Delta-Q and FOREST: spatially explicit cumulative watershed effects models for small forested watersheds

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Cumulative watershed effects (CWEs)

- the physical and ecological impacts that result from multiple land use disturbances over space and time.

Hydrologic CWEs

- Changes in timing and magnitude of flows;

Sedimentary CWEs

- Changes in erosion or deposition;
- degraded water quality, reservoir sedimentation, and changes in channel morphology.

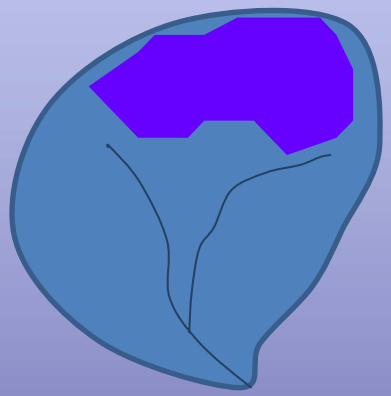
Some causes of CWEs in forested watersheds

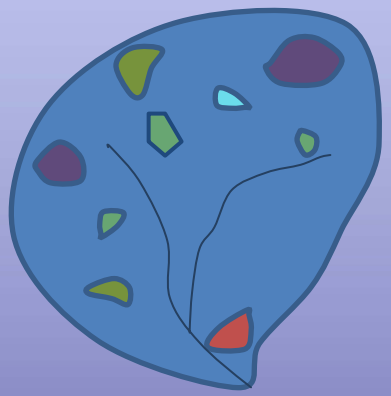
CWEs and land managers

Land managers may be required by NEPA or state laws to:

- Compare the CWEs of different forest management scenarios, and
- Account for “past, present, and reasonably foreseeable future” impacts.

Which management scenario results in more CWEs?

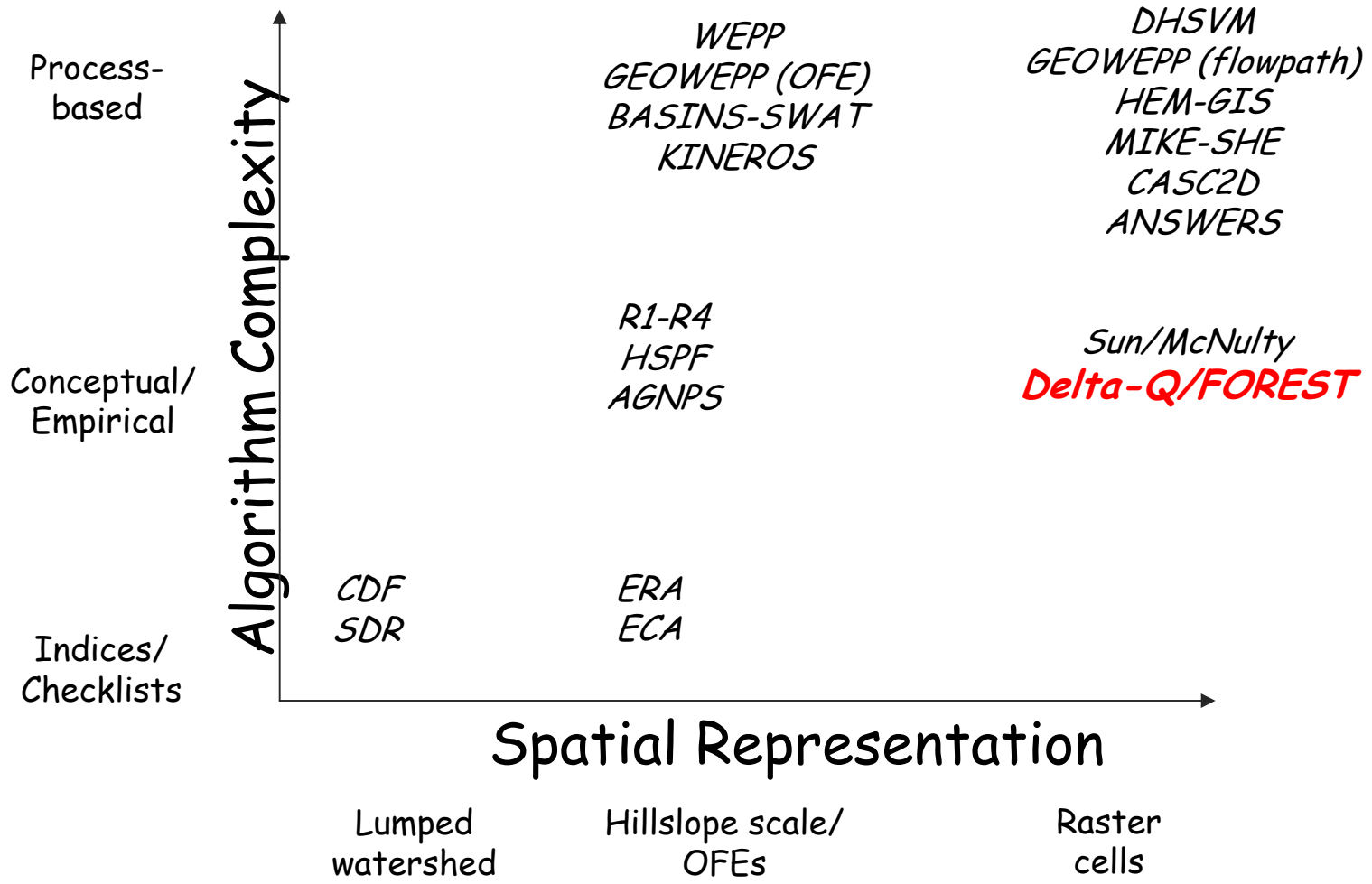




Legal challenges to land management decisions highlight three main issues with CWEs analyses:

1) CWEs analyses did not account for disturbances over time;
2) Models were not sufficiently evaluated with measured data; and
3) Model assumptions were inadequately disclosed.

