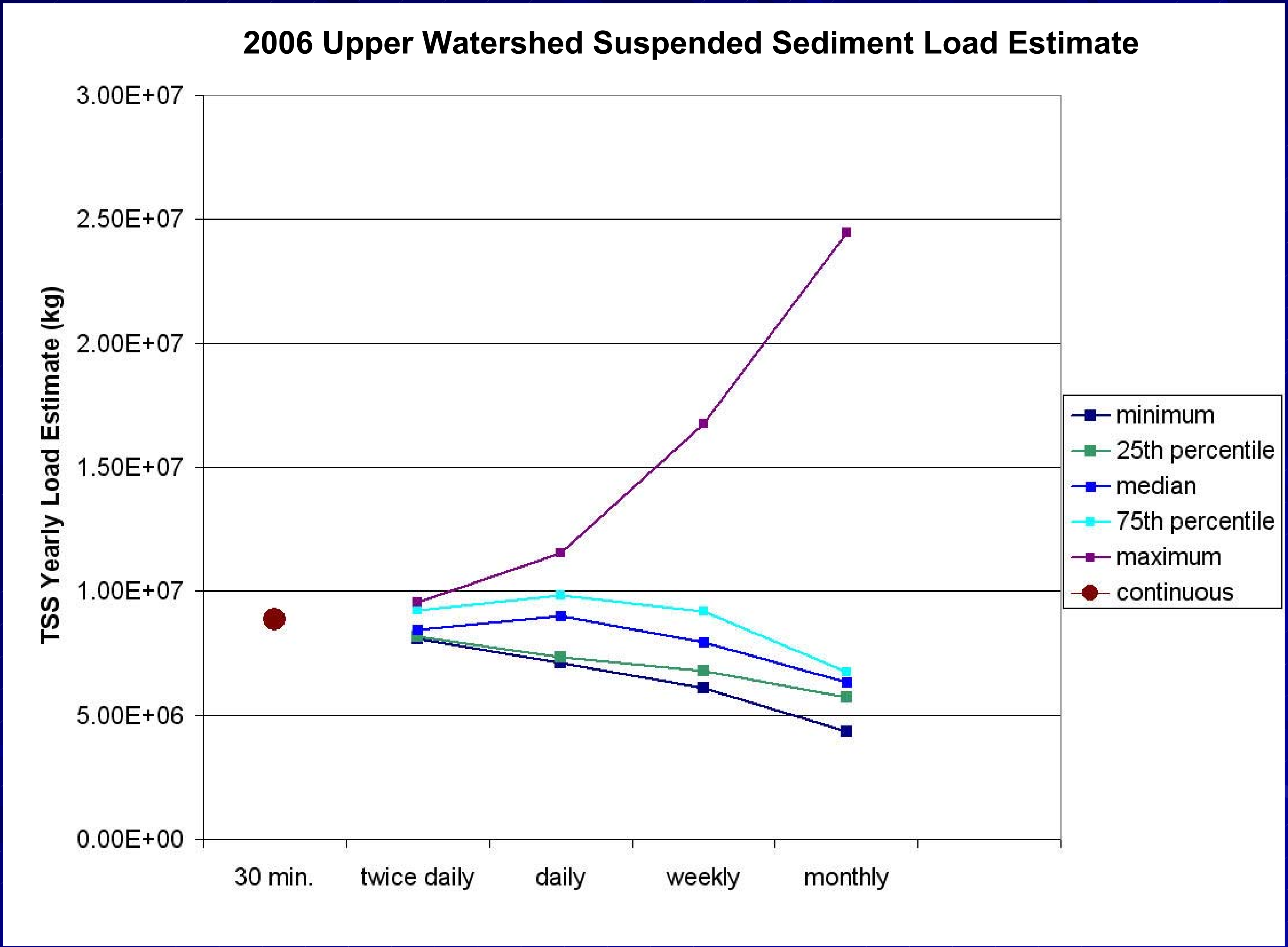
Turbidity vs TSS

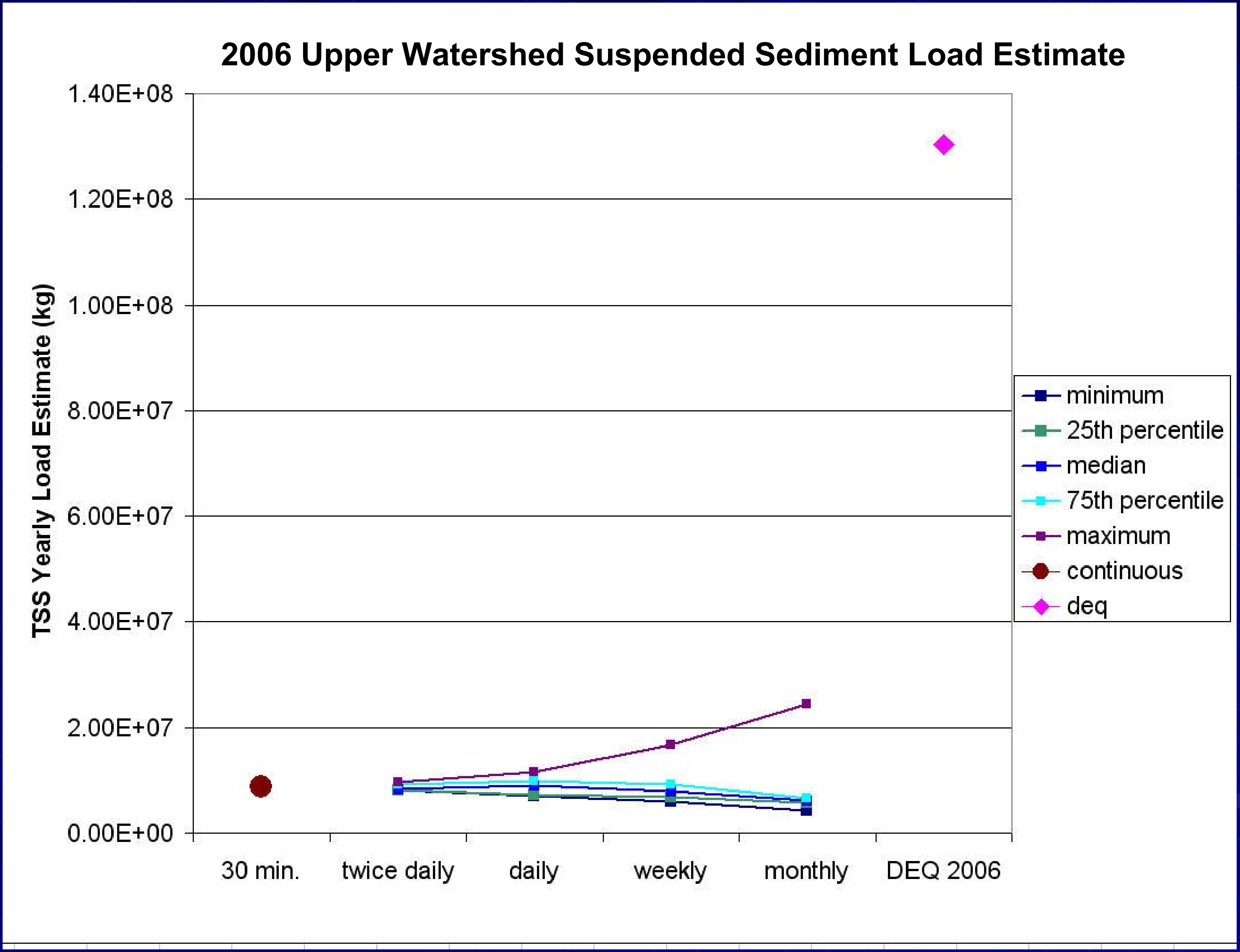


Lower Site

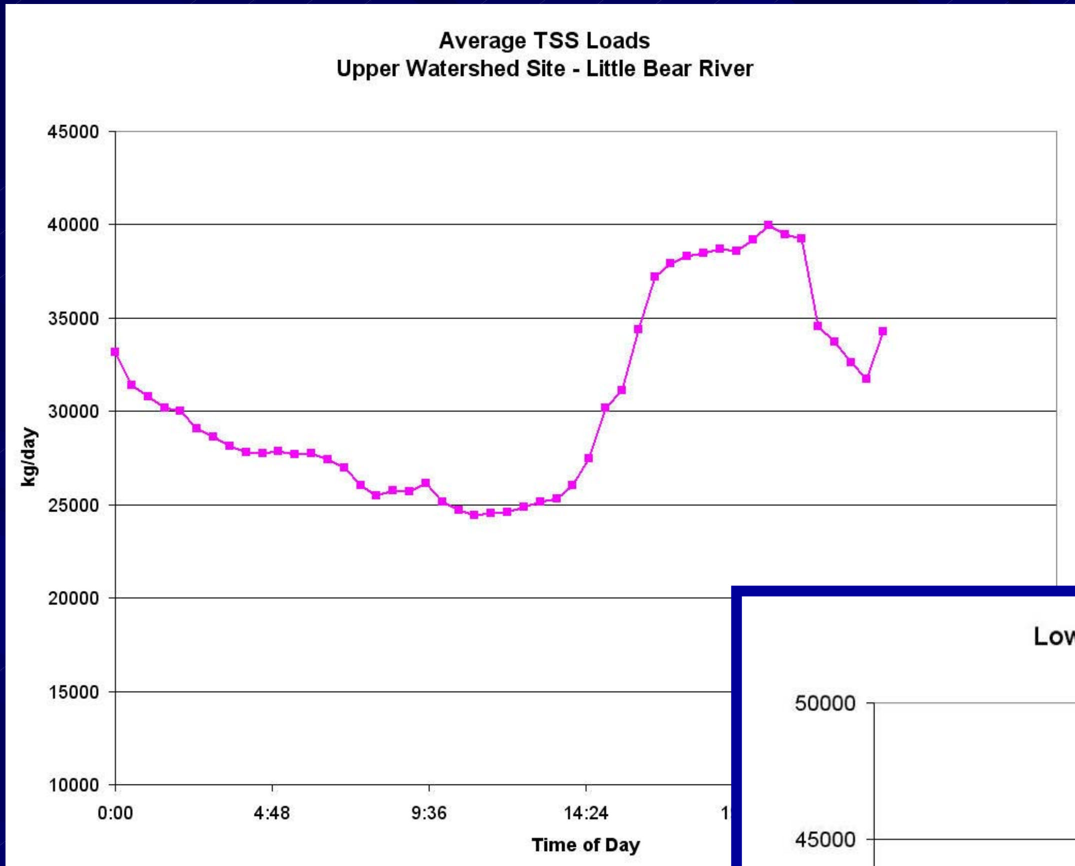
Turbidity vs TSS



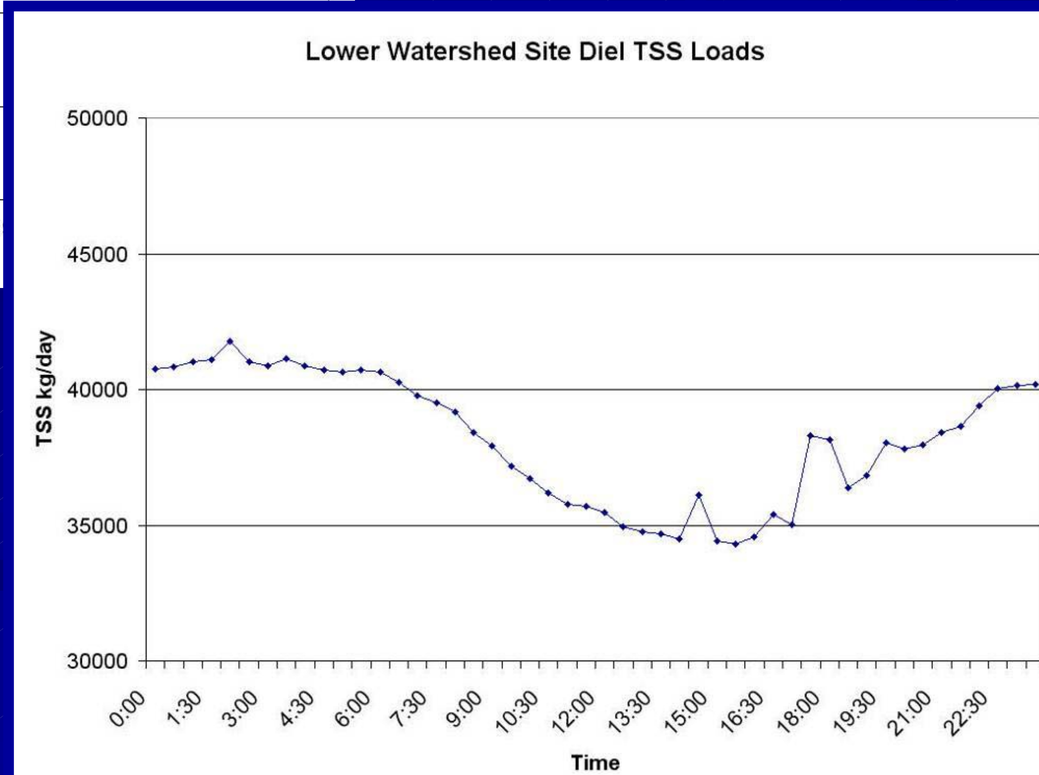

2006 Upper Watershed Suspended Sediment Load Estimate
TSS Yearly Load Estimate (kg)
3.00E+07
2.50E+07
2.00E+07
1.50E+07
1.00E+07
5.00E+06
0.00E+00
30 min.
twice daily
daily
weekly
monthly
minimum
25th percentile
median
75th percentile
maximum
continuous



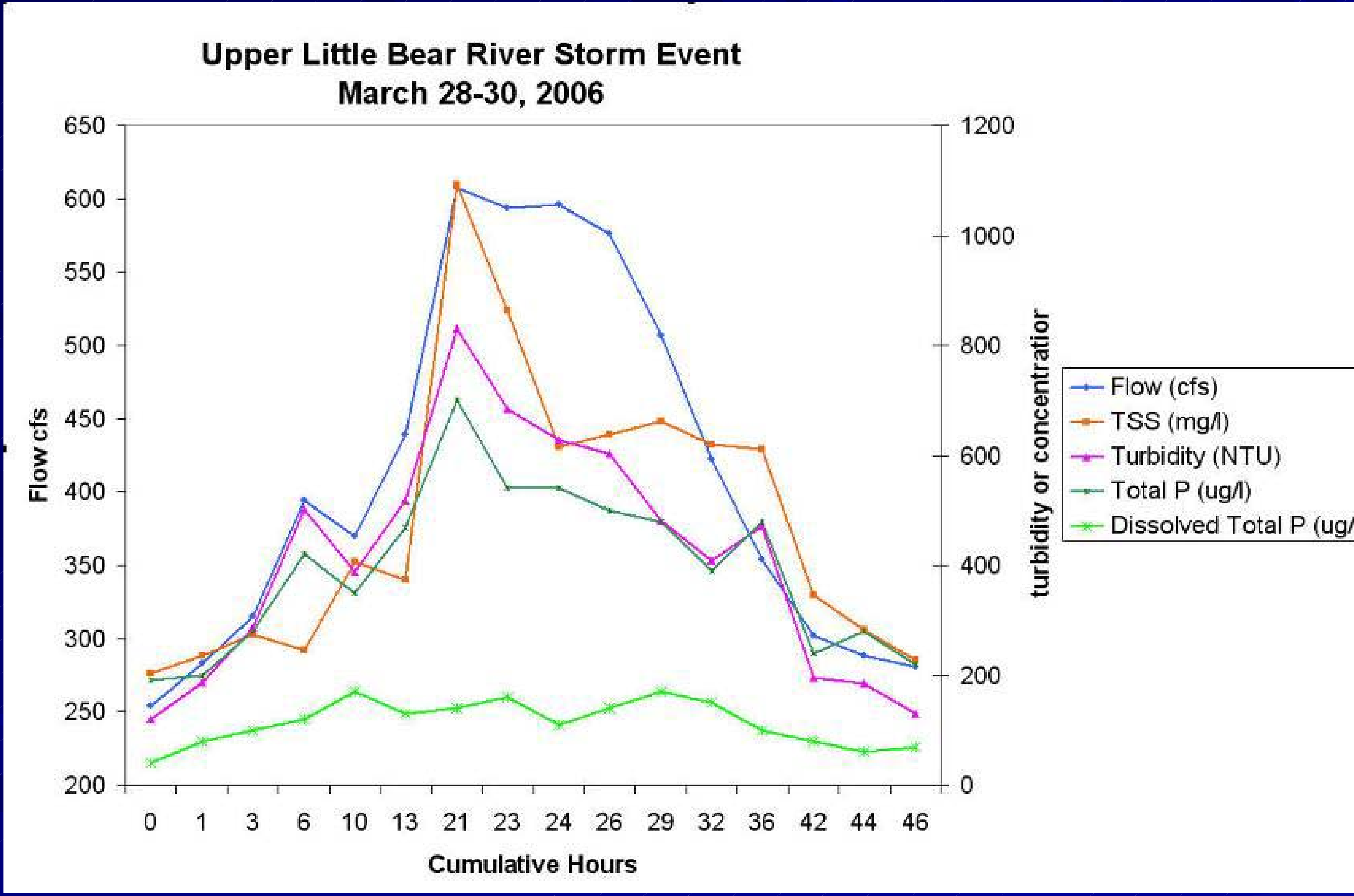
2006 Upper Watershed Suspended Sediment Load Estimate
TSS Yearly Load Estimate (kg)
1.40E+08
1.20E+08
1.00E+08
8.00E+07
6.00E+07
4.00E+07
2.00E+07
0.00E+00
30 min.
twice daily
daily
weekly
monthly
DEQ 2006
minimum
25th percentile
median
75th percentile
maximum
continuous
deq



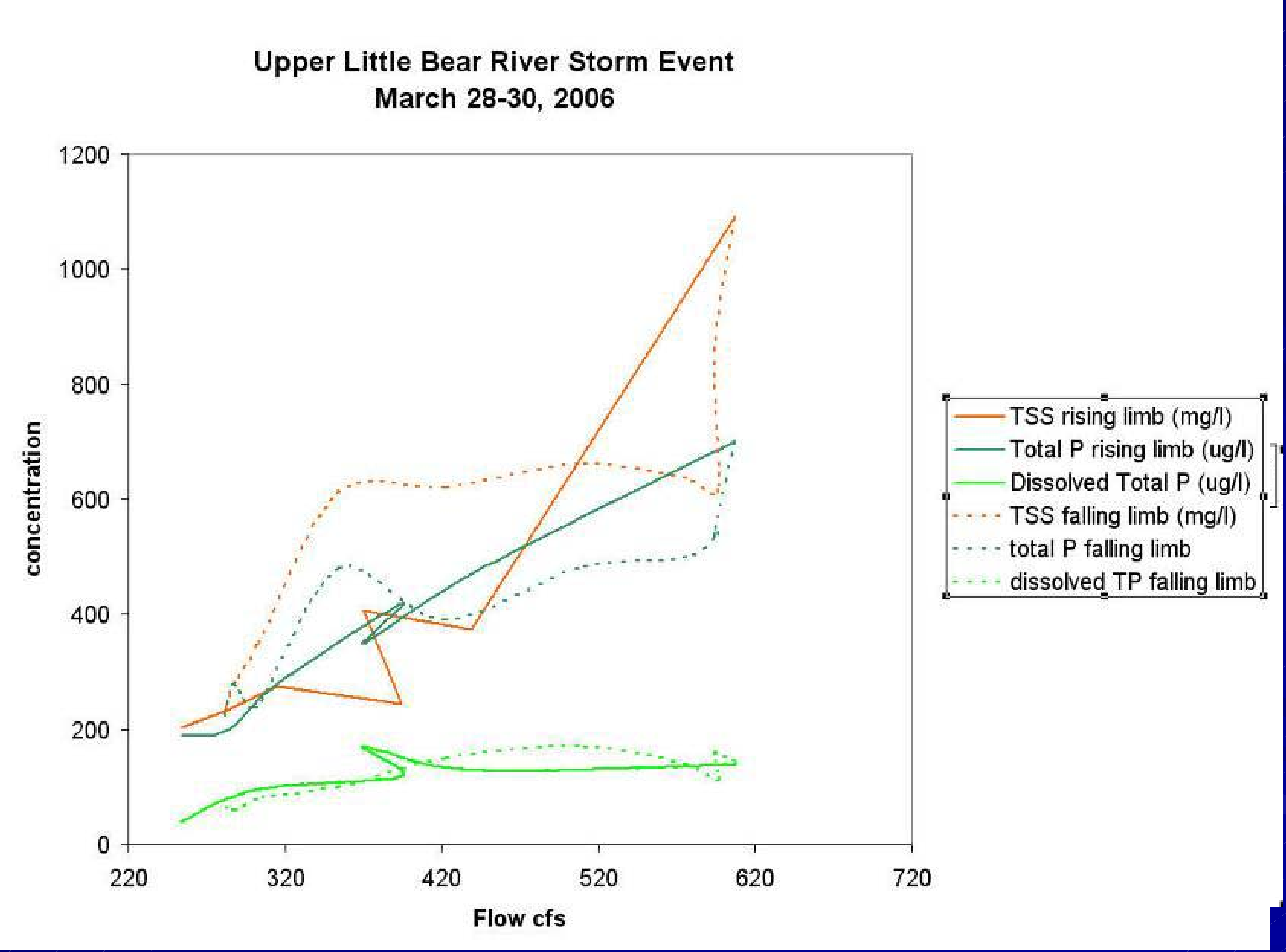
Average TSS Loads
Upper Watershed Site - Little Bear River
45000
40000
35000
30000
25000
20000
15000
10000
kg/day
0:00
4:48
9:36
14:24
Time of Day



Lower Watershed Site Diel TSS Loads
50000
45000
40000
35000
30000
TSS kg/day
0:00
1:30
3:00
4:30
6:00
7:30
9:00
10:30
12:00
13:30
15:00
16:30
18:00
19:30
21:00
22:30
Time



Upper Little Bear River Storm Event
March 28-30, 2006
Flow cfs
650
600
550
500
450
400
350
300
250
200
1200
1000
800
600
400
200
0
turbidity or concentratior
0
1
3
6
10
13
21
23
24
26
29
32
36
42
44
46
Cumulative Hours
Flow (cfs)
TSS (mg/l)
Turbidity (NTU)
Total P (ug/l)
Dissolved Total P (ug/


Upper Little Bear River Storm Event
March 28-30, 2006
concentration
1200
1000
800
600
400
200
0
220
320
420
520
620
720
Flow cfs
TSS rising limb (mg/l)
Total P rising limb (ug/l)
Dissolved Total P (ug/l)
TSS falling limb (mg/l)
total P falling limb
dissolved TP falling limb

