Effects of Forest Management on Runoff: Principles and Potential

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Goals and Objectives

1. Provide an overview of how forest management affects streamflows, including:
   - Basic principles and processes;
   - Timing of changes in flow;
   - Rate of recovery (i.e., return to “background”);
   - Variability among sites;
   - Changes observed from paired watershed studies;
2. Discuss possible effects of different management scenarios;
3. Answer any question related to the topic.

Law of Continuity (basic water balance)

Inputs = Outputs ± Change in storage (1)

Precipitation = Interception + Evaporation + Transpiration + Runoff ± Change in storage (2)

$$P = I + E + T + Q \pm \Delta S \quad (3)$$

Law of Continuity (con't)

$$P = I + E + T + Q \pm \Delta S \qquad (3)$$

Usually lump evaporation and transpiration;

Change in storage on annual basis ≈ 0;

Runoff is output of interest, so rearranging leads to:

$$\mathbf{Q = P - I - ET} \qquad (4)$$

Law of Continuity (con't)

$Q = P - I - ET$ (4)

Forest harvest generally decreases interception and transpiration, so using equation 4:

$\uparrow \mathbf{Q = P - \downarrow I - \downarrow ET}$ (5)

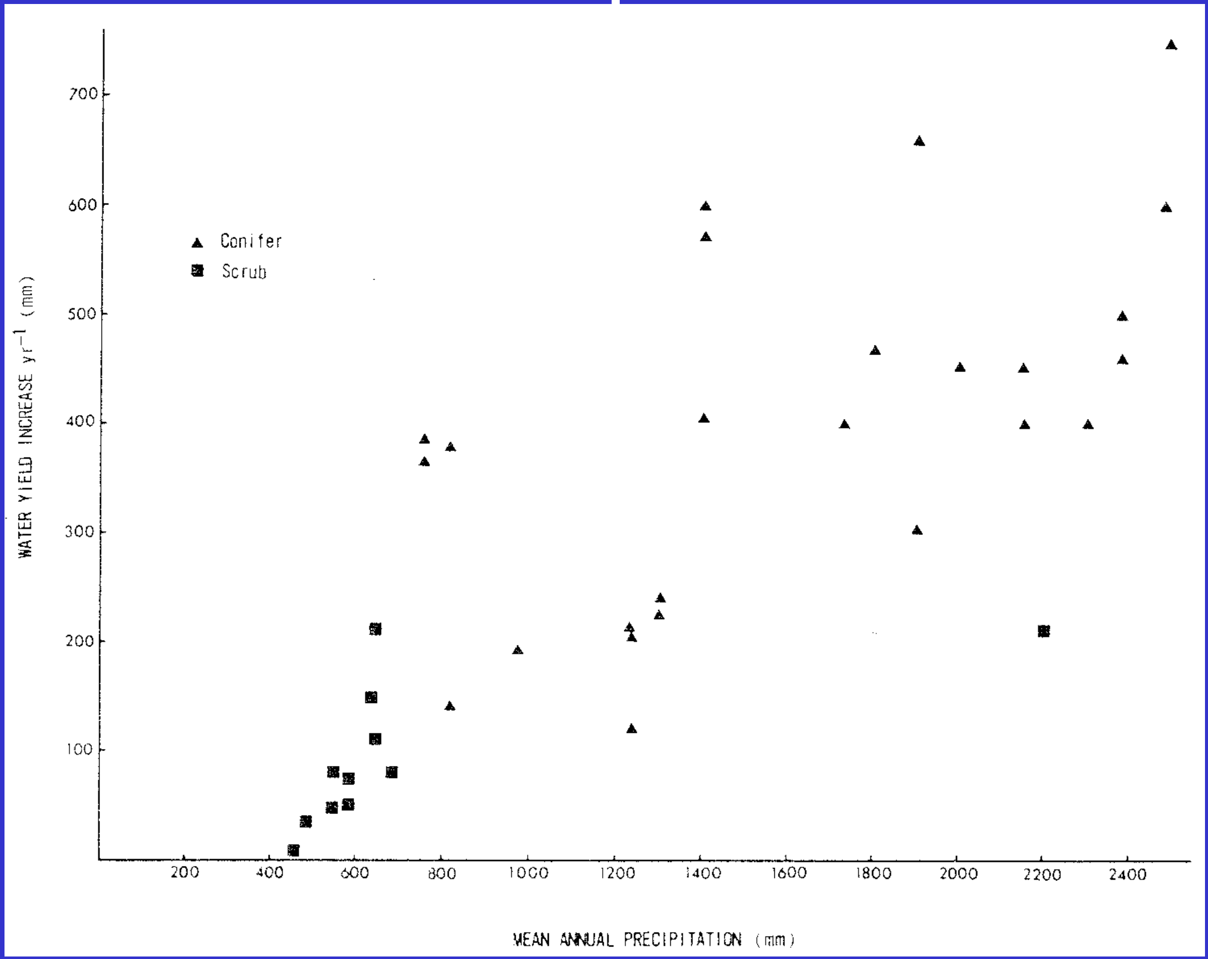
Law of Continuity (con't)

$\uparrow Q = P - \downarrow I - \downarrow ET$ (5)

Possible complications:

- Forest harvest often increases soil evaporation until sites are revegetated, so some of the transpiration "savings" are lost to evaporation;
- Where fog drip is important, forest harvest can decrease precipitation and thereby decrease runoff;
- Interception and evapotranspiration are interdependent.

Water Yield Increase vs. Annual Precipitation



Bosch and Hewlett,1982

Is an increase in runoff always good?

Usefulness or value of an increase in runoff depends on:

- Timing of the increase;
- Effect on the size of the larger peak flows;
- Effect on sediment transport and channel erosion;
- Effects on downstream aquatic resources.

Need to be more specific

Are we interested in a change in:

- Annual water yields?
- Specify peak flows of concern:

  Increase in largest floods?
  Increase in smaller peak flows?
  Increase in sediment transport rates?
  Increase in bank erosion or channel scour?

- Change in the magnitude and frequency of low flows?

Basic Precepts

1. Can't separate water quality from water quantity, e.g.:

- Forest management will also affect erosion rates from roads, skid trails, site preparation, etc.;
- Forest management will affect fire risk, and wildfires can greatly increase the size of peak flows and erosion rates;

2. Difficult to make simple generalizations:

Effects of a given management action will vary with site factors, including:

- Amount, type, and intensity of precipitation;
- Amount and type of vegetation cover;
- Infiltration rates;
- Soil depth;
- Rooting depth of the vegetation;
- Slope;
- Bedrock type;
- Rate and type of vegetative regrowth.

Forest Management Can Affect the Size of Peak Flows by Different Mechanisms

1. Reduce interception
   - Increase net precipitation;
   - Increase snow water equivalent;

2. Reduced ET leads to higher antecedent moisture conditions and increased runoff early in storms;

3. Compaction can:
   - Reduce infiltration rates and generate overland flow;
   - Reduce soil moisture storage capacity;

Peak flow mechanisms (con't)

4. Increase snowmelt rate by increasing direct solar radiation and transfer of heat to the snowpack;

5. Roads can:
   - Generate surface runoff by infiltration-excess (Horton) overland flow;
   - Intercept subsurface stormflow;

6. Changes in the timing of runoff could potentially synchronize peak flows within a basin.

Forest Management Effects on Low Flows: Key Mechanisms

1. Dominant factor is reduction in ET, resulting in more downslope drainage:
   - Higher soil moisture contents;
   - Less groundwater drawdown;
   - Progressively less effect over time and under drier conditions;
   - Thinning probably less effective than clearcutting due to scavenging of "excess" water by residual trees
2. Reduced interception has minimal effect because so little of summer precipitation is converted to runoff (typically much less than 5% of rainfall converted into runoff in western U.S.);

4. Accurate predictions require:

Site-specific data (e.g., precipitation, infiltration rates, soil depth);

Quantification of proposed management actions:

- Area;
- Percent and type of vegetation to be treated;

5. Need comprehensive analysis at different spatial and temporal scales of:

- Hydrologic cycle;
- Processes that generate runoff;
- Erosion processes.

<u>Key Questions and Issues</u>

- What do we want as our desired condition?

- What is the effect of different management scenarios?

