Measuring and Modeling Cumulative Watershed Effects

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Acknowledgements

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Many others . . . .

Definition of Cumulative Effects from NEPA

"Cumulative impact is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time."

“Federal agencies have struggled with preparing cumulative effects analyses since CEQ issued its regulations in 1978…Court cases…have added little in the way of guidance and direction”

(CEQ, 1997, p.4)

Overall Goal and Direction

- Use field measurements and existing data to formulate, calibrate, and--to the extent possible--validate procedures for assessing and predicting cumulative watershed effects on small catchments (10-100 km^2);
- Concerned with both changes in runoff and changes in sediment production;
- Emphasis is on changes in sediment production because this is believed to be more important and more amenable to study;

Overall Goal and Direction

- Focus is on measuring and predicting sediment production and delivery at the hillslope scale, as catchment-scale measurements difficult, expensive, and integrate different processes and activities;
- Initial work has concentrated on public and private lands in the Central Sierra Nevada, but now expanding our work to the Sierra and Lassen National Forests;
- Methods, process-based understanding of the controlling factors, and modeling approaches should be more widely applicable.

Continuum of Approaches for Assessing Cumulative Effects

Qualitative, low cost, more uncertainty, less explicit ↔ **Quantitative, high cost, less uncertainty, more explicit**

Checklists	Indices	Conceptual/ empirical models	Detailed models (e.g., GeoWEPP, SEDMOD2, DHSVM)

Reid (1993) noted that:

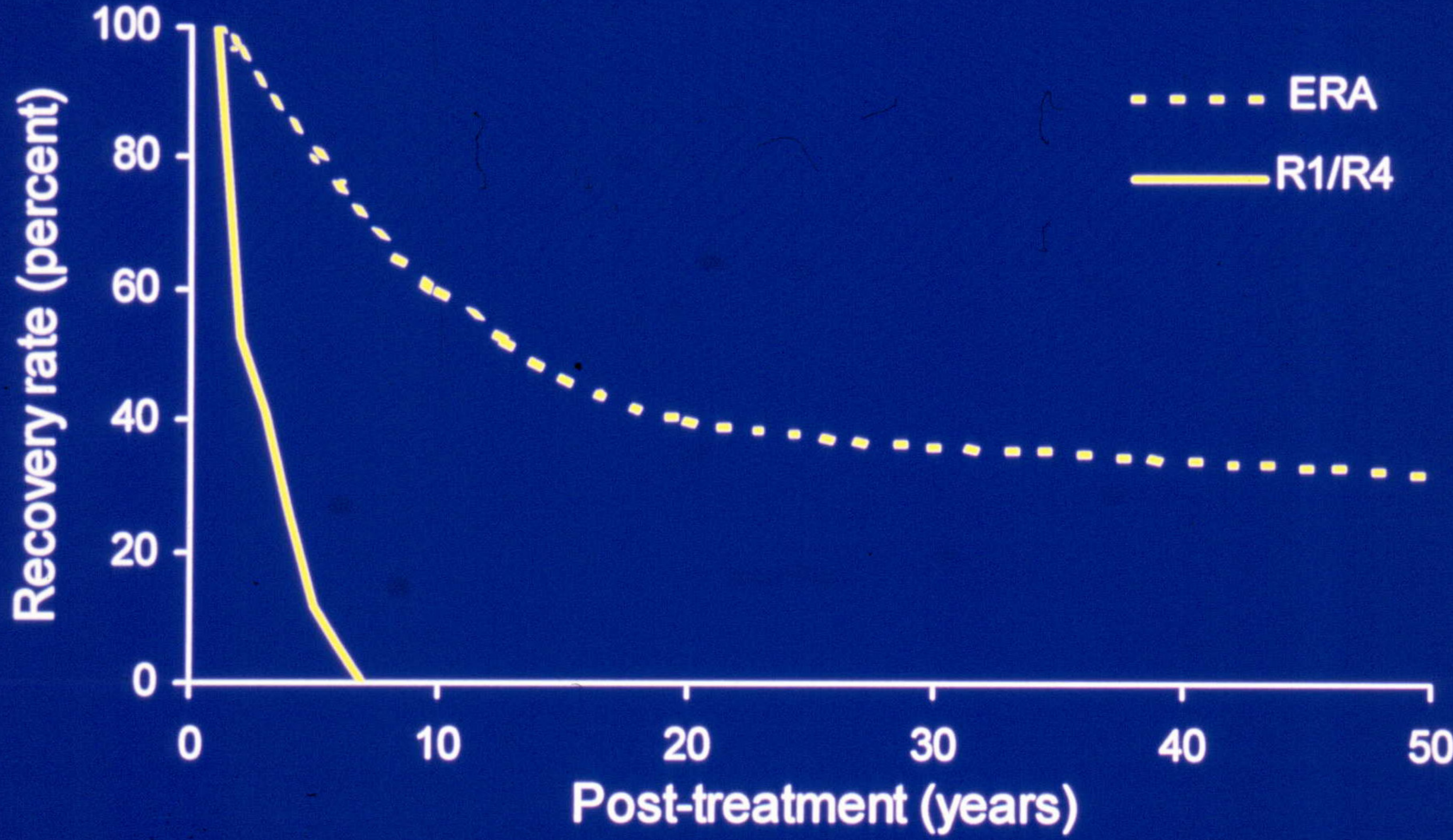
“When methods originate from management agencies, they tend to be simple, incomplete, theoretically unsound, unvalidated, implementable by field personnel, and heavily used.

Methods developed by researchers are more likely to be complex, incomplete, theoretically sound, validated, require expert operators, and unused.” (p. 35)

Limitations of Current USFS Region 5 Cumulative Effects Procedure (Equivalent Roaded Area, or ERA)

- Lumped conceptual model;
- Doesn’t explicitly separate changes in flow from changes in sediment;
- Excessively long recovery curves;
- Little validation at site or watershed scale.

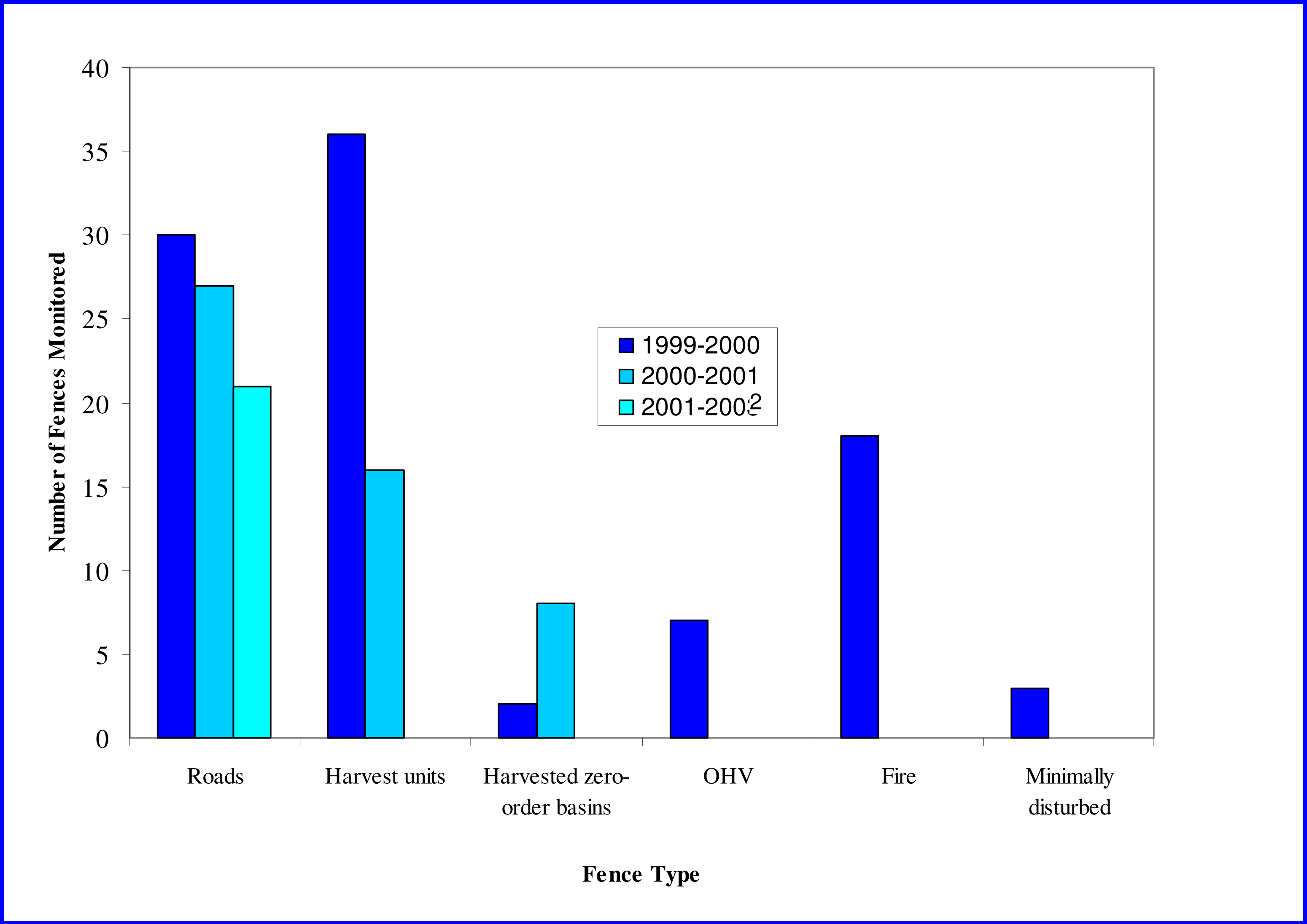
Recovery Rates: Tractor Logging



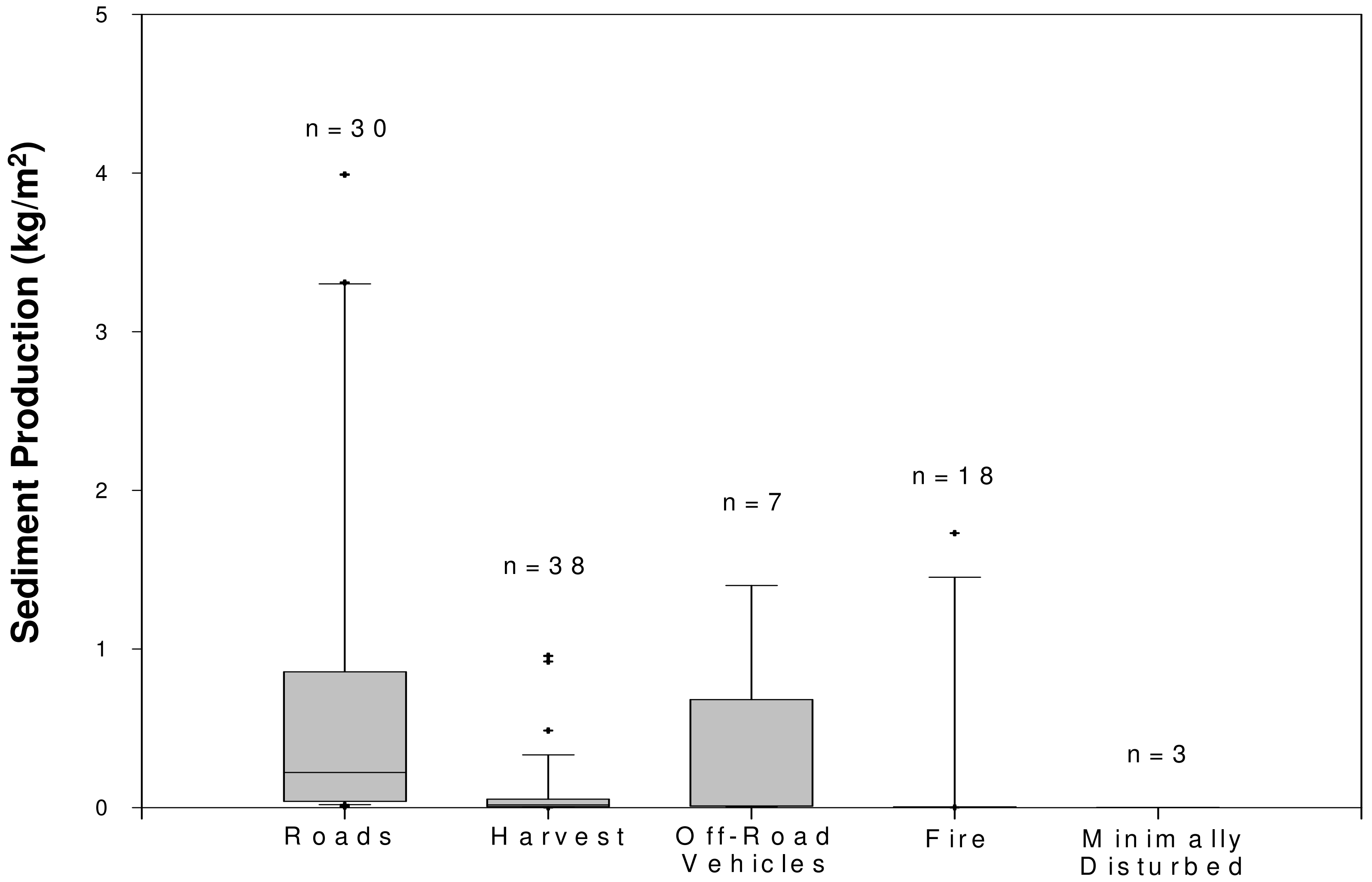
Methods: Sediment Production

- Using sediment fences to collect and weigh sediment to nearest 0.1 kg;
- Measure site characteristics (contributing area, percent cover, rainfall erosivity, soil type, slope, etc.);
- Develop and test sediment production models.

Number of Sediment Fences by Land Use and Year (nearly 400 fence-years)

