Erosion Modeling for Land Management in the Tahoe Basin – Soil disturbance & restoration detection thresholds

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Soils Restoration – Local to Watershed Processes - Hypotheses

1. Improved “soil function” at local-scale (e.g. infiltration, aggregate stability, microbial community structure, soil strength…) leads to reduced sediment fines and nutrient loadings.
2. Reductions in sediment loadings may be “detectable” within a few years of pre- and post-project monitoring.
3. Focused discharge and sediment sampling during the daily and seasonal rising limb of the hydrograph provides the nearest approximation to actual daily sediment loading from Tahoe west shore streams.
4. “Disconnecting” adjoining eroding areas reduces sediment loading disproportionately to area treated.

Related Project Objectives

- Compare sediment load-flow relationships developed from estimated and measured data for Ward and Blackwood Creeks to provide some insight into the relative bias or systematic error of previous efforts.
- Develop measured TSS, fine-sediment particle (FSP<20 micron) and nutrient (TKN, TN & TP) load-flow relationships for Homewood (HMR) Creek.
- Using hourly estimates of mean daily flows and total daily sediment loads, determine which hourly period(s) if sampled alone best represent the daily sediment loading from Ward and HMR Creeks.
- Determine if there is a change in HMR Creek watershed sediment yield (kg/ha) per unit flowrate following soils restoration and erosion pathway disconnection work completed in the catchment during summers of 2006-2010.

Process-level Soils Information - Conclusions

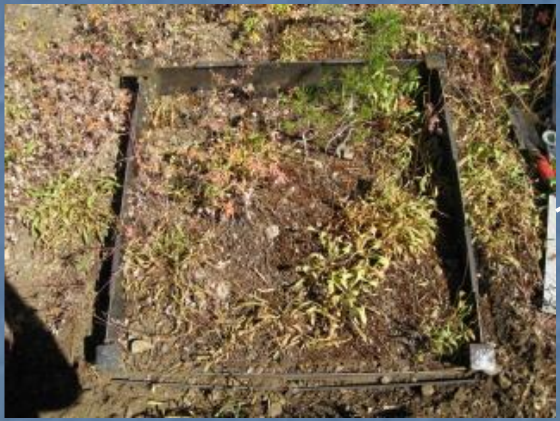
- Understanding fundamental soil processes is important towards restoration or monitoring success, but often such information is lacking.
- Relative levels of aggregation, possible crusting, repellency, OM %, and microbial community structures in the soil may be linked to runoff particle-size distributions, sediment and nutrient loadings from catchments.
- Similarly, knowledge of these soil processes should provide insight into the relative merits of various treatments.
- Presumably, plot-scale processes affect those at the watershed scale.

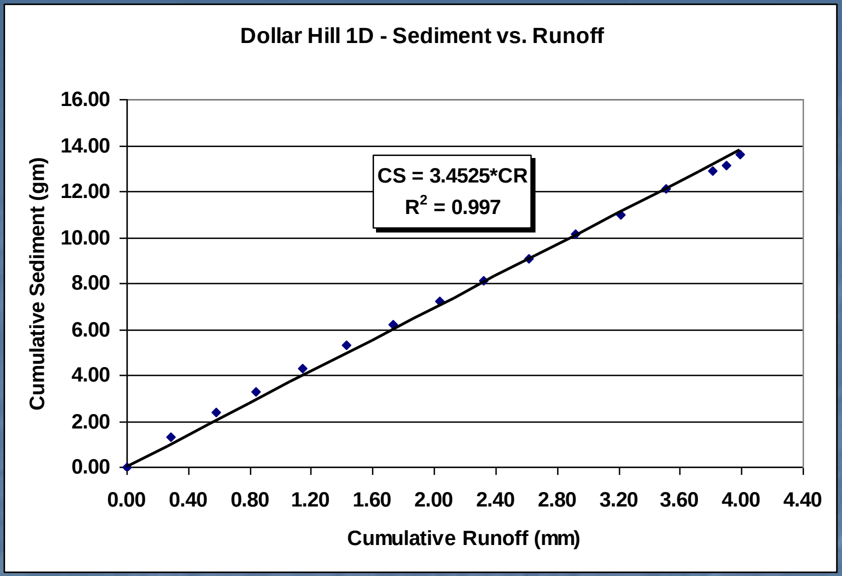
Soil Restoration – Watershed effects

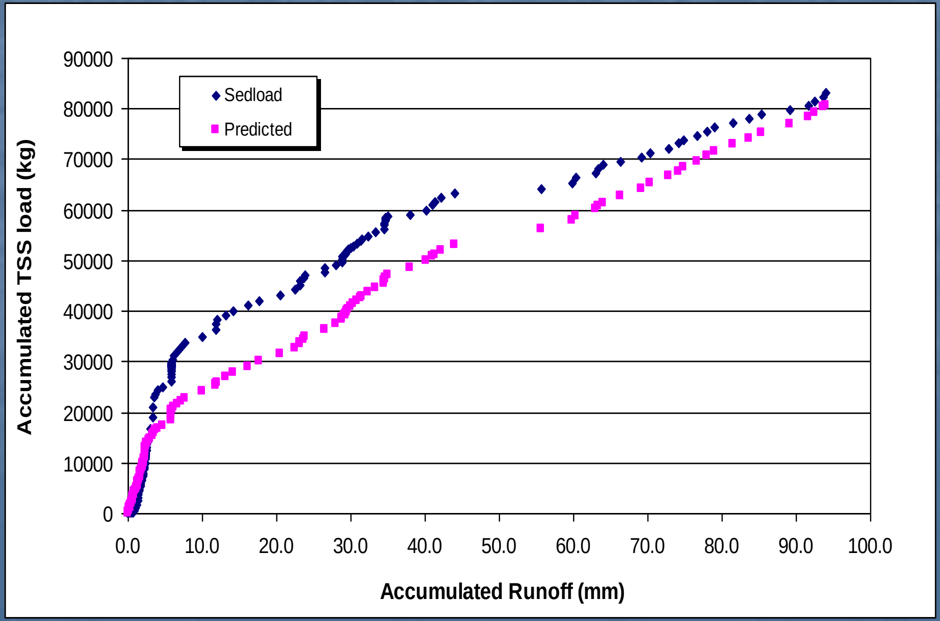
Sediment Yield Curves – incorporate soil, slope, cover, strength aspects of soil "functionality" into an "effective" erodibility…

- scale to watershed area through surface runoff routing of different SY areas on daily basis.
- determine changes in watershed sediment & fines loading after restoration within watershed.
- determine stream monitoring required to measure minimum soils restoration, or disturbance effects on watershed sediment loading within a prescribed confidence level.