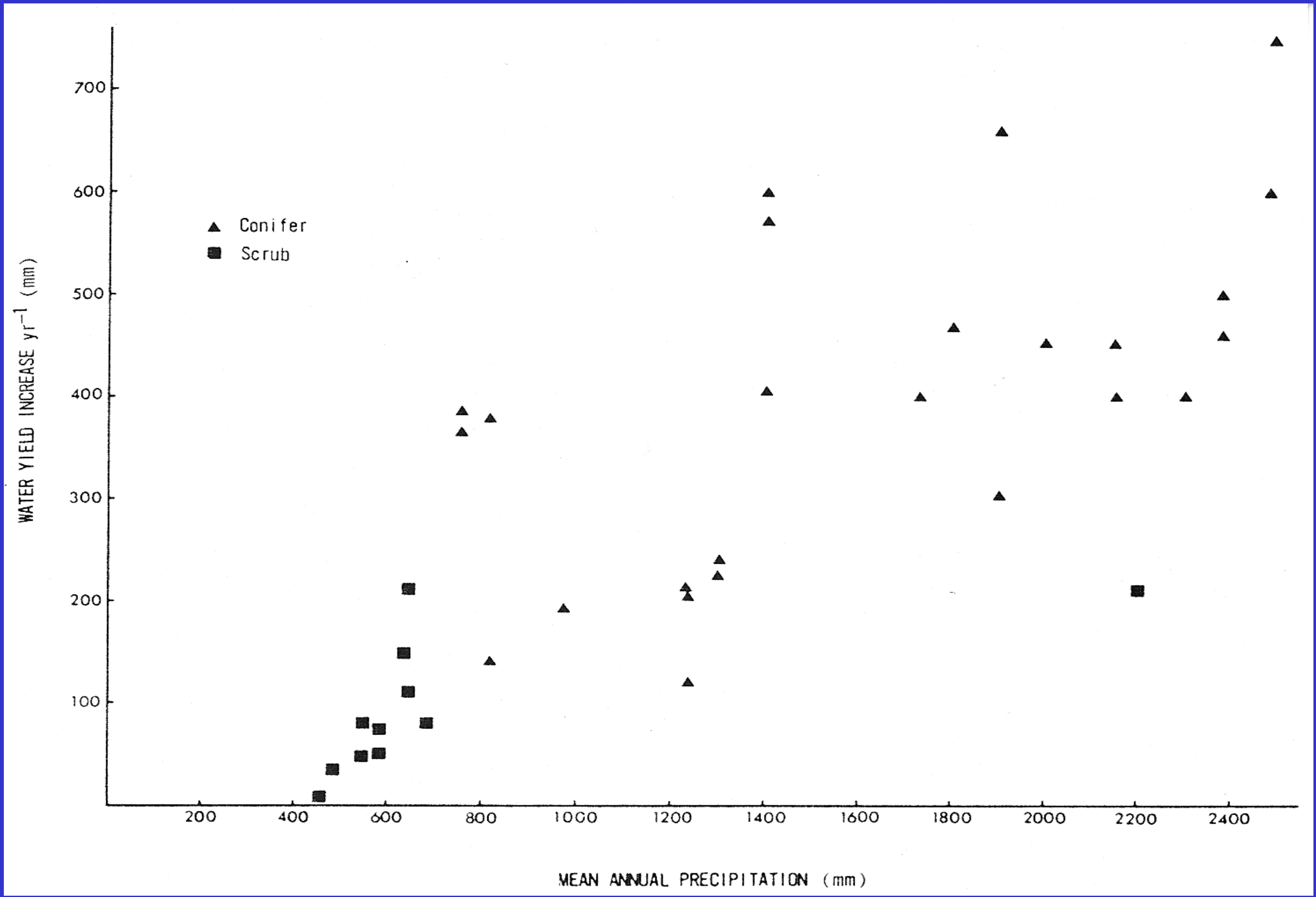
- Decisions ultimately are not purely scientific decisions, as they involve assessing costs vs. benefits, value judgements, etc.

- Focus here is on technical issues in order to provide technical guidance.

Caveats on Increasing Water Yields

1. Need annual precipitation to be at least
   450-500 mm (18-20 in.);

Water Yield Increase vs. Annual Precipitation



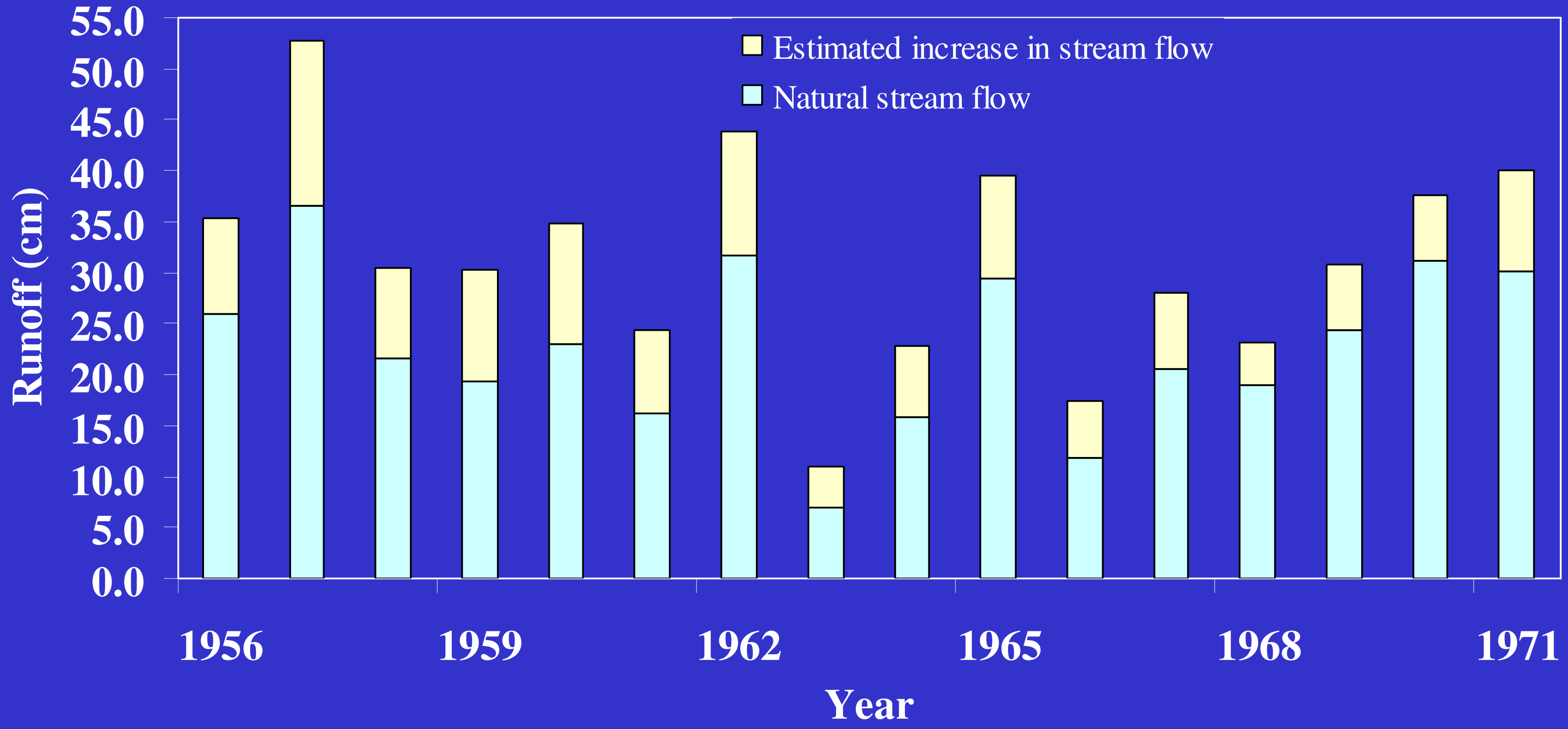
Bosch and Hewlett,1982

Caveats on Increasing Water Yields (con't)

1. Limited by annual precipitation;

2. **High interannual variability;**

Predicted and Increased Runoff for Fool Creek, CO: 1956-1971



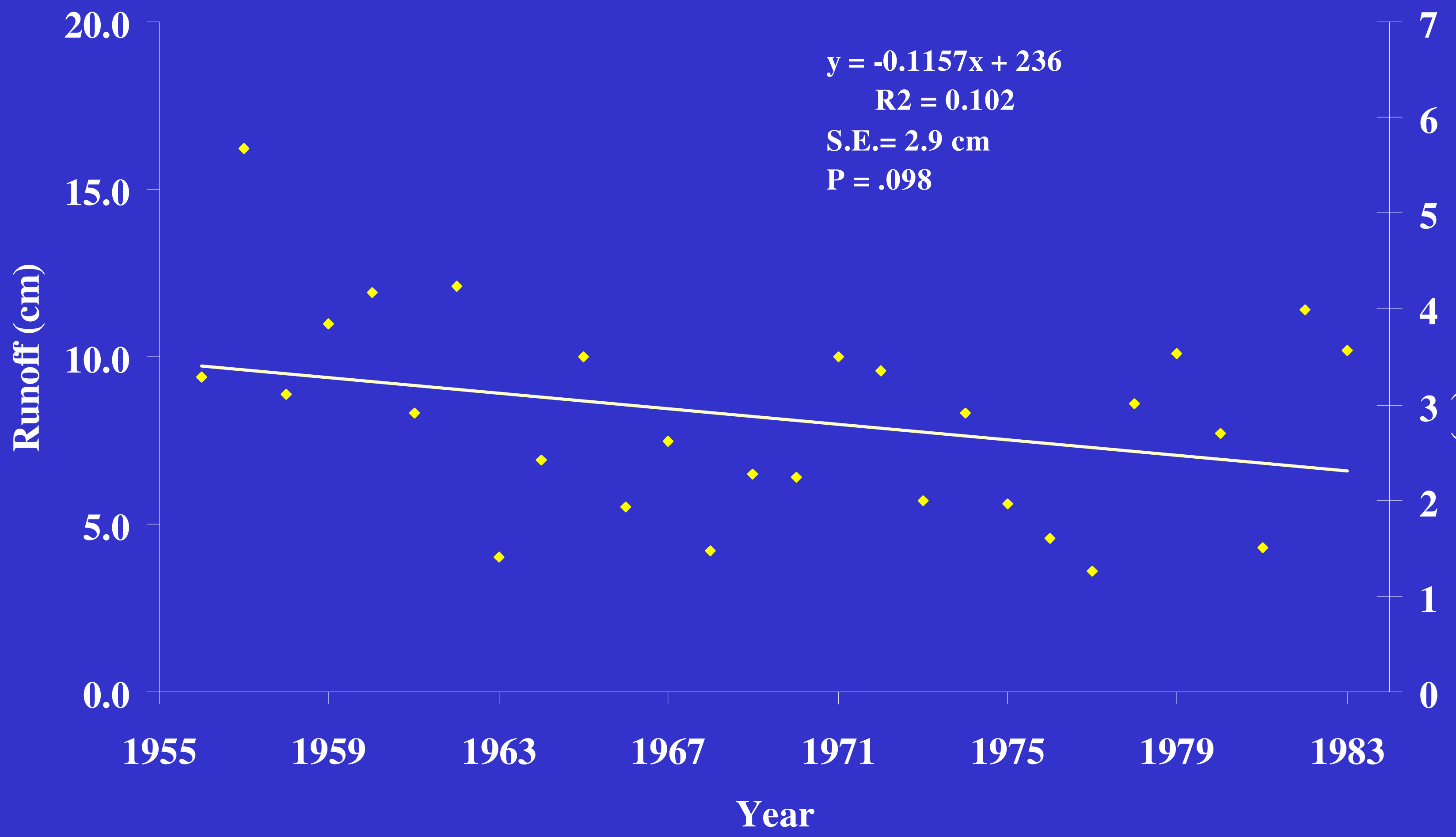
Potential for Increasing Water Yields (con't)