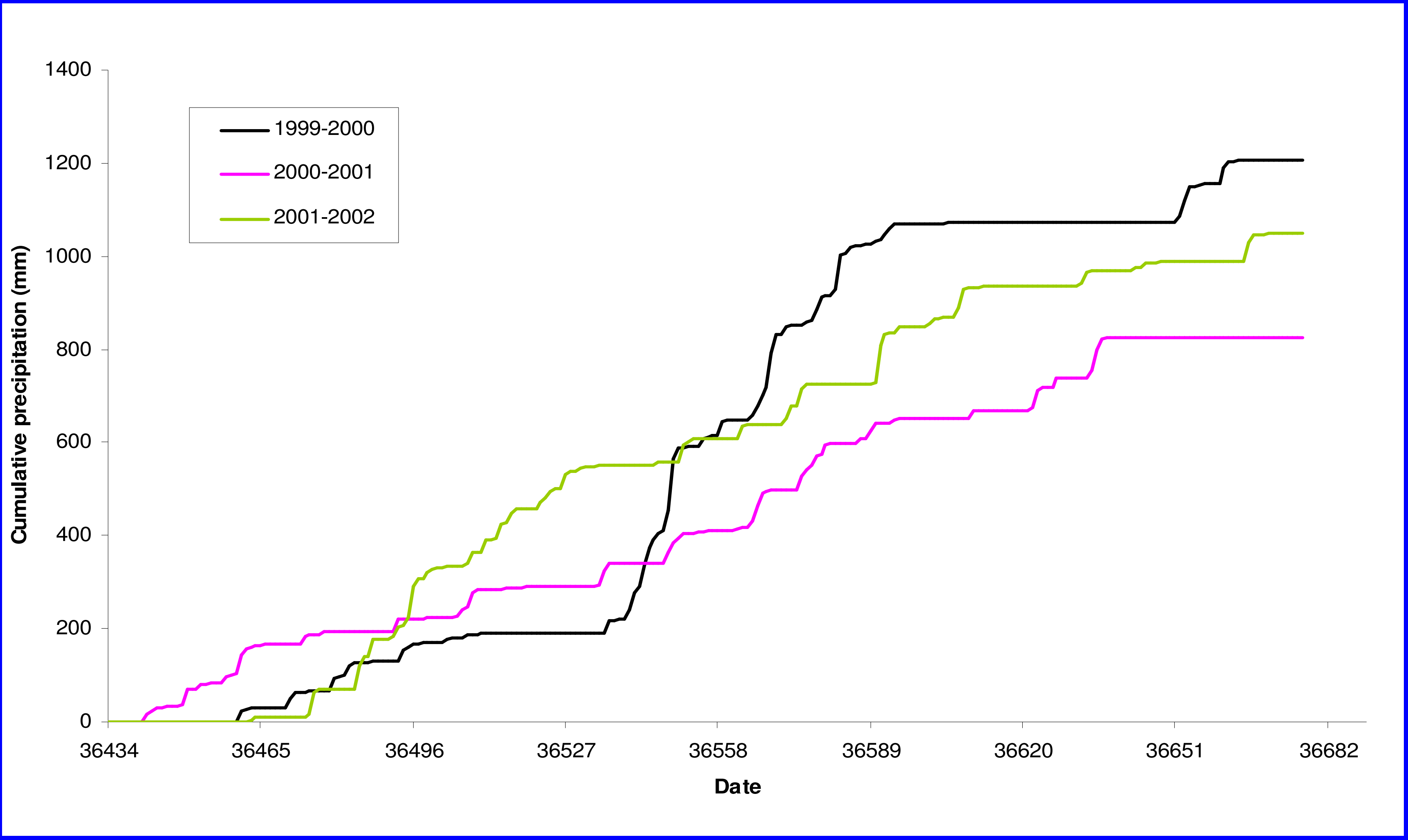


Sediment Production: 1999-2000

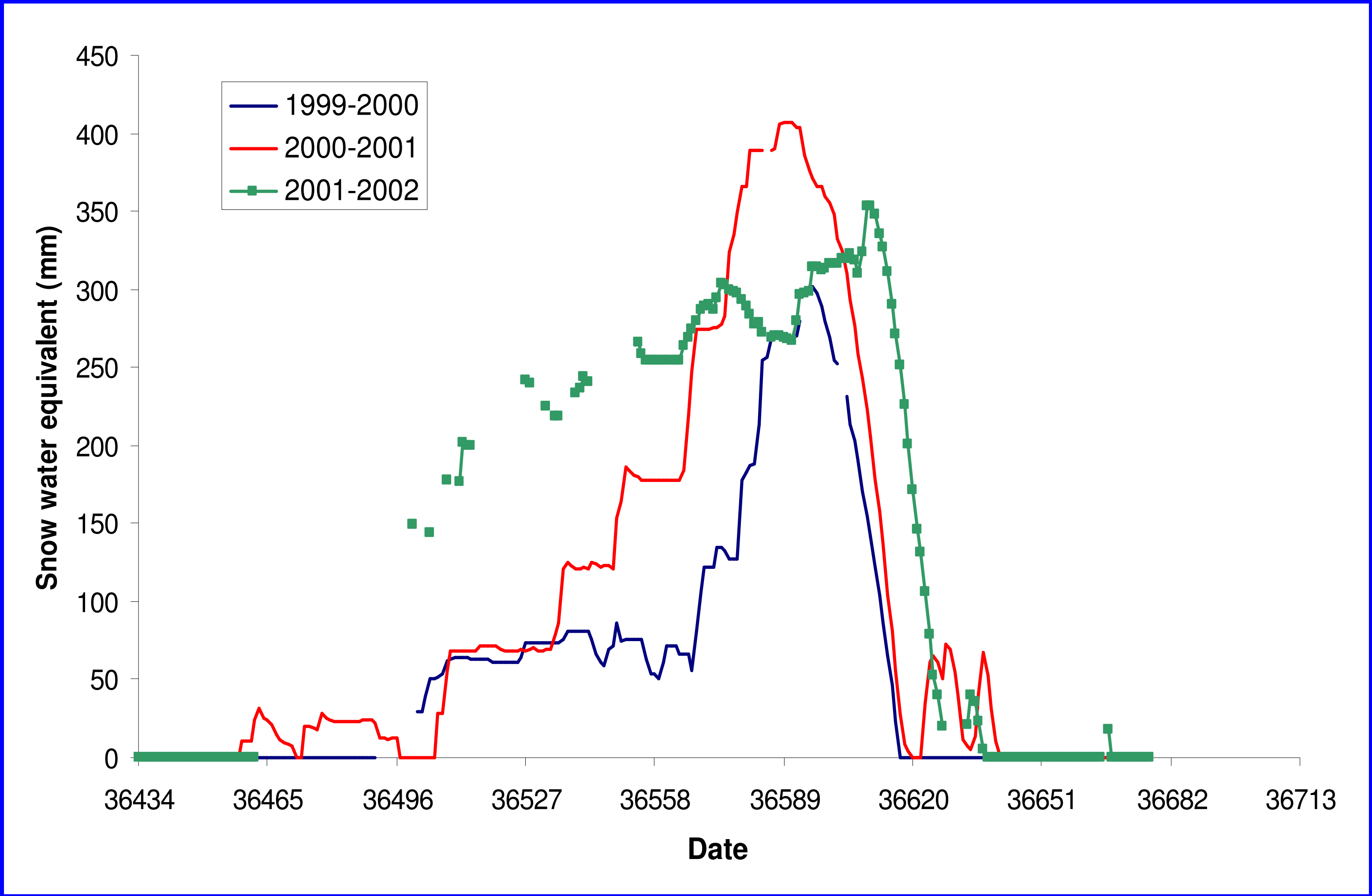


Sediment Production from Different Fire Severities: 1999-2000 Wet Season

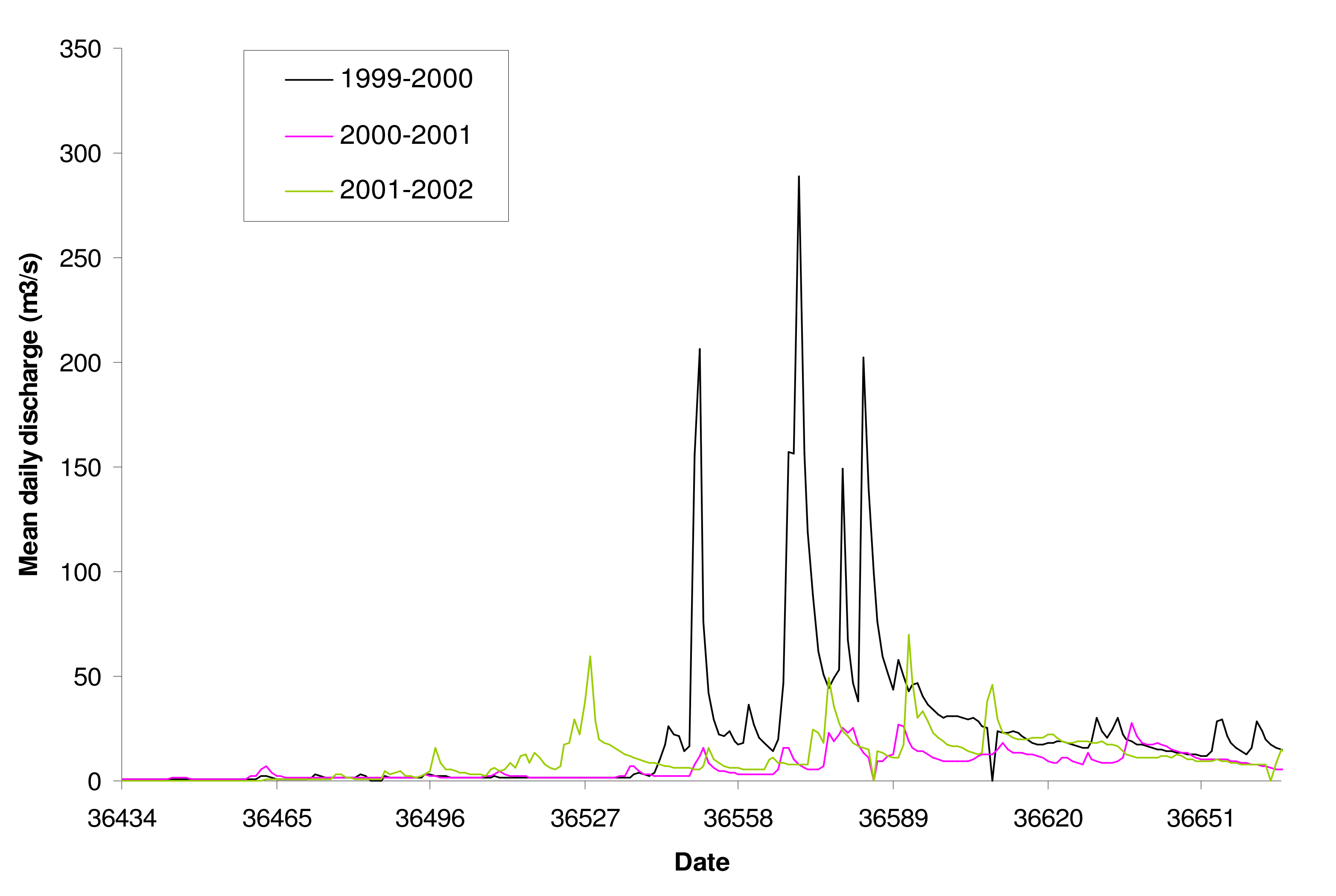
Cumulative Precipitation at Pacific House (1036 m)



Snow Water Equivalent for Robbs Powerhouse (1570 m)



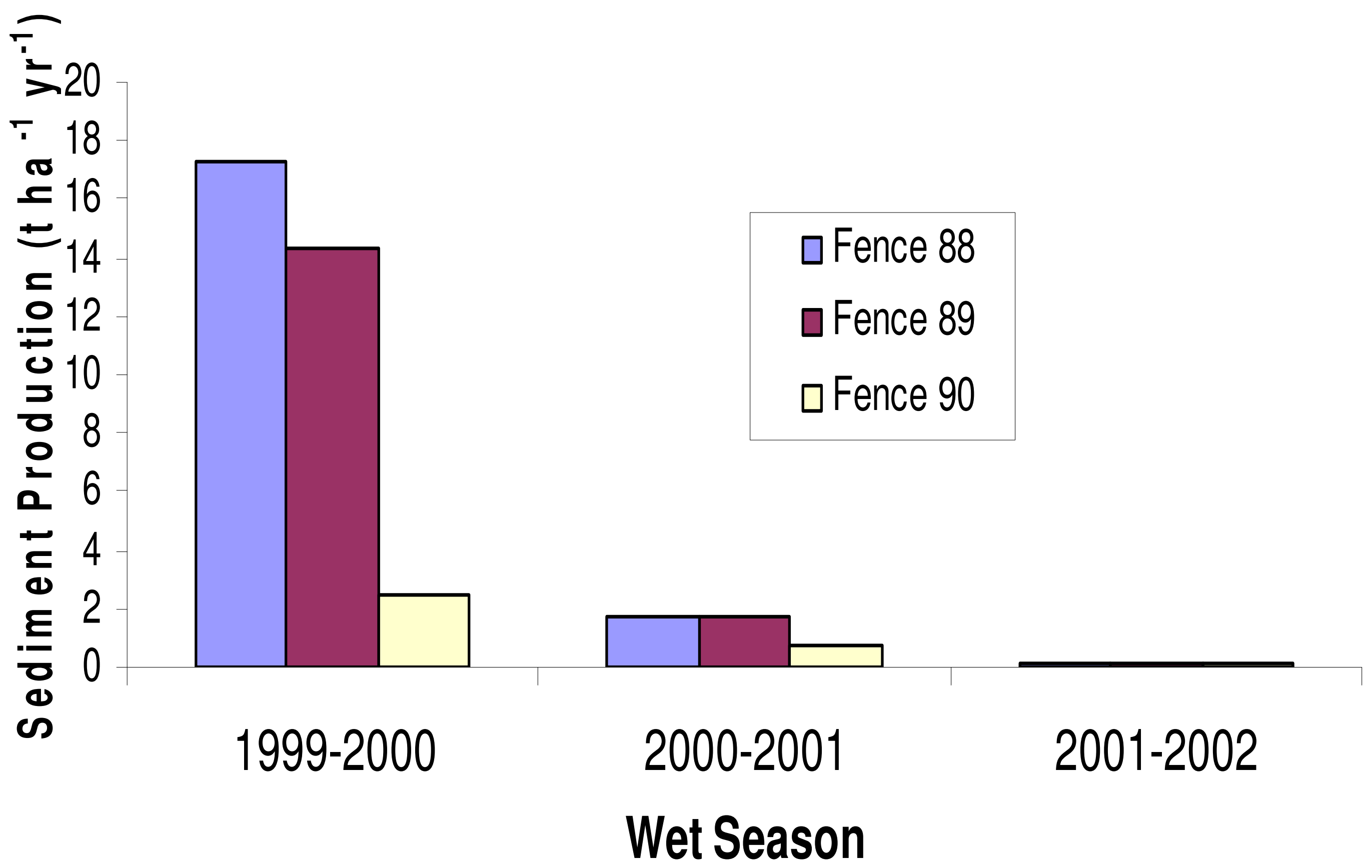
Mean Daily Discharge by Wet Season for the Michigan Bar Gage, Cosumnes River



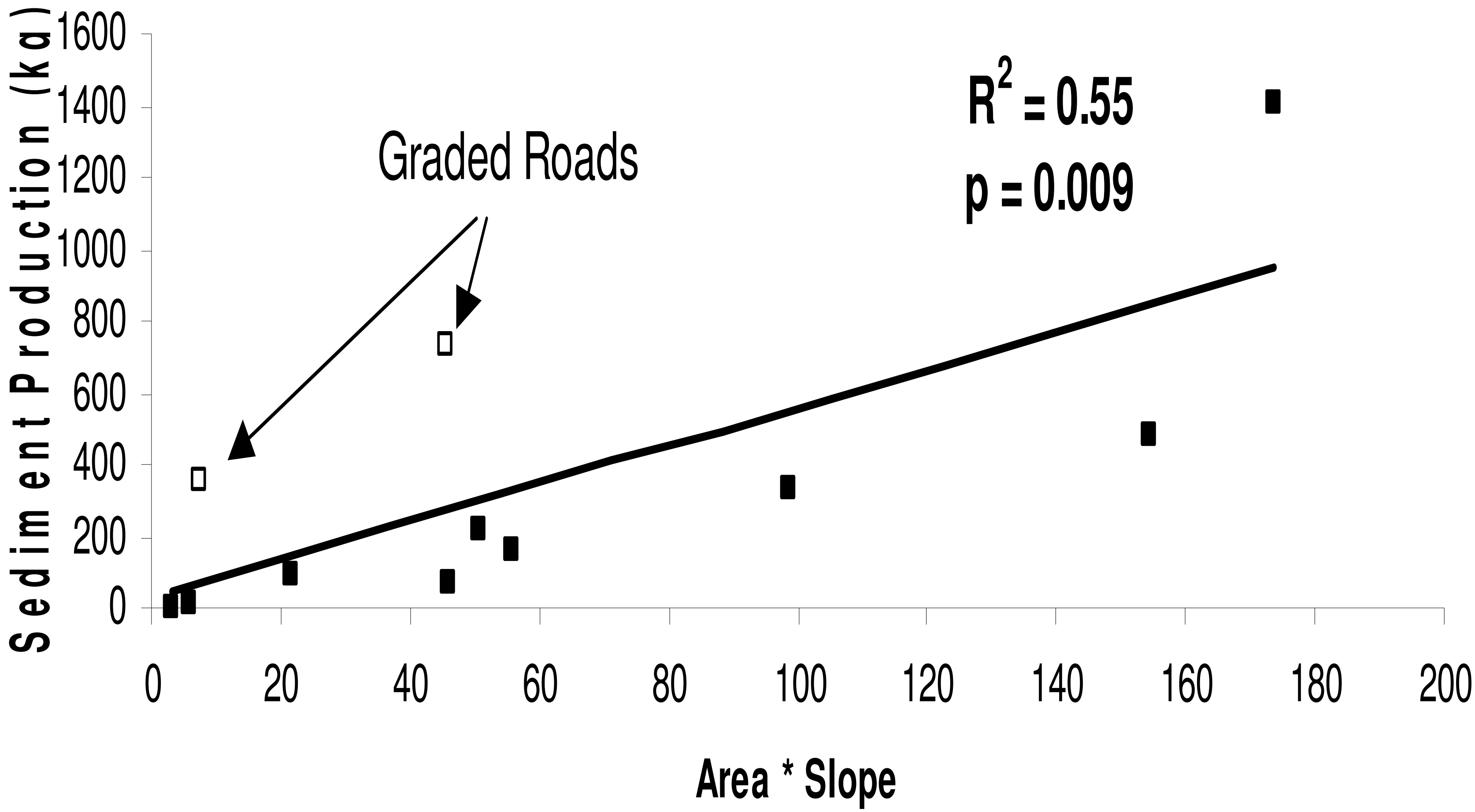
Annual Precipitation, Annual Erosivity, and Maximum Storm Erosivity for Three Wet Seasons

		Erosivity	
Wet Season	Annual Precipitation (mm)	Annual Erosivity (MJ mm ha-1 hr-1)	Max. Storm Erosiv. (MJ mm ha-1 hr-1)
1999-2000	1290	847	252
2000-2001	890	441	98
2001-2002	1057	456	83

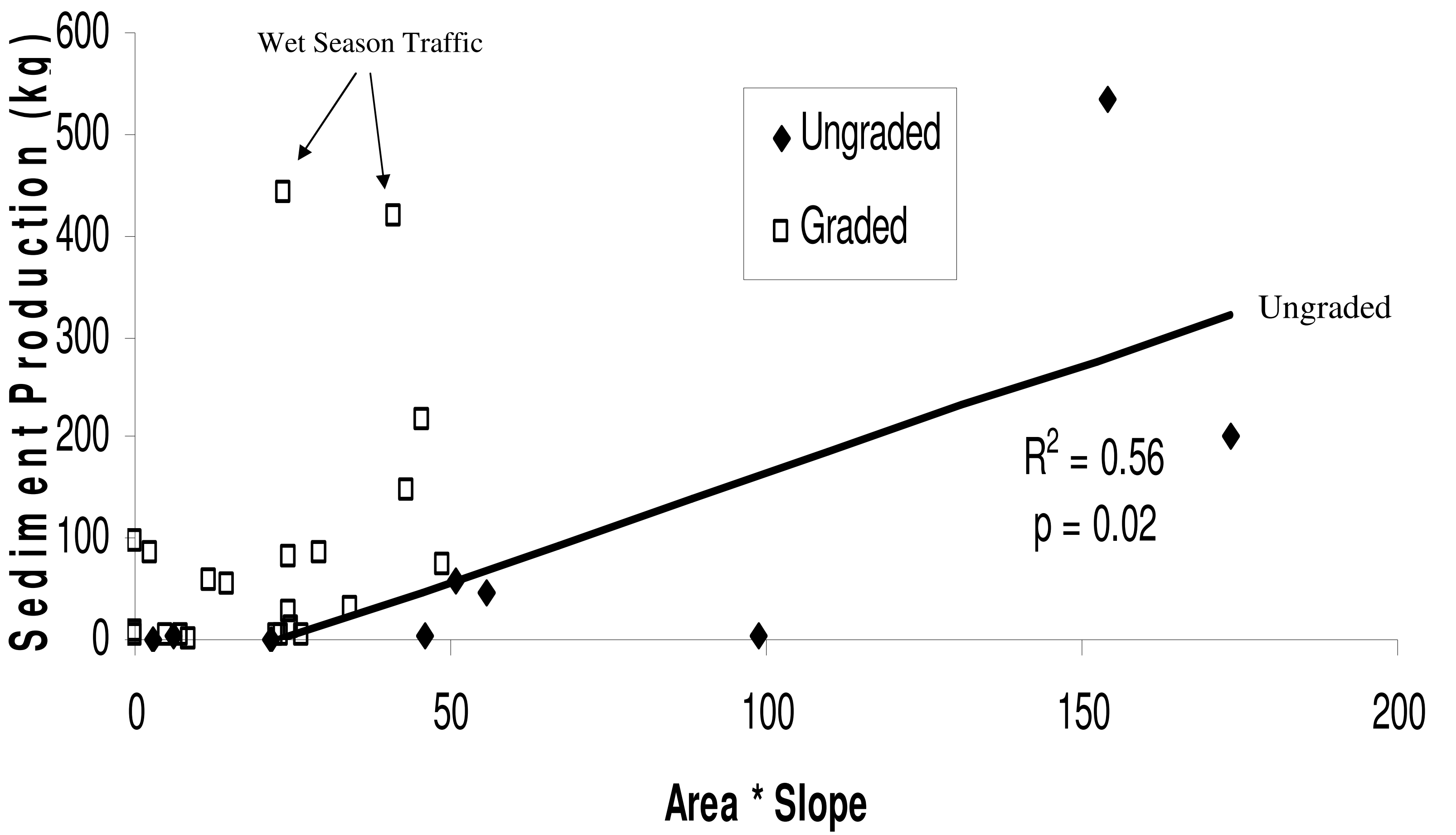
Recovery in Sites Burned at High Severity: Pendola Fire



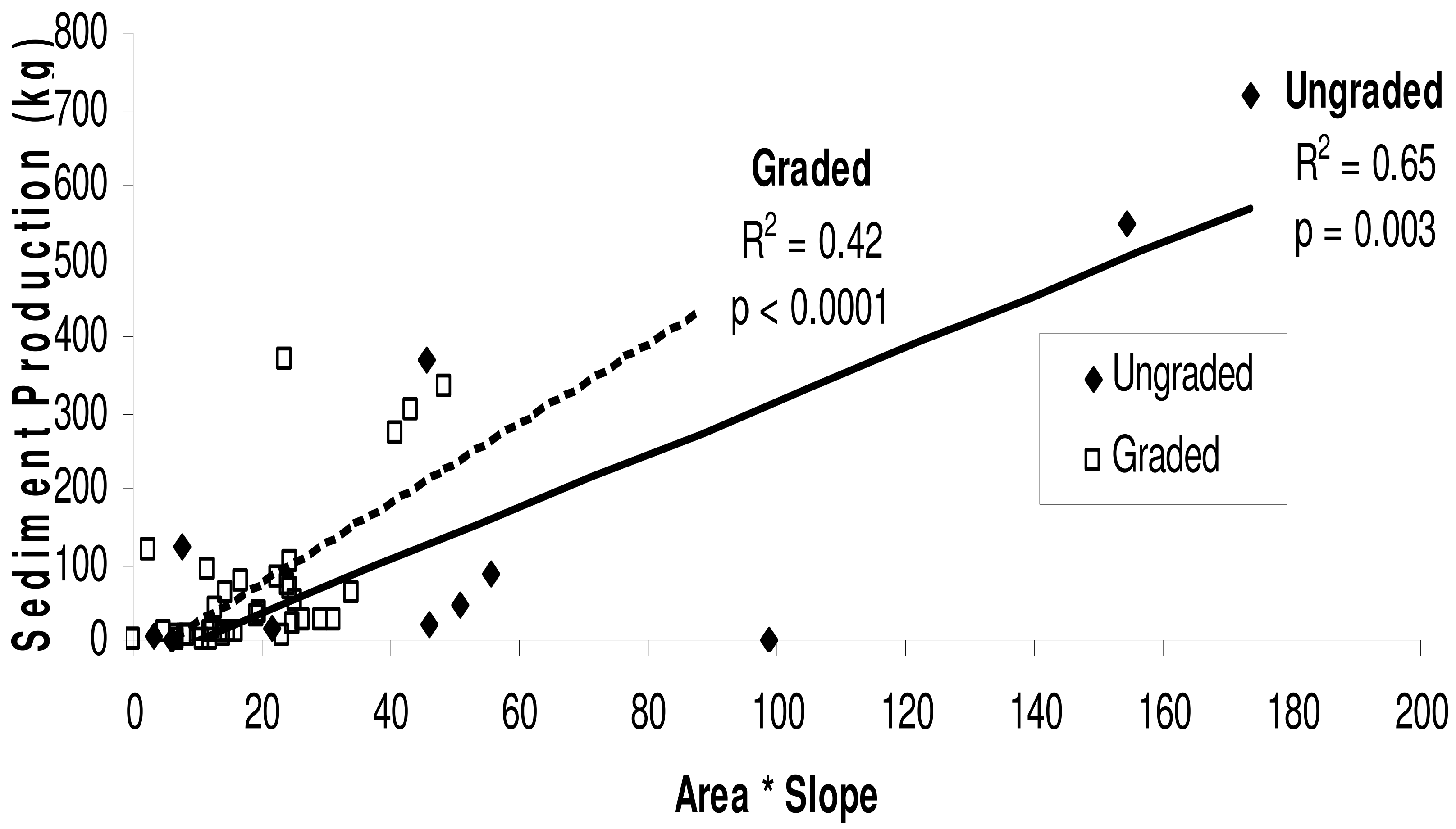
Sediment Production vs. Area*Slope for Native Surface Roads: 1999-2000 Wet Season