Existing CWEs models



Outline

- Development of Delta-Q and FOREST
- Model testing:
  - Verification and evaluation
  - Sensitivity analyses
- Fieldwork to assess sediment delivery from timber harvest units

Delta-Q and FOREST (FORest Erosion Simulation Tools)

A series of 13 models designed to calculate:

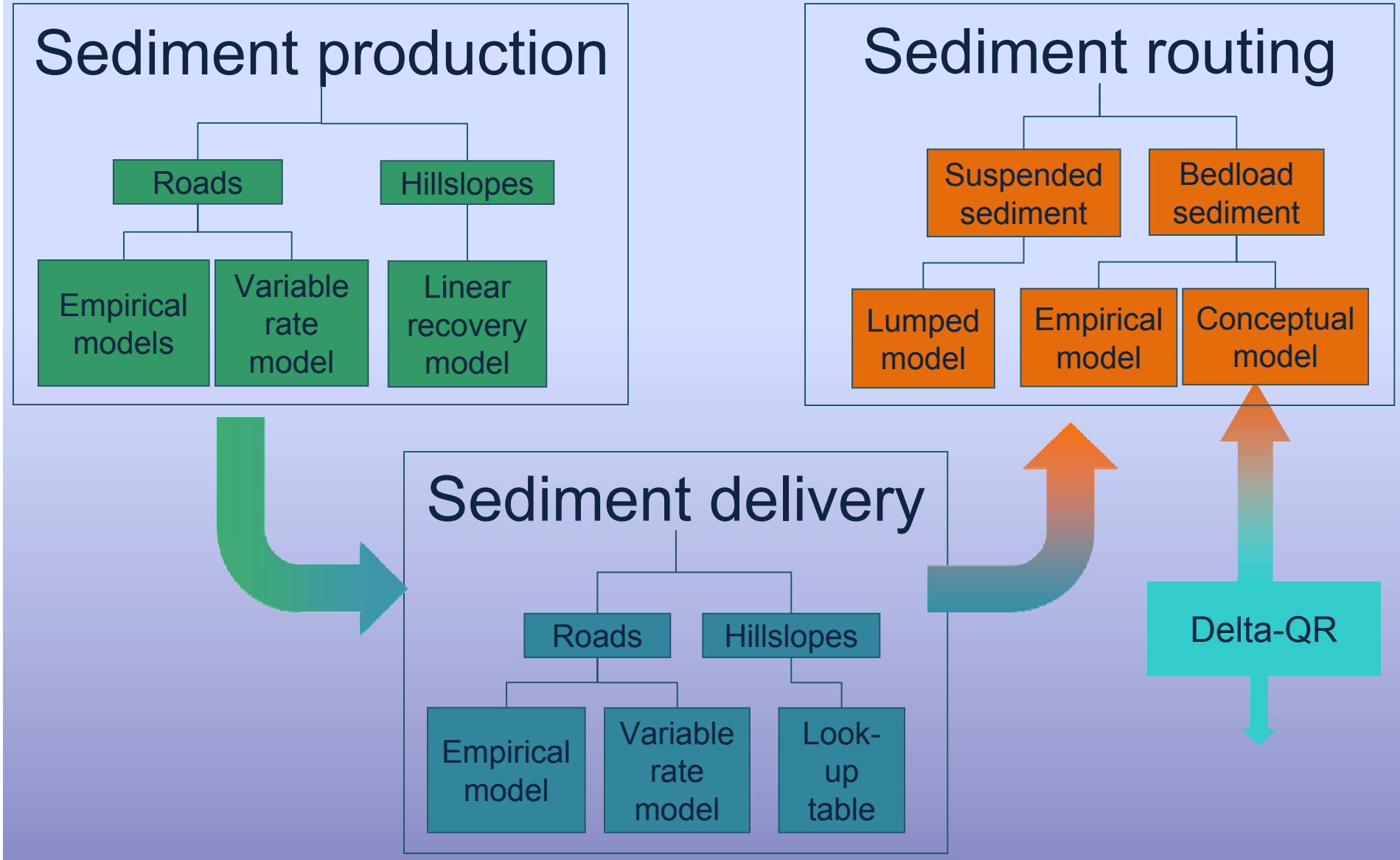
- Annual changes in relative and absolute 1st, 50th and 99th percentile flows (Delta-Q),
- Annual sediment production, delivery and yield (FOREST),

…from roads, fires, and forest management.

Delta-Q and FOREST objectives

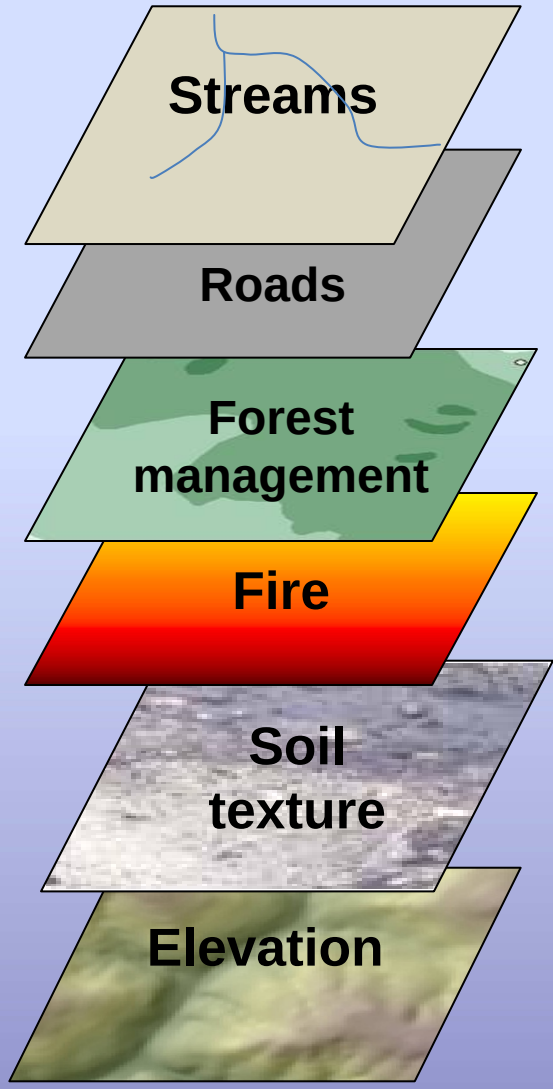
- Empirical and conceptual models,
- Spatially and temporally explicit,
- Use readily available data, and
- Provide a GUI, default parameter values, and online help files.