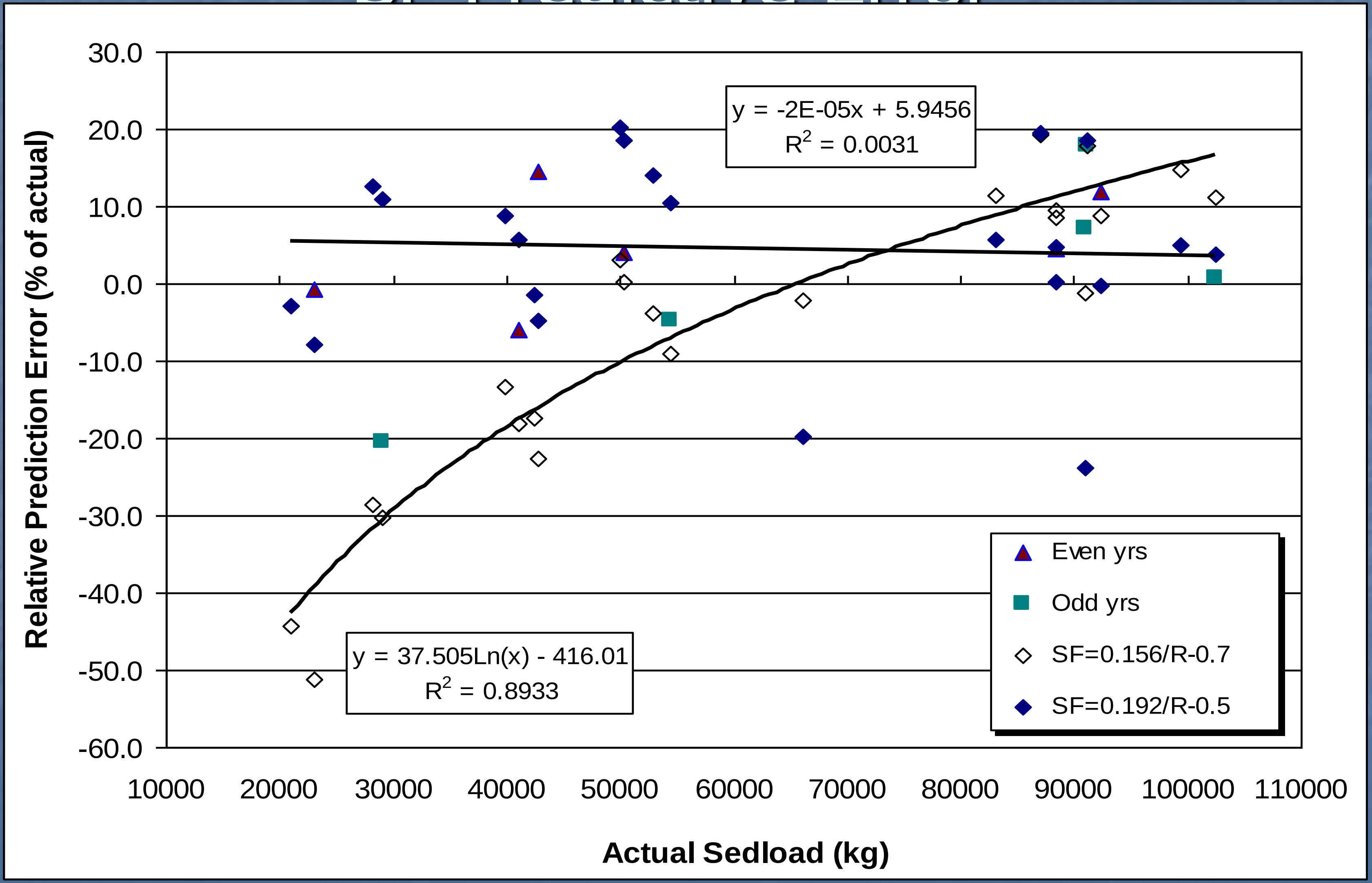
Scaling from plots to basins







HMR Creek Sediment Loading -Relative SF Predictive Error



Modeling Results Review

- Daily SF analyses enabled more detailed assessment and allows for evaluation of disturbance or restoration efforts on loading changes from the basin.
- SF's are runoff magnitude dependent; particularly at small runoff values.
- SF's are highly variable at low runoff due to sediment loading hysteresis effects and dominance of channel factors.
- For HMR Creek at 1 mm of runoff, SF = 0.192 suggests that the RS plot-scale data was <u>~5 times</u> that needed to represent the basin sediment loading.
- Seasonal or annual sediment loads can be predicted within 20-30%, rather than orders of magnitude.
- Comparisons of SF functions with adjacent Madden & Quail basins were similar & suggest possible wider use.

"Proof of Concept" Modeling to Detect Soil Functionality Changes

Example Application – Fuels harvesting/thinning in Madden Cr. Watershed.

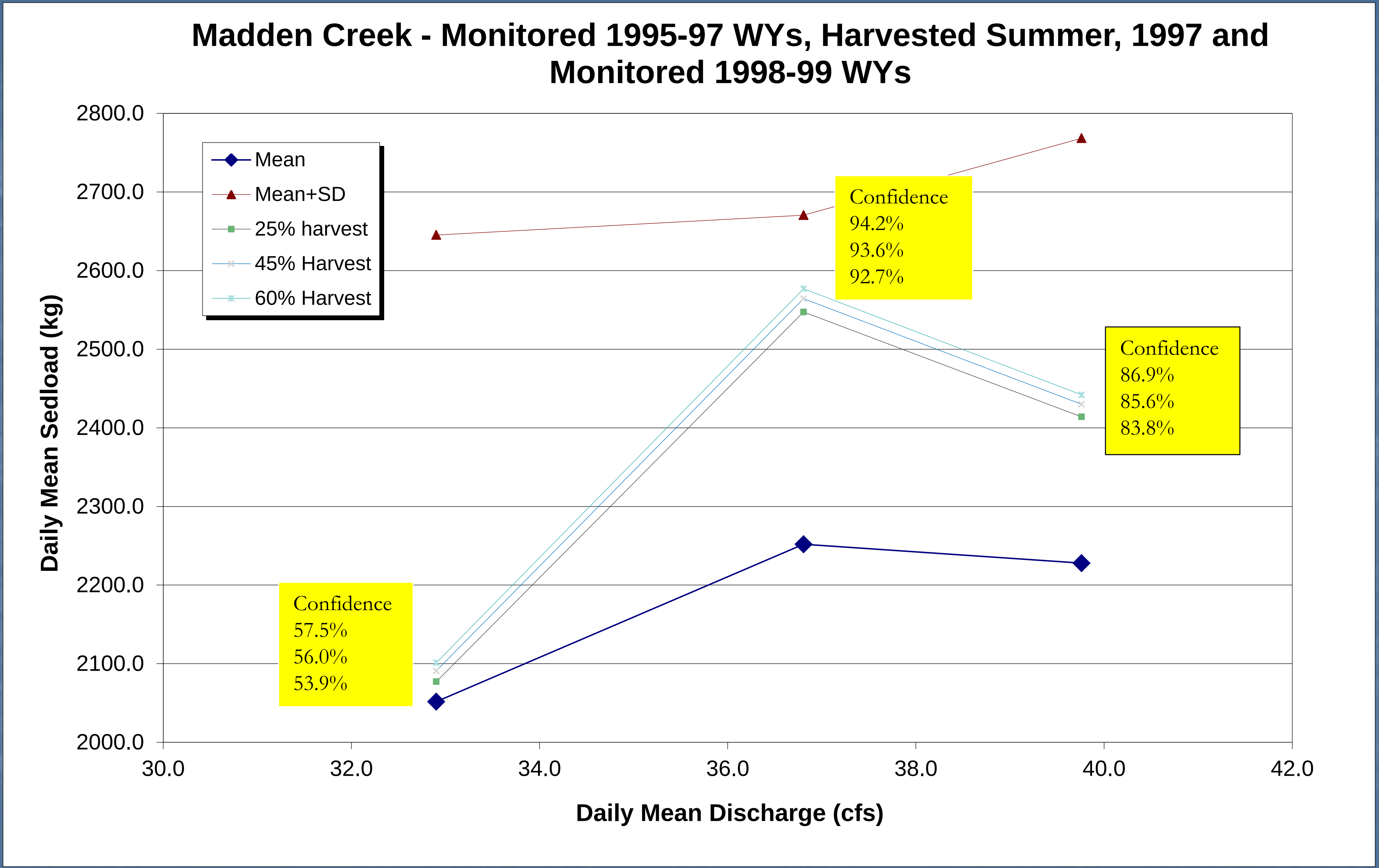
- Using existing fire road infra-structure, harvest-thinning operations from mid-range slope forests assumed to result in soil functional degradation to that equivalent to ski-runs.
- Modeled effects based on daily flows and sed-loading analyses for period 1994-2004.
- Due to dependence of sed-loading on flows, results are considered by incremental flow steps