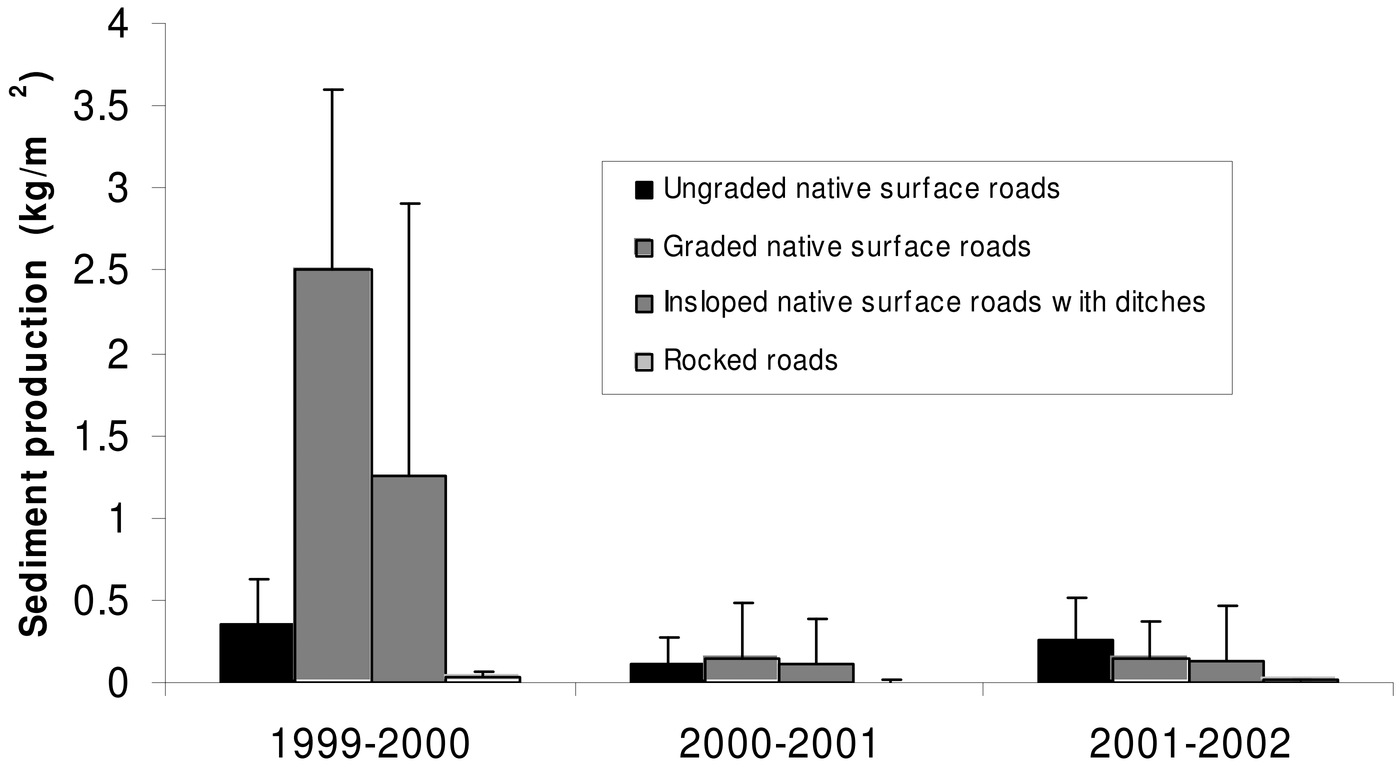
Sediment Production vs. Area * Slope for Graded and Ungraded Native Surface Roads: 2000-2001 Wet Season

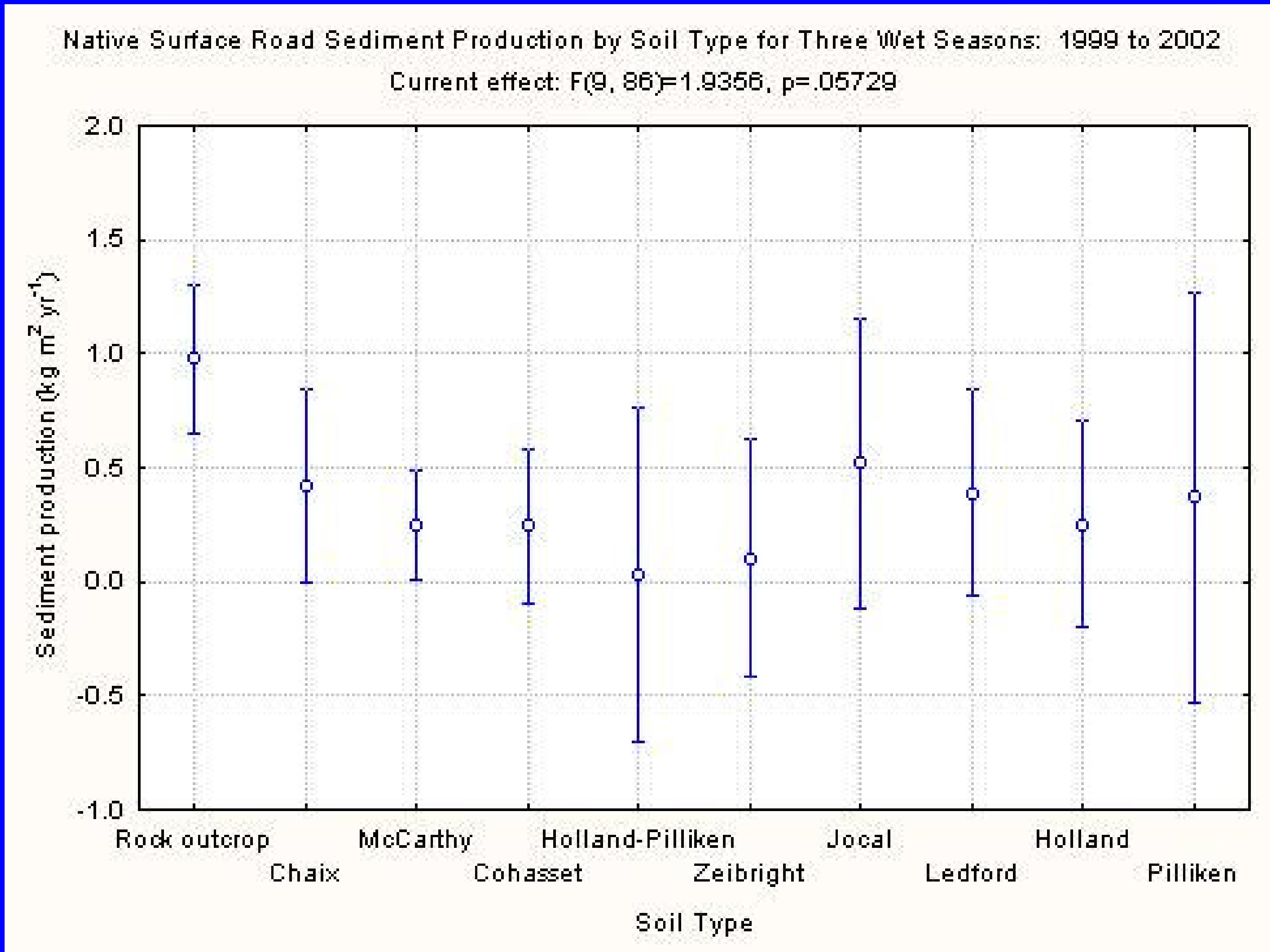


Sediment Production vs. Area * Slope for Ungraded and Graded Roads: 2001-2002 Wet Season



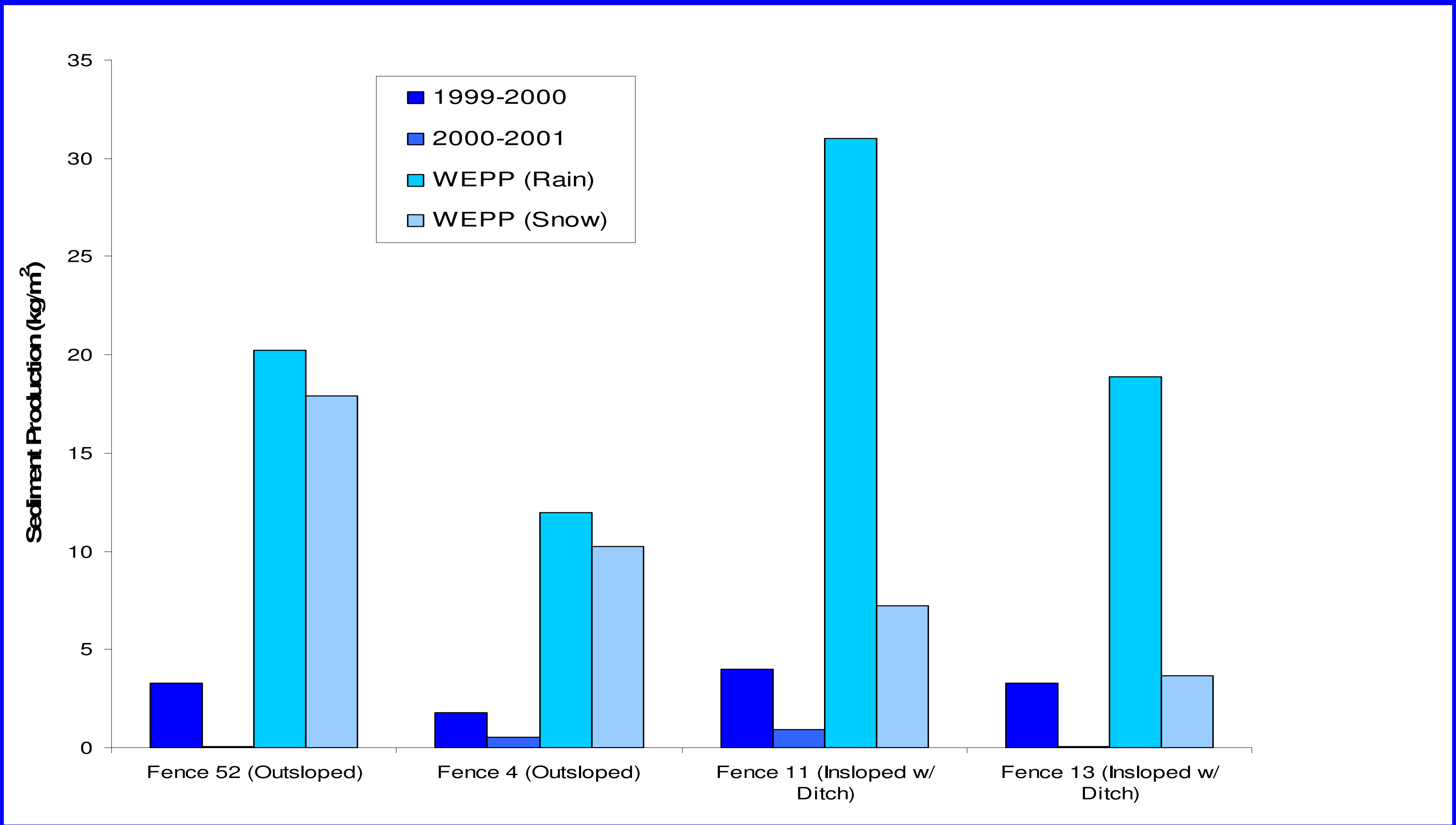
Magnitude and Interannual Variability in Sediment Production Rates by Road Type and Road Surface





Native Surface Road Sediment Production by Soil Type for Three Wet Seasons: 1999 to 2002
Current effect: F(9, 86)=1.9356, p=.05729
Sediment production (kg m-2 yr-1)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Rock outcrop
Chaix
McCarthy
Cohasset
Holland-Pilliken
Zeibright
Jocal
Ledford
Holland
Pilliken
Soil Type

Field-measured Road Sediment Production vs. WEPP Predictions for Insloped and Outsloped Roads

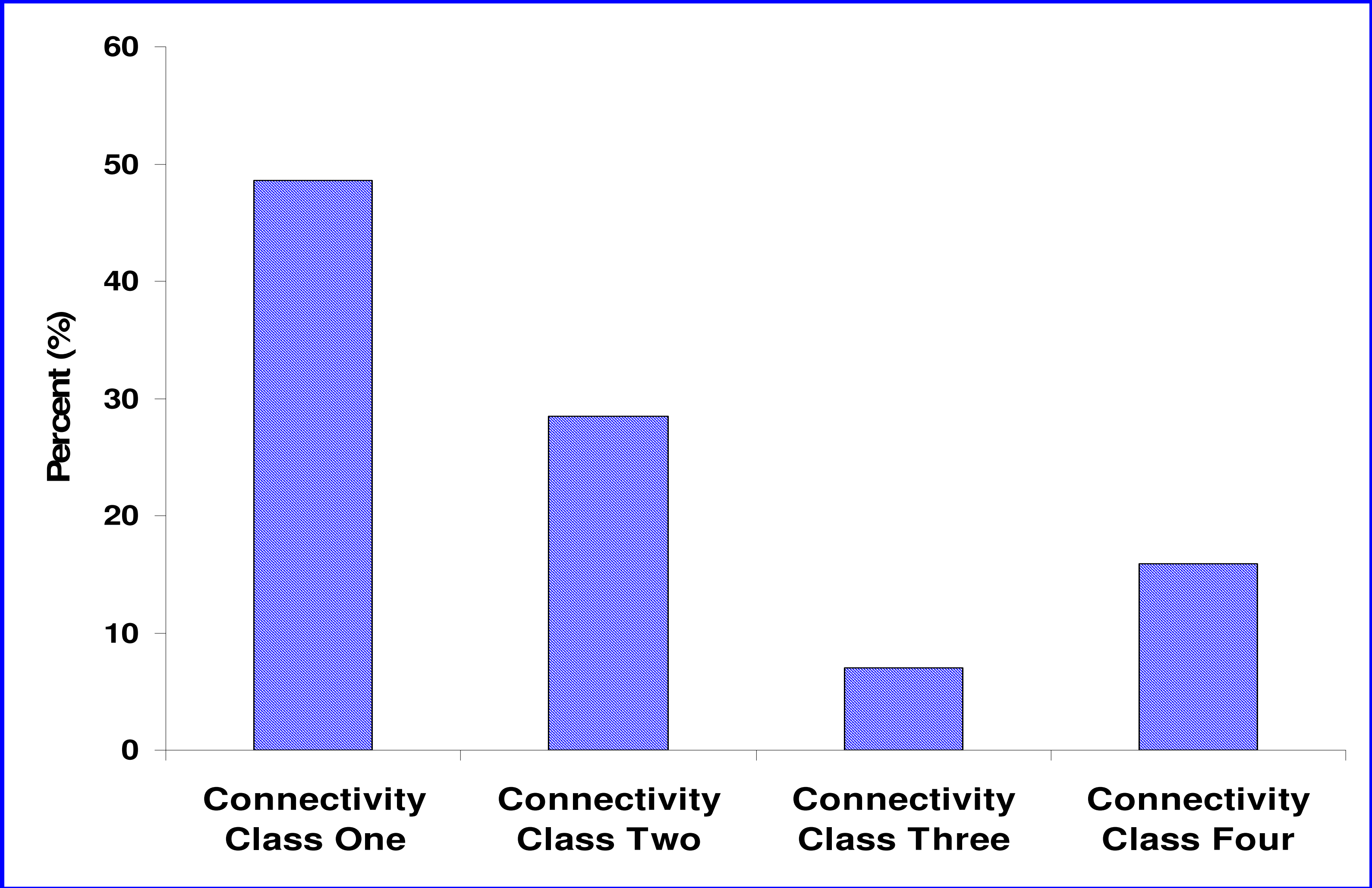


Does sediment production matter if it doesn’t reach the stream network?

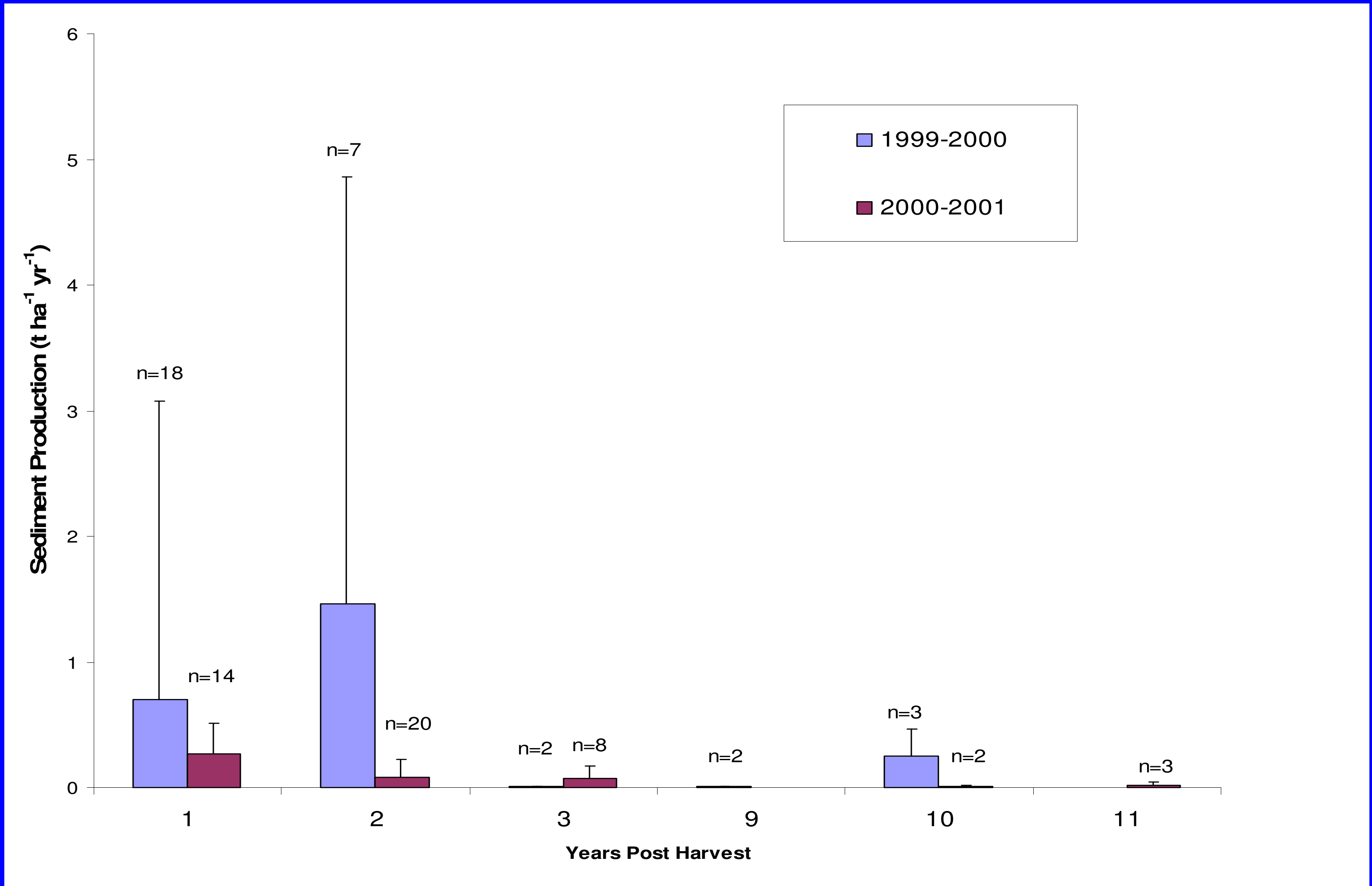
Road Segment Connectivity Classes

- Connectivity Class 1: no signs of gullying or sediment transport below outlet;
- Connectivity Class 2: gullies or sediment plumes <20 m in length;
- Connectivity Class 3: gullies or sediment plumes >20 m in length, but more than 10 m from stream channel;
- Connectivity Class 4: gullies or sediment plumes to within 10 m of a stream channel.