1. Limited by annual precipitation;

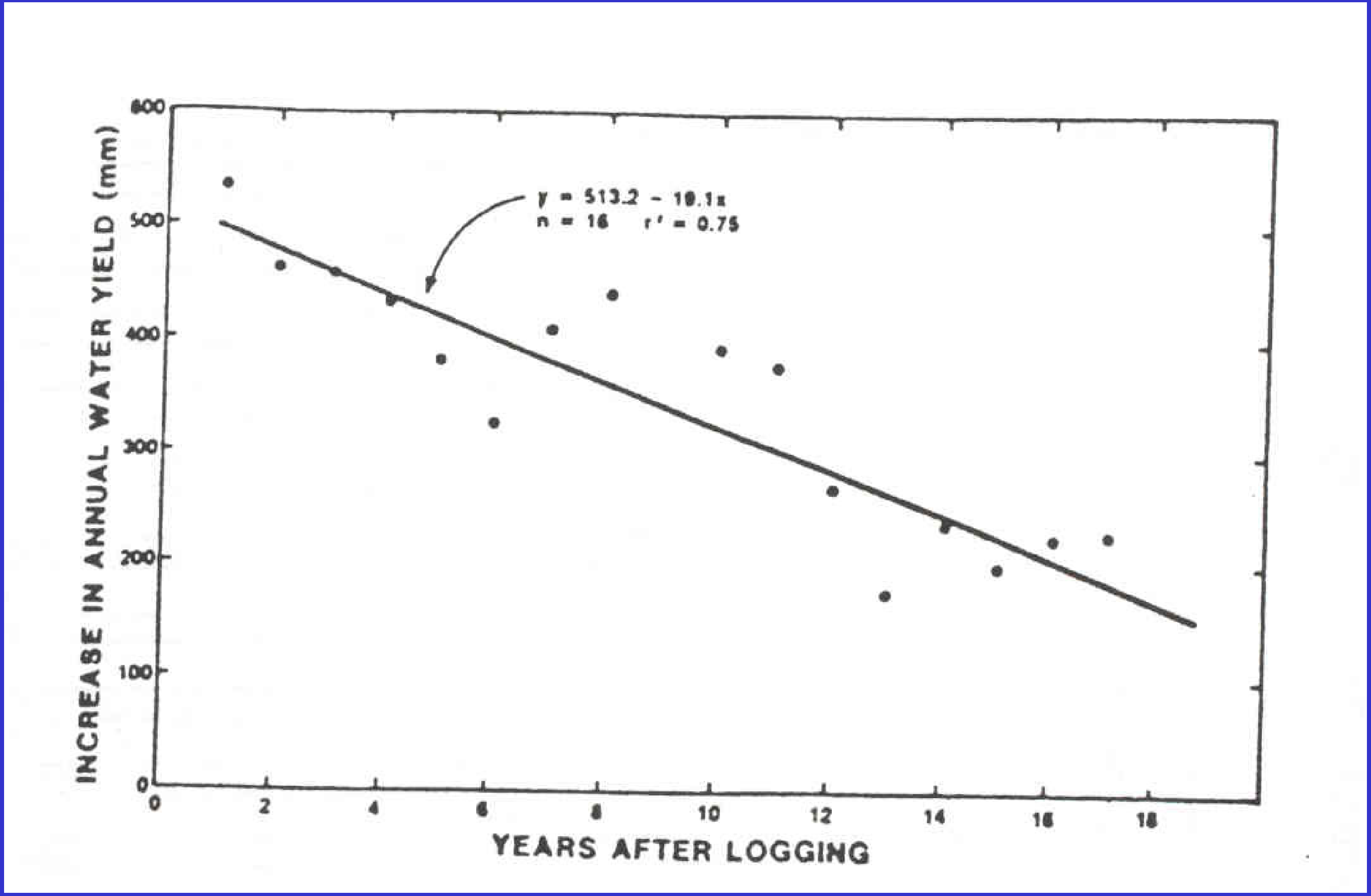
2. High interannual variability (less in dry years);

3. **Water yield increases decline over time, resulting in lower long-term average; repeated treatments over time or within a watershed needed to sustain a water yield increase;**

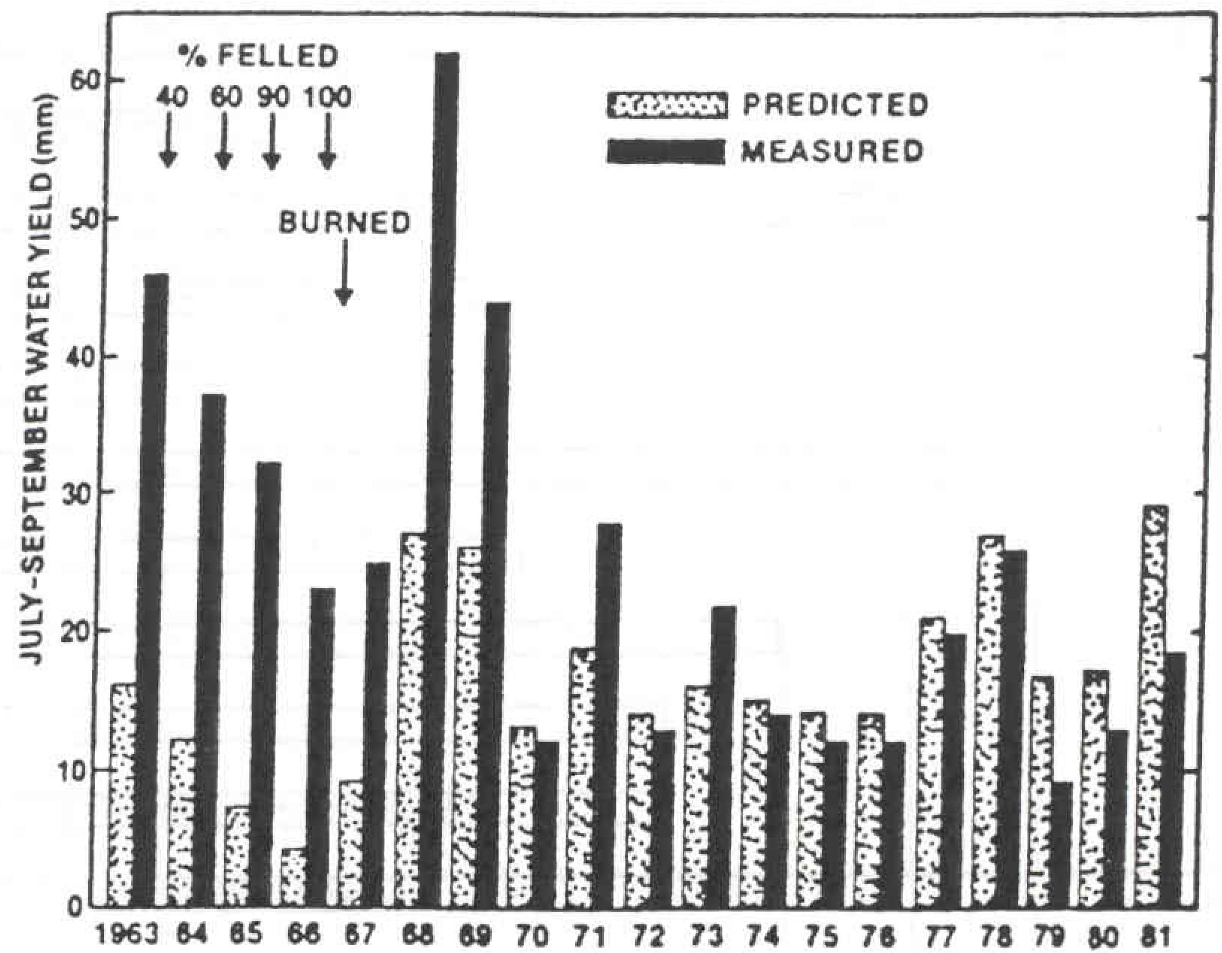
Increased Runoff for Fool Creek, CO: 1956 - 1983



Increase in Annual Water Yields over Time: Watershed 1, H.J.Andrews Experimental Forest (Harr 1983)



July-September Streamflow Over Time: Watershed 1, H.J.Andrews Experimental Forest (Harr, 1983)



Rate of Recovery Depends Upon Processes

- In Colorado, 60-70 years for recovery of annual water yields in subalpine spruce-fir forest because winter interception rates so slow to recover (vs. 15-40 years for aspen);
- Shorter recovery in drier sites, as less vegetation needed to restore interception and evapotranspiration rates;
- Can be very rapid recovery or even a decrease in water yields if there is a change in vegetation type;

→ Repeated treatments necessary to sustain a water yield increase.