Homewood and Madden Creek general land-uses (2008)

Land-use Category	Homewood Creek (260.9 ha)			Madden Creek (529.5 ha)		
	Area (m^2)	Fraction of WS (%)	Slope (%)	Area (m^2)	Fraction of WS (%)	Slope (%)
Dirt Roads	84,497	3.24	49.3	54,135	1.03	49.1
Ski-run Areas-	439,173	16.83	49.6	613,033	11.64	46.8
Forested Areas	2,027,276	77.70	~43	4,574,505	86.86	~45
Residential	31,451	1.21	14.0	19,559	0.37	20.3
CICU – Imperv.	4768	0.45	17.9	0	0	NA
CICU - Pervious	7082		10.6	0	0	NA
Paved Roads	15,013	0.58	18.5	3792	0.07	15.0
Annual Runoff (mm) & range		70	9.3-193.1		64.5	8.6-181
Ann. SY (kg/ha/mm) & range		6.14	1.8-11.3		7.88	2.9-13.3
Soils Fractions (Volcanic/Granitic)		0.89	0.11		0.93	0.07

Harvest/Thinned Areas as Fraction of mid-slope forests and basin areas

EP3 Fraction	Area (m^2)	Forest Fraction	WS Fraction
5	129935	2.84%	2.47%
10	259869	5.68%	4.93%
15	389804	8.52%	7.40%
20	519738	11.36%	9.87%
25	649673	14.20%	12.34%
35	909542	19.88%	17.27%
45	1169411	25.56%	22.21%
60	1559215	34.08%	29.61%



Madden Creek - Monitored 1995-97 WYs, Harvested Summer, 1997 and Monitored 1998-99 WYs
Daily Mean Sedload (kg)
Daily Mean Discharge (cfs)
Mean
Mean+SD
25% harvest
45% Harvest
60% Harvest
Confidence
57.5%
56.0%
53.9%
Confidence
94.2%
93.6%
92.7%
Confidence
86.9%
85.6%
83.8%
2800.0
2700.0
2600.0
2500.0
2400.0
2300.0
2200.0
2100.0
2000.0
30.0
32.0
34.0
36.0
38.0
40.0
42.0

Madden Prelim Harvest Analyses

- Comparison of 11-yr record sed-loading with and w/o harvesting operations that have a mild, presumably temporary effect on sed-loading rates are difficult to detect across all flowrates with any confidence.
- Detection of changes in sed-loading perhaps more likely at mid-range flowrates, but depends on previous years effects on channel conditions.
- Need to consider both inter-annual event effects as well as shorter time scale processes to get a better handle on measuring sed-load changes with sufficient confidence.

"Proof of Concept" Modeling to Detect Soil Functionality Changes

Example Application – Soils restoration in Homewood (HMR) Creek Watershed.

Restored Road & Ski-run area Fractions (%)		Area (m^2)	WS Fraction (%)
50	0	42,249	1.62
50	10	86,166	3.30
50	20	130,083	4.99
50	30	174,000	6.67
50	40	217,918	8.35
50	50	261,835	10.0

HMR Creek Restoration Confidence Levels of Detection for 1994-2004

Baseline	Flow	Confidence Levels of Detection Restoration fractions of Road/Ski-run areas					
N	**(cfs)**	**50/50%**	**50/40%**	**50/30%**	**50/20%**	**50/10%**	**50/0%**
21	28.4	98.9%	97.7%	95.5%	91.9%	86.3%	78.5%
37	22.0	99.8%	99.3%	98.2%	95.8%	91.2%	85.7%
52	18.5	99.9%	99.9%	99.6%	98.5%	95.6%	89.0%
31	15.2	97.6%	97.6%	96.1%	93.9%	90.9%	75.0%
61	12.5	98.5%	97.4%	95.6%	92.7%	88.7%	74.8%
50	9.92	95.1%	92.6%	89.2%	84.7%	79.2%	70.5%

Comparison Periods	Baseline – No restoration				50%, 50% Restoration			50%, 40% Restoration		50%, 30% Restoration		50%, 20% Restoration	
	N	Mean Q (cfs)	Mean Sed (kg/d)	Std. Dev. (kg/d)	N	Mean Sed (kg/d	CL (%)	Mean Sed (kg/d	CL (%)	Mean Sed (kg/d	CL (%)	Mean Sed (kg/d	CL (%)
Monitored 1995-96, restoration '96, monitored '97-98	29	18.6	780	93.8	15	716	97.8	725	95.9	734	92. 8	743	88.1
Monitored 1995-96, restoration '96, monitored '97-99	29	18.6	780	93.8	23	713	99.3	721	98.4	730	96.7	739	93.4
Monitored 1995-96, restoration '96, monitored '97-99	18	15.4	712	153.2	9	681	76.7	689	70.3	697	63.1	706	55.4
Monitored 1995-96, restoration '96, monitored '97-98	8	12.1	814	69.6	29	653	99.9	661	99.9	669	99.9	677	99.9
Monitored 1995-96, restoration '96, monitored '97-99	8	12.1	814	69.6	46	642	99.9	650	99.9	658	99.9	666	99.9
Monitored 1995-96, restoration '96, monitored '97-98	14	9.87	614	92.1	13	545	91.3	551	88.9	558	86.2	565	82.9
Monitored 1995-96, restoration '96, monitored '97-99	14	9.87	614	92.1	15	537	95.2	543	93.6	550	91.5	557	88.9