TSS Load	Upper Site	Lower Site
Annual (kg)	8.9×10^6	1.4×10^7
Runoff (% of total)	89%	54%
Baseflow (% of total)	11%	46%
Storms (% of baseflow)	<1%	16%

Conclusions

- High frequency surrogate monitoring can greatly improve estimates of loads
- Monthly sampling results in highly variable loading estimates.
- Predictable diel patterns → potential for systematic error
- Two sites in same watershed show very different annual patterns
- In west, spring runoff delivers up to 90% of total load
- Storms may represent significant portion of baseflow loads

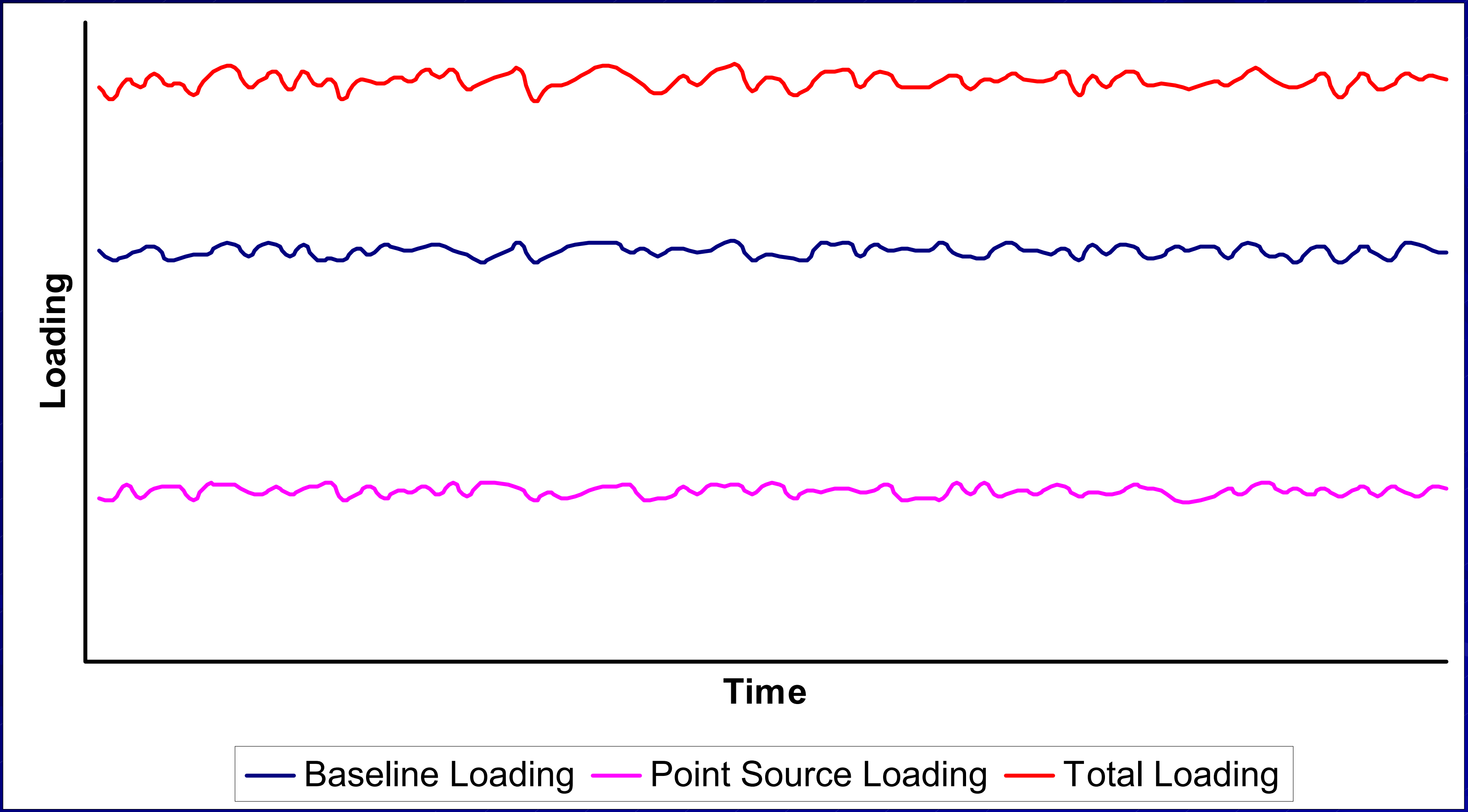
Where are we headed?

- EPA funded Watershed Information System provides integrated online access to time series and spatial data and analysis tools for presenting and interpreting data
- NSF Test bed project → additional 6 sites + 4 climate stations
- Develop Bayesian networks to include land use changes, climatic variability, seasonal variability, network of multiple stations to predictive value offlows and concentrations.

Funded by CSREES Conservation Effectiveness Assessment Grant

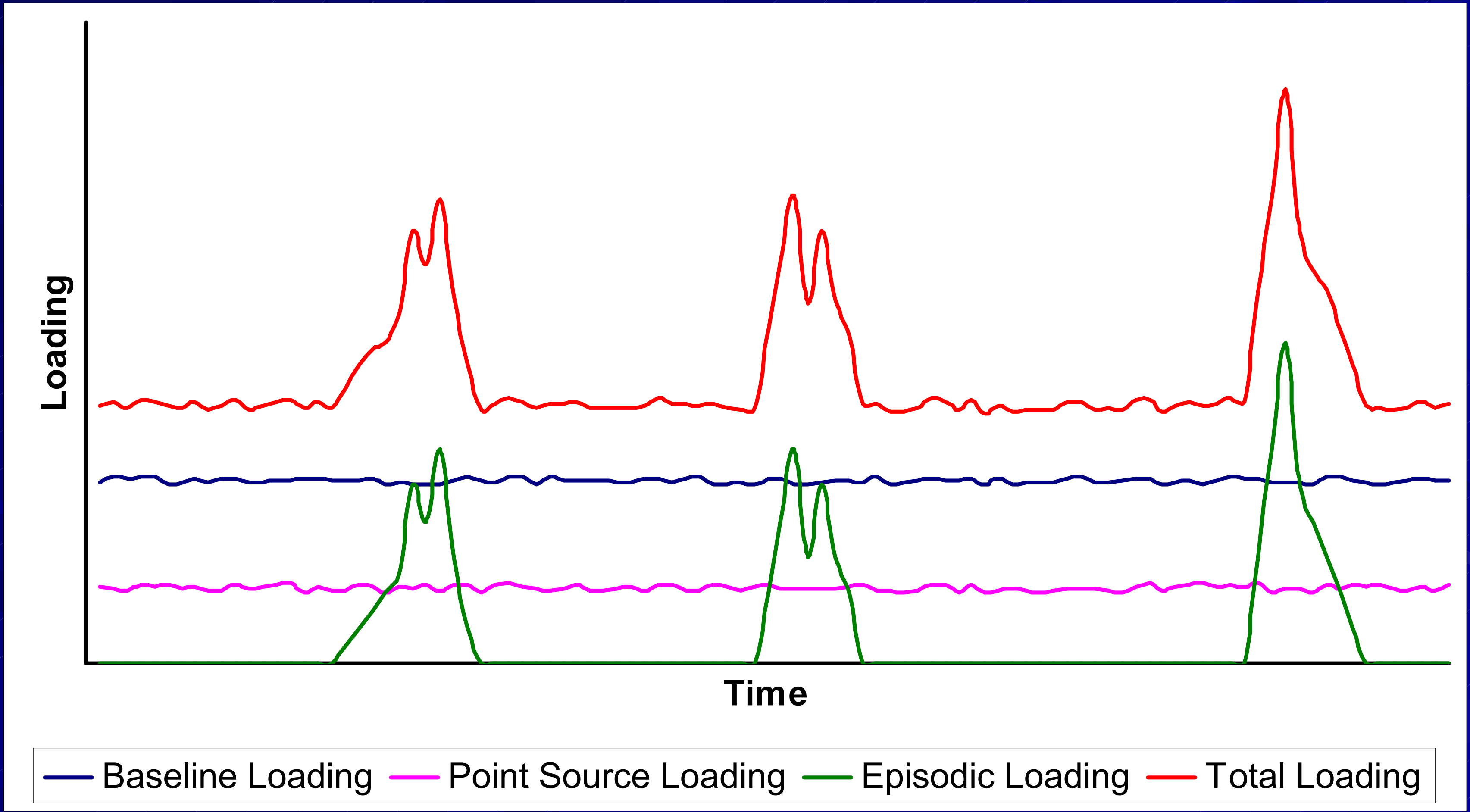
Project conducted in partnership with NRCS, Utah Division of Water Quality

Simplified Conceptual Model
Phosphorus Loading



Simplified Conceptual Model Phosphorus Loading

How large are the bumps versus the baseline?



WQ efforts in Little Bear

- Hydrologic Unit Area Project
- TMDL Project, 319 funds
- Additional cost share programs
- Other planning (eg Phase II, Source Water Protection)

Little Bear River Hydrologic Unit Area

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Overview

Introduction
Located in the southern end of beautiful Cache Valley, the Little Bear River meanders from its headwaters in the South and East Forks to its confluence with Cutler Reservoir. The 122 miles of perennial streams and 228 miles of intermittent streams draw water from a 194,432 acre watershed supporting a variety of land uses including forest and rangeland, irrigated and dry cropland, pasture and urban areas.

In 1990, the Little Bear River became part of a five year on going water quality project with the goal of raising water quality awareness and voluntarily implementing specific conservation practices to help improve and protect the quality of water in the river.

As Utah's first USDA-assisted, Hydrologic Unit Area Water Quality Project, the Little Bear River Project (LBRP) continues to showcase resource management systems that have been implemented and duplicated throughout the state.

Identified as a high priority watershed by the Utah Non-Point Source Task Force, LBRP staff collected inventory data during 1990 - 92 on potential sources of water quality problems in the watershed. Scoping meetings with area residents, conservation groups, local, state, and federal agencies indicated a number of resource concerns in the watershed. With limited staff and financial resources the project steering committee targeted stream restoration activities, manure management, and erosion reduction on grazing lands as their top priorities and developed a plan to guide implementation of the project's goals.

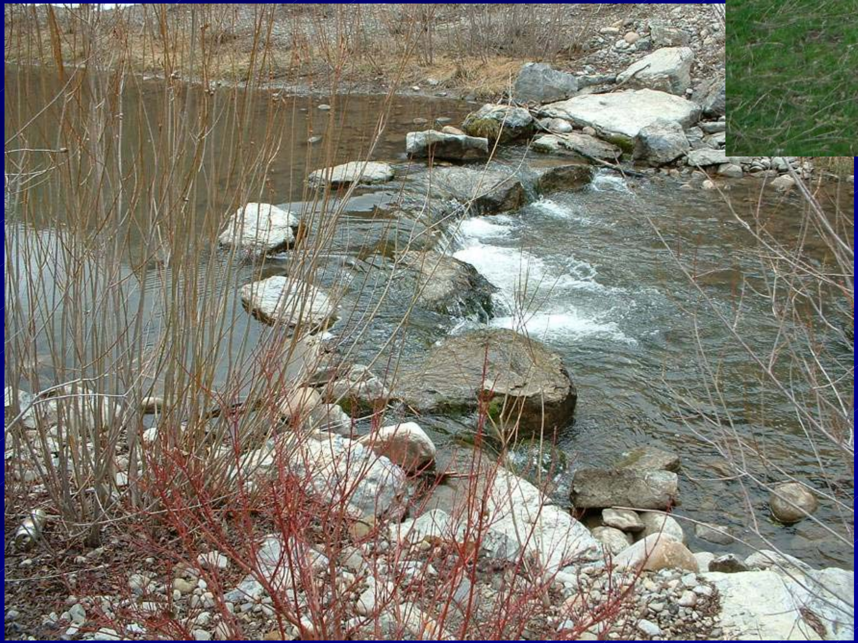
Project staff have worked with landowners and area decision-makers to address water quality concerns throughout the project area. Through coordinated resource management planning efforts a broad array of partners provided guidance and input into project priorities and activities.