Potential for Increasing Water Yields (con't)

1. Limited by annual precipitation;
2. High interannual variability (less in dry years);
3. Decline over time results in lower long-term average;

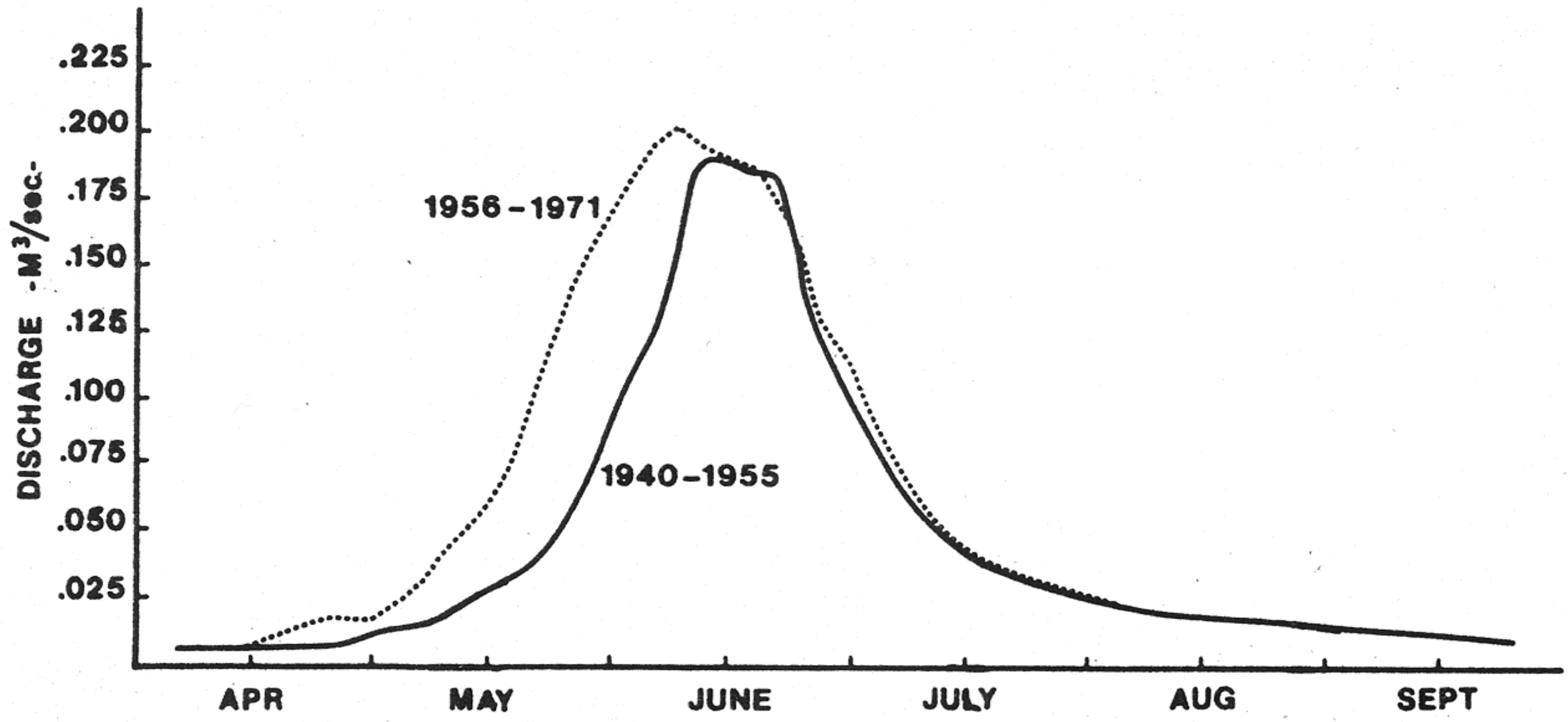
4. **Timing of increase may limit usefulness.**

Timing of Water Yield Increases

- Most of the increase in runoff from forest harvest comes during the initial period of soil moisture recharge;
  - Fall in rain-dominated areas;
  - Spring in snowmelt-dominated areas;
- Increase in baseflows depends on soil moisture drainage, which requires deeper soils and/or groundwater storage;

→ Reservoir storage needed to capture most of the “extra” runoff generated by forest management.

Pre- and Post-treatment Hydrographs: Fool Creek, CO



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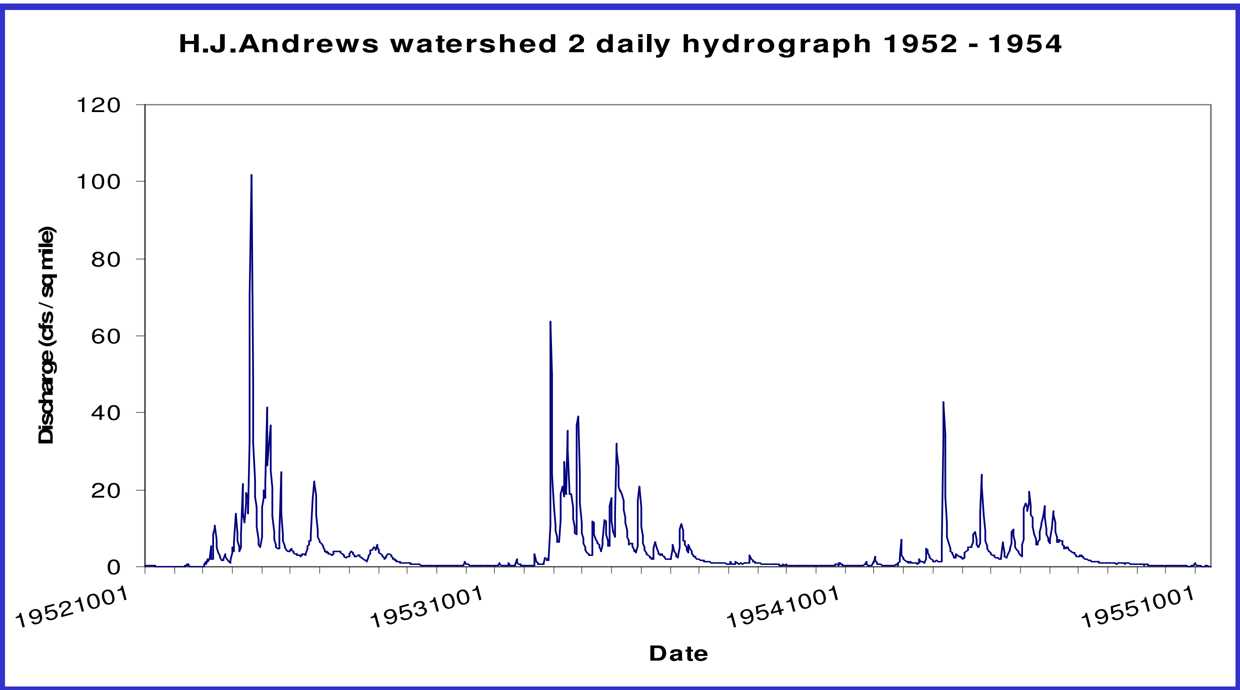
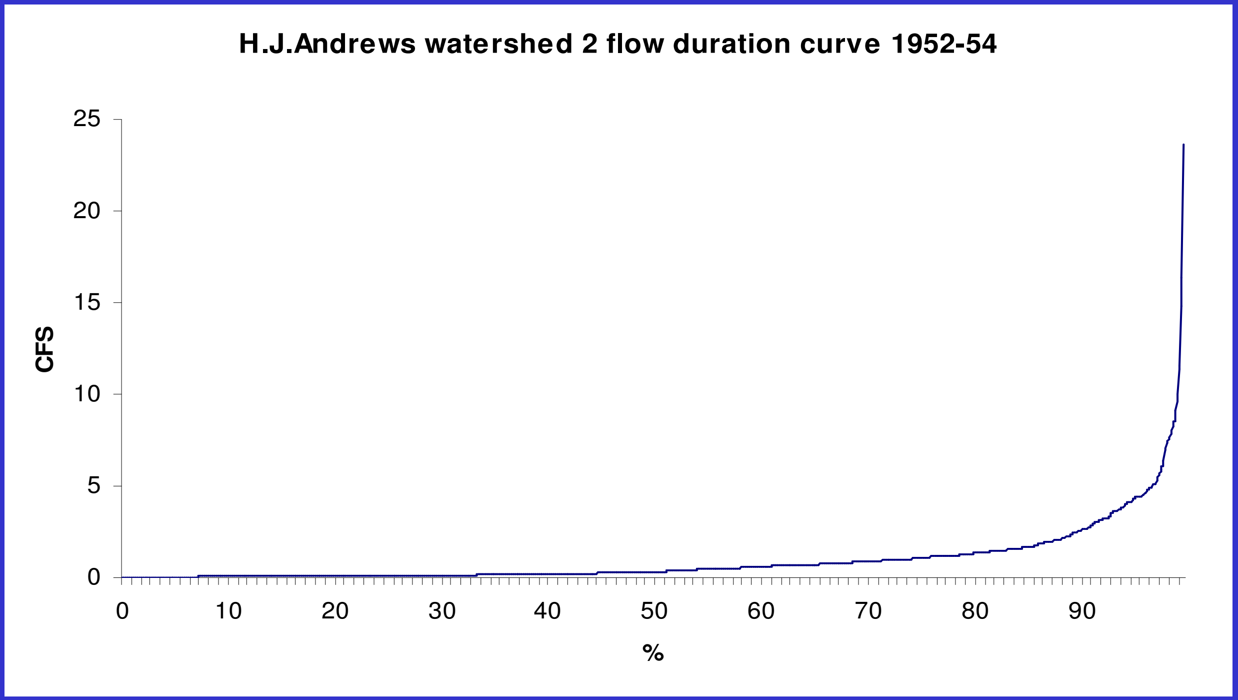
6. Difficult to "own" or claim increase in flow due to forest harvest;
7. **Careful treatments should minimize adverse effects on water quality and downstream aquatic resources.**