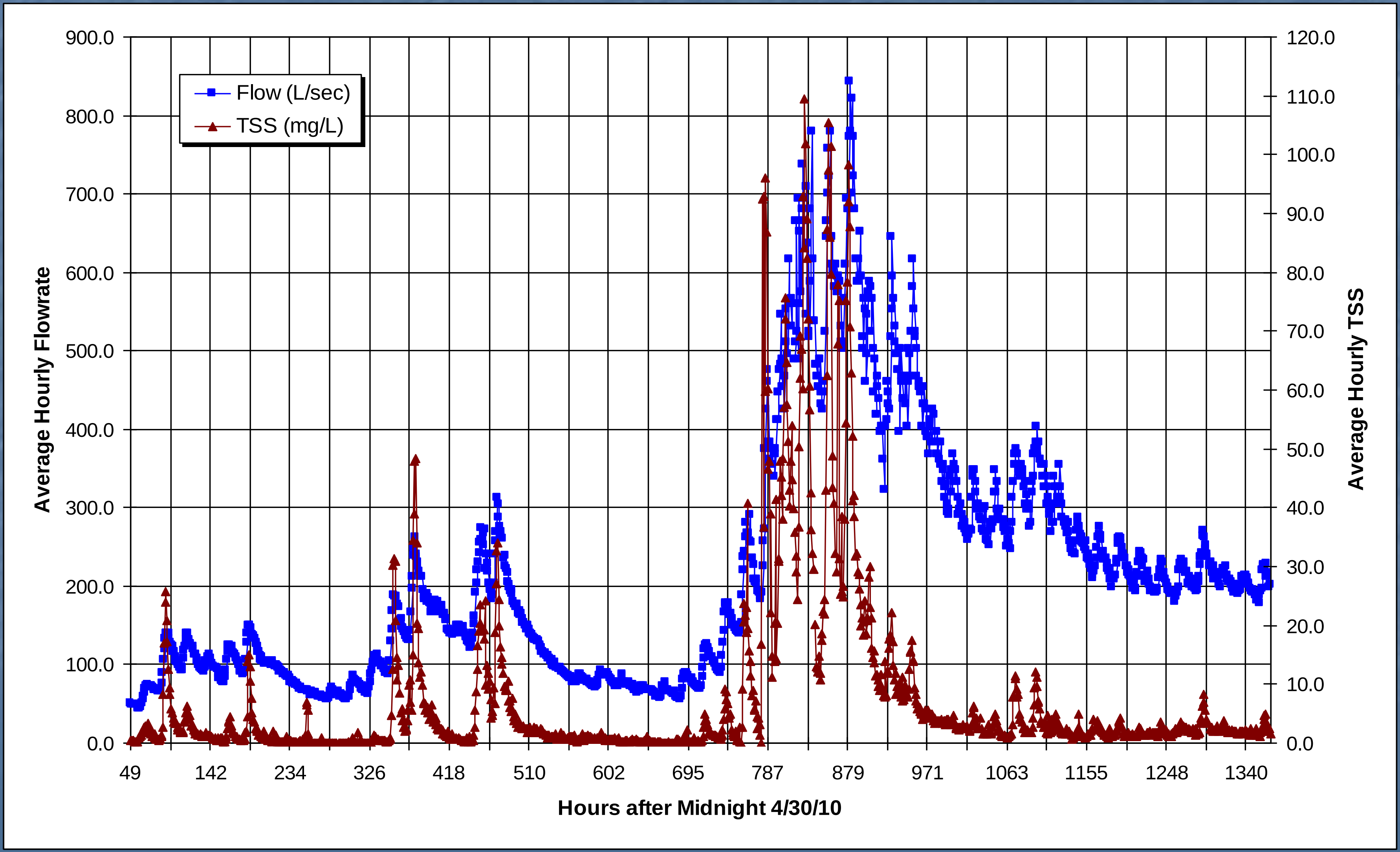
Can we improve on monitoring of Hillslope Restoration changes ?
Basics – Sedloading & Streamflow

- Extensive datasets (1999-2001) from Blackwood and Ward Canyons (Andy Stubblefield PhD) and HMR Creek (2009-2011) on Tahoe west shore.
- Data collected at 15-min intervals enables analyses at multiple time steps (e.g. 1, 4, 12 hrs).
- Considerable hysteresis between TSS concentrations (mg/L) & flow (cfs) in daily and seasonal hydrographs.
- Diurnal daily flow peaks increase with increasing temperature (typically from April-June).
- TSS-loads increase as greater surface areas are exposed and channel flow velocities increase (non-linearly).
- Seasonal overlay at play as channels "scoured" by rain-on-snow, or other large flow events.

Processes – Sedloading & Streamflow

- At small time scales (~1 hr), flow and sed-load peaks occur simultaneously and recession limb sed-loads only a fraction of rising limb values.
- Diurnal hydrograph rising limb event durations consistently ~6 hrs and progressively increase average Q and sed-load through April-May until major event occurs that "cleans" channel.
- Increasing sample averaging >~6 hr decreases sed-load variability, but then includes recession limb hysteresis problems.

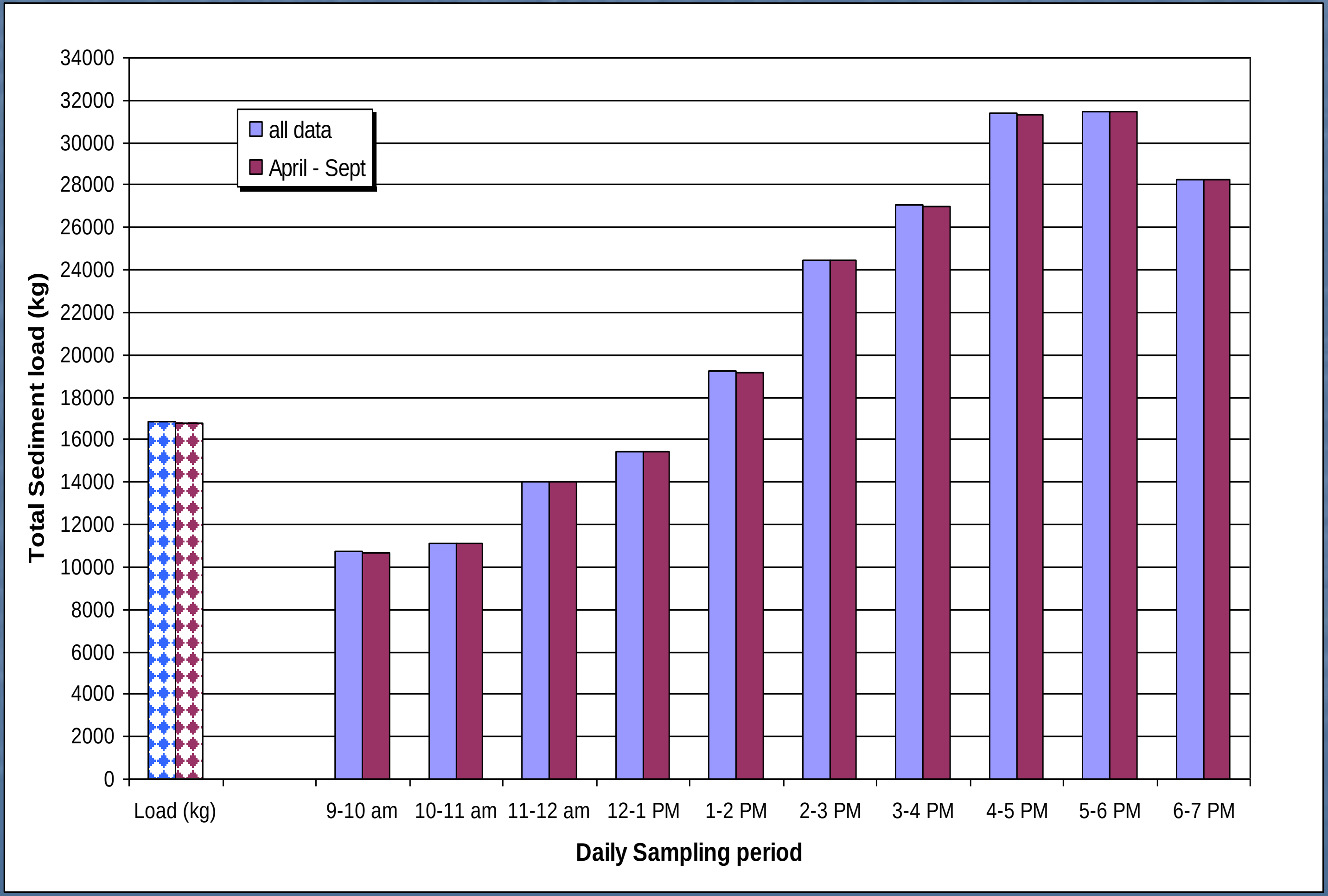
Hysteresis in Streamflow & Sediment load at HMR Creek, April-May 2010