FOREST sub-models and data flows



Delta-Q and FOREST inputs

- GIS layers,
- Initial changes in flow and sediment production with recovery times for each type of disturbance,
- Road width, mean annual precipitation, and
- Other parameters vary by model selection



Delta-Q and FOREST outputs

- GIS layers of hillslope and road sediment production and sediment delivered to streams from hillslopes and roads.
- Summary tables of annual changes in flow, sediment production, delivery, and sediment yields by watershed.

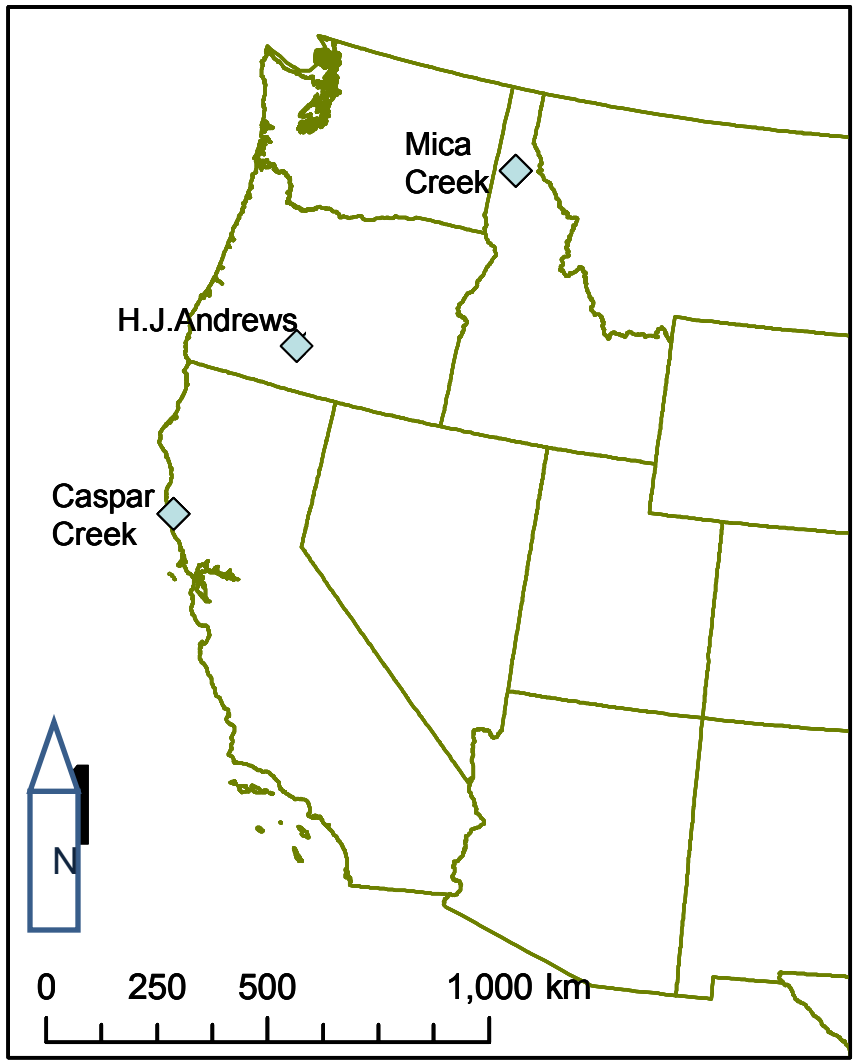
Model Testing

- Verification determines that the models function as intended.
- Evaluation tests the models' ability to accurately reproduce a measured set of values.
- Sensitivity analyses help users to parameterize and understand models by testing model responses to varied inputs
  - not covered today!

Model verification

- Changes in flow and sediment yields were dominated by the CWEs of burned areas;
- Magnitude of effects and timing of recovery were consistent with inputs indicating that models functioned as planned; and
- Model runs showed repeatable and consistent results.

Evaluation of Delta-Q and FOREST



Three sites were selected to compare measured to modeled values:

Caspar Creek, California;

H.J. Andrews, Oregon; and

Mica Creek, Idaho.

Watershed disturbances and measured data

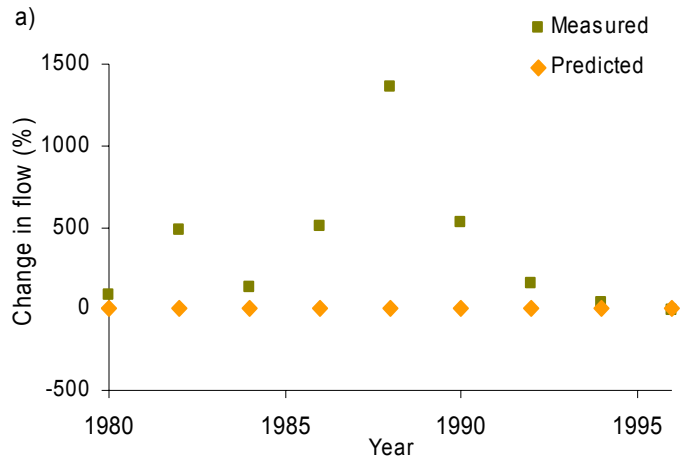
Sites	Watersheds	Disturbances	Data
Caspar Creek	North Fork South Fork	49% clearcut, 65% select cut	Discharge, suspended sediment, weir pond sediment (1963-2004)
H.J. Andrews	WS2 Mack Creek	Control, 18% clear cut	Discharge (1980– 1996)
Mica Creek	Watershed 1 Watershed 2 Watershed 3	50% clearcut, 50% select cut, control	Discharge, suspended sediment (1992-2004)