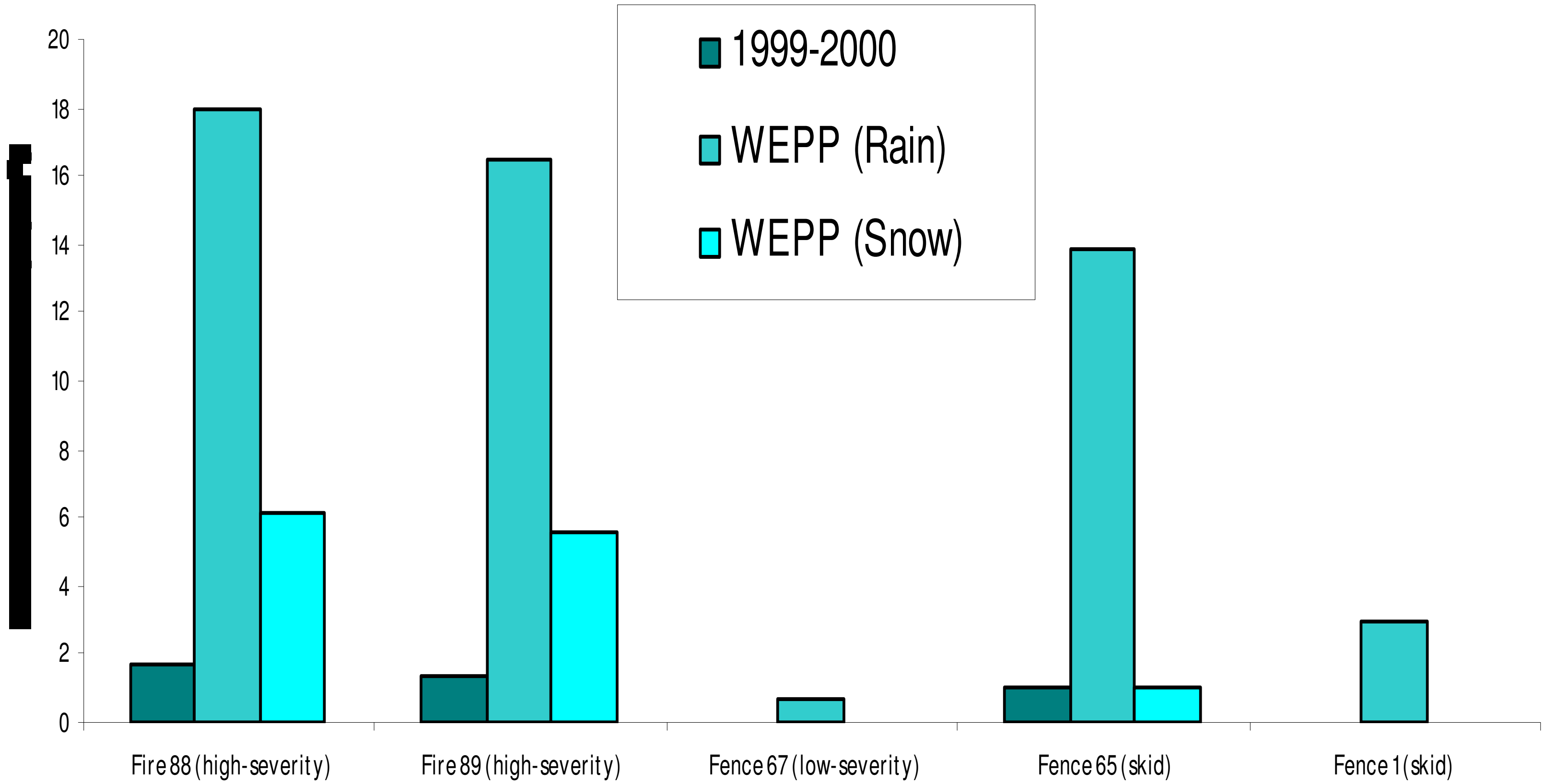
Percentage of Road Segments by Connectivity Class (n=285 segments)



Sediment Production from Skid Trails by Year and Years Post-harvest



Measured Sediment Production Rates vs. Values Predicted using WEPP: Burned and Harvested Sites



Modeling Goals

- Explicitly separate changes in flow from changes in sediment yields;
- Calculate changes on a catchment scale (approx. 10-100 km^2) using spatially-explicit procedures;
- Sum effects from multiple activities;
- Modular approach to allow for additional land uses and different predictive algorithms;
- Allow users to select magnitude of change and rate of recovery;

Modeling Goals (2)

- Use input data from existing GIS layers (e.g., harvest, fires, roads, streams, DEMs);
- Transparent to user;
- Look-up tables for data from scientific literature;
- Readily usable by forest resource specialists;
- Help users evaluate uncertainty and sensitivity by allowing user to change model coefficients and predictive modules.

Modules Being Developed

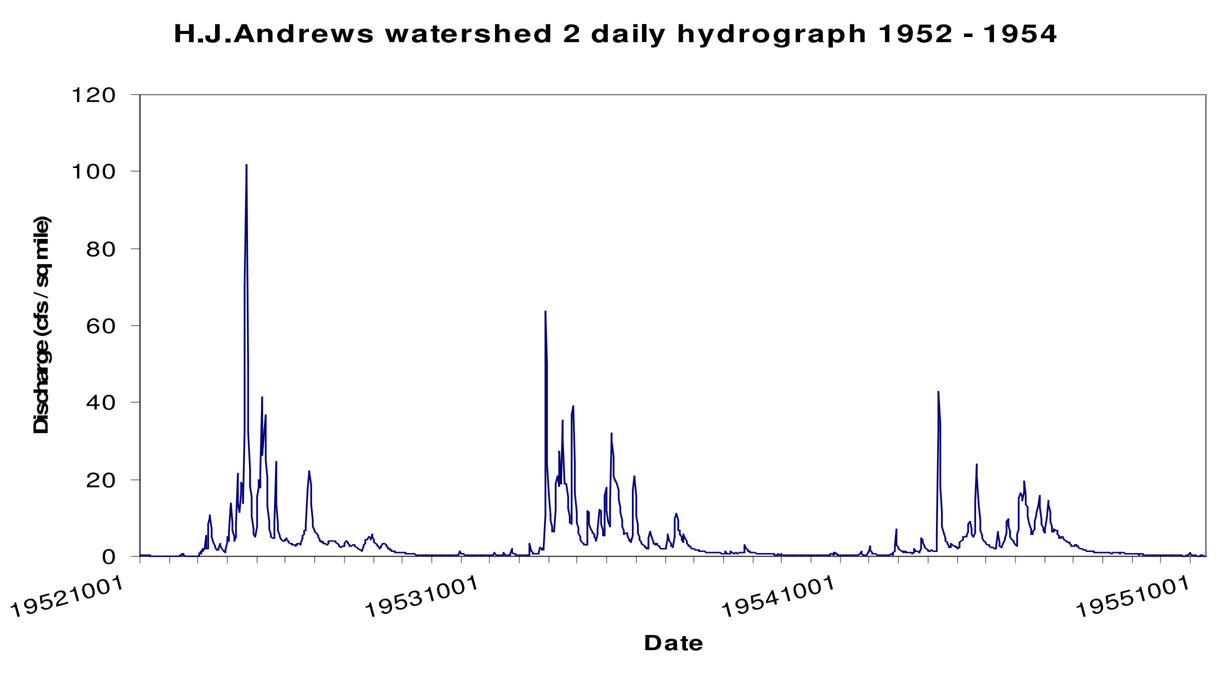
- **DELTA-Q:** Calculates changes in low, median, and high flows from forest management and fires; now being distributed;

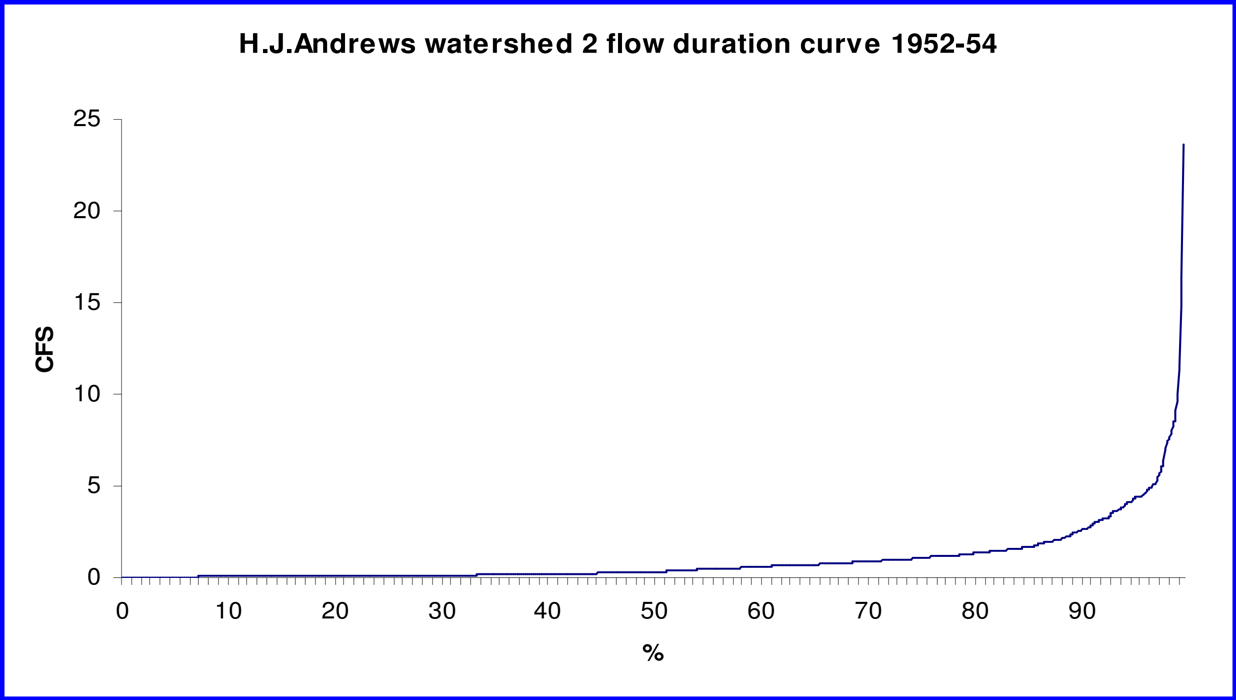
- **SEDPROD:** Calculates sediment production from forest harvest, roads, and fires; nearly ready for beta testing;

- **SEDELIVERY:** Calculates sediment delivery to stream network and downstream travel rates to reach of interest.

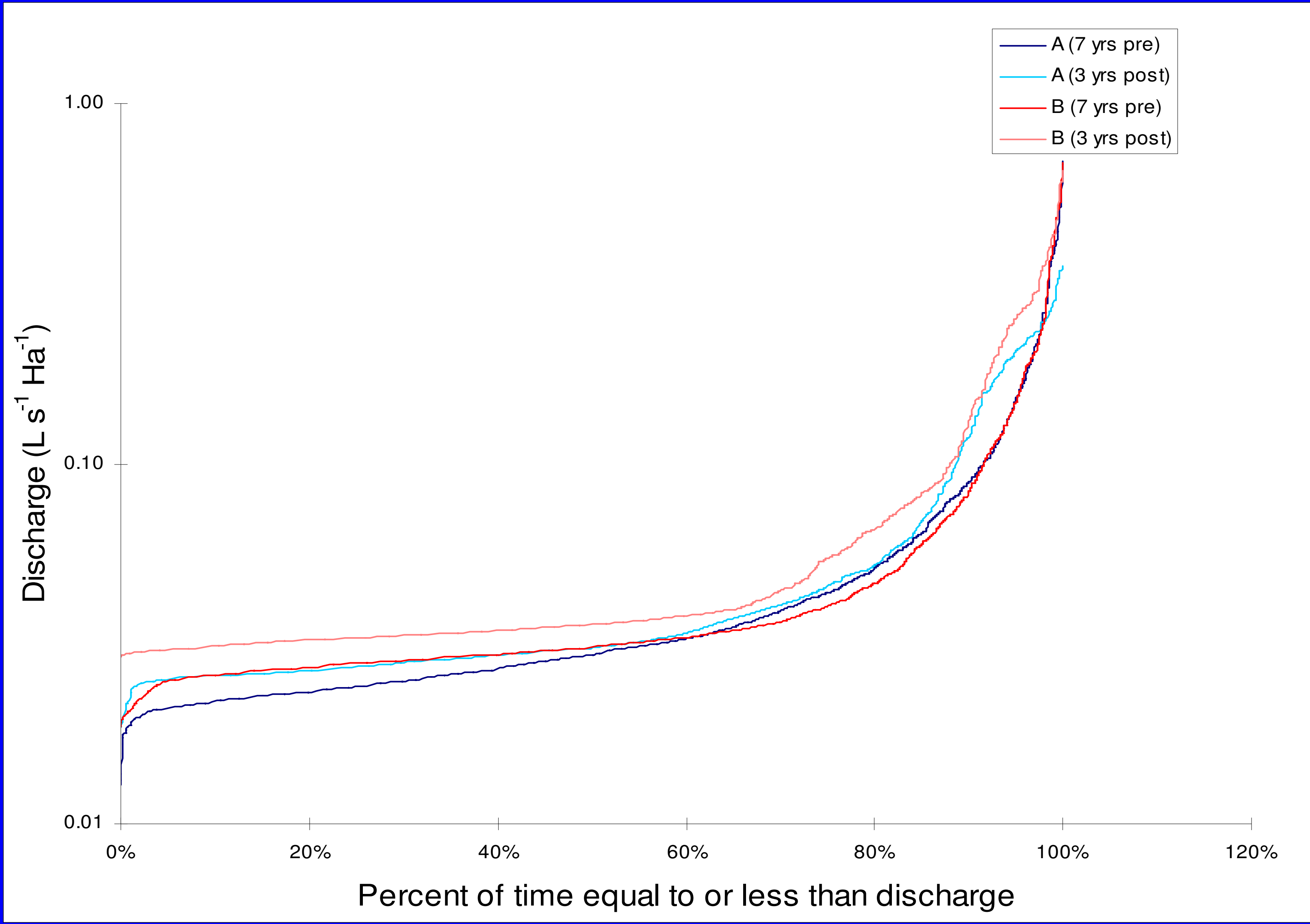
Predicting Changes in Flow

- No paired watershed data for the Sierra;
- Analysed changes in selected flow percentiles from 26 paired-catchment experiments by comparing pre- and post-treatment flow duration curves;
- Adjusted flow duration curve on treated basin for changes in flow observed from the control basin.

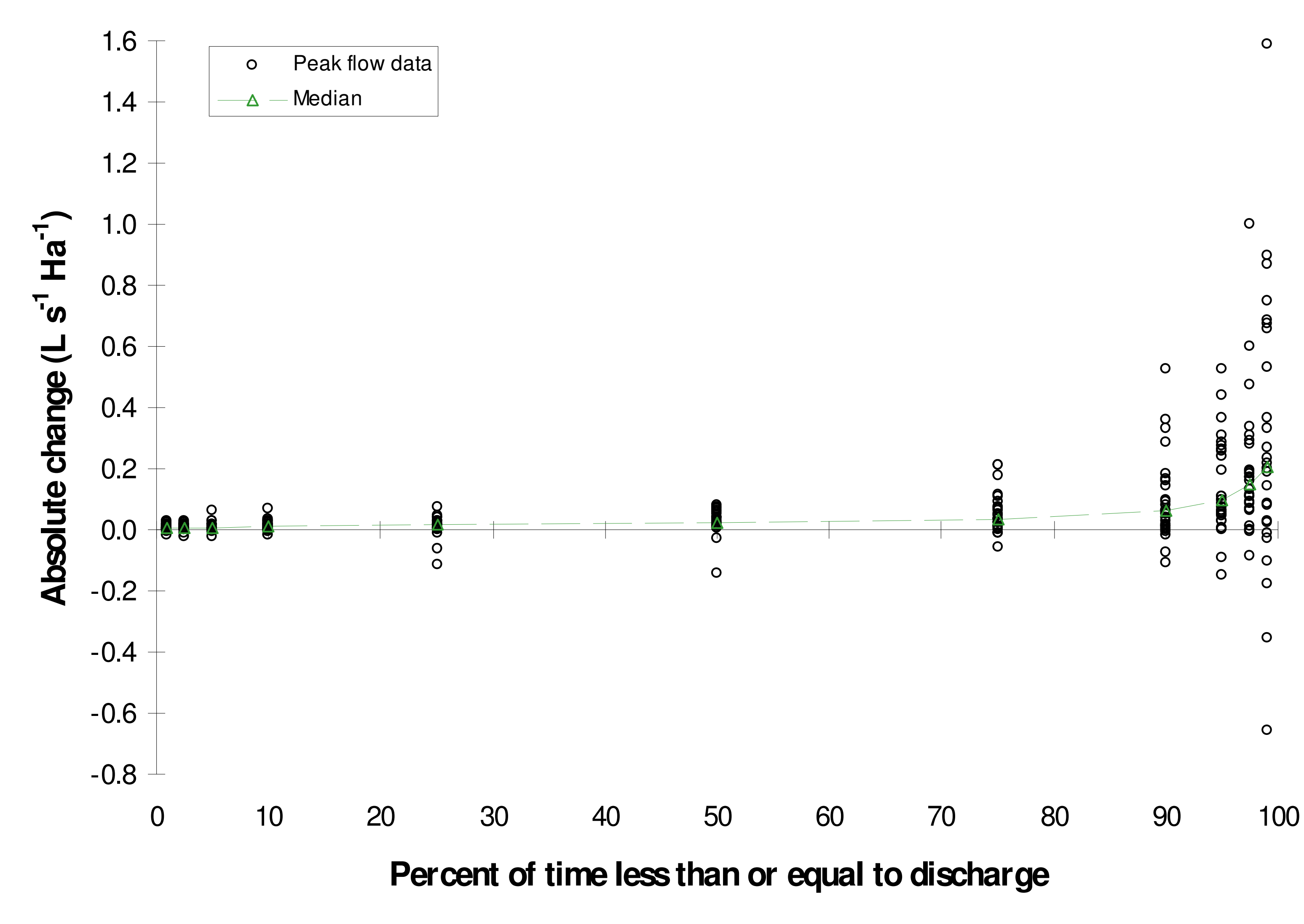

H.J.Andrews watershed 2 daily hydrograph 1952 - 1954
Discharge (cfs / sq mile)
0
20
40
60
80
100
120
19521001
19531001
19541001
19551001
Date