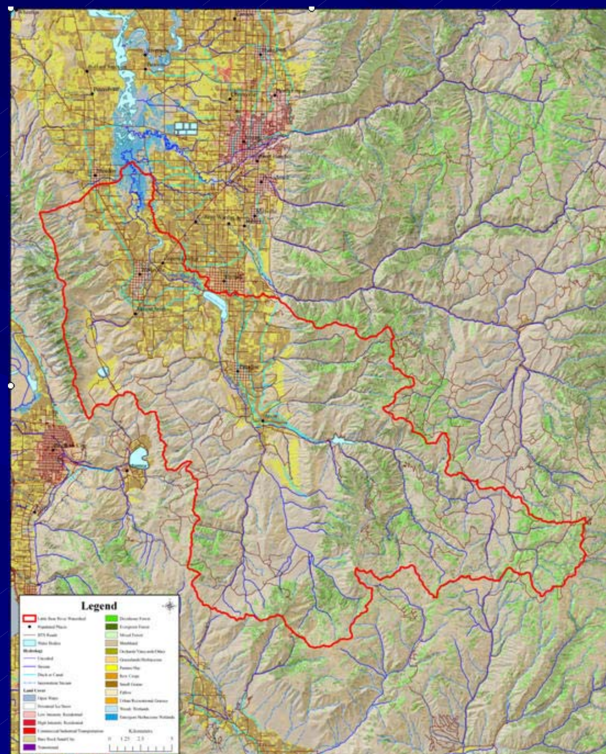
Utah Department of Environmental Quality
Division of Water Quality
TMDL Section

Little Bear River Watershed TMDL

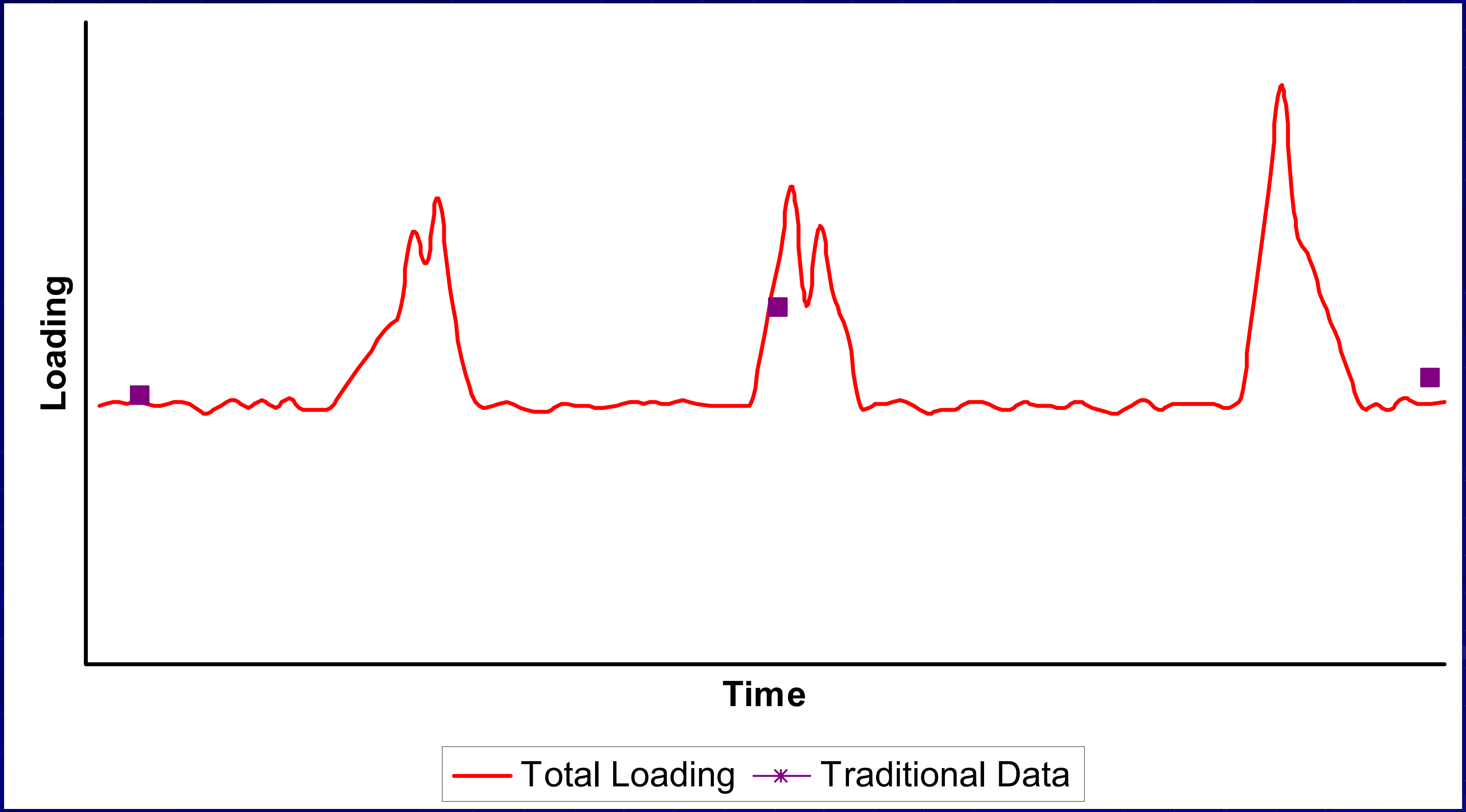
Waterbody ID	Little Bear River & Tributaries
Location	Cache County, Northern Utah
Pollutants of Concern	Total Phosphorus Hydrologic Modification
Impaired Beneficial Uses	Class 3A: Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
Loading Assessment 1998-99 Load -Above Cutler - Above Hyrum TMDL Target Load - Above Cutler - Above Hyrum Load Reduction - Above Cutler - Above Hyrum	 22 kg/day 8.4 kg/day 9.0 kg/day 6.0 kg/day 13 kg/day 2.4 kg/day
Defined Targets/Endpoints	• 14 Animal Waste Mgt. Systems • 25% reduction of cropland runoff • 10 miles of streambank restoration • Not to exceed 0.05 mg/l total phosphorus concentration in stream • Install BMP's on 7500 acres designated as critical
Implementation Strategy	BMP's Animal Waste Mgt. / Irrigation Water Mgt. Riparian Rehabilitation / Nutrient Mgt. Streambank Stabilization / Range/Pasture Mgt. Animal Waste Storage Facilities / Point Source Control
This document is identified as a TMDL for Little Bear River and is officially submitted to the U.S. EPA to act upon and approve as a TMDL.	






Legend

Simplified Loading Conceptual Model



How Do We Use Monitoring Data to Estimate Pollutant Loads?

- Simple Average Approach
  - Average all flow observations for a period
  - Average all concentrations for a period
  - Load = Average Flow * Average Concentration

$$L_{avg} = \left(\frac{\sum_{i=1}^{n} Q_i}{n} \right) \left(\frac{\sum_{j=1}^{m} C_j}{m} \right)$$

Where:

L_{avg} = average load for a time period

Q_i = Instantaneous observations of flow

n = number of flow observations

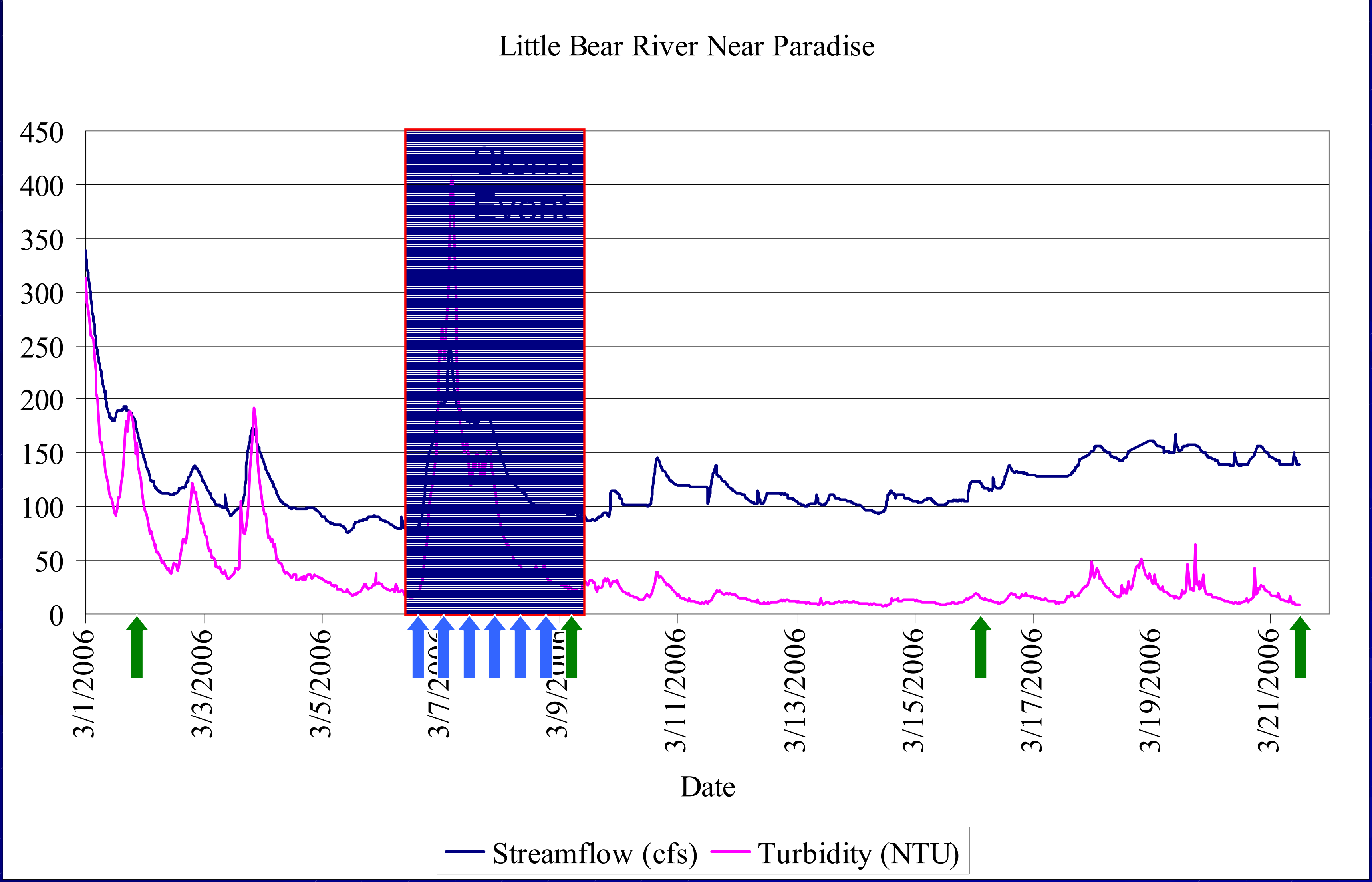
C_j = Instantaneous observations of concentration

m = number of concentration observations

Issues With Load Estimation Approaches

- Simple Average Approach
  - Uses all available data
  - **Averaging ignores correlation between the flows and concentrations**
  - **For example- what if we have predominantly flows from a wet year and concentrations from a dry year?**
- Paired Data Approach
  - Limits data to those that are paired and tosses the rest
- Both Approaches
  - **What if the data are limited – do either of these approaches give us an accurate estimate?**

Continuous Monitoring Data
Little Bear River Near Paradise



- Using existing monitoring data

_____ samples

_____ stations

_____ years.

Intervals between samples_____-

Parameters…..