Evaluation of Delta-Q

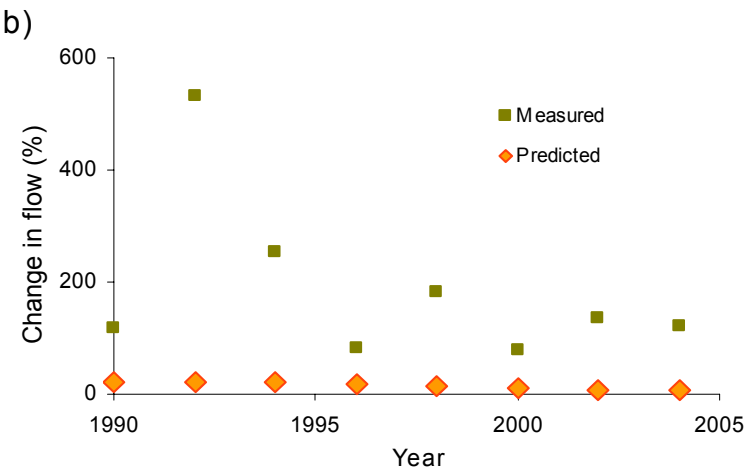
Annual values were compared for changes in the 1st, 50th, and 99th percentile flows at:

- North Fork,
- Mack Creek,
- Watersheds 1 and 2.

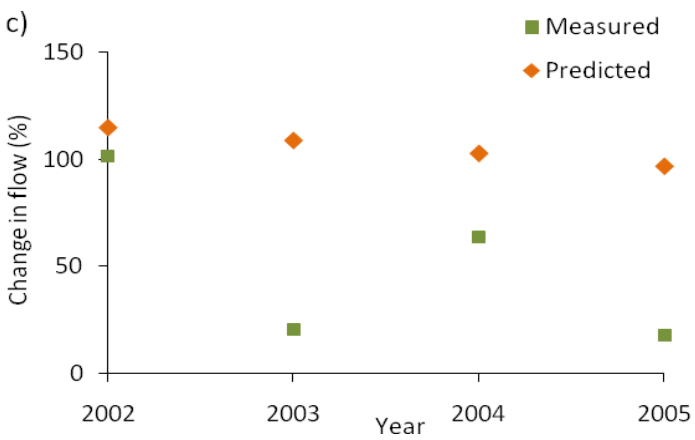
Comparison of measured and predicted 1st percentile flows



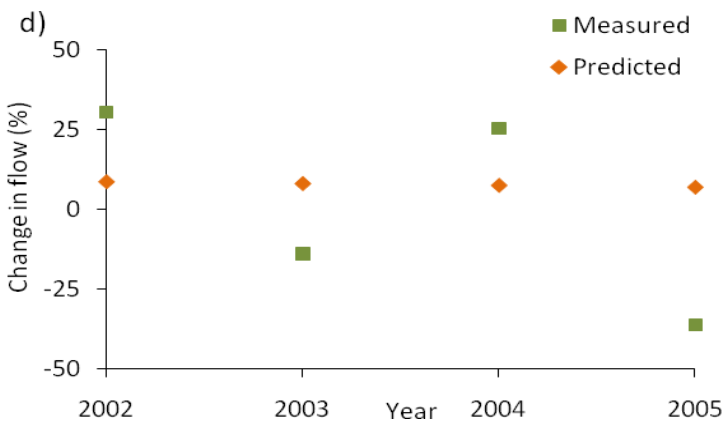
Mack Creek



North Fork



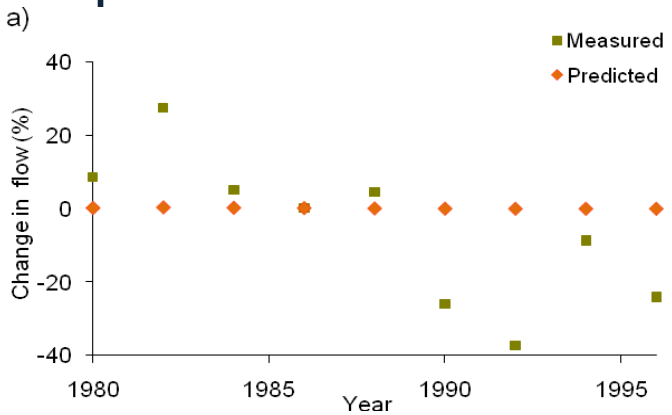
Watershed 1



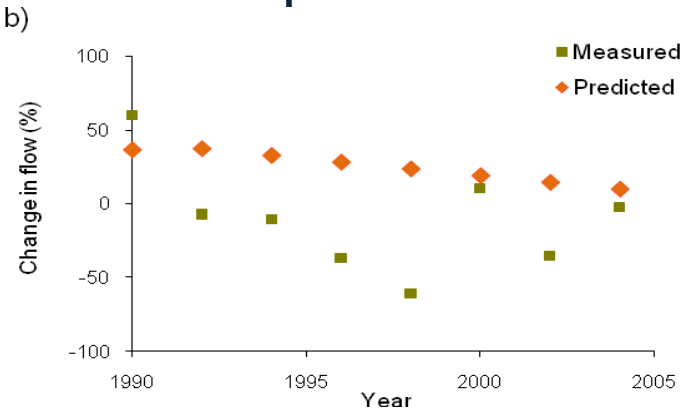
Watershed 2

For the 1st percentile, small changes in absolute flows can result in large percent changes and large prediction errors;

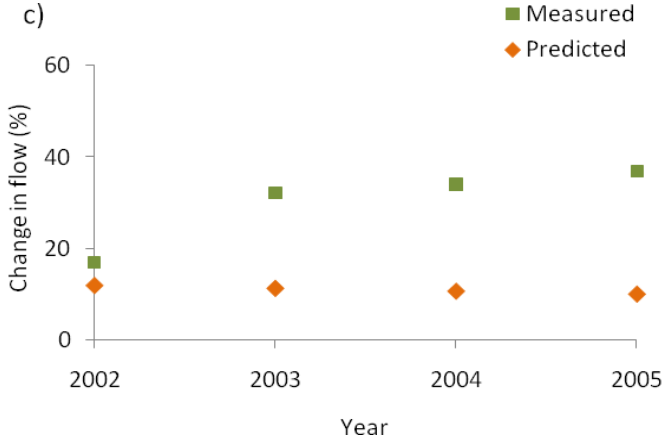
Comparison of measured and predicted 50th percentile flows