H.J.Andrews watershed 2 flow duration curve 1952-54
CFS
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
%

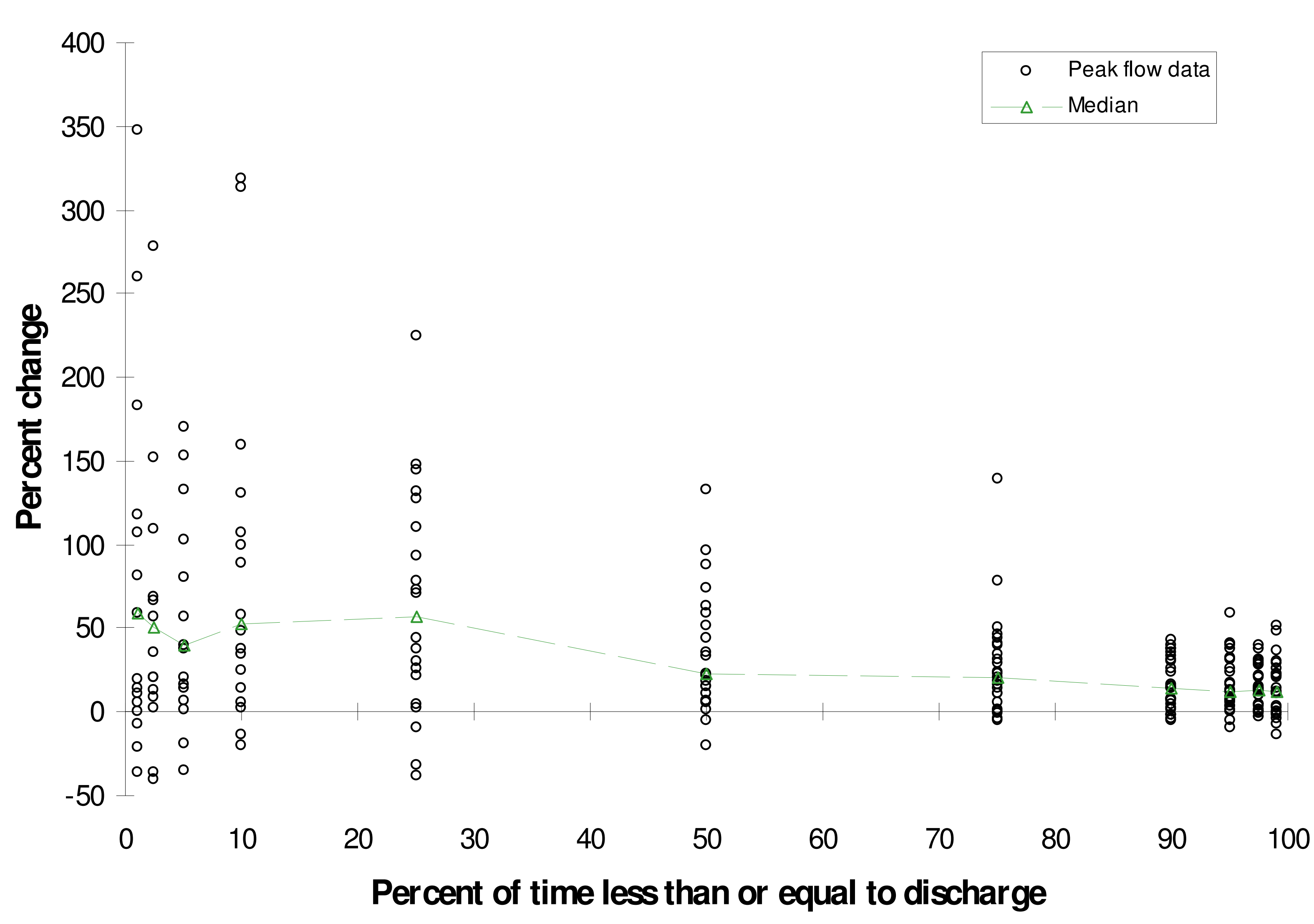
Pre- and Post-treatment FDCs



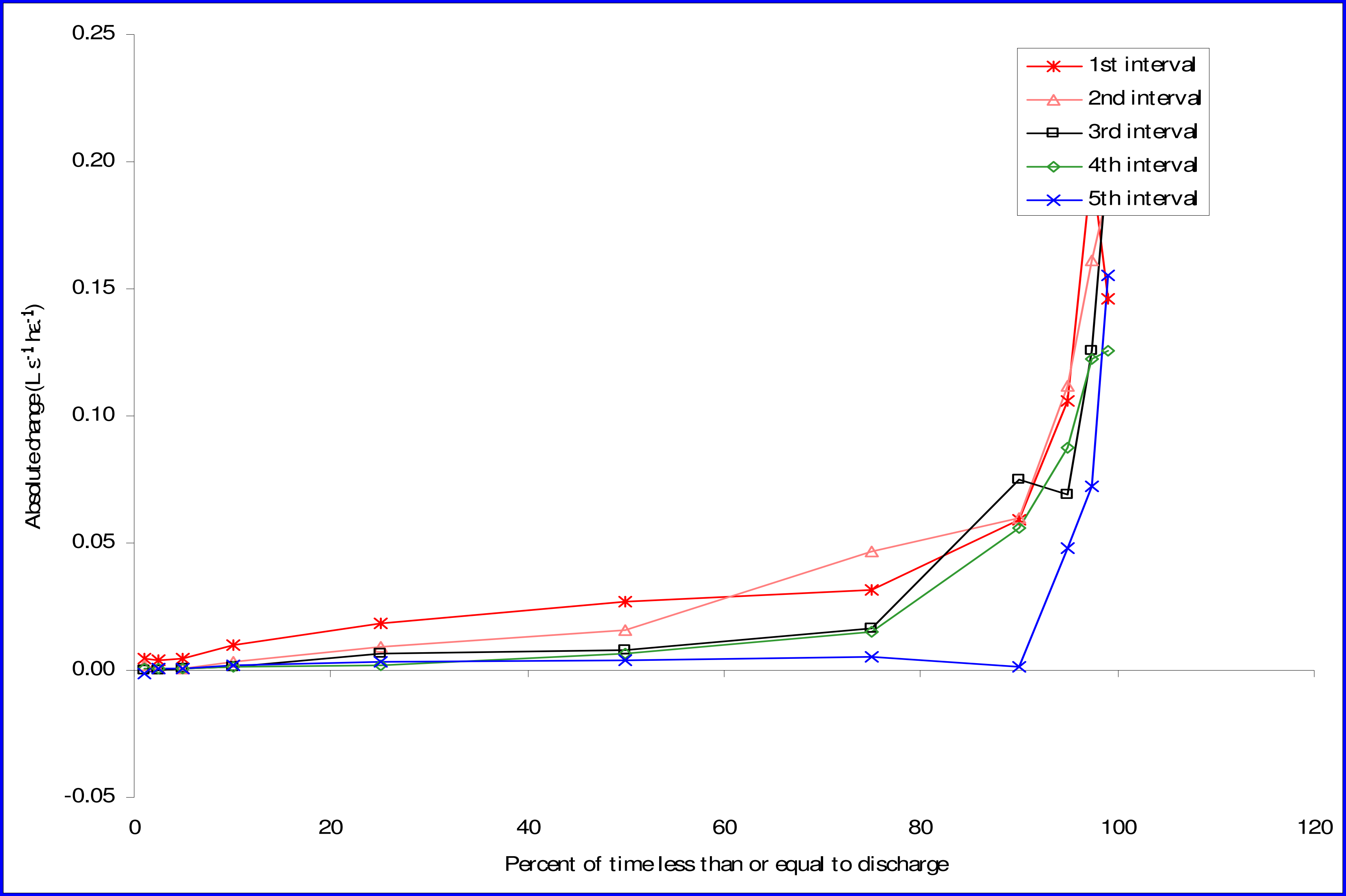
Absolute Change in Flow



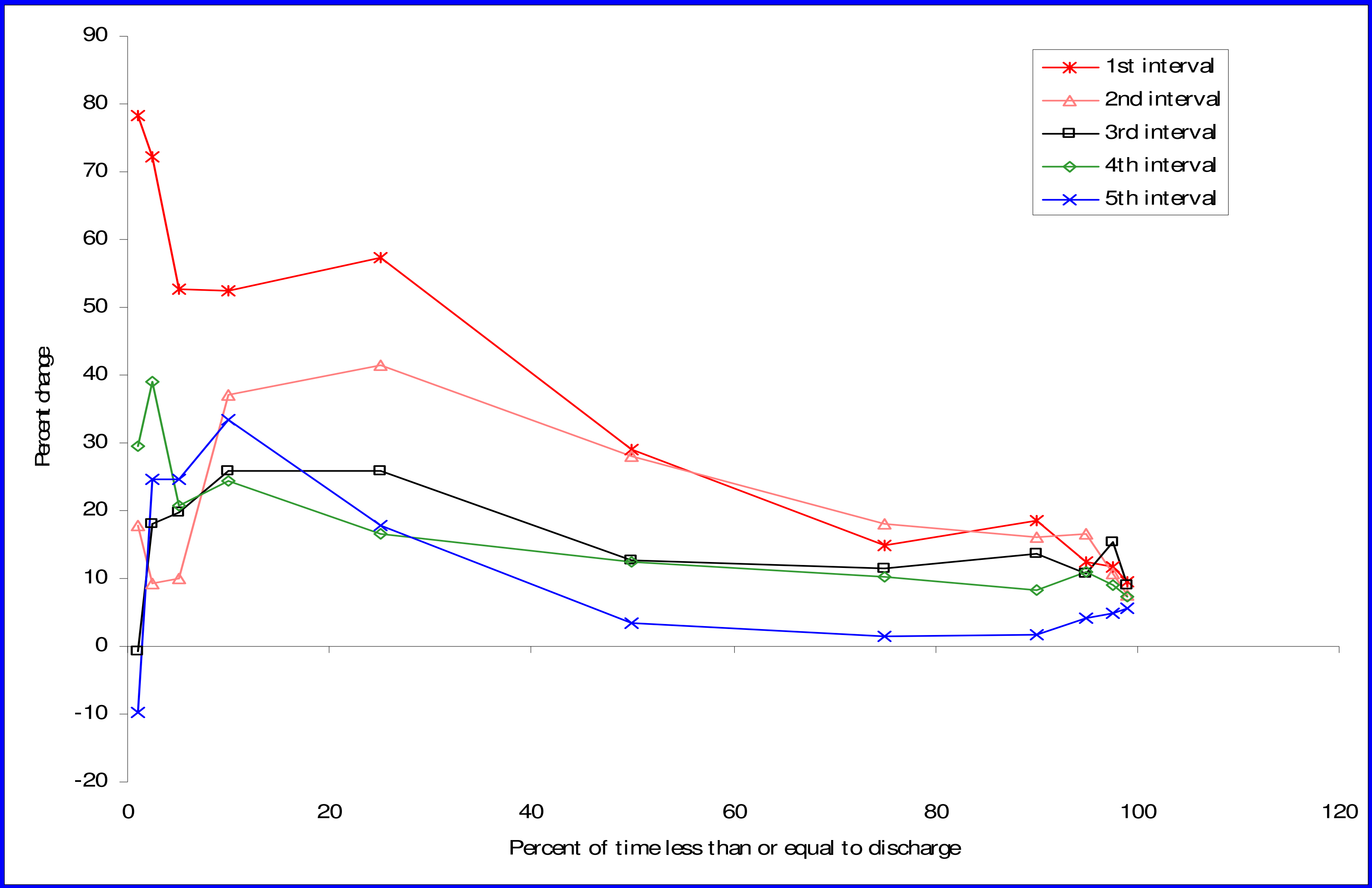
Percent Change in Flow



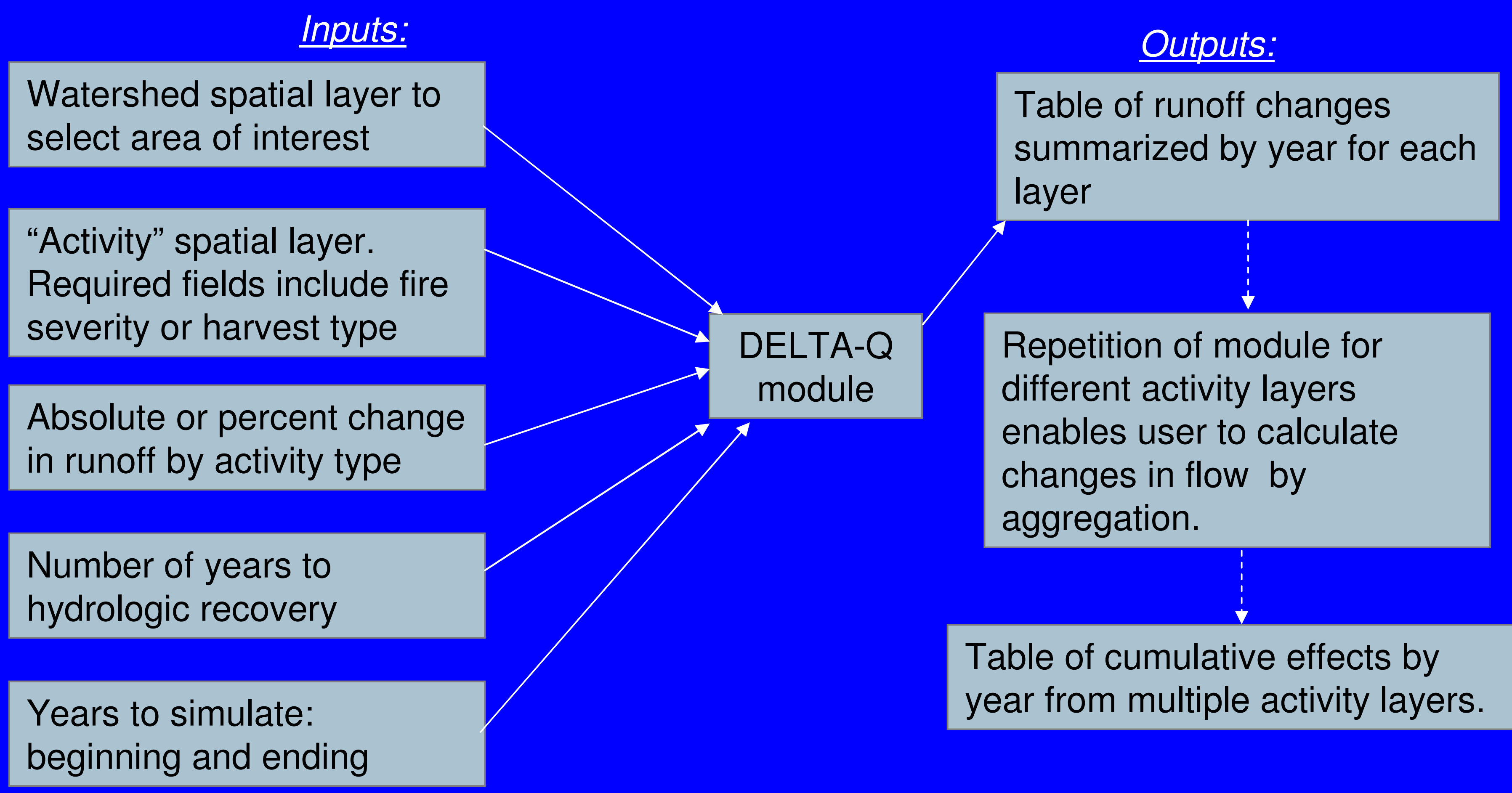
Absolute Change in Flow Over Time



Percent Change in Flows Over Time



Schematic of Delta-Q Module



Equations for Predicting Absolute and Percent Change in Flow

$$D(Q) = \sum_{i=1}^{m} \left[1 - \frac{x(i)}{n} \right] * \frac{A(i)}{AWS} * d(q)$$

Percent

$$D(Q) = \sum_{i=1}^{m} \left[1 - \frac{x(i)}{n} \right] * A(i) * d(q)$$

Absolute

where:

D(Q) = total change in flow (cfs or percent) in the watershed being modeled;

i = polygon identification number;

m = total number of affected polygons;

x (i) = years since activity in area ***i***;

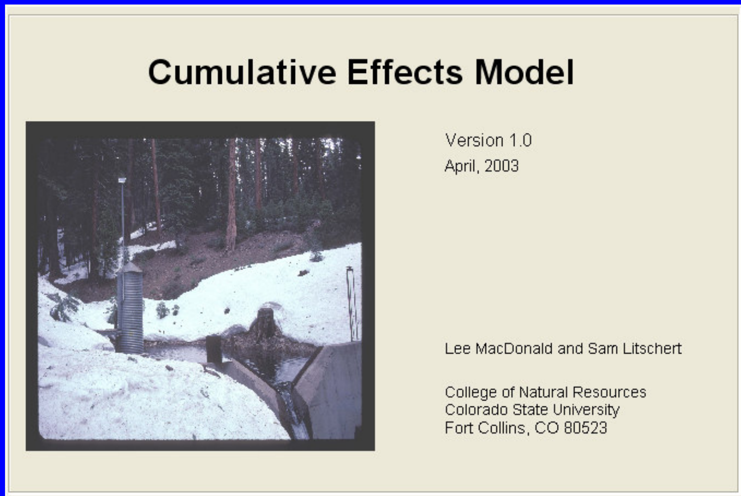
n = number of years to full hydrologic recovery;

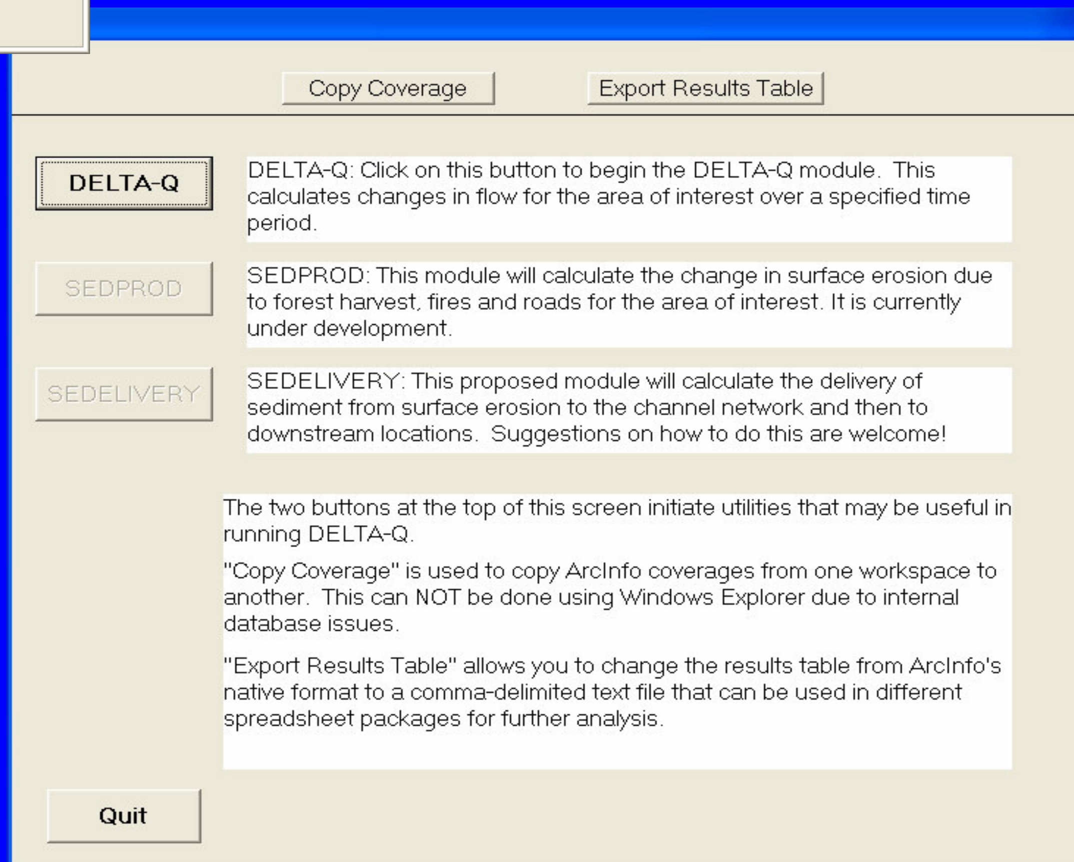
A (i) = area (m^2) of activity;

AWS = area of watershed.