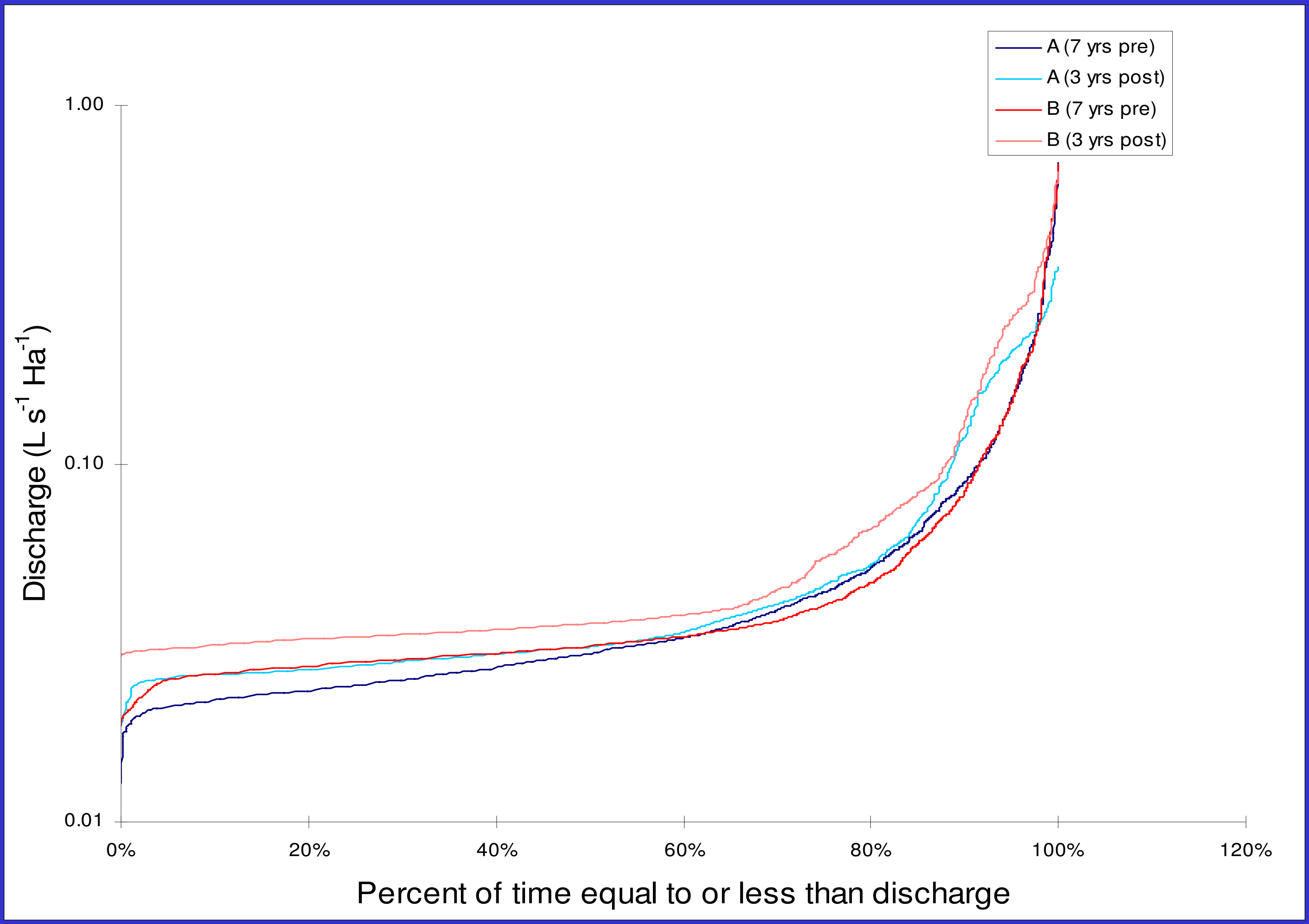
Effects of Forest Management on Flows:

An analysis of paired-watershed studies using flow duration curves

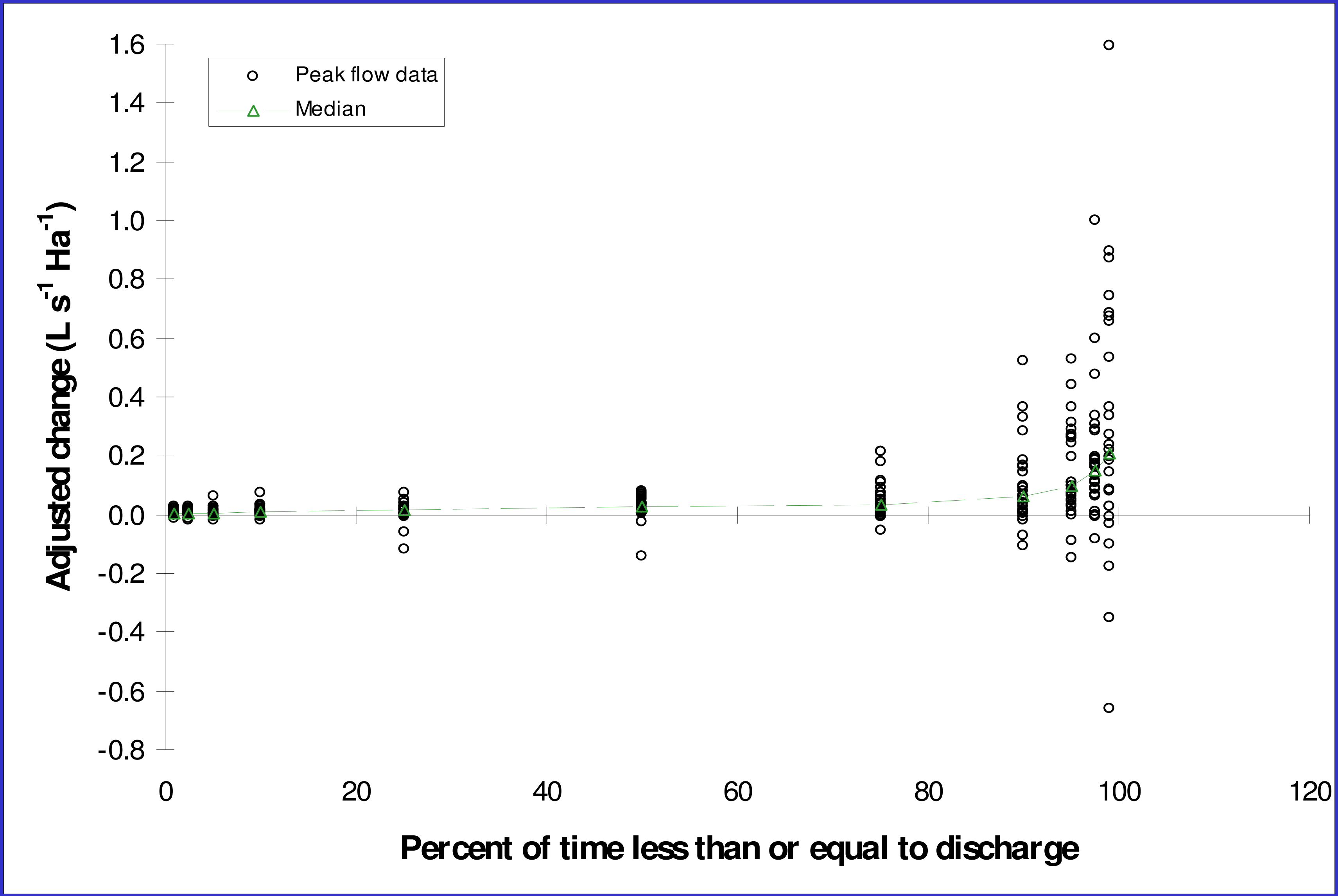

H.J.Andrews watershed 2 daily hydrograph 1952 - 1954
Discharge (cfs / sq mile)
120
100
80
60
40
20
0
19521001
19531001
19541001
19551001
Date