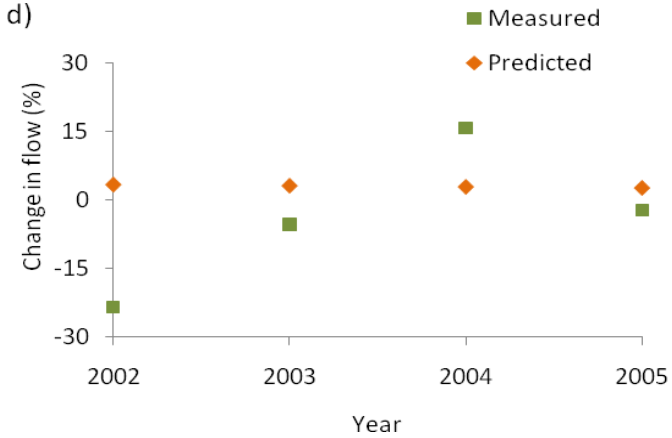
Mack Creek



North Fork



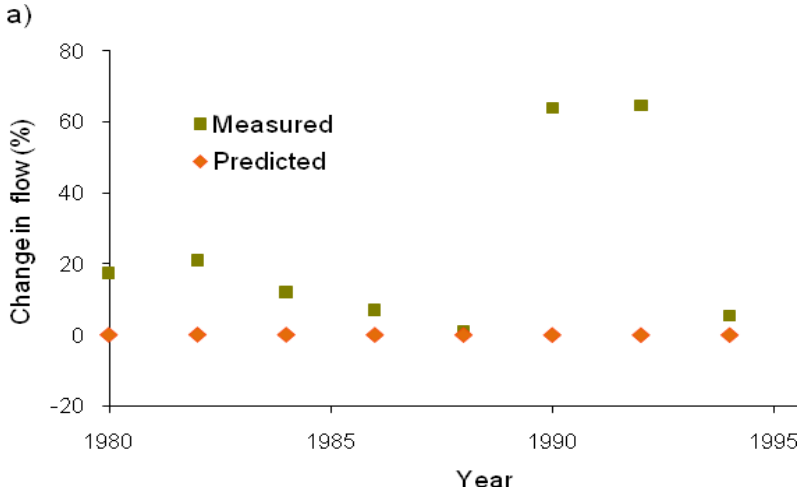
Watershed 1



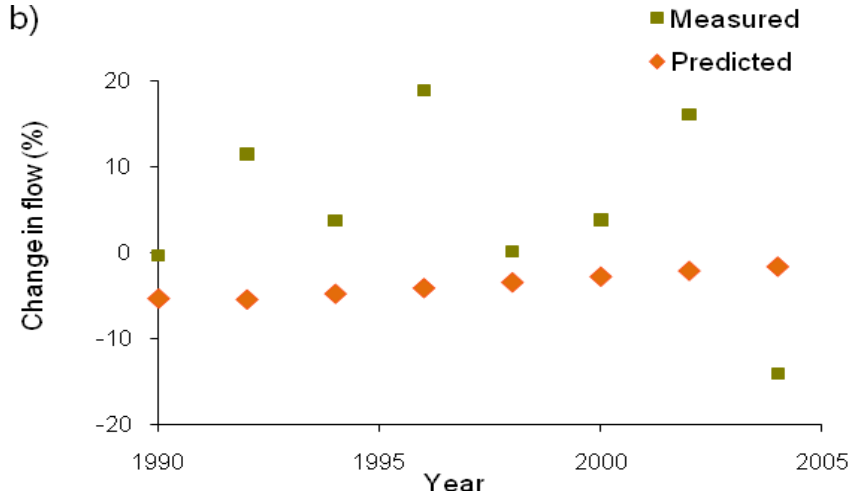
Watershed 2

Predicted percent changes in flows were more accurate for the 50th and 99th percentiles than for 1st percentile, as 50th and 99th flows are larger and less sensitive to climatic fluctuations.

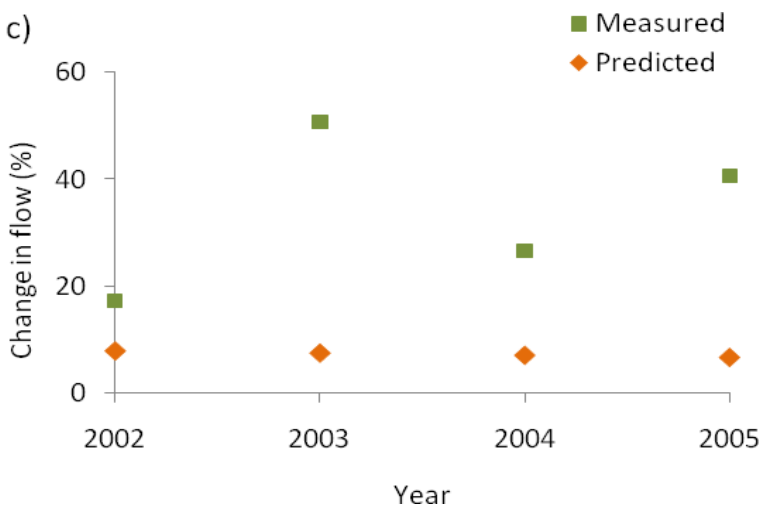
Comparison of measured and predicted 99th percentile flows