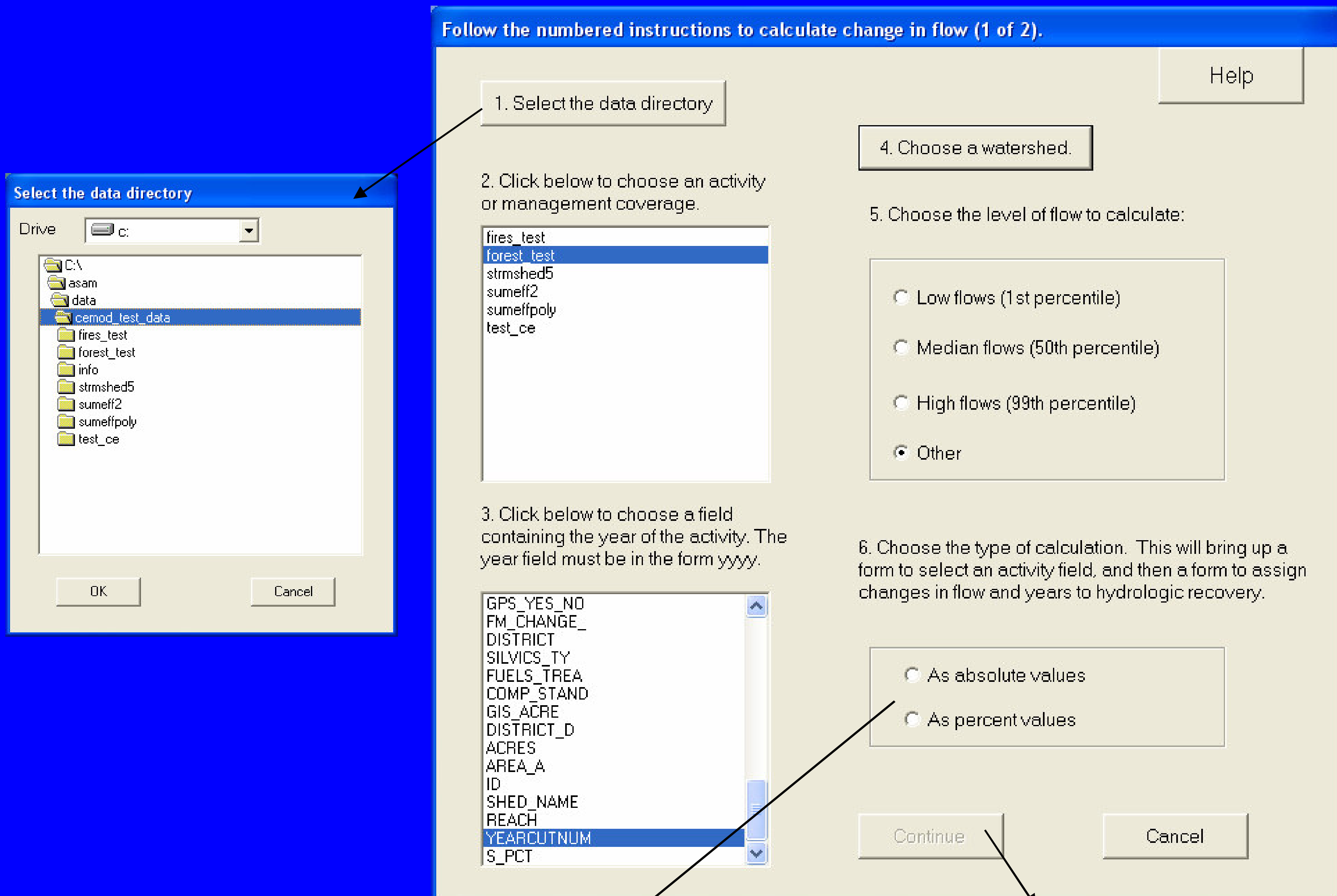
d(q) = is the change in runoff in absolute (cfs/mi2) or percentage terms for each activity or polygon.

Cumulative Effects Model: Delta-Q Module User Interface





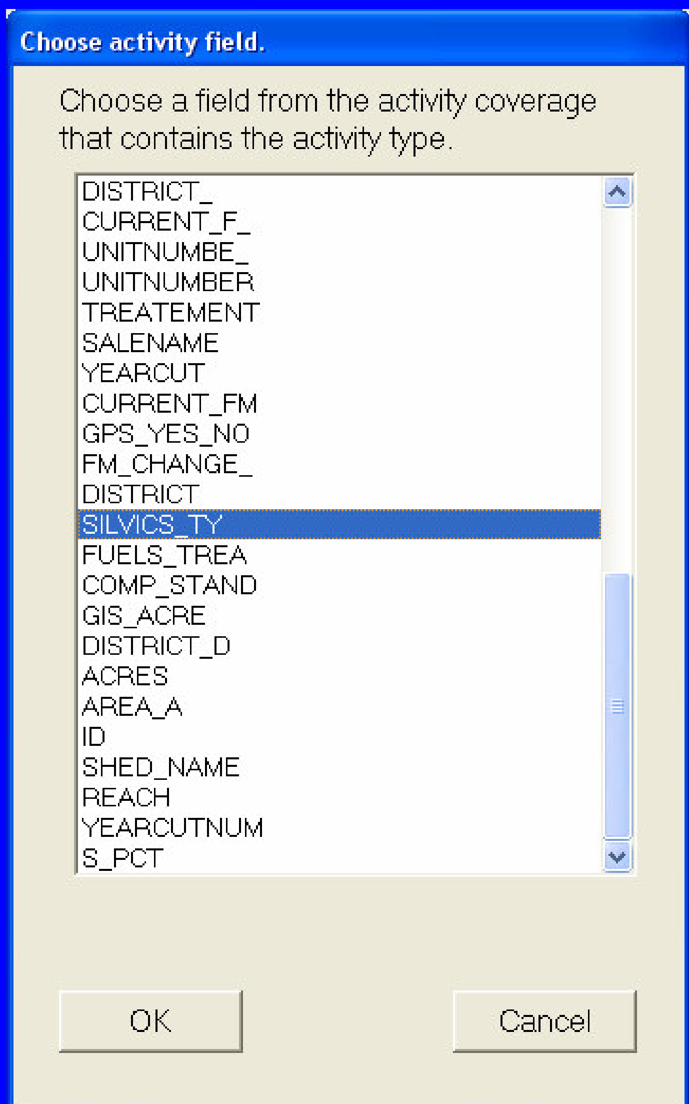
Delta-Q Module: First input form

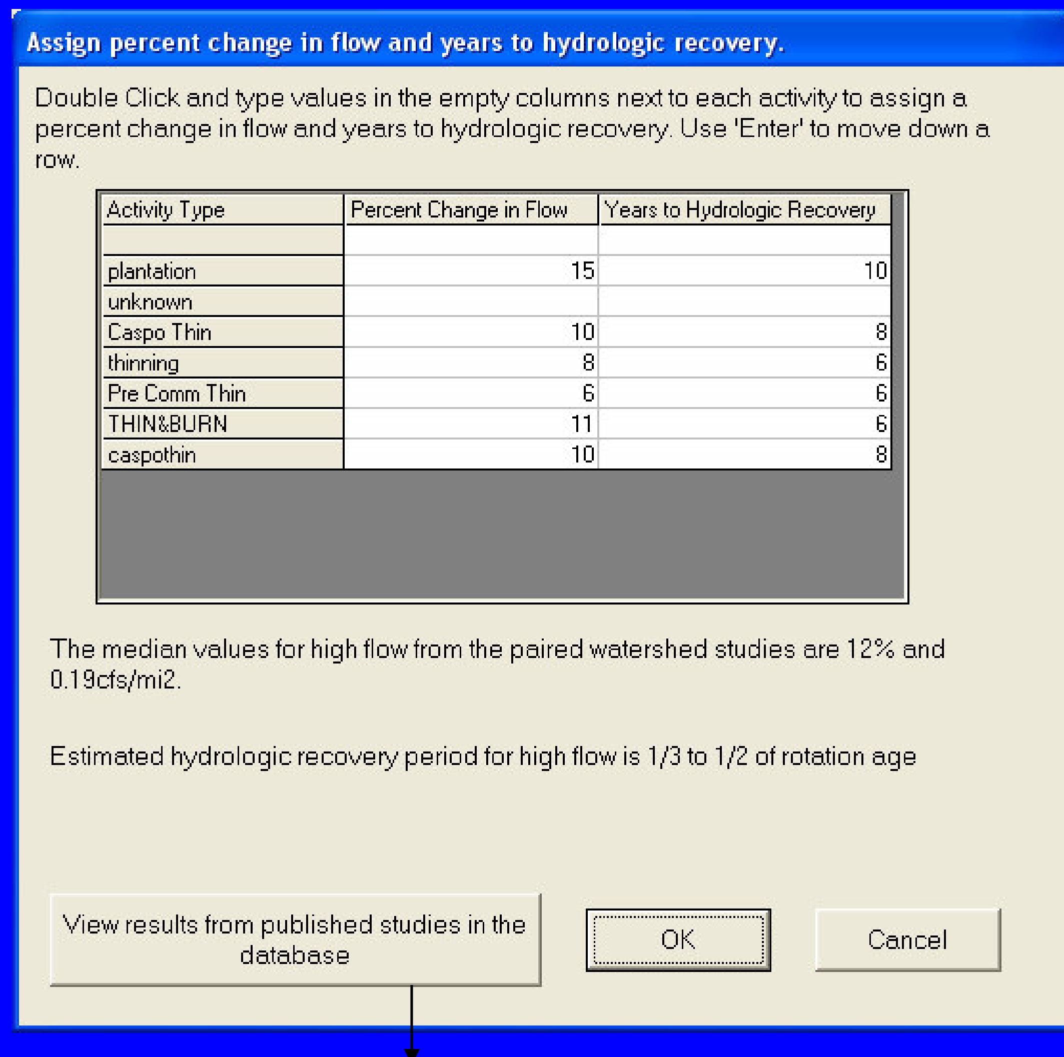


Choose activity item and input values

Continue to input form 2

Choose activity item and input values





View database for help with input values slide

View database of 26 paired watershed studies for help with input values

Data from paired watershed studies.

Study Number	Location	Basin Name	Area (mi2)	Vegetation	Annual Precip. (mm)	Percent Veg Removed	Harvest Type	1st Pct or Low FLow %	1st Pct or Low FLow cfs/mi2	1st Pct or Low FLow L s/ha
1	Arizona	Thomas Creek	0.87	60-89% conifer	768	26	Selection			
2	California	Casper Creek S	1.63	>= 90% conifer	1109		Selection	108	0.0477	0.00521
3	Colorado	Fool Creek	1.11	>= 90% conifer	635	40	Patch cut			
4	Colorado	Wagon Wheel	0.31	60-89% hardwood	533	100	Clearcut	19.5	0.0401	0.00439
5	Massachusetts	Cadwell Creek 1	0.62	60-89% hardwood	1067	34	Mixed			
6	Minnesota	S4N	0.08	mixed	772	72	Clearcut			
7	Minnesota	S4S	0.04	60-89% hardwood	772	89	Clearcut			
8	New Hampshire	Hubbard Brook 2	0.06	60-89% hardwood	1327	100	Clearcut			
9	New Hampshire	Hubbard Brook 4	0.13	60-89% hardwood	1365		Clearcut	260	0.0686	0.0075
10	New Hampshire	Hubbard Brook 5	0.08	60-89% hardwood	1377	95	Clearcut			
11	New Zealand	Maimai 8	0.01	>=90% hardwood	2518	90	Clearcut			
12	North Carolina	Coweeta 37	0.16	>=90% hardwood	2244	100	Clearcut	50.9	0.183	0.02
13	North Carolina	Coweeta 6	0.03	>=90% hardwood	1000	100	Clearcut	10.9	0.0903	0.00987
14	Oklahoma	Clayton Creek 1	0.02	mixed	1194	98	Clearcut			
15	Oregon	Coyote Creek 1	0.26	>= 90% conifer	1229	50	Selection	13.8	0.00251	0.000274
16	Oregon	Coyote Creek 2	0.26	>= 90% conifer	1229	30	P			
17	Oregon	Coyote Creek 3	0.19	>= 90% conifer	1229	100	C			
18	Oregon	Deer Creek	1.17	mixed	2474	25	P			
19	Oregon	Fox Creek 1	0.22	>= 90% conifer	2730	25	P			
20	Oregon	Fox Creek 3	0.27	>= 90% conifer	2730	25	P			
21	Oregon	H.J.Andrews 1	0.37	>= 90% conifer	2200	100	C			
22	Oregon	H.J.Andrews 10	0.03	>= 90% conifer	2300	100	C			
23	Oregon	H.J.Andrews 3	0.38	>= 90% conifer	2200	33	P			
24	Oregon	H.J.Andrews 6	0.05	>= 90% conifer	2190	100	C			
25	Oregon	H.J.Andrews 7	0.05	>= 90% conifer	2190	60	S			
26	Oregon	Needle Branch	0.27	60-89% conifer	2483	82	C			

Complete References by Study Number

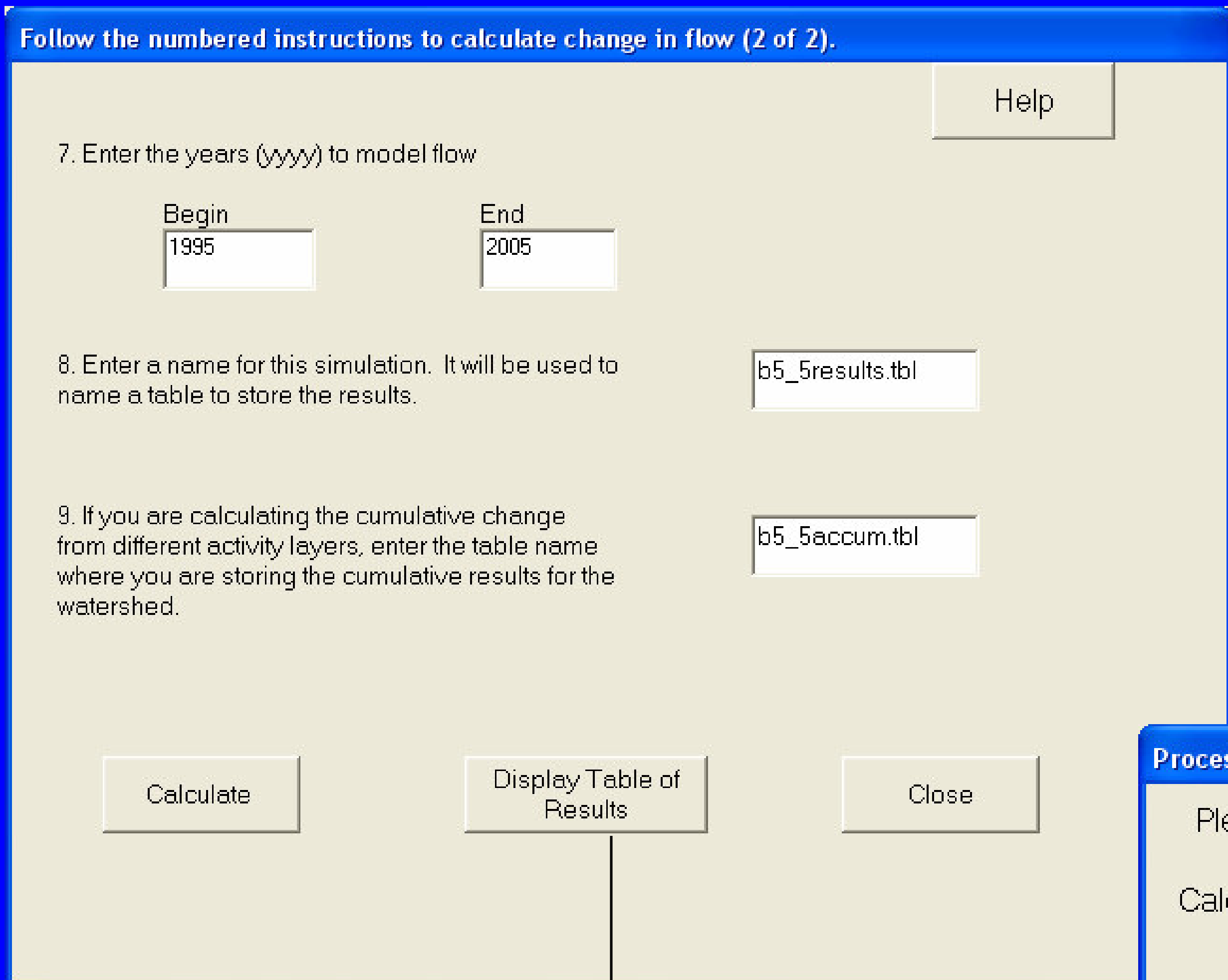
Data from paired watershed studies.