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

Pre- and Post-treatment FDCs

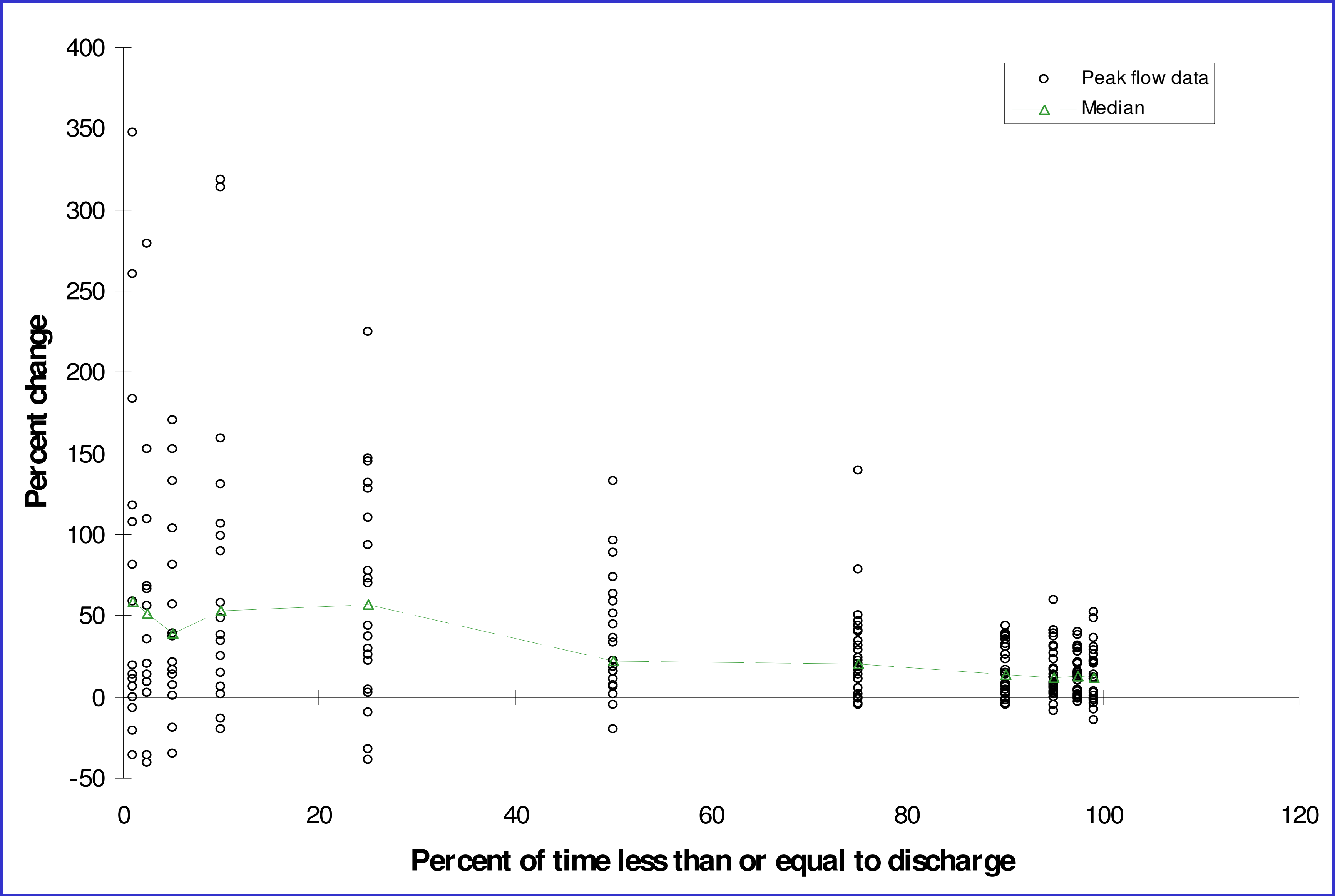


Absolute Changes in Flow



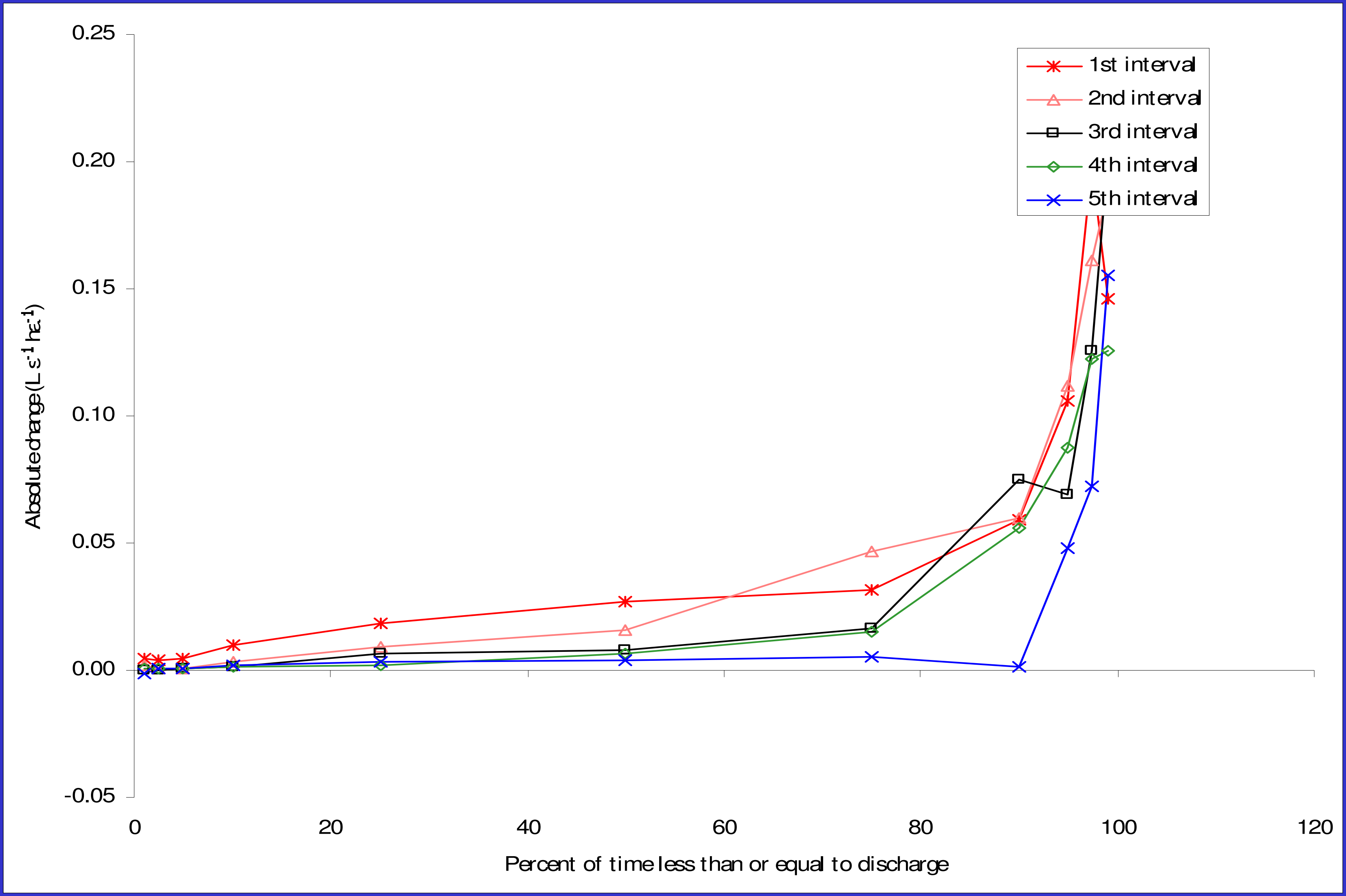
* Approximately 0.05 cfs/mi2 at low end from very heavy harvest

Percent Change in Flow

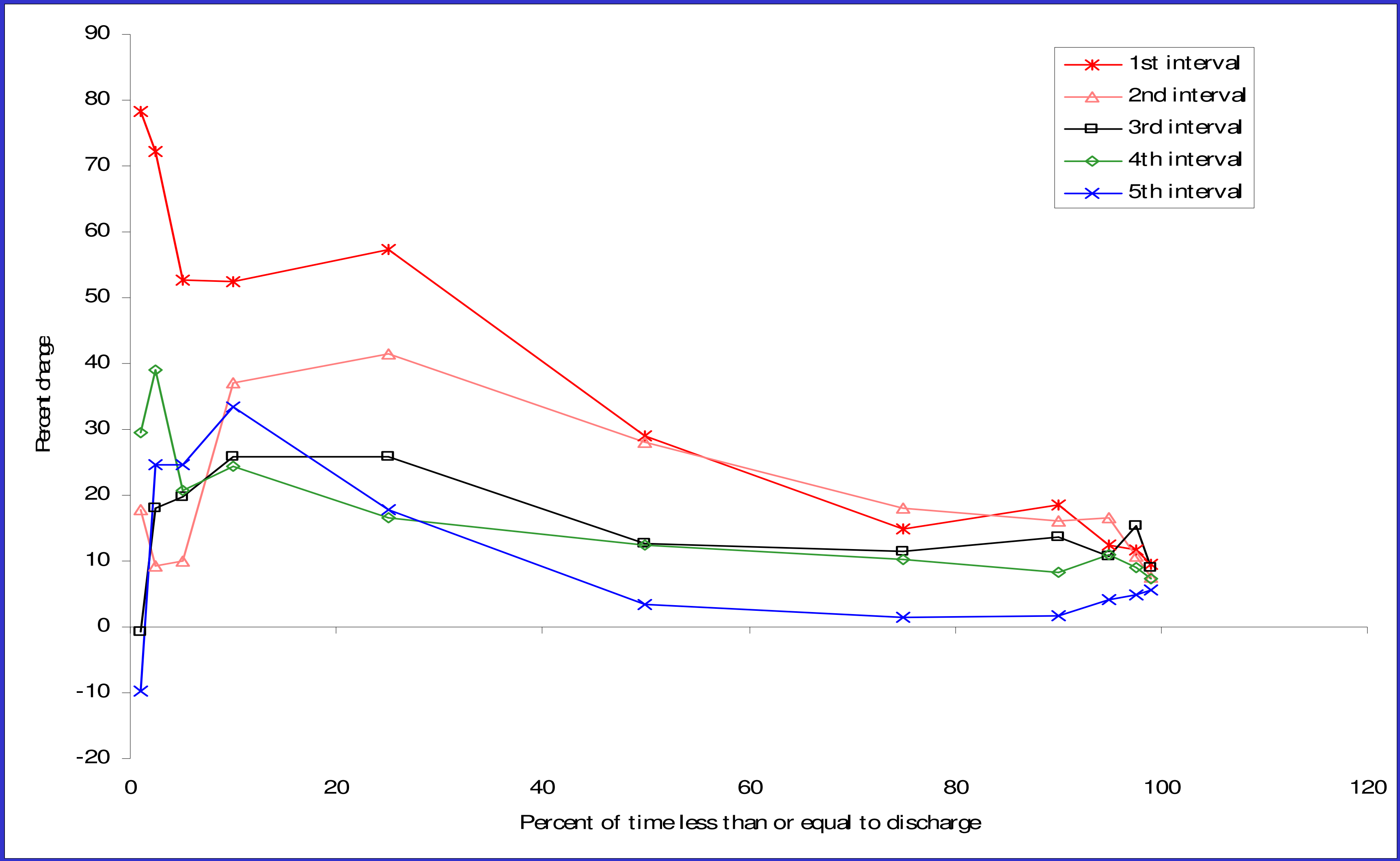


A large percent increase in a small number is still a small number.