  - Can we discern a difference in current phosphorus loads vs. those of 15 years ago?

- Can we discern a difference in current phosphorus loads vs. those of 15 years ago?

- Is traditional monitoring adequate to characterize natural or anthropogenic variability in flow or phosphorus concentrations?

- Do instream monitoring data used in TMDLs focus too much on point source loads when intermittent or infrequent nonpoint source loads are important?

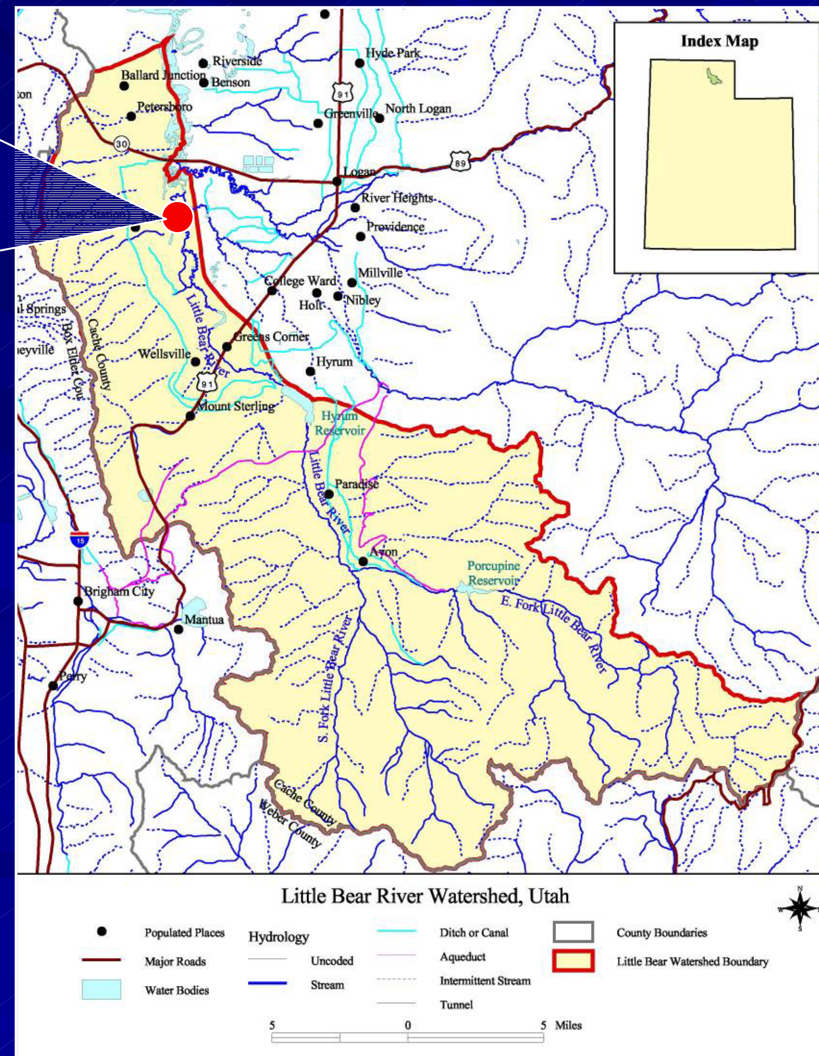
Background - The Problem

- Need to characterize the flux of phosphorus through the Little Bear River watershed
- Mass Load = Concentration * Flow
- Requires streamflow and phosphorus concentrations
- **This is also the classic TMDL problem**

What Data Do We Have to Work With?

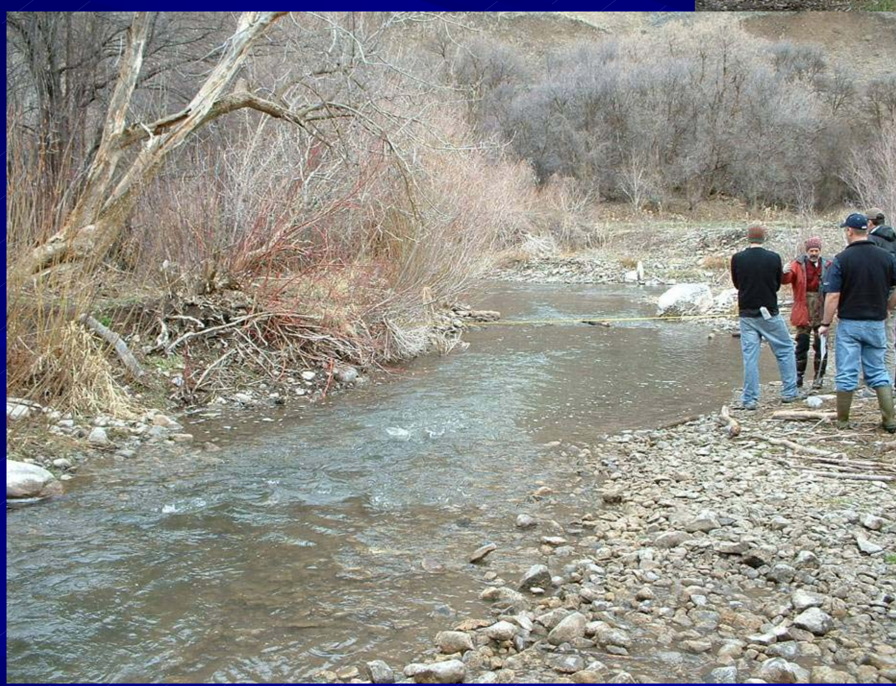
- Traditional monitoring approaches
  - weekly
  - bi-weekly
  - monthly or even less frequent grab samples (gasp!)
- Focused on assessing compliance and characterizing general conditions

Consider Total Phosphorus
Little Bear River at Mendon Road



Objective

- Characterize total phosphorus loading to Cutler Reservoir from the Little Bear River
- Use existing monitoring data to calculate:
  - annual average loads
  - seasonal average loads
  - monthly average loads
  - **Dare I say – calculate a daily load?**
- Characterize base flow loads versus periodic event based loads



Little Bear River at Mendon Road
All Utah DWQ TP Data
No Streamflow Gage Available

Streamflow observations

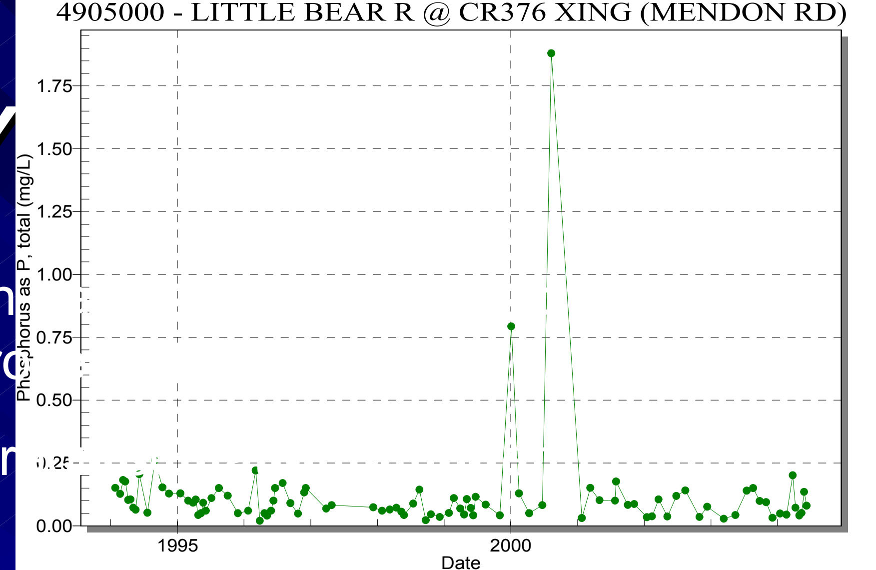
162 observations from 1976 - 2004

Total Phosphorus observations

241 observations from 1976 – 2004

(one outlier of 6 mg/L removed for plotting)

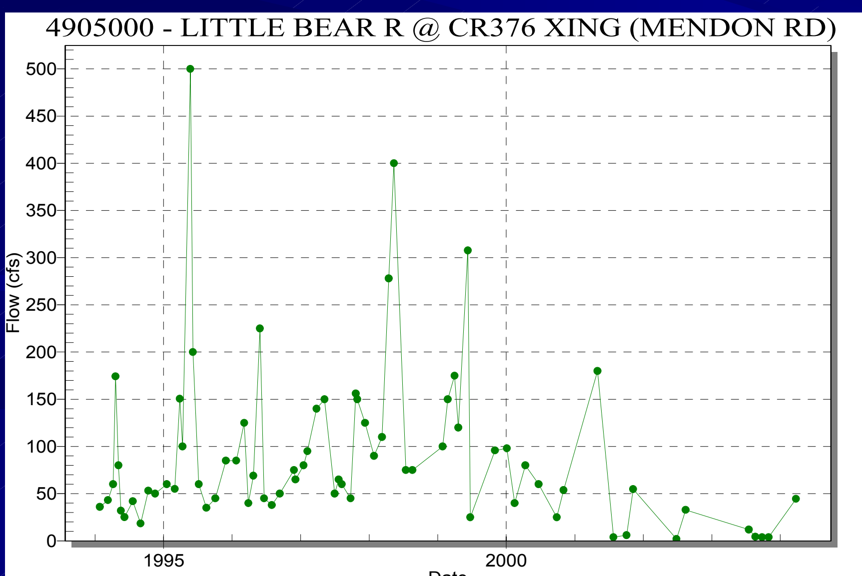
Last 10 Y



- In the past 20 years or so, ~$5 Million
  share funds in this watershed to impro
- Data more than 10 years old are not r
  conditions

