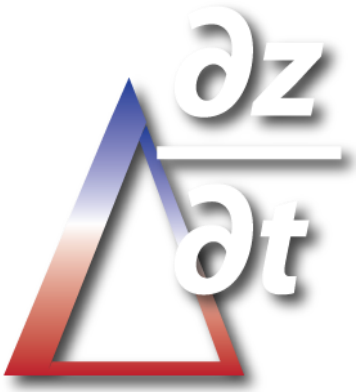
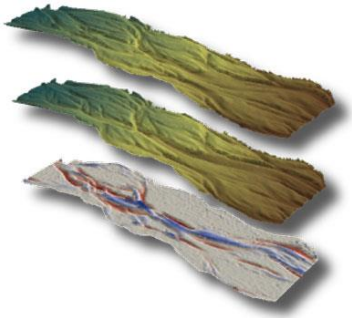
GEOMORPHIC CHANGE DETECTION



NOT
ACTUALLY
RIGHT



NORTH
ARROW
RESEARCH

BY END OF SESSION

You should understand:

1. GCD techniques and how they are applied to monitoring rivers
2. How we account for uncertainties in DEMs
3. How to interpret DoDs

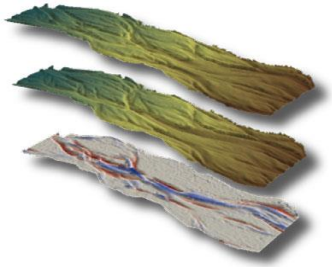
GCD ≠ Glen Canyon Dam

GCD = Geomorphic Change Detection

≈ ?