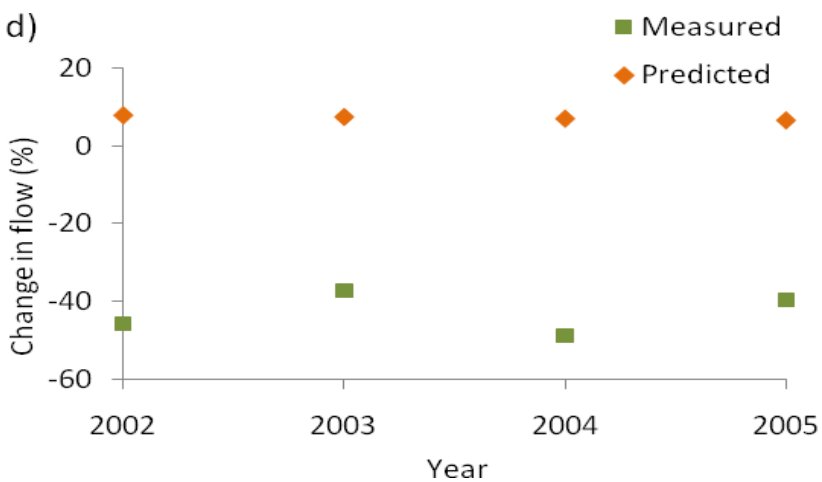
Mack Creek



North Fork



Watershed 1



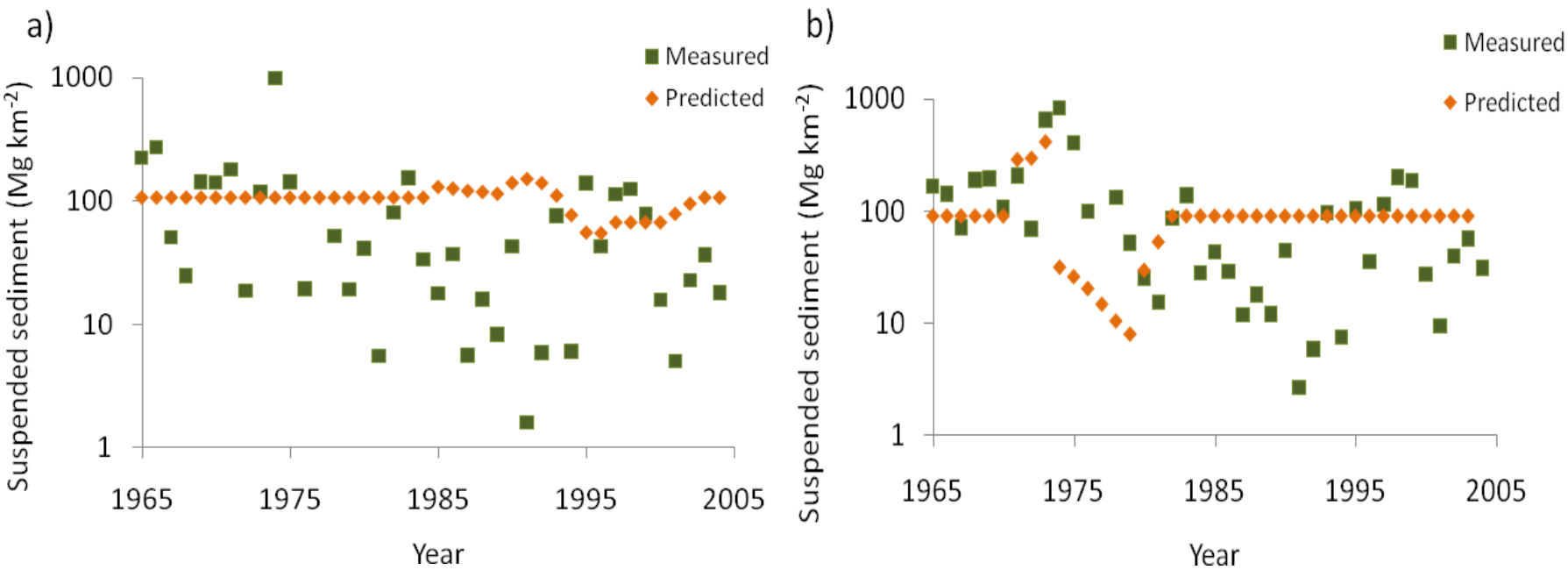
Watershed 2

Evaluation of FOREST

1) Annual suspended sediment yields at Caspar Creek, and

2) Annual predicted bedload yields against measured values from weir ponds at Caspar Creek.