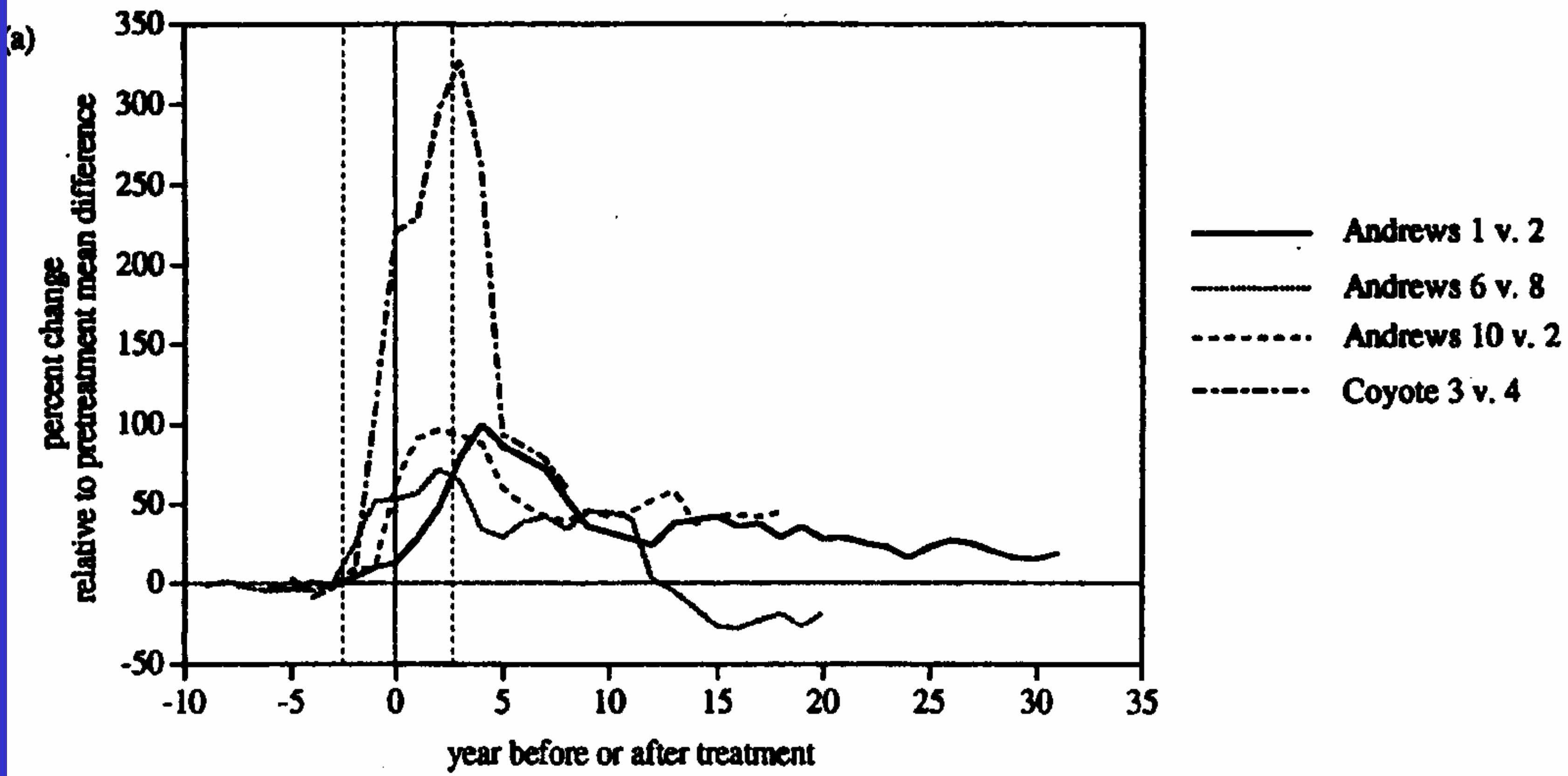
Absolute Change in Flow Over Time



Percent Change in Flows Over Time

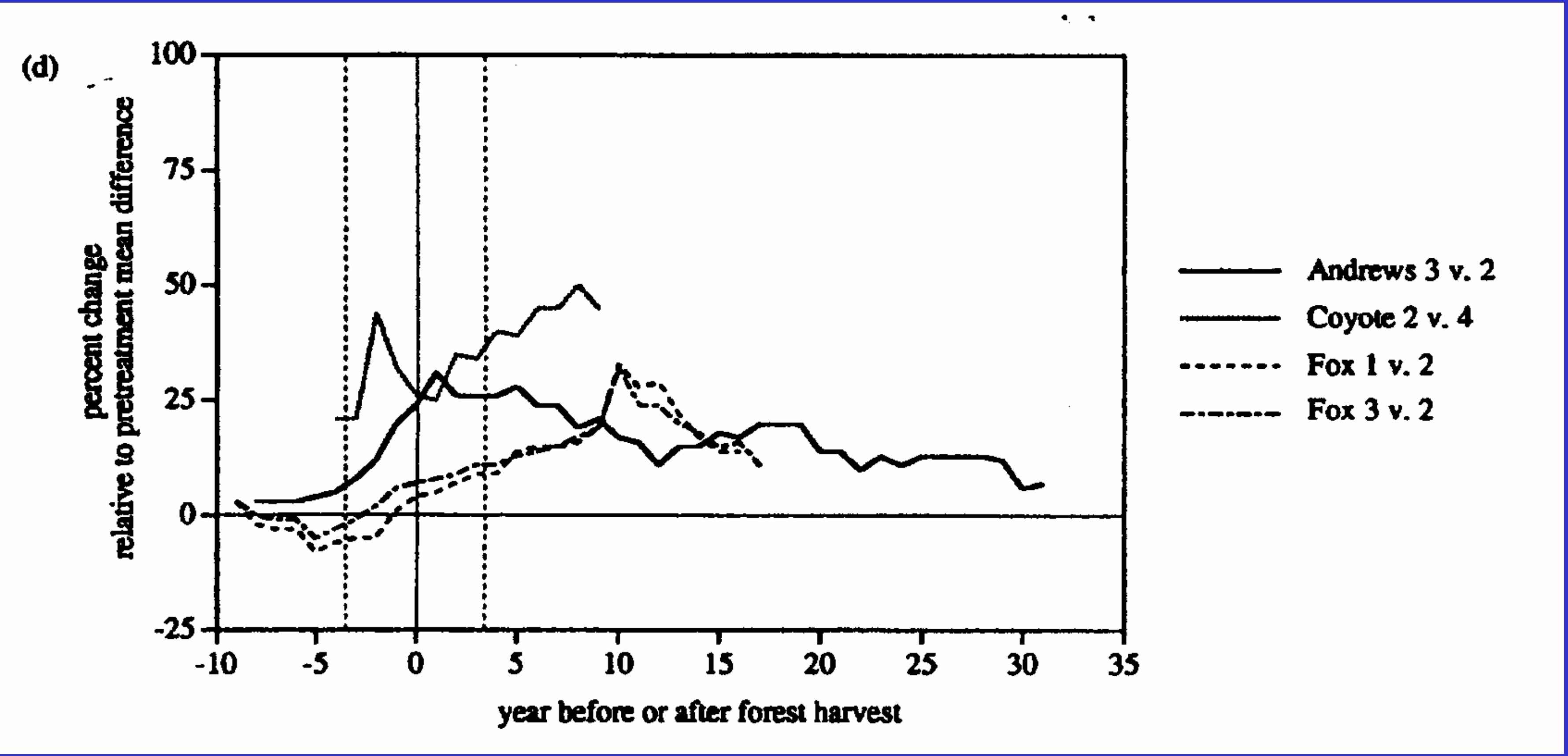


Trends in small fall peak discharge events by year before and after 100% clear cut



Each smoothed line is a running mean of percent change for a given subpopulation of events in a treated-control basin pair. Widths of moving windows (vertical dashed lines) make the treatment effect appear before year 0 (Jones 2000).

Trends in large peak flows over time before and after 25% cut in basins with roads



Each smoothed line is a running mean of percent change for a given subpopulation of events in a treated-control basin pair. Widths of moving windows (vertical dashed lines) make the treatment effect appear before year 0 (Jones 2000).

Difficulty of Treating Large Areas

- Paired-watershed study set up in southern Wyoming to test water yield increase at the operational scale (4100-acre basin); various management constraints reduced area cut to just 24% of the watershed area;
- Estimated potential increases in water yield from National Forests in California only about 0.6 inches (Rector and MacDonald, 1987);
- Estimated potential water yield increase from Sierra Nevada 0.25 inches (Kattelman et al., 1983)
- Multiple owners will make coordinated efforts more difficult.

Detectability of Water Yield Increases

- Can predict increases if site conditions are known;
- Treatment threshold of 20-25% applies to:
  - Paired-watershed experiments;
  - Very accurate discharge measurements.;
- Change more difficult to detect over time:
  - At one location;
  - Using typical USGS gauging stations;

→ Highly unlikely to detect a statistically significant change in flows in most management situations.