DoD ≠

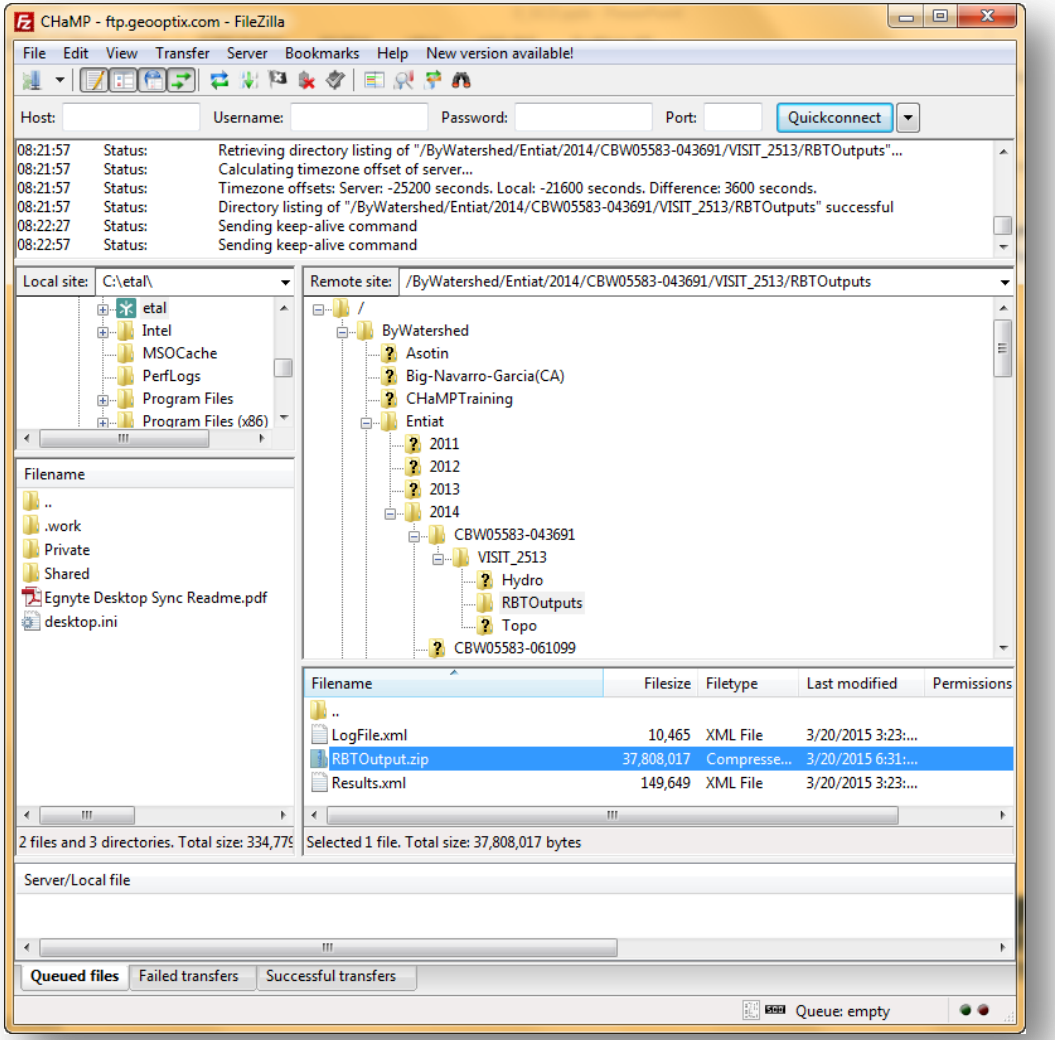
DoD = DEM of Difference =



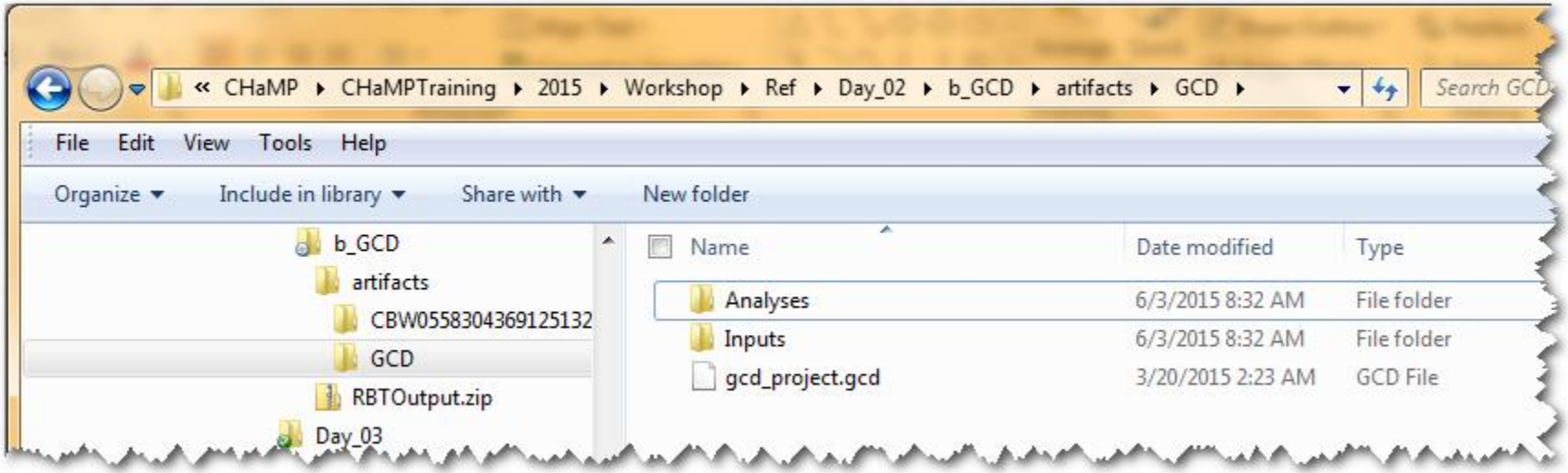
IF YOU DOWNLOAD GCD PROJECT….

- What does it mean?
- How can I interpret results?
  - Map
  - Tabular
- How can I do additional analyses?