Comparison of measured and predicted suspended sediment at Caspar Creek



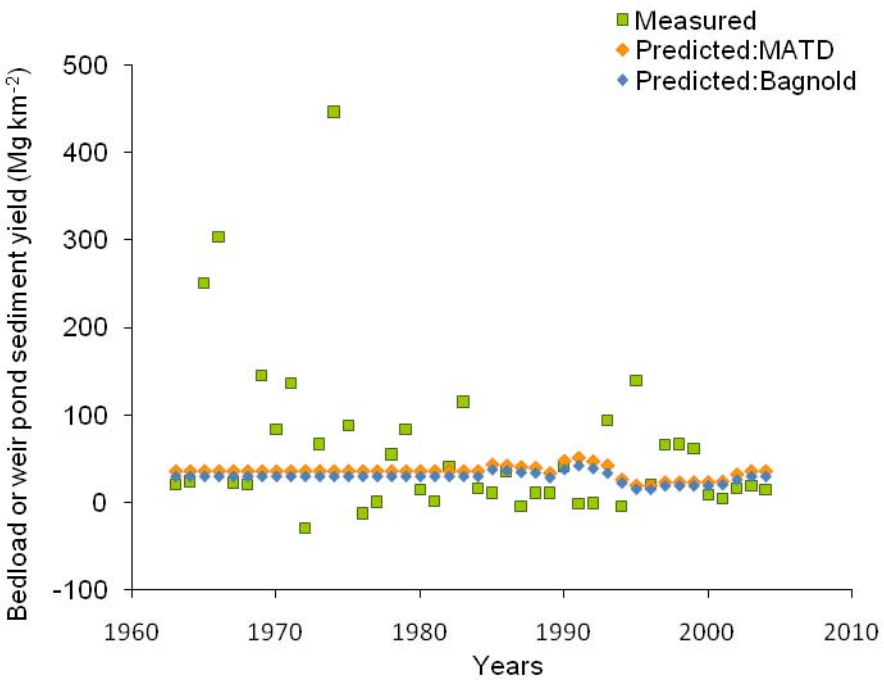
North Fork

South Fork

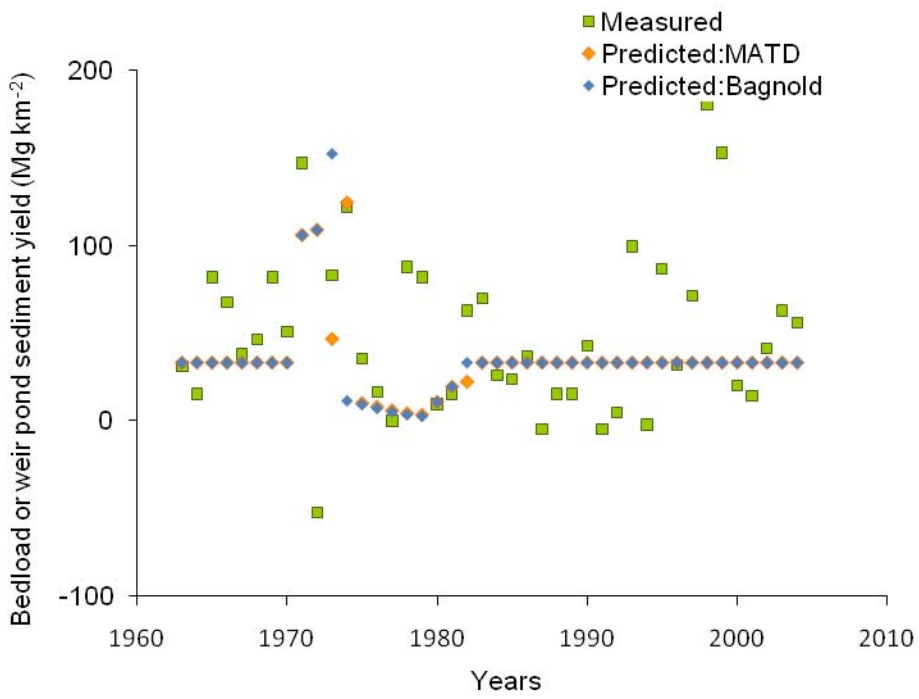
FOREST over-predicts suspended sediment yields on average:

- The background sediment production rate is too high;
- Sediment delivery is too low from 3 to 10 years after harvest because the predicted regrowth is too efficient at filtering sediment.

Comparison of measured weir pond and predicted bedload sediment at Caspar Creek using mean annual travel distance and Bagnold's equation



North Fork



South Fork

Comparison of measured weir pond and modeled bedload sediment (1)

- Weir pond values were under-predicted but weir pond ≠ bedload because:
  - some suspended sediment settles in weir ponds; and
  - FOREST limited to particles ≤ 2mm;
- Sediment yields are highly correlated with precipitation which is extremely variable;
- Negative weir pond values indicate considerable measurement errors.

Comparison of measured weir pond and modeled bedload sediment (2)

- In the South Fork, other events that caused sedimentary CWEs and complicated validation:
  - Failure of a splash dam in 1967 released > 800 Mg of sediment;
  - 15 landslides were mapped;
  - A single landslide released 700 Mg of sediment in 1974;
  - A landing was located on the toe of an old landslide and released more sediment than expected

  (Rice *et al .,* 1979).

Modeling conclusions (1)

Delta-Q and FOREST:

- Require minimal, readily available data inputs;
- Provide a step-by-step GUI and help files to guide users;
- Provide spatially and temporally explicit results in the form of GIS layers and tables that have multiple uses;
- Provide a reasonable first order estimate of CWEs.

Modeling conclusions (2)

Using the models, land managers can:

- Identify source areas for sediment on hillslopes and roads;
- Predict which stream reaches have the greatest risk for sedimentation;
- Show the effect of different recovery rates on CWEs;
- Assess past and current CWEs among watersheds;
- Predict CWEs for different scenarios in the same watershed or among watersheds; and
- Document and support scenarios that minimize CWEs.

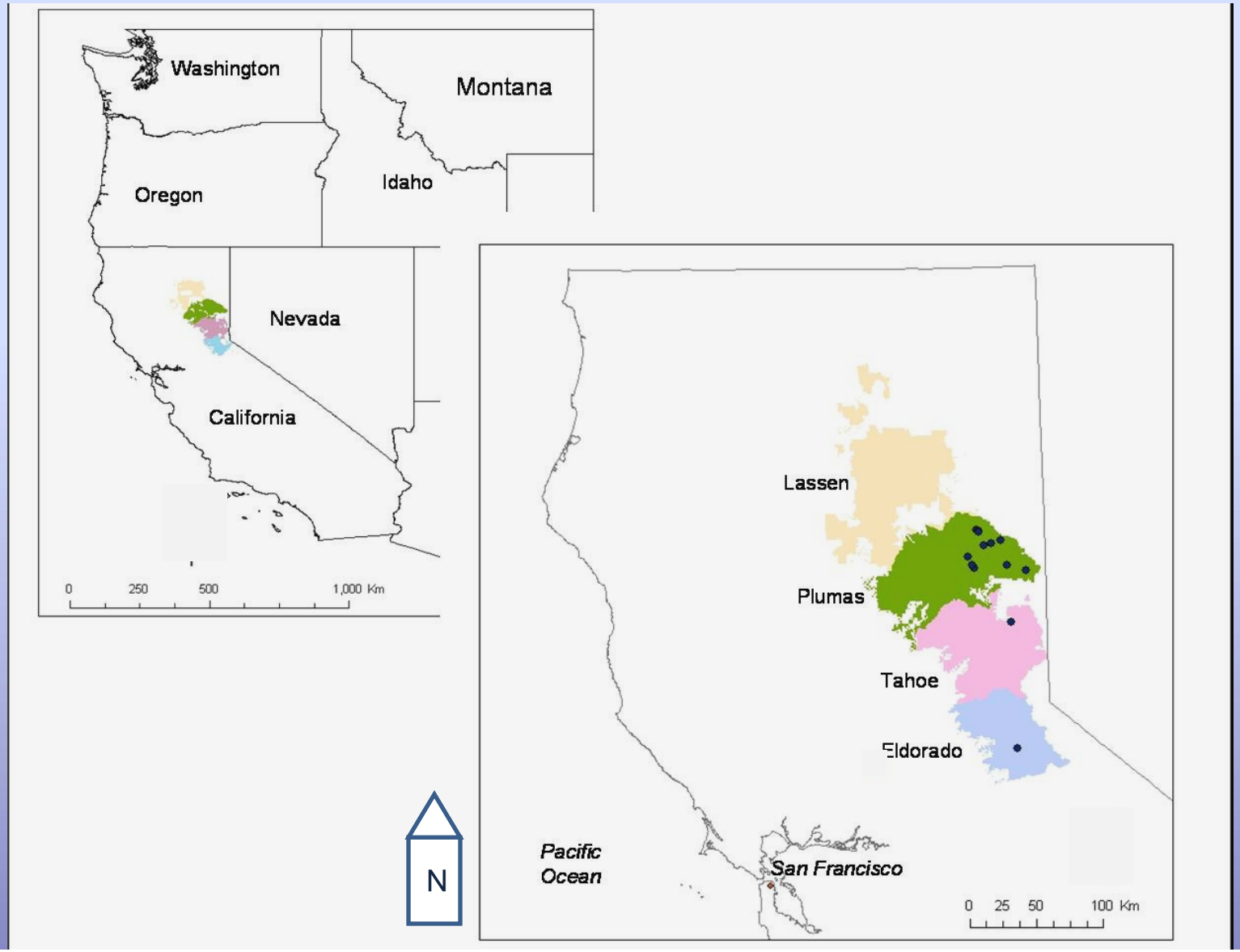
Assessing hillslope delivery from timber harvest areas