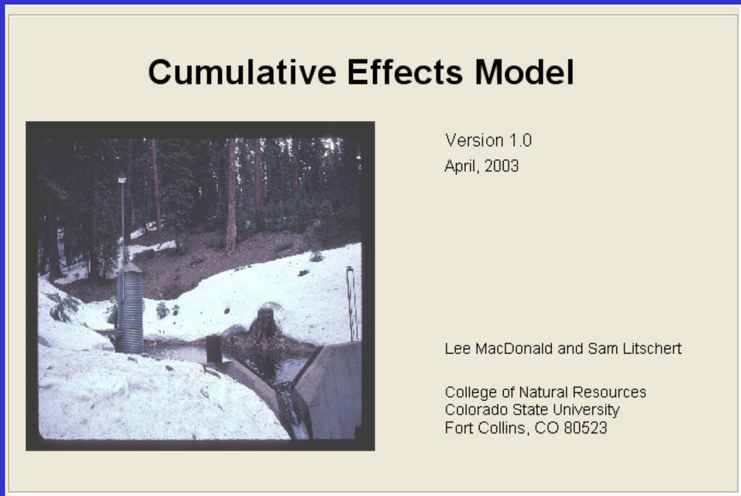
Predictability of Water Yield Increases

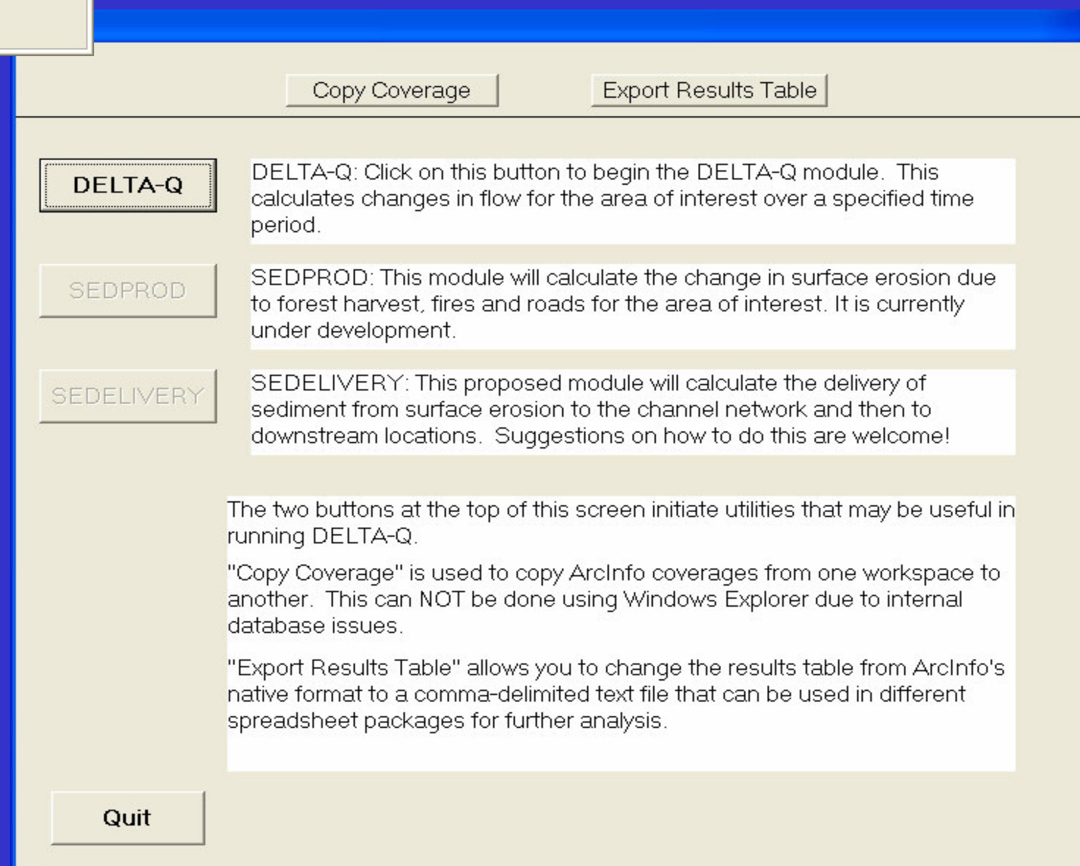
- Can predict increases using existing models (e.g., WRENSS) with reasonable accuracy if data are available;
- Nevertheless, prediction of relative change more accurate than prediction of absolute values.

Modules Being Developed

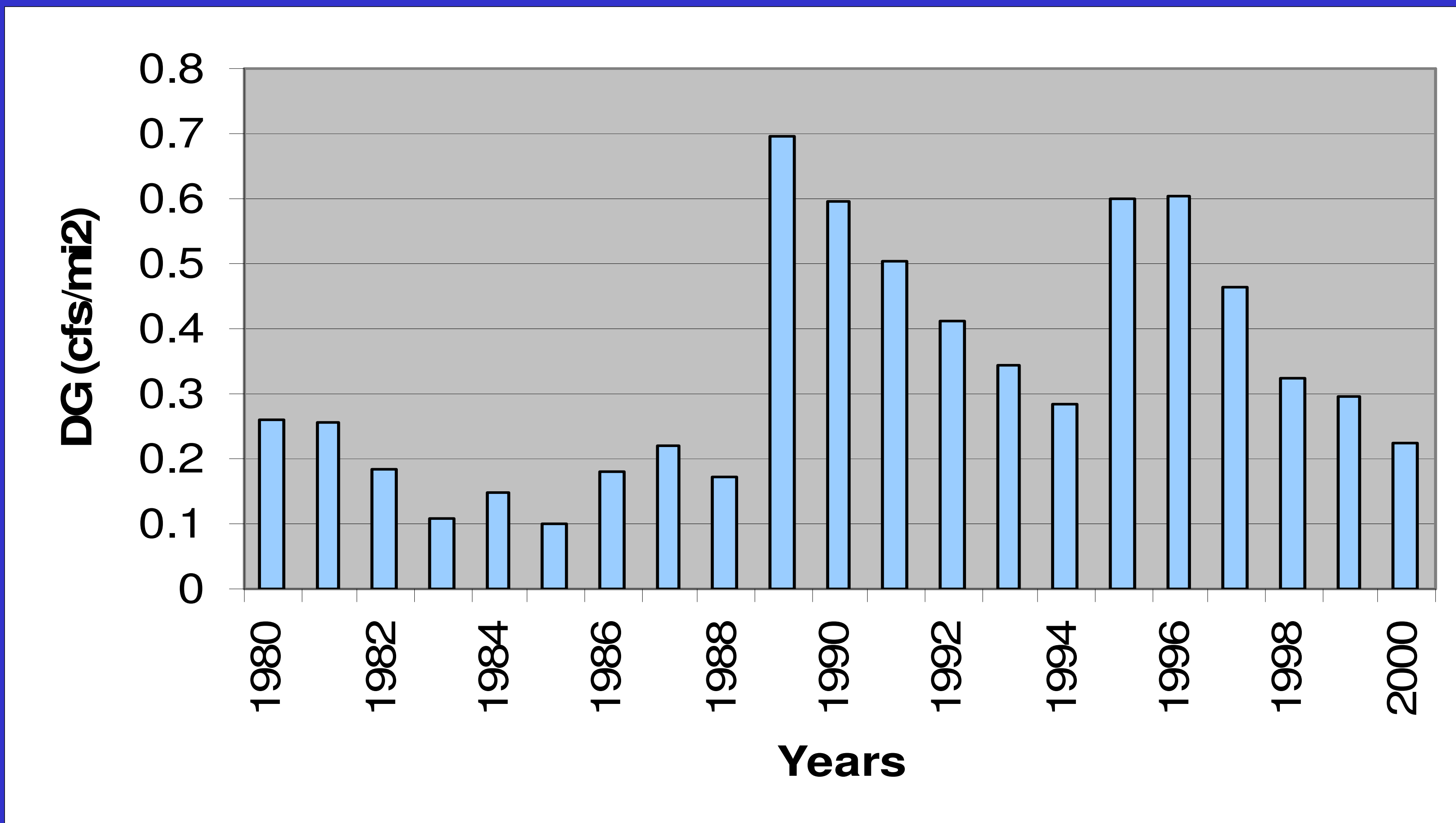
- **DELTA-Q:** Calculates changes in low, median, and high flows from forest management and fires; now being distributed;
- **SEDPROD:** Calculates sediment production from forest harvest, roads, and fires; nearly ready for beta testing;
- **SEDELIVERY:** Calculates sediment delivery to stream network and downstream travel rates to reach of interest.

Cumulative Effects Model: Delta-Q Module User Interface





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



Need to Consider Historic Context

Possible increase in in forest density due to fire suppression and harvest causing:

→ Decrease in water yields;

→ Increased risk of high-severity wildfires;

Presence of roads, settlements, and other land uses may also be affecting runoff.

Management Options: Effects on Water Quality

- Careful treatments and BMPs should minimize on-site erosion rates;
- Roads and skid trails probably are the dominant chronic sediment sources;
- Absence of action will increase risk of high-severity fires, which may be dominant sediment source in areas not dominated by mass movements.

Conclusions - 1

Potential to increase water yields limited by:

- Area suitable for treatment;
- Timing of increases (both inter-annually and seasonally);
- Cost;
- Hydrologic recovery;
- Lack of detectability;
- Ownership and use of any increase in runoff;
- Lack of treatment will lead to increasing risk of high-severity wildfires;
- Terrain, cost, public acceptance, and other issues may limit the area to be treated.

Conclusions -2

- Intensive removal of forest vegetation does increase annual water yields, but most of the water comes during moderate or high flows;
- Smaller increases in dry years;
- Increase in baseflows is rapidly eliminated by vegetative regrowth;
- Pattern of forest harvest has greater effect on magnitude of increase in baseflows than highflows.