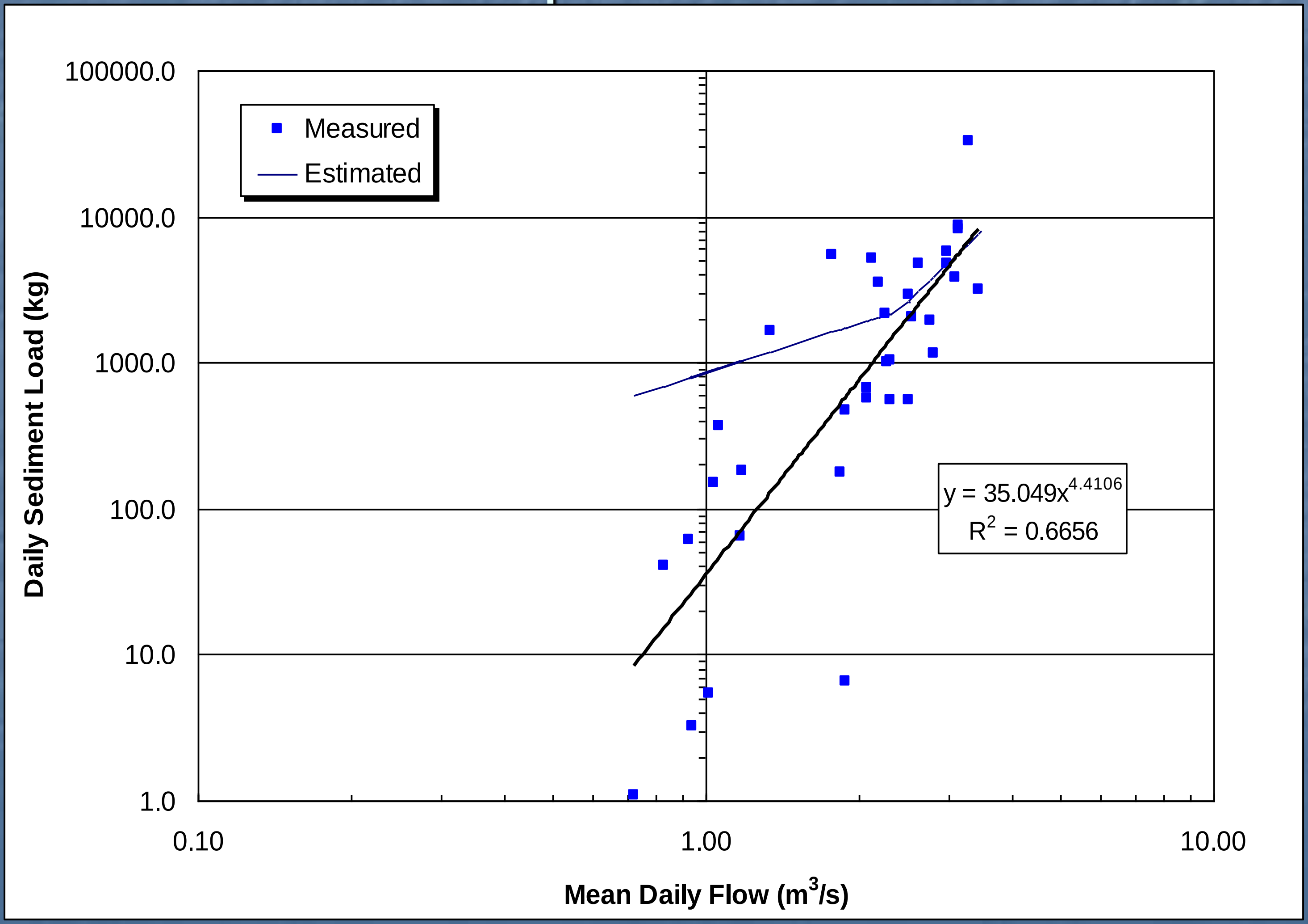
Linear regression relationships for turbidity probes in Homewood Creek (2009-2011)

Relationship	**n**	**Slope**	**Intercept**	**R^2**
TSS (mg/L) vs Turbidity (ntu)	57	1.802	-0.093	0.975
FSP (mg/L) vs Turbidity (ntu)	36	0.491	0.178	0.855
TKN (ppb) vs Turbidity (ntu)	34	3.878	282.3	0.038
TN (ppb) vs Turbidity (ntu)	34	18.62	103.8	0.811
TP (ppb) vs Turbidity (ntu)	34	2.187	22.32	0.887