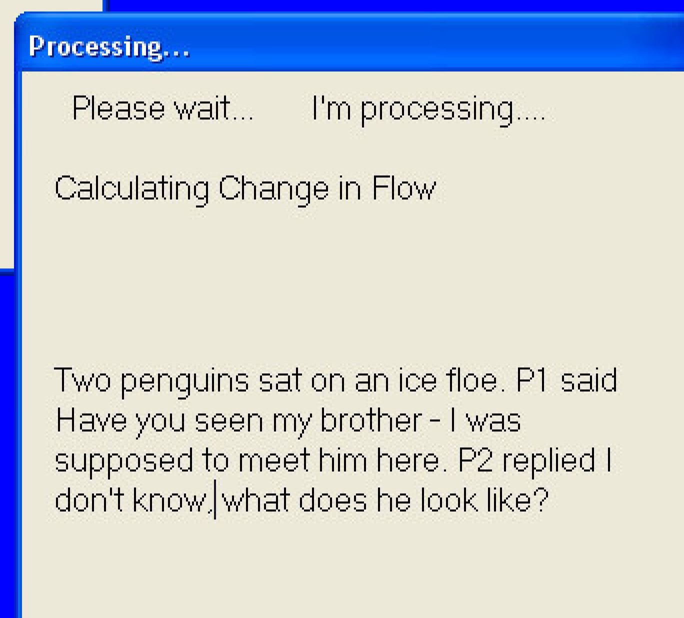
Study Number	Location	1st Pct or Low FLow %	1st Pct or Low FLow cfs/mi2	1st Pct or Low FLow L s/ha	50th Pct or Median Flow %	50th Pct or Median Flow cfs/mi2	50th Pct or Median Flow L s/ha	99th Pct or High Flow %	99th Pct or High Flow cfs/mi2	99th Pct or High Flow L s/ha
1	Arizona				416	0.0032	0.029	2.7	0.02	0.183
2	California	108	0.0477	0.00521	35.9	0.01	0.0915	-7.7	-0.32	-2.93
3	Colorado							22.2	0.21	1.92
4	Colorado	19.5	0.0401	0.00439	11.1	0.00329	0.0301	48.4	0.12	1.1
5	Massachusetts				22.1	0.01	0.0915	51.8	0.59	5.4
6	Minnesota				133	0.00951	0.087	10.9	0.07	0.64
7	Minnesota							21.5	0.18	1.65
8	New Hampshire				73.8	0.06	0.549	30.3	0.79	7.22
9	New Hampshire	260	0.0686	0.0075	1.7	0.00283	0.0259	13.7	0.3	2.74
10	New Hampshire				5.9	0.00576	0.0527	11.2	0.19	1.74
11	New Zealand				18.5	0.02	0.183	20.3	0.81	7.41
12	North Carolina	50.9	0.183	0.02	6.2	0.01	0.0915	5.9	0.17	1.55
13	North Carolina	10.9	0.0903	0.00987	15.4	0.02	0.183	-1	-0.00923	-0.0844
14	Oklahoma							26.1	0.48	4.39
15	Oregon	13.8	0.00251	0.000274	7	0.00466	0.0426	-1.2	-0.02	-0.183
16	Oregon	81.1	0.000832	0.000091	88.3	0.02	0.183	3.4	0.07	0.64
17	Oregon	58.7	0.0234	0.00256	96.6	0.06	0.549	29.1	0.61	5.58
18	Oregon	0	0	0	15.5	0.03	0.274	-2.3	-0.09	-0.823
19	Oregon	-36.3	-0.0915	-0.01	-20.4	-0.13	-1.19	0.6	0.02	0.183
20	Oregon	-20.7	-0.0368	-0.004023	-5.1	-0.02	-0.183	-3.6	-0.16	-1.46
21	Oregon	347	0.0915	0.01	63	0.07	0.64	22.4	0.62	5.67
22	Oregon	1330	0.0915	0.01	59.2	0.05	0.457	-14.1	-0.6	-5.49
23	Oregon	644	0.0915	0.01	33.2	0.03	0.274	21.1	0.68	6.22
24	Oregon	183	0.0915	0.01	44.6	0.04	0.366	11.9	0.33	3.02
25	Oregon	-7	-0.0117	-0.00128	51.2	0.03	0.274	12.2	0.24	2.19
26	Oregon	118	0.0543	0.00594	22.2	0.05	0.457	36.1	1.45	13.3

Complete References by Study Number

Close

Delta-Q module: second main input form





Display results table

Display Results Table

Results Table

SHED_NAME	Year	Activity Area (mi2)	Change in Flow	Units
'Alder A'	1995	1.127	1.11	'pct'
'Alder A'	1996	1.127	0.88	'pct'
'Alder A'	1997	1.127	0.66	'pct'
'Alder A'	1998	1.124	0.43	'pct'
'Alder A'	1999	0.928	0.24	'pct'
'Alder A'	2000	0.928	0.05	'pct'
'Alder A'	2001	0.093	0.04	'pct'
'Alder A'	2002	0.093	0.02	'pct'
'Alder A'	2003	0.085	0.00	'pct'
'Alder B'	1995	0.376	0.63	'pct'
'Alder B'	1996	0.376	0.41	'pct'
'Alder B'	1997	0.376	0.19	'pct'
'Alder B'	1998	0.333	0.00	'pct'
'Alder C'	1995	0.072	0.12	'pct'
'Alder C'	1996	0.072	0.08	'pct'
'Alder C'	1997	0.072	0.04	'pct'
'Alder C'	1998	0.072	0.00	'pct'
'Big Hill A'	1995	0.368	1.94	'pct'
'Big Hill A'	1996	0.462	2.28	'pct'
'Big Hill A'	1997	0.462	2.01	'pct'
'Big Hill A'	1998	0.462	1.74	'pct'
'Big Hill A'	1999	0.461	1.47	'pct'
'Big Hill A'	2000	0.461	1.20	'pct'

b5_5results.tbl was exported to b5_5results.tbl.txt

Accumulate Effects

→ Accumulate values and show results

If no records appear for a certain year, it is because there has been no activity during that year and previous activities have attained hydrologic recovery.

Close

Accumulate Values and Show Results

Cumulative changes in flow.

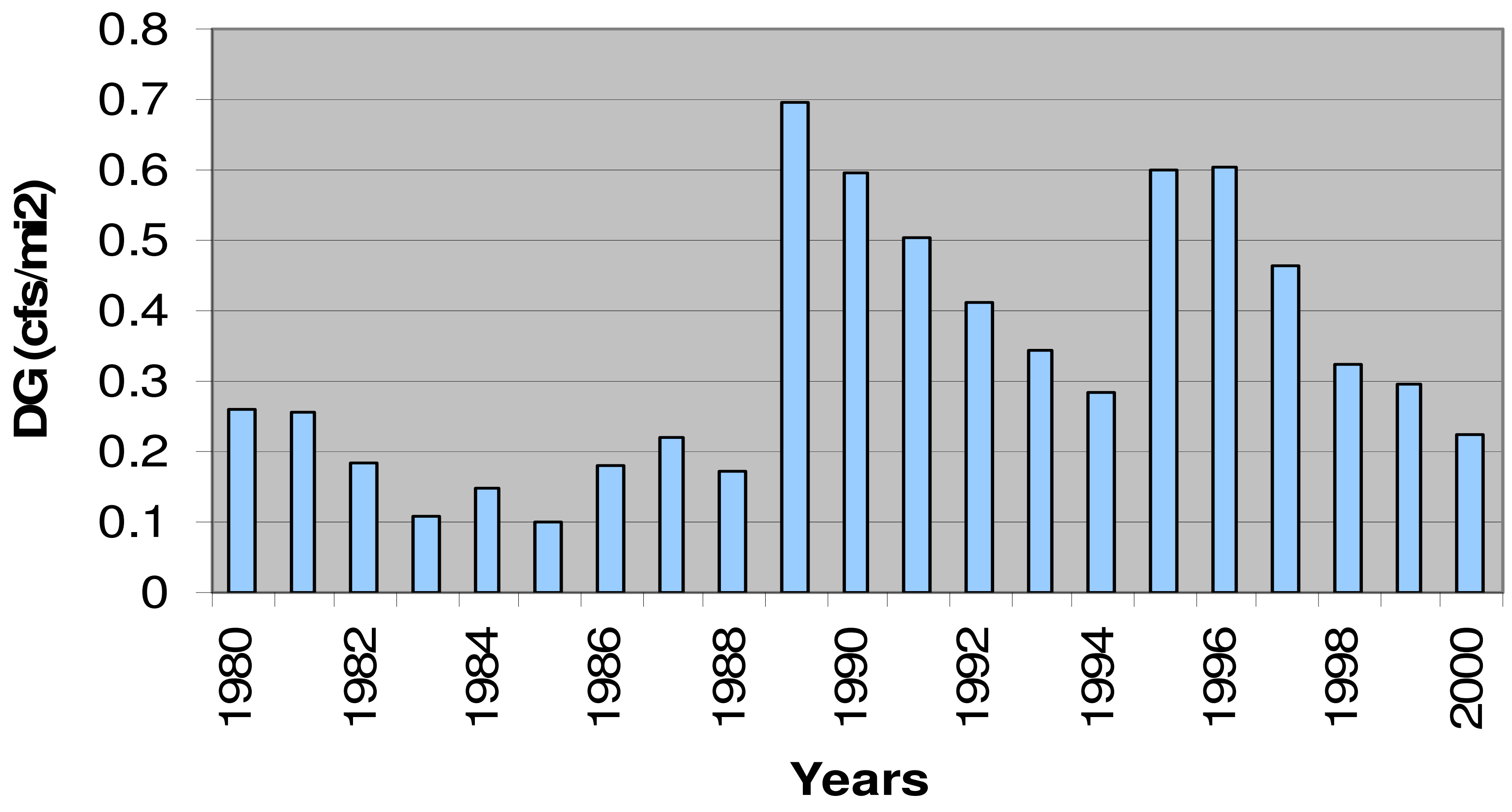
SHED_NAME	Year	Sum Change in Flow	Unit
'Alder A'	1995	1.12	'pct'
'Alder A'	1996	0.89	'pct'
'Alder A'	1997	0.66	'pct'
'Alder A'	1998	0.43	'pct'
'Alder A'	1999	0.24	'pct'
'Alder A'	2000	0.05	'pct'
'Alder A'	2001	0.04	'pct'
'Alder A'	2002	0.02	'pct'
'Alder A'	2003	0.00	'pct'
'Alder B'	1995	0.63	'pct'
'Alder B'	1996	0.41	'pct'
'Alder B'	1997	0.19	'pct'
'Alder B'	1998	0.00	'pct'
'Alder C'	1995	0.12	'pct'
'Alder C'	1996	0.08	'pct'
'Alder C'	1997	0.04	'pct'
'Alder C'	1998	0.00	'pct'
'Big Hill A'	1995	23.19	'pct'
'Big Hill A'	1996	22.28	'pct'
'Big Hill A'	1997	20.76	'pct'
'Big Hill A'	1998	19.24	'pct'

b5_5accum.tbl was exported to
b5_5accum.tbl.txt

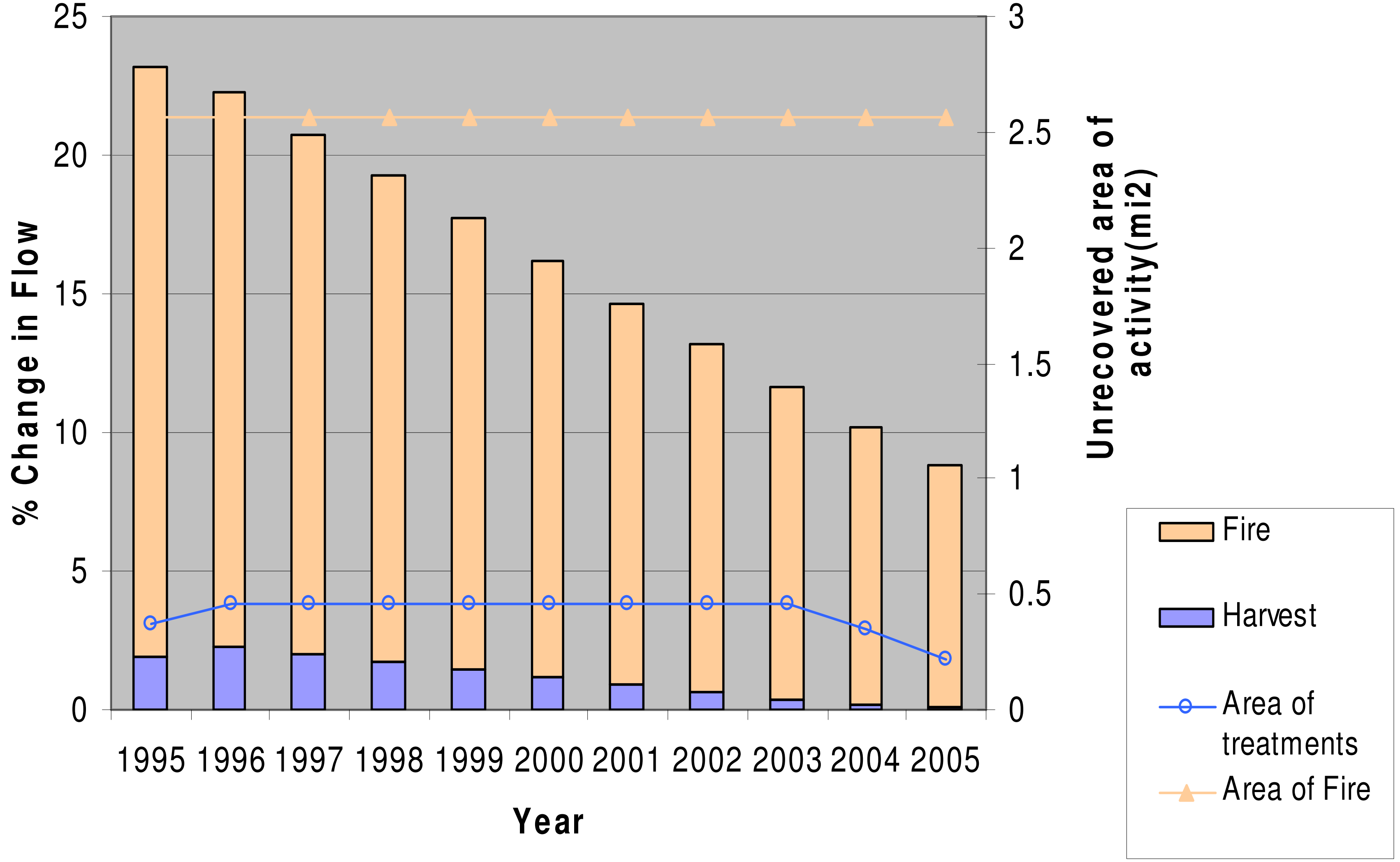
Export Table

Close

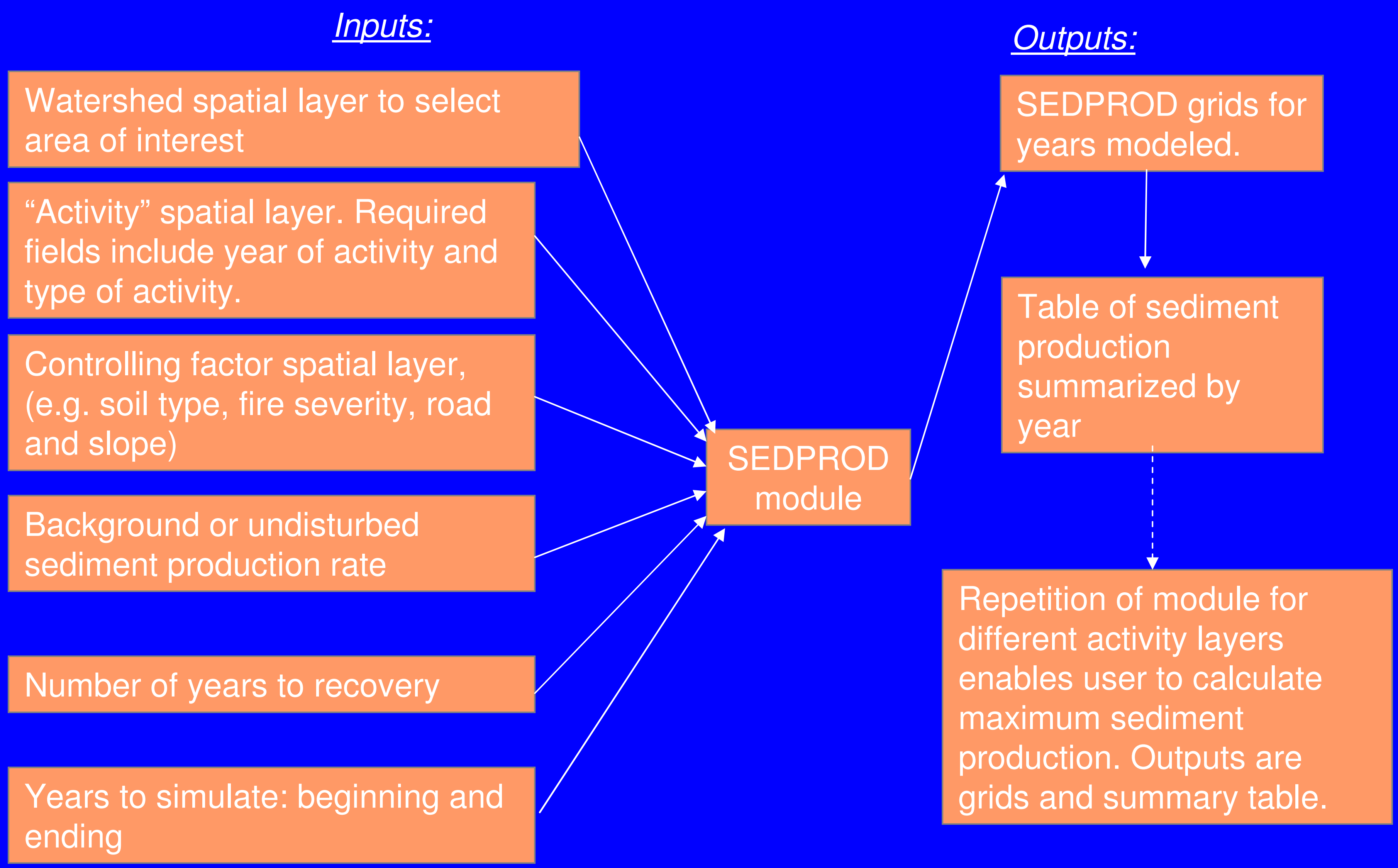
Predicted Change in 99th Flow Percentile: Dry Creek, 1980-2000