  1994-2004: 99 Total phosphorus observations

  72 Streamflow observations



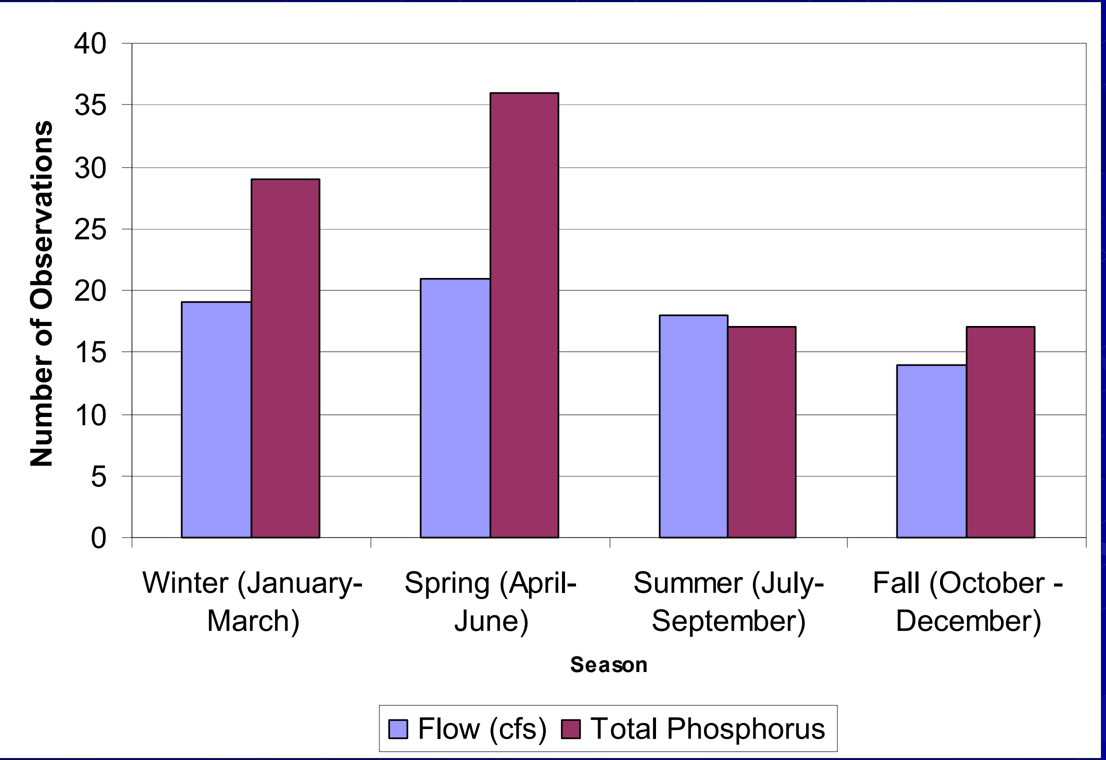
Total Phosphorus

99 observations from 1994 – 2004

59 % Reduction in available data

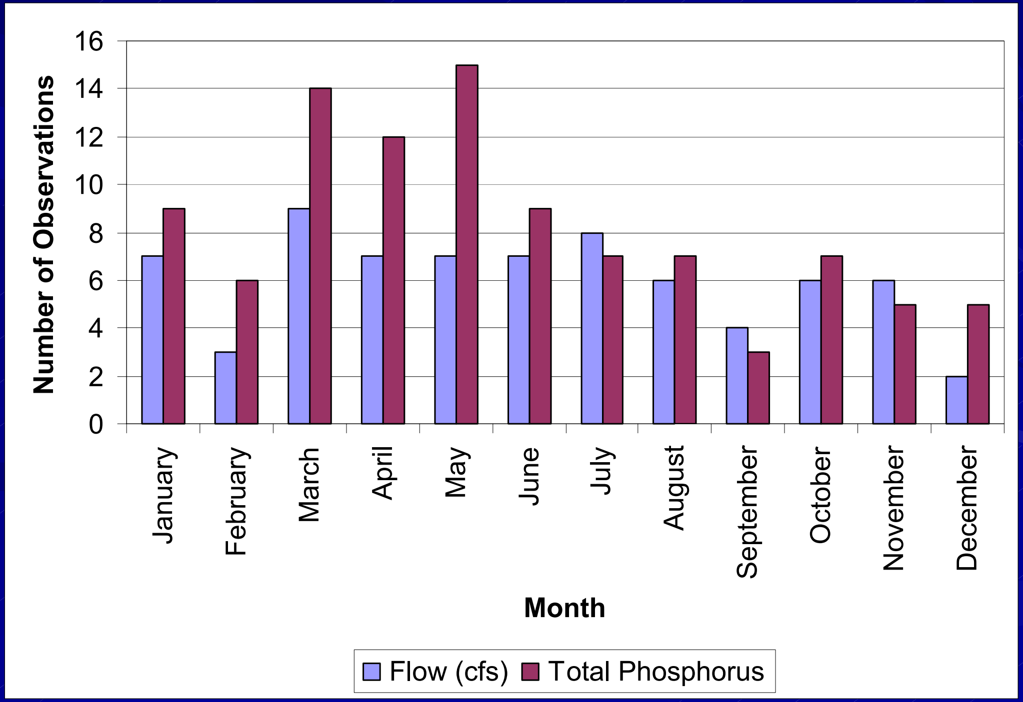
Little Bear River at Mendon Road - Utah DWQ 4905000 (1994-2004)		
	Number of Observations	
Season	Flow (cfs)	Total Phosphorus (mg/L)
Winter (January-March)	19	29
Spring (April-June)	21	36
Summer (July-September)	18	17
Fall (October - December)	14	17

What if I want to calculate seasonal loads?



Little Bear River at Mendon Road - Utah DWQ 4905000 (1994-2004)		
	Number of Observations	
Month	**Flow (cfs)**	**Total Phosphorus (mg/L)**
January	7	9
February	3	6
March	9	14
April	7	12
May	7	15
June	7	9
July	8	7
August	6	7
September	4	3
October	6	7
November	6	5
December	2	5

What if we want to calculate monthly loads?



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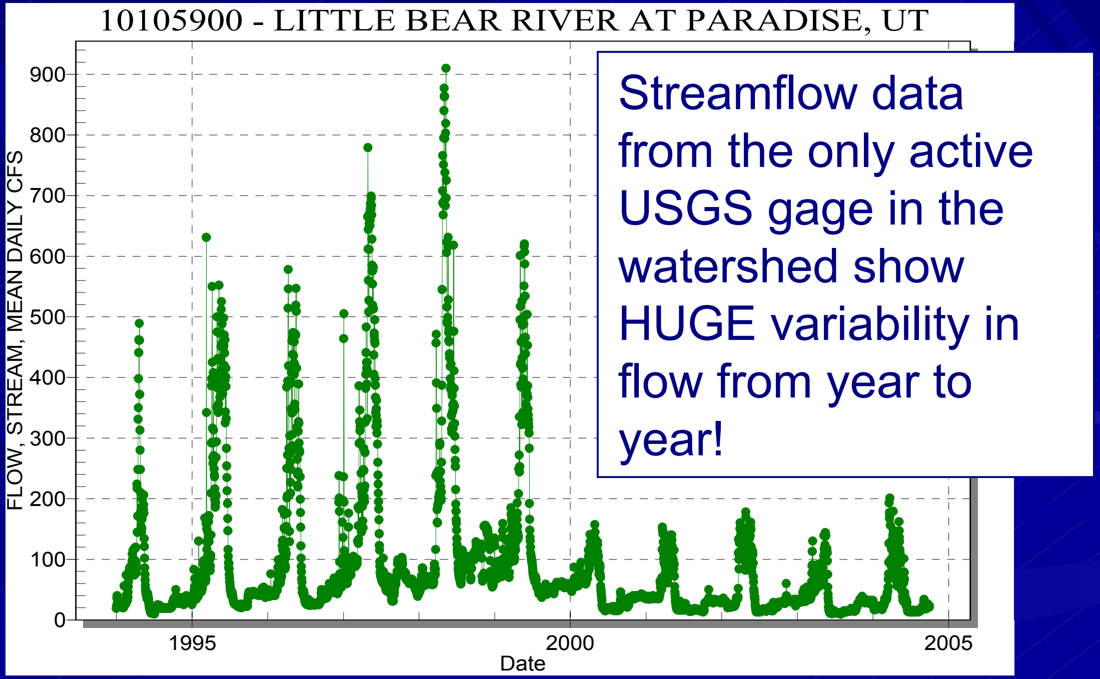
1999	7	10
2000	6	5
2001	4	7
2002	2	8
2003	4	8
2004	1	8

What about interannual variability?

Time Period	Average TP Concentration (mg/L)
1994-1999	0.0921
2000-2004	0.1533

The average TP concentration during the dry years is 60 % higher than for the wet years



- What about weekly or even daily variability?
- Remember we wanted to characterize periodic events?
- It is a Total Maximum ***Daily*** Load Right?

Back to the Original Questions

Given We know that there are important processes that occur on a daily or even hourly time interval that are important

- How can we capture the natural and anthropogenic variability in total phosphorus loads?

Continuous Monitoring

- Continuous monitoring of streamflow is relatively easy
  - Monitor water level and relate stage to discharge
  - Requires establishment of stage-discharge relationship
  - Must establish over a range of flow conditions

- **BUT:** No technology currently exists to continuously monitor total phosphorus
  - We don’t have enough graduate students or dollars to collect that many wet samples!!!

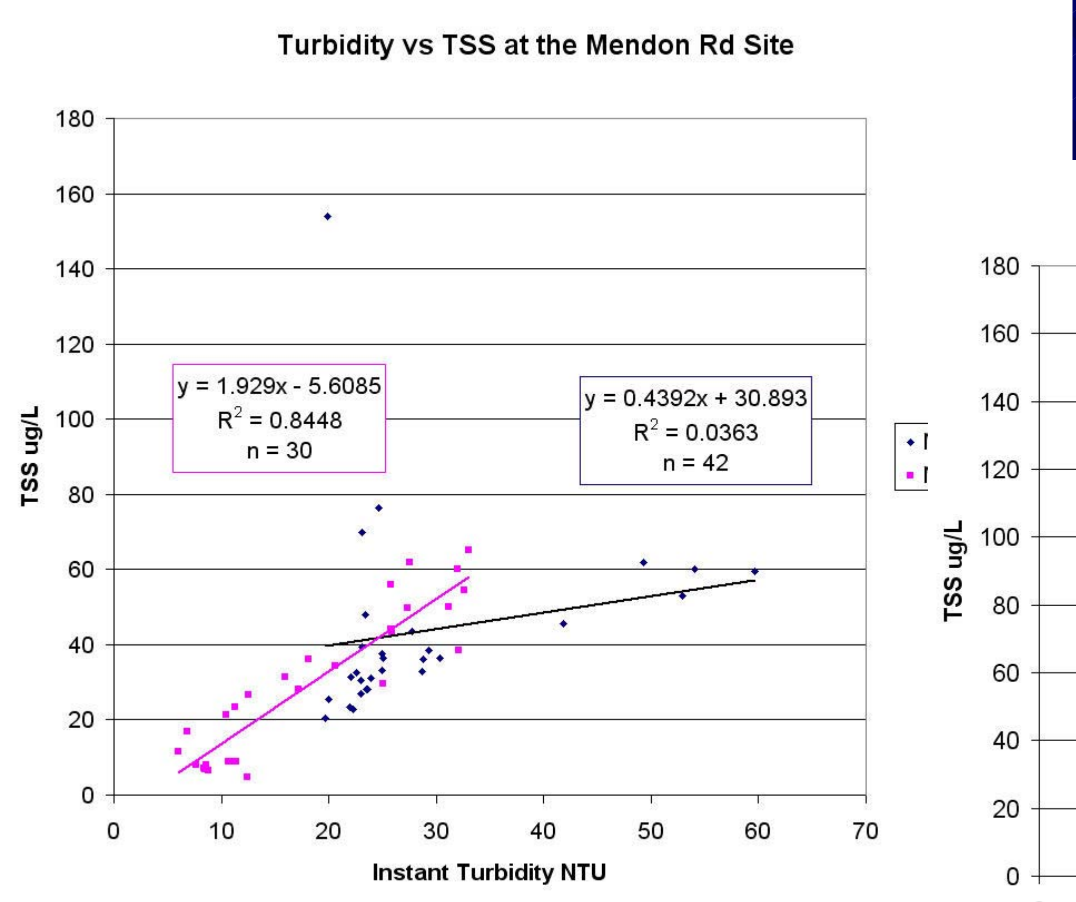
The Solution: A Continuous Monitoring Approach