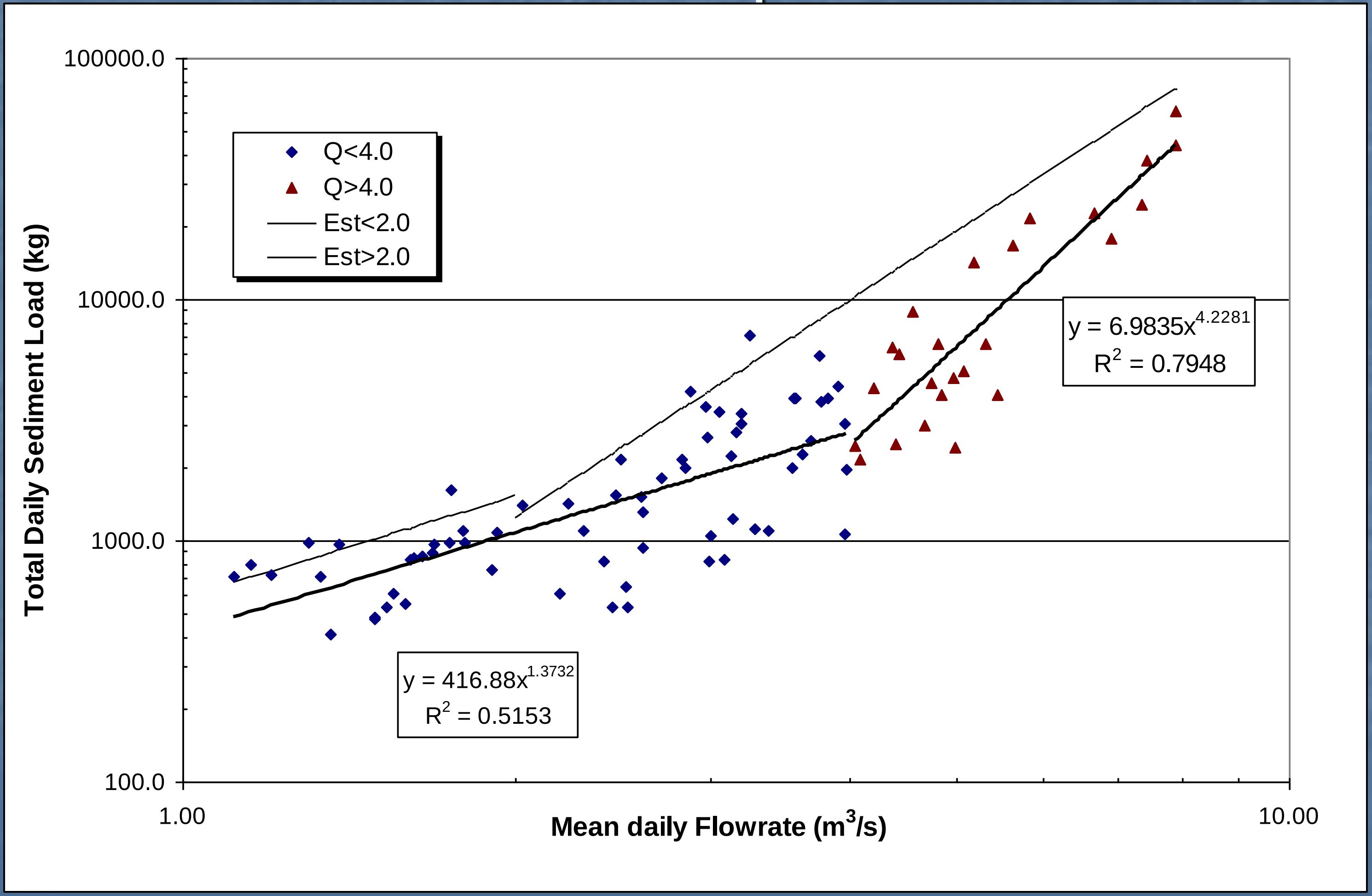
Total annual and spring-summer sediment load from Homewood Creek in 2010 WY as measured and estimated by different sampling periods



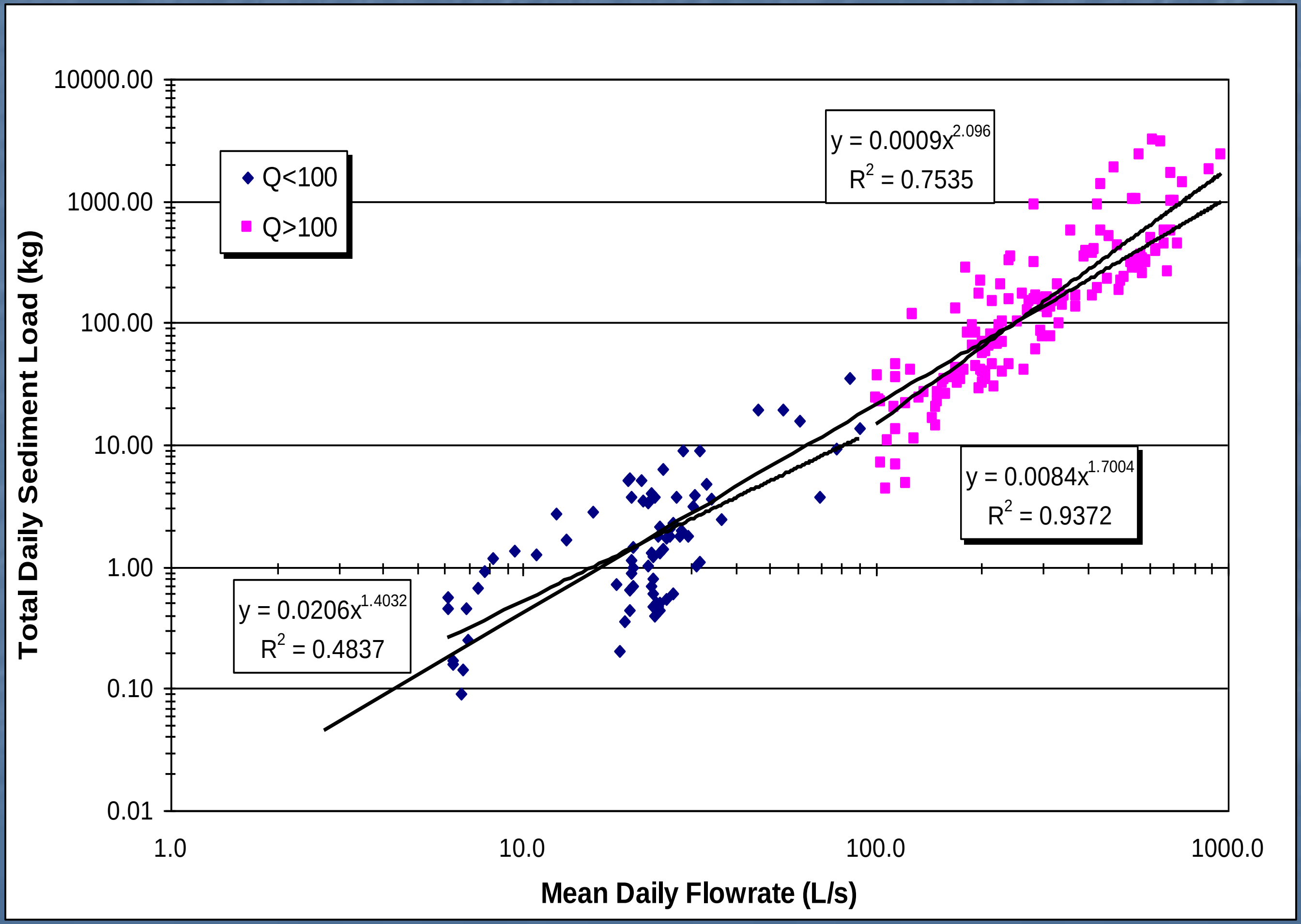
Comparison of estimated (1997-2002) and measured (April-May 2001) daily Sediment Load-Flow relationships for Blackwood Creek