Big Hill Watershed : Modeled Change in Peak Flows

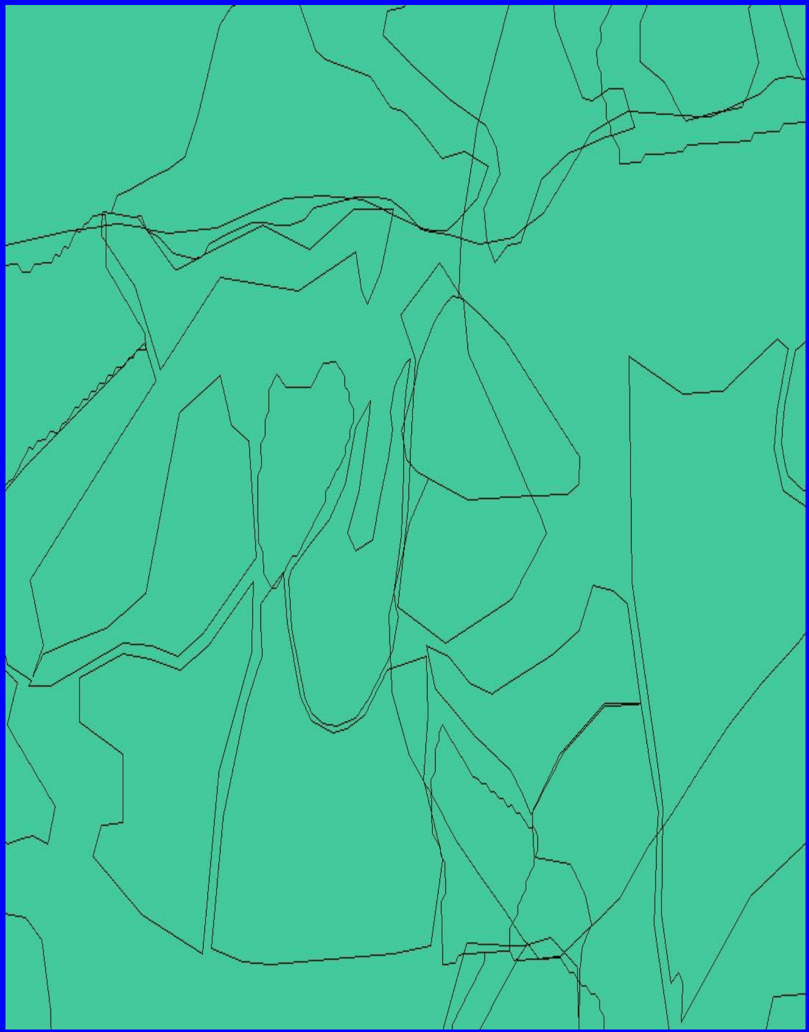


Schematic of SEDPROD Module

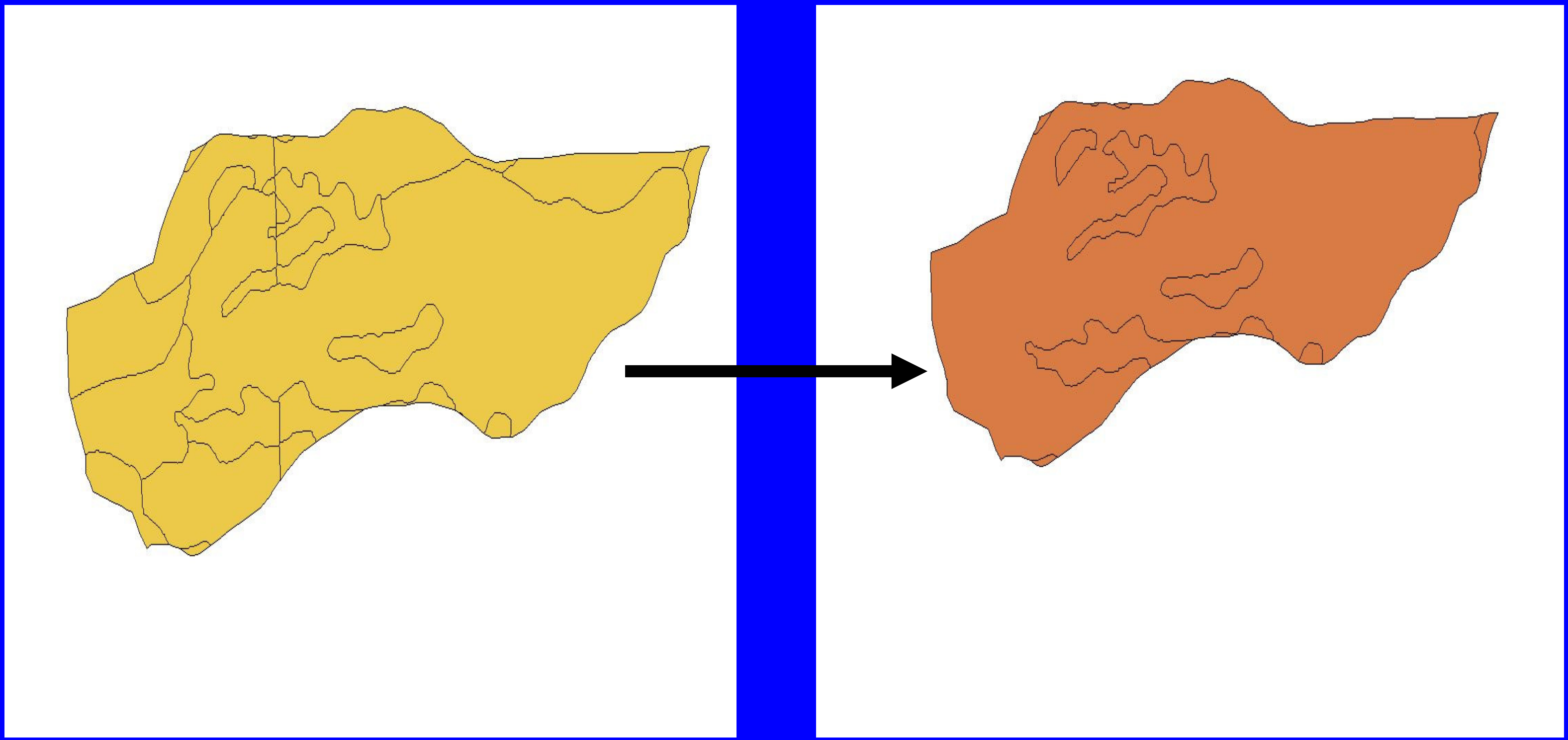


Creating Activity Layers

- Combining fire, plantation, and all sales layers results in 2,093 polygons for our 14 planning watersheds;
- Layer can be simplified by lumping silvicultural treatments.



Soils Are Lumped to Reduce Complexity of Land Cover Layer



Lumping silvicultural treatments and soil types reduces the number of polygons from 30,000 to 1,500.

Equation for SEDPROD Module

For each raster cell, calculations are based the number of years since the altering activity, the number of years until full hydrologic recovery, and the sediment production by controlling factor.

$$SP = \left[1 - \frac{Yrs}{Yrs\_hr} \right] * sp\_cf$$

where:

SP = Total sediment production in the watershed being modeled;

Sp_cf = Sediment production for each type of controlling factor, e.g.soil type.

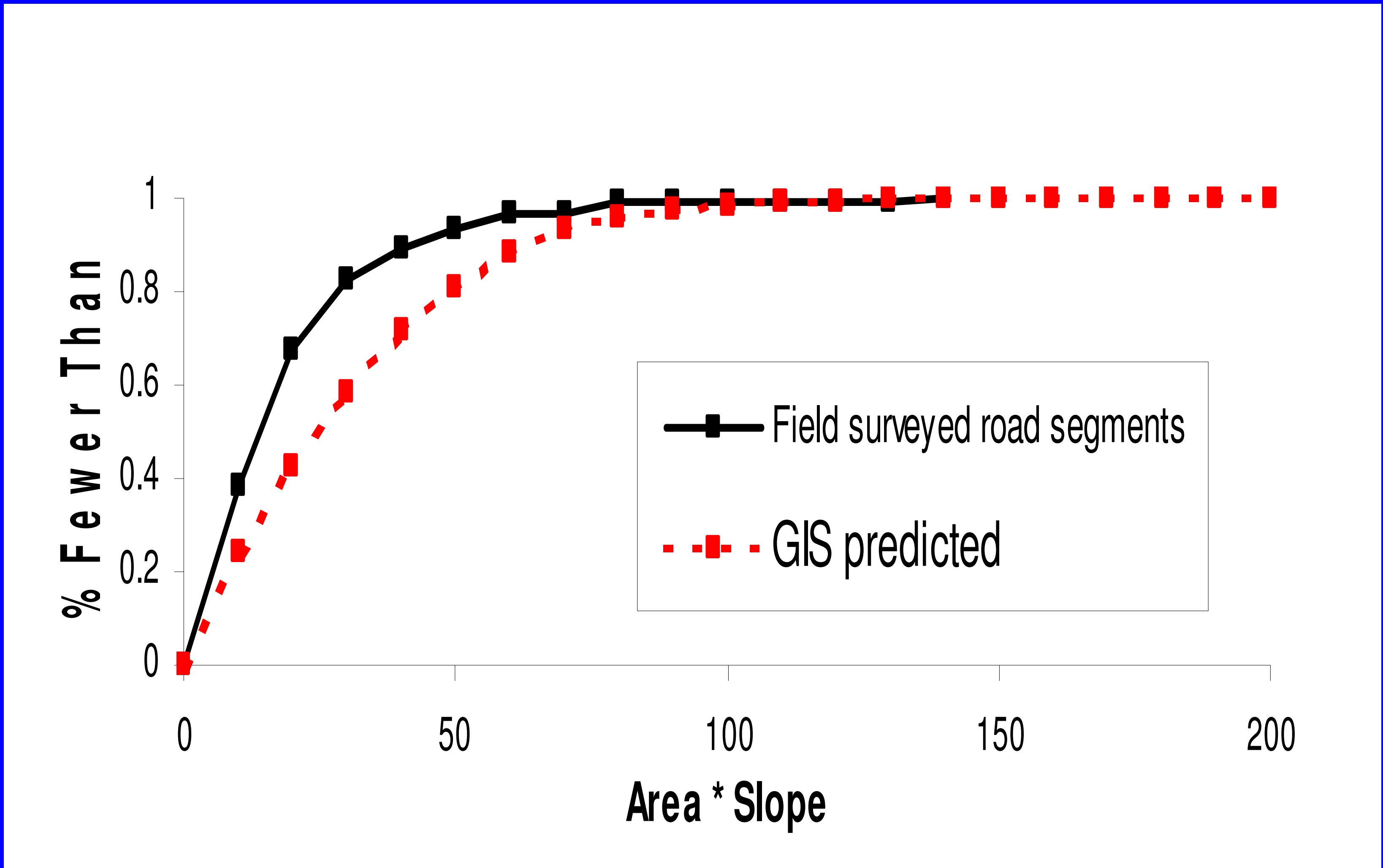
Yrs = Years since activity

Yrs_hr = Years to full recovery;

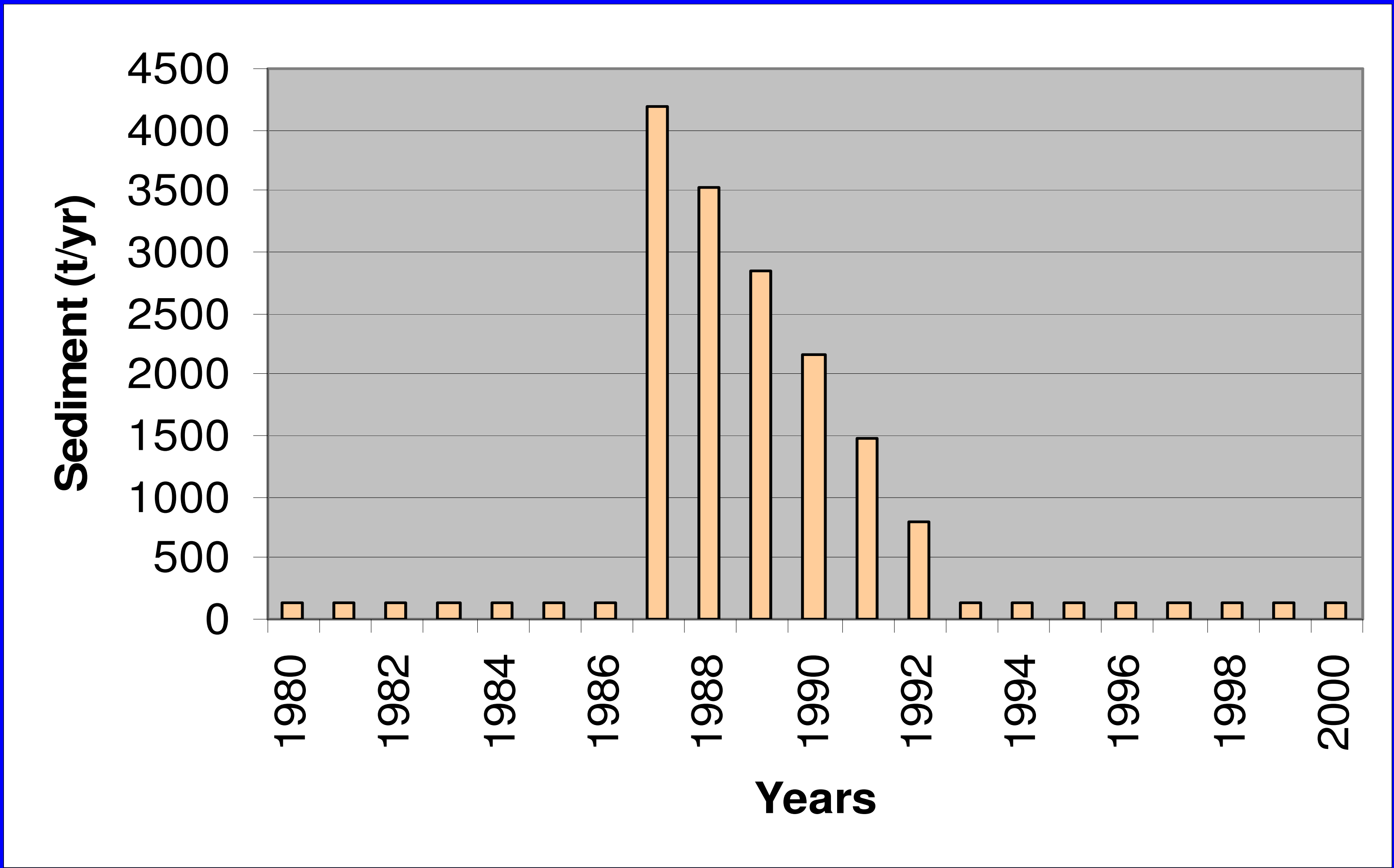
Predicting Road Surface Erosion: GIS-based Approach

- Variety of tools: Empirical models, Road-WEPP, or SEDMOD2;
- Road gradients can be derived by overlapping the roads data layer with a DEM, but this will generate some bias;
- Should adjust for road surface treatments and types (grading, rocking, drainage class), but this requires detailed field data;
- High interannual variability.

Use of Field vs. GIS-based Data



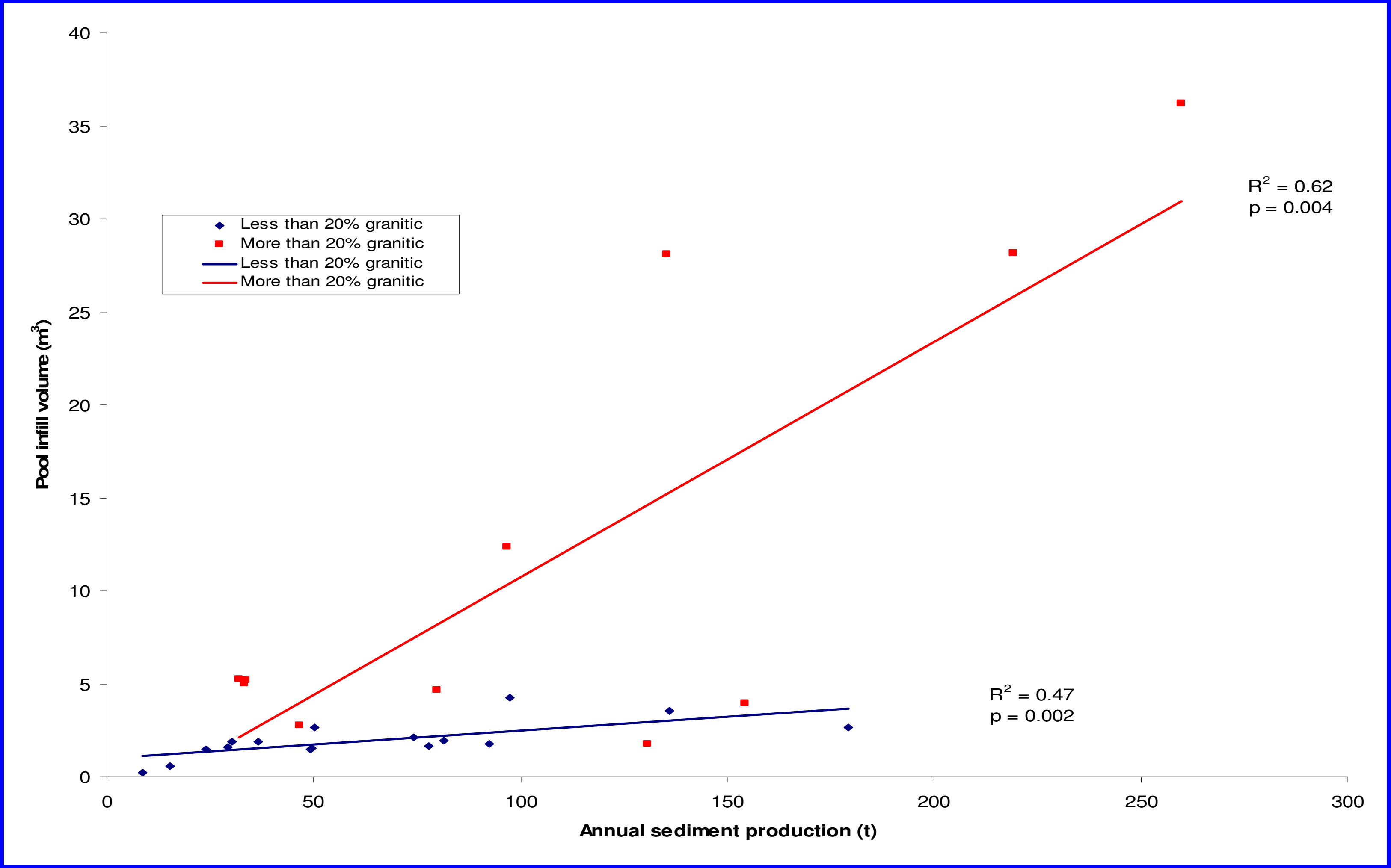
Predicted Sediment Production: Dry Creek, 1980-2000



Determining the validity and sensitivity of the predicted CWEs

- Compare predictions with past and current data (where available);
- Conduct a sensitivity analysis;
- Internal and external peer reviews.

Pool Infill Volume vs. Predicted Sediment Production



Most assessment procedures are more useful on a relative than absolute scale due to:

- Imperfect landscape knowledge;
- Problems of quantifying cause-and-effect relationships;
- Inability to validate complex models.

Constraints on CWE Modeling

- Limited amounts of data from Sierra Nevada (and elsewhere!);
- Will never have data to calibrate all anthropogenic and natural disturbances on all sites;
- Generally will need to aggregate activities and site characteristics for modeling;
- Difficult to characterize non-linearities in processes, and the many interactions among site factors and management activities;

Constraints on CWE Modeling - 2

- Limited understanding of sediment delivery from hillslopes and through stream networks;
- Completeness of GIS layers;
- Accuracy of GIS layers;
- Changes in flow and sediment need to be related to designated beneficial uses and water quality standards (which in turn may be controversial or uncertain);

Constraints on CWE Modeling - 3

- Modeling changes in sediment much more complex than changes in flow due to problems of delivery as a function of channel morphology, discharge, particle size, etc.;
- Developing robust, user-friendly interface more time consuming than developing model algorithms.

Alternative to Modeling is Adaptive Management

- Basic idea is that one monitors past and current activities;
- Problems are identified, and management changes are initiated to prevent similar problems in future;
- Suggested as a more flexible, cost-effective alternative to “excessive” regulation.

Adaptive Management: Limitations

- Requires regular monitoring and rapid feedback to management decisions;
- Requires ability to rapidly detect change;
- Resource must be highly responsive to changes in management;
- Minimal persistence of adverse effects.

Next Steps

- Collect existing data from published and unpublished USFS studies in Region 5;
- Initiate studies in other areas using sediment fences to document sediment production and delivery rates;
- Evaluate road connectivity in other areas (e.g., higher rainfall, steeper vs. flatter terrain, different soil/geologic types);

Next Steps

- Evaluate sediment production and delivery from fires (Cesium-137? increase in channel density and size? sediment fences?);
- Construct sediment budgets for several small watersheds in conjunction with the Kings River Watershed Project, Sierra N.F.;
- Complete and distribute SEDPROD;
- Add/modify DELTA-Q in response to users;
- Develop and disseminate SEDDELIVERY model.

Help Needed!!

- Construct and monitor sediment production from landslides, roads, etc. (we can help install sediment fences, but can’t monitor);
- Evaluate connectivity between roads, harvest units, and fires (OR suggest sites for us to evaluate);
- Provide feedback on Delta-Q.

(do I really want to get involved on the North Coast??)

Conclusions

- Management-induced changes in sediment usually more important than changes in flow;
- Unpaved roads, high-severity fires, and mass movements are dominant sources of sediment in forested areas;
- Very high variability between sites and between years;
- Most roads are not connected to streams except at stream crossings;

Conclusions (2)

- Relatively few sites contribute most of the sediment to the stream network;
- Need improved models to assess and predict cumulative watershed effects;
- Model calculations and predictions are just that; empirical models sensitive to the data set used for model development;
- Model validation difficult at both site and watershed scale;

Conclusions (3)

- Adaptive management may not be a viable approach for cumulative watershed effects because of long lags in response, long recovery periods, difficulty of detecting change, and difficulty of relating observed change(s) to specific management actions;
- Implication is that we should focus on minimizing the effects of each action at the local scale;
- Monitoring is essential to evaluating the effect of management actions and ensuring sound resource management.

My question to you:

If we're not monitoring the effects of our actions (or inactions), can we really claim to be managing the resources of concern?

Questions?