- Timber harvest is the largest area of disturbance in forested watersheds;
- Harvested areas can generate from 1 to 5 times more erosion than undisturbed areas;
- Sediment production that reaches the streams is a problem; and
- Lack of hillslope delivery data and models.

Fieldwork objectives

- Determine the frequency of off-site rills and sediment plumes from timber harvest units;
- Measure the connectivity and other physical characteristics of the sediment pathways; and
- Develop an empirical model for predicting sediment delivery from timber harvest units to streams.

-Walked the downslope edges of 200 harvest units on four National Forests searching for rills and sediment plumes



Methods when a rill or sediment plume was identified

- Collected feature type, length, depth, width, years since harvest, hillslope gradient, surface roughness, mean annual precipitation, soil type, and hillslope aspect.
- Classified features as connected when they came within 10 m of a stream channel.
- Excluded roads and fires.

Results

- Found 15 rills and 4 sediment plumes;
- Lengths ranged from 10 to 220 m;
- Harvest units ranging in age from 2 to 18 years;
- Length was significantly related to mean annual precipitation, cosine of the aspect, elevation, and hillslope gradient (R^2 = 64%, p = 0.004);
- 6 of the 19 features were connected to streams;
- 5 of the 6 features originated from skid trails.

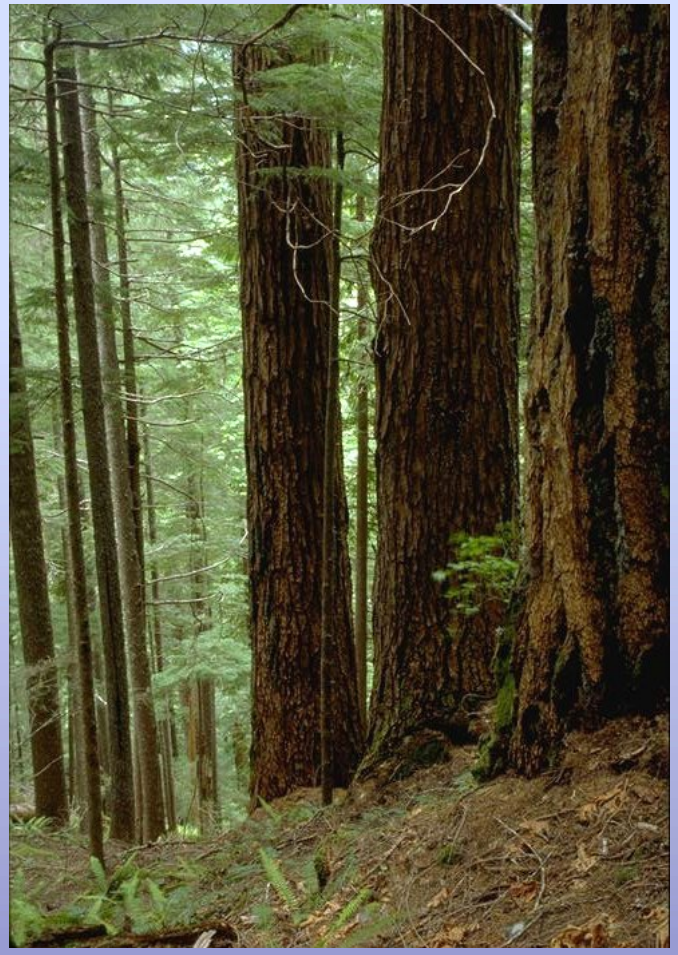
Conclusions and suggestions

- Timber harvest alone rarely initiated large amounts of surface runoff and surface erosion;
- Newer harvest practices were more effective;
- Legacy effects should be monitored;
- Sediment delivery from timber harvest may be further reduced by:
  - locating skid trails away from streams,
  - constructing more frequent water bars,
  - maintaining high surface roughness downslope of water bars, and
  - ripping skid trails after harvest.

Summary

- Developed, verified, evaluated, and analyzed sensitivity of Delta-Q and FOREST; and

- Conducted fieldwork to assess sediment delivery from timber harvest units to streams.



Suggestions for future research

1. More long term measured data for discharge and sediment;
2. Model improvements:
   - Sub-models for landslides, bed and bank erosion;
   - Stochastic function
   - A timeline for roads construction and maintenance;
3. Independent evaluations of Delta-Q and FOREST and comparison to other models are needed but:
   - 2 evaluators found the early models easy to use, and
   - Nick Hayden (UCSB) found FOREST results to be more accurate than SWAT.

Questions?

Thanks!

- Advisor: Lee MacDonald
- Committee: Melinda Laituri, Brian Bledsoe, Sara Rathburn
- Funding: USFS R5 and Stream Technology Team
- Data: Caspar Creek, H.J. Andrews, Mica Creek, Eldorado, Plumas, Lassen, & Tahoe NF;
- Fellow students, friends and family;
- John and Hitch.