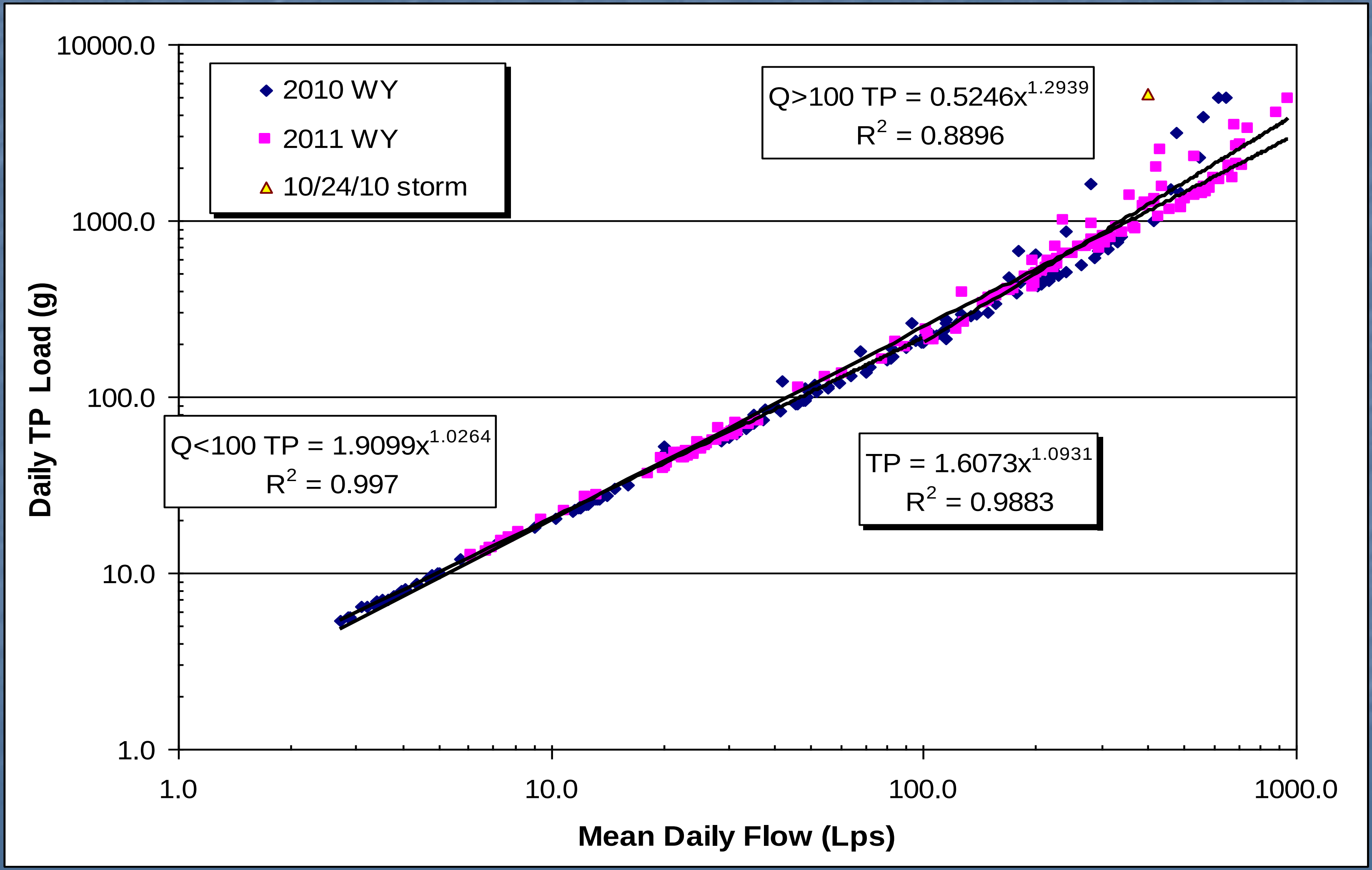
Comparison of estimated (1997-2002) and measured (April-May 1999-2000) daily Sediment Load-Flow relationships for Ward Creek



Daily measured (2009-2011) sediment (TSS) Load-Flow relationships for HMR Creek



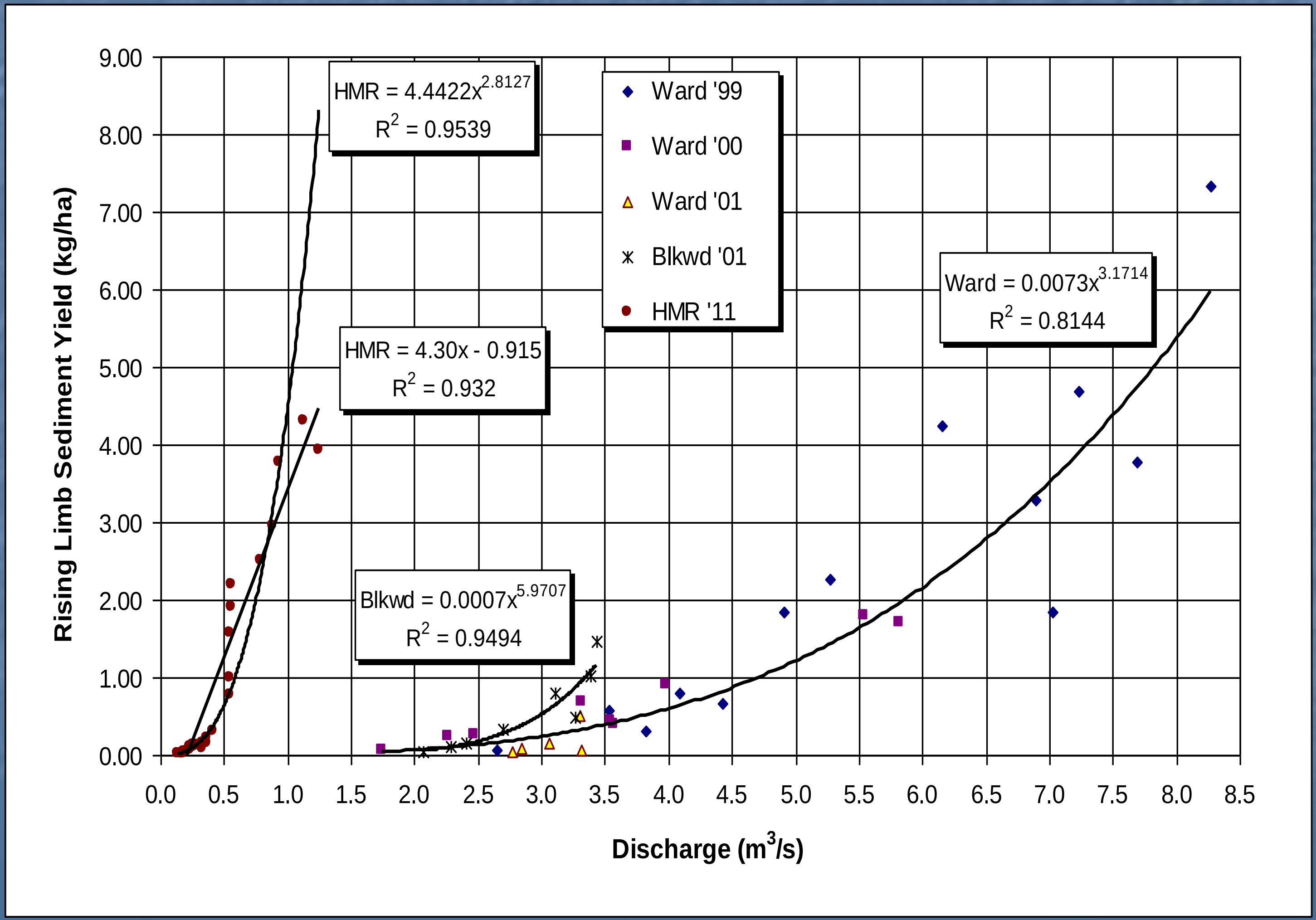
Daily measured (2009-2011) total phosphorous (TP) Load-Flow relationships for HMR Creek