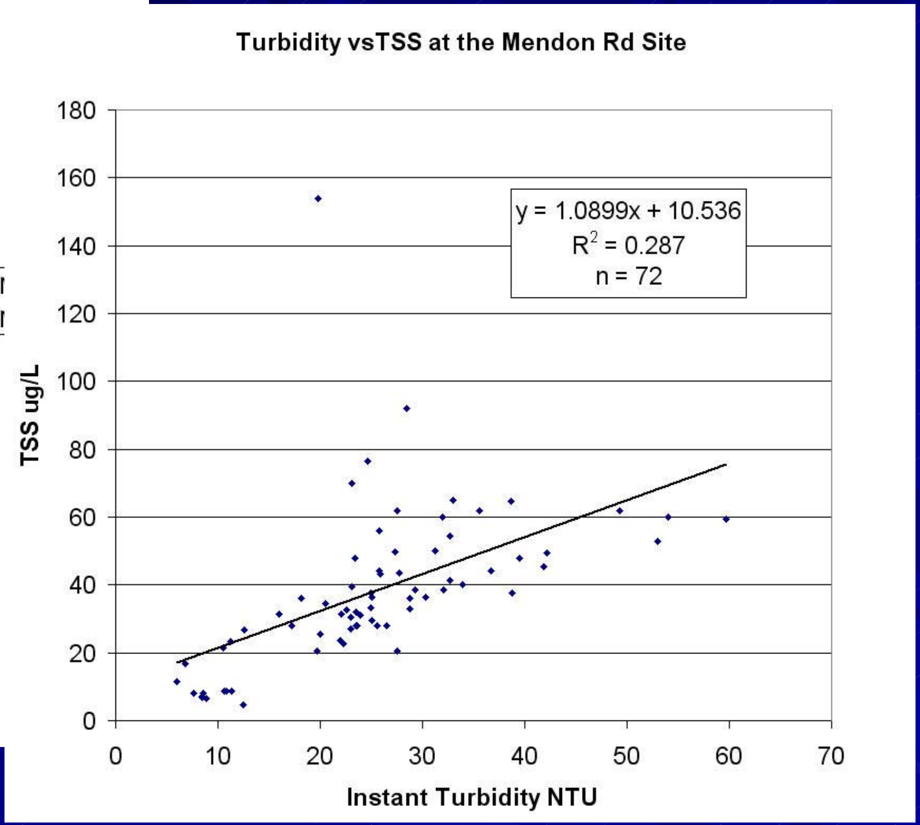
- The obvious answer: **collect higher frequency data**

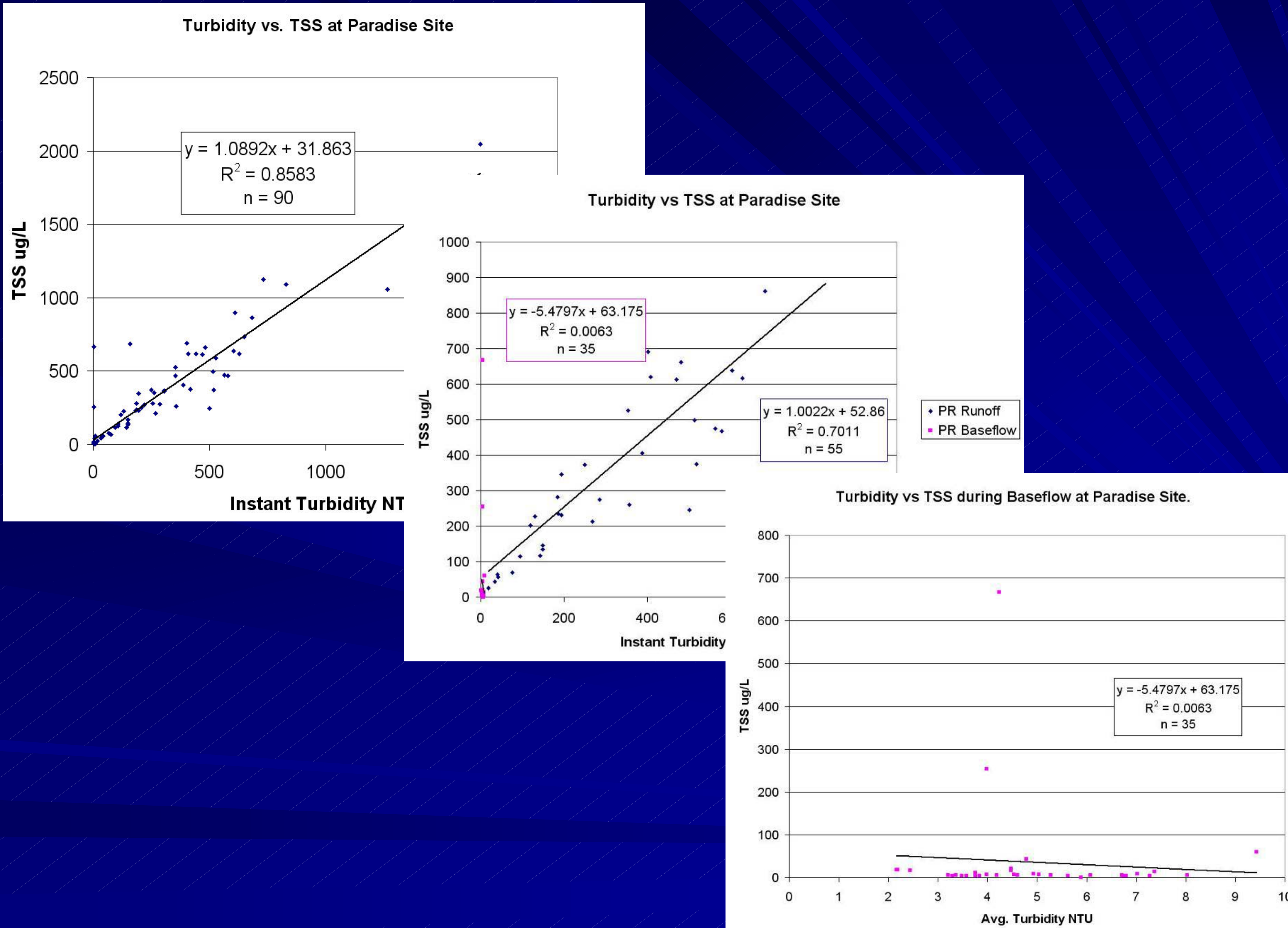
- Collect continuous data to characterize flow and total phosphorus concentrations

Little Bear River Sampling Program
Periodic Baseline Sampling

- Wet samples collected weekly or bi-weekly depending on the time of year and analyzed for:
  - Total phosphorus
  - Dissolved phosphorus
  - Total suspended solids
- At the same time spot checks of turbidity with a portable field meter
- Establish relationships between total phosphorus, total suspended solids, turbidity, and flow

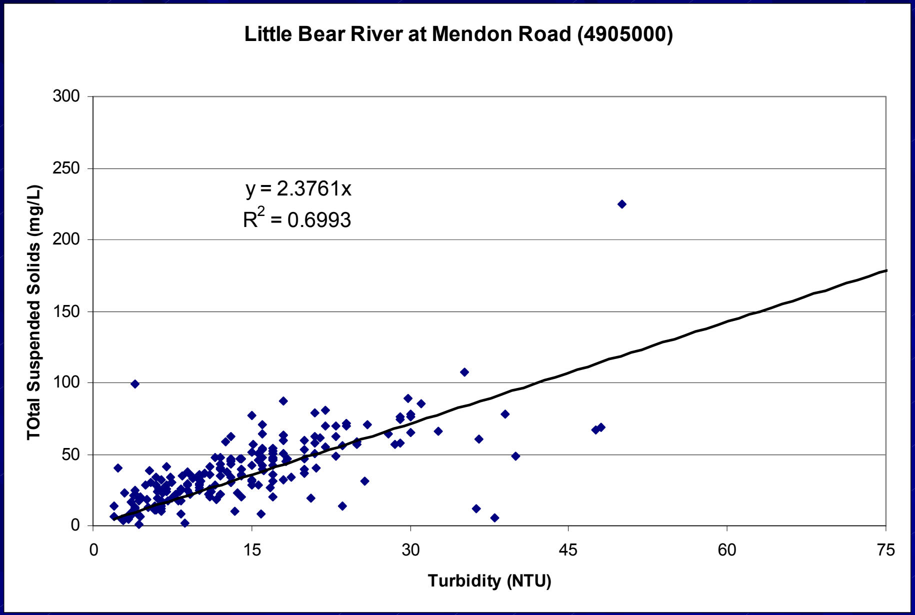

Turbidity vs TSS at the Mendon Rd Site
y = 1.929x - 5.6085
R^2 = 0.8448
n = 30
y = 0.4392x + 30.893
R^2 = 0.0363
n = 42
TSS ug/L
Instant Turbidity NTU
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70

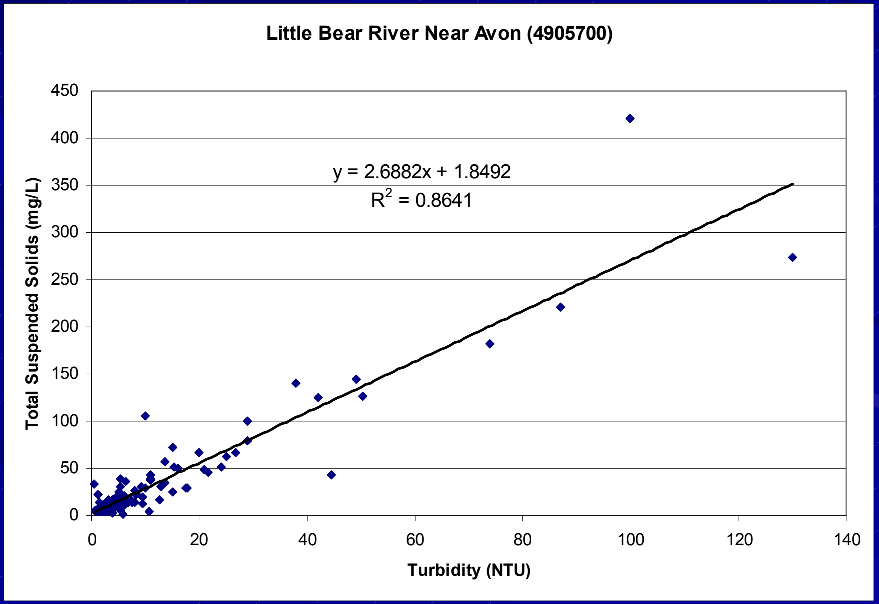

Turbidity vsTSS at the Mendon Rd Site
y = 1.0899x + 10.536
R^2 = 0.287
n = 72
TSS ug/L
Instant Turbidity NTU
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70


Turbidity vs. TSS at Paradise Site
y = 1.0892x + 31.863
R2 = 0.8583
n = 90
TSS ug/L
Instant Turbidity NT
2500
2000
1500
1000
500
0
0
500
1000
Turbidity vs TSS at Paradise Site
y = -5.4797x + 63.175
R2 = 0.0063
n = 35
y = 1.0022x + 52.86
R2 = 0.7011
n = 55
PR Runoff
PR Baseflow
TSS ug/L
Instant Turbidity
1000
900
800
700
600
500
400
300
200
100
0
0
200
400
Turbidity vs TSS during Baseflow at Paradise Site.
y = -5.4797x + 63.175
R2 = 0.0063
n = 35
TSS ug/L
Avg. Turbidity NTU
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10

Continuous measurements

- Turbidity as a surrogate for total suspended solids and/or TP
- Relationships are site specific and are likely seasonal





How Do We Use Monitoring Data to Estimate Pollutant Loads?

- Paired Observations Approach
  - Consider only paired observations over a particular time period

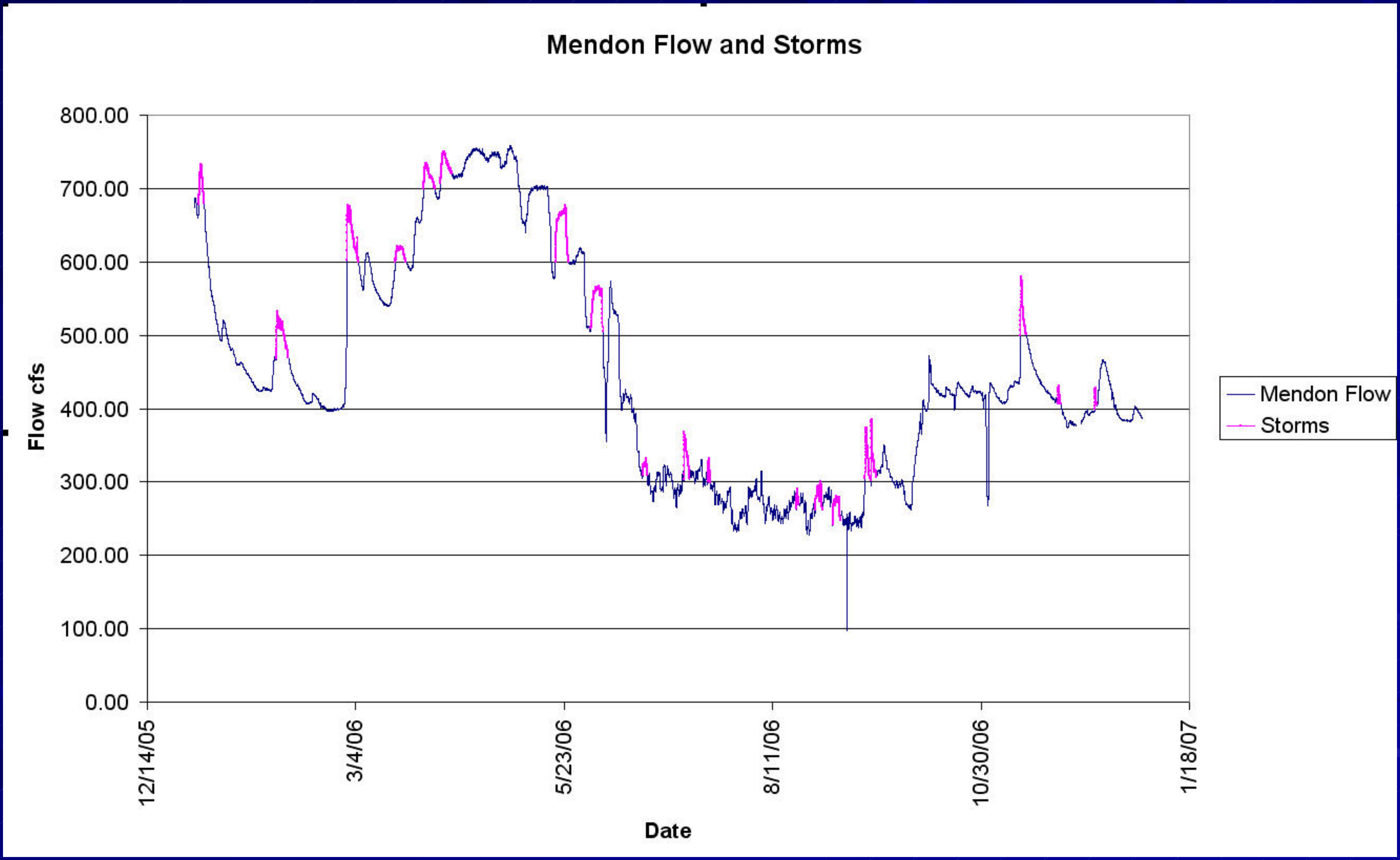
$$L_{avg} = \frac{\sum_{i=1}^{n} Q_i C_i}{n}$$

Where:

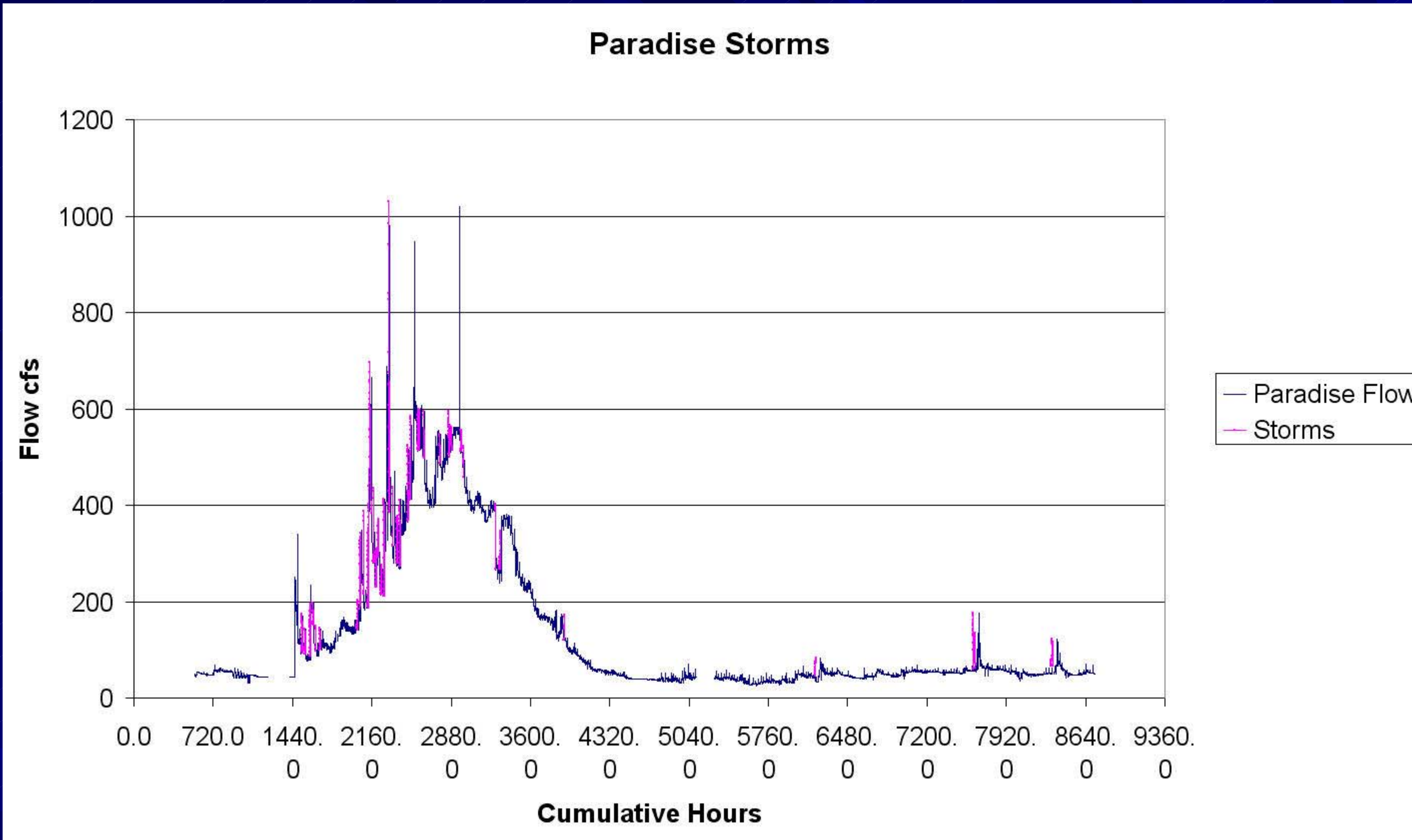
L_{avg} = Average pollutant load for a time period

Q_i and C_i = Paired observations of flow and concentration

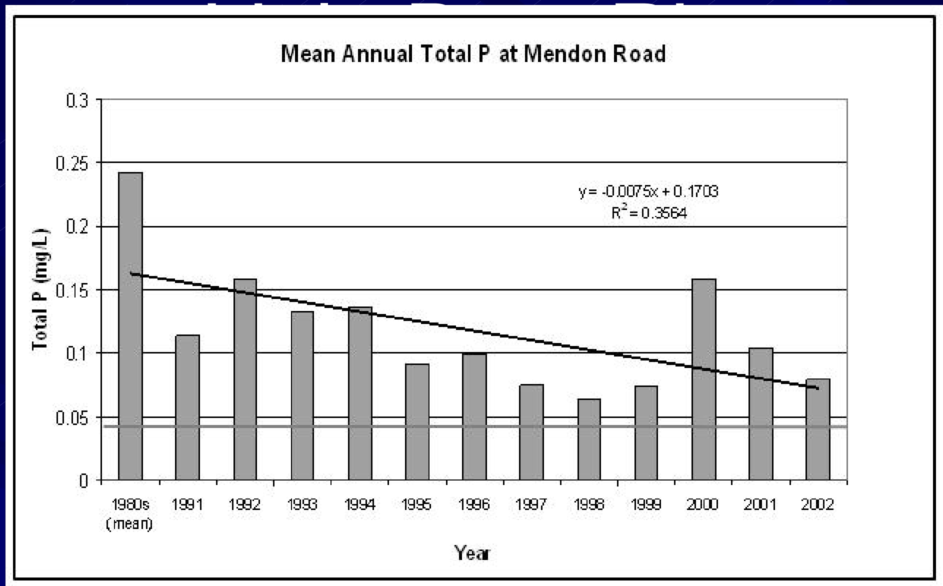
N = number of instantaneous flow/concentration pairs



Mendon Flow and Storms
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Flow cfs
12/14/05
3/4/06
5/23/06
8/11/06
10/30/06
1/18/07
Date
Mendon Flow
Storms


Paradise Storms
Flow cfs
1200
1000
800
600
400
200
0
0.0
720.0
1440.0
2160.0
2880.0
3600.0
4320.0
5040.0
5760.0
6480.0
7200.0
7920.0
8640.0
9360.0
Cumulative Hours
Paradise Flow
Storms

nitoring program



<u>1994-2004</u>

99

72

Little Bear River at Mendon Road - Utah DWQ 4905000 (1994-2004)		
	Number of Observations	
Month	Flow (cfs)	Total Phosphorus (mg/L)
January	7	9
February	3	6
March	9	14
April	7	12
May	7	15
June	7	9
July	8	7
August	6	7
September	4	3
October	6	7
November	6	5
December	2	5

TSS Load (kg)	Upper Site	Lower Site
Annual	8.9×10^6	1.4×10^7
Runoff	8.0×10^6	7.6×10^6
Baseflow	9.0×10^5	6.4×10^6
Baseflow storm events	4.9×10^3	1.0×10^6

TSS Load (kg)	Upper Site	Lower Site
Runoff (% of total)	**89%**	**54%**
Baseflow (% of total)	**11%**	**46%**
Storms (% of baseflow)	**<1%**	**16%**

Little Bear River monitoring program

At the outlet site:	1976-2004	1994-2004
Total Phosphorus	241	99
Stream Flow	162	72