Summary of optimal hourly sampling period at West-shore creeks based on the different statistical methods

Analysis Method	Creek	Data Period	Optimal sampling	Associated Figs or Tables
Annual Load	HMR	2010 WY	1 PM	Fig. 4
	HMR	2011 WY	3 PM	Fig. 5
RMSE	Blackwood	4-5/2001	5-6 PM	Table 5
	Ward	4-6/1999-00	3-4 PM	Table 5
	HMR	2009-11	4-5 PM	Table 5
T-test	Ward	4-6/1999-00	1-2 PM	Table 6
	HMR	2010 WY	3-4 PM	Table 6
	HMR	2011 WY	4-5 PM	Table 6
Regressions	Ward	4-6/1999-00	3 PM	Fig.12
	HMR	2010 WY	noon	Fig.13
	HMR	2011 WY	2-3 PM	Fig.14

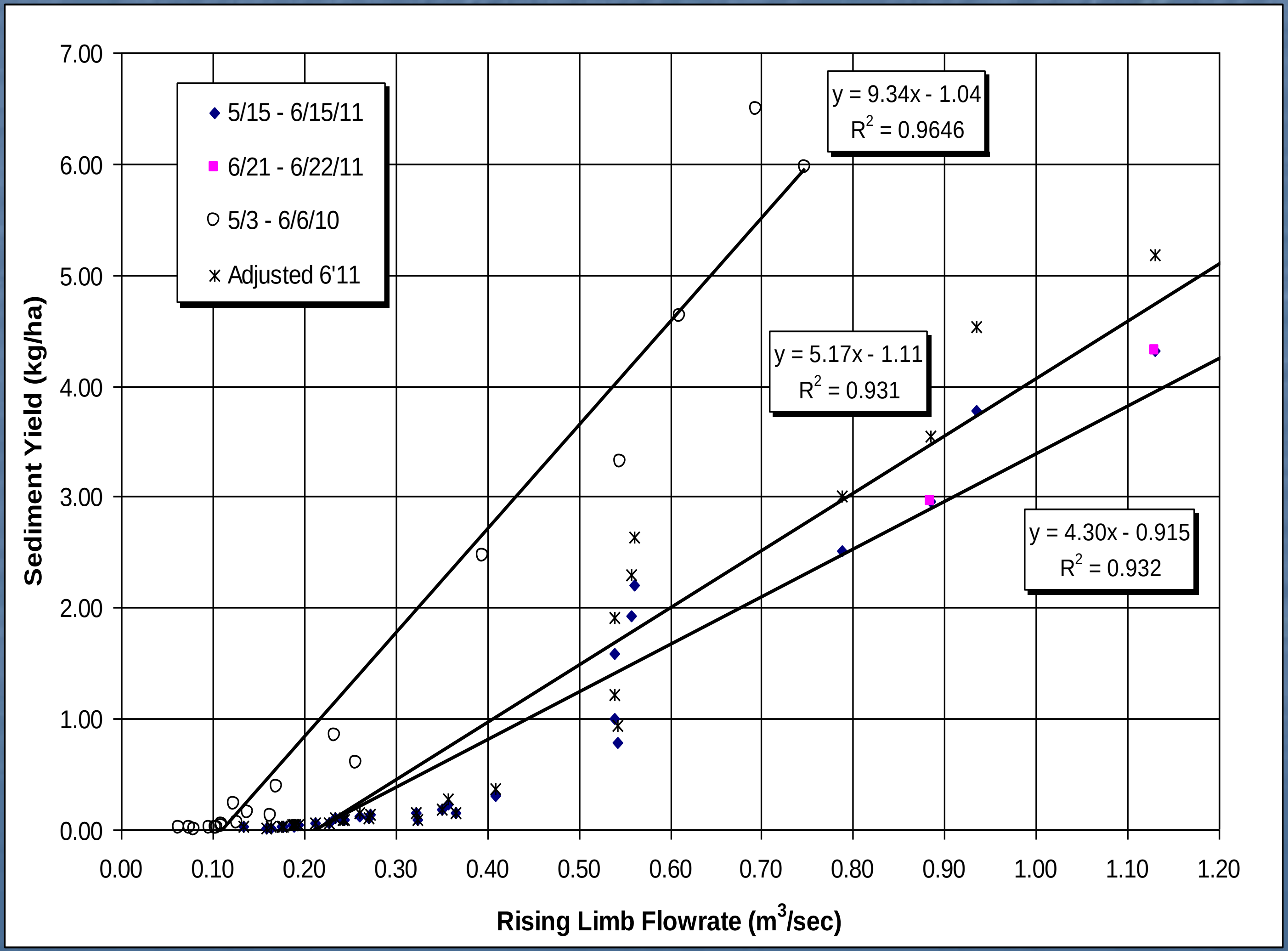
Hydrograph rising limb sediment yields at HMR, Blackwood and Ward Creeks during spring snowmelt periods



Summary of soils restoration work in the HMR Creek watershed (WS)

Summer-Year	Type	Area (m^2)	Roaded area Fraction (%)	Ski-run area Fraction (%)	Net WS Fraction (%)
2006	Road	2234	2.6	--	0.09
2007	Road	7483	8.9	--	0.37
2008	Road	4515	5.3	--	0.55
2009	Road	4145	4.9	--	0.70
	Ski-run	3143	--	0.7	0.82
2010	Road	5603	6.6		1.04
	Totals	**27,123**	**28.4**	**0.7**	**1.04**

Hydrograph rising limb sediment yields at HMR Cr. during spring snowmelt periods in 2010 & 2011



Where do we go from here ?

- Detection of soil restoration or disturbance effects are difficult to measure at the watershed scale as affected areas are often small overall – *nothing new there…!*
- Original estimated load-flow relationships may slightly over-estimate actual daily loads from Ward & Blackwood creeks.
- Continuous flow/TSS monitoring through late spring snowmelt period can assess changes in TSS, FSP and nutrient loadings following "treatments" within watershed.
- Measurement of daily hydrograph rising limb sediment loads during the seasonal rising limb hydrograph may enable quantitative assessment of load reductions within specified confidence levels.

Related Papers

- **Grismer, M.E.**, C. Shnurrenberger, R. Arst and M.P. Hogan. 2009. Integrated Monitoring and Assessment of Soil Restoration Treatments in the Lake Tahoe Basin. Environ. Monitoring & Assessment. 150:365-383.
- **Grismer, M.E.**, Drake, K.M. and M.P. Hogan. 2010. Adaptive Management and Effective Implementation of Sediment TMDLs in the Lake Tahoe Basin. Watershed Science Bulletin. Fall (Oct.), pp.42-48.
- **Grismer, M.E.** 2012. Erosion Modeling for Land Management in the Tahoe Basin, USA: scaling from plots to small forest catchments. Hydrological Sciences J. 57(5):1-20.
- **Grismer, M.E.** 2012. Detecting Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Modeling Predictions. Hydrological Processes. Submitted.
- **Grismer, M.E.** 2012. Soil Disturbance/Restoration effects on Stream Sediment Loading in the Tahoe Basin – Detection Monitoring. Hydrological Processes. Submitted.