In the `RBTOutput.zip`



GCD OUTPUT BY VISIT…

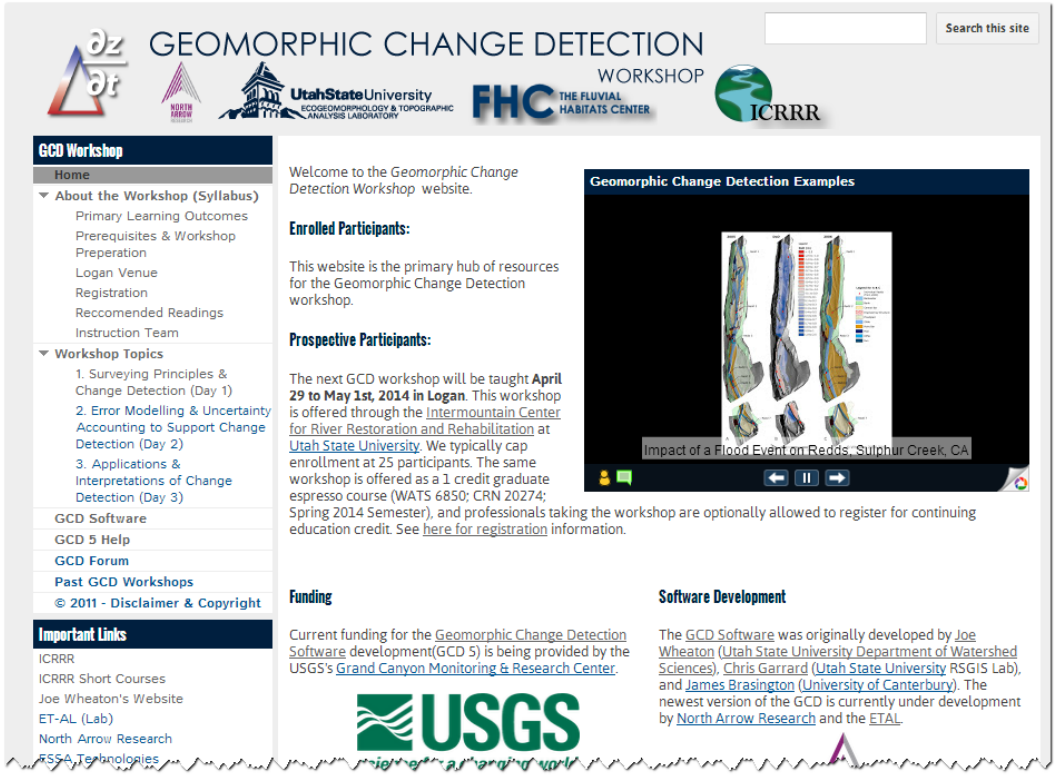


- In the `RBTOutput.zip` is the artifacts folder. In that is:
  - The Visit RBT Outputs
  - The GCD project folder…

WORKSHOP WEBSITE

gcdworkshop.joewheaton.org

- No need for frantic note taking…
- Syllabus
- Workshop Topics
  - Lecture Slides
  - Exercises
  - Additional Resources & References
- Links to Software & Help Forums



http://gcdworkshop.joewheaton.org

WARNING: We normally cover this material in 2 to 3 day workshops!

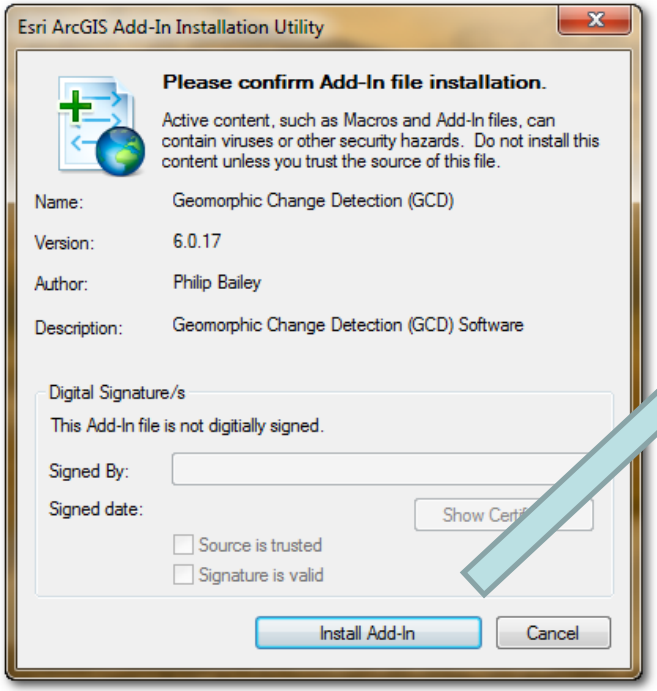
LET'S BREAK SOMETHING…

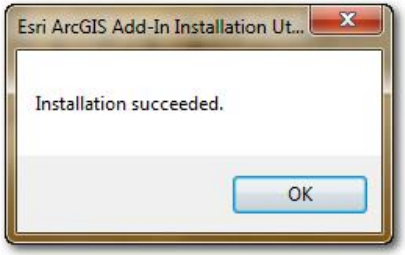
- Make sure ArcGIS 10.X is Installed, but Not Open
- Download Latest GCD 6 from: gcd.joewheaton.org/downloads
  - http://gcd.joewheaton.org/downloads

1

2

3

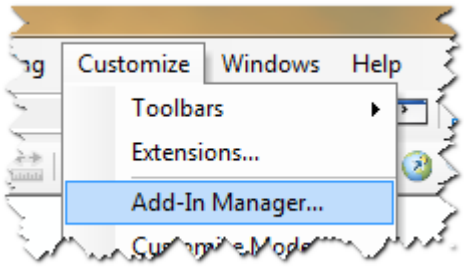




MAKE SURE IT WORKED!

1. Start ArcGIS
2. Go to Add-In Manager
3. Check its there
4. Turn Toolbar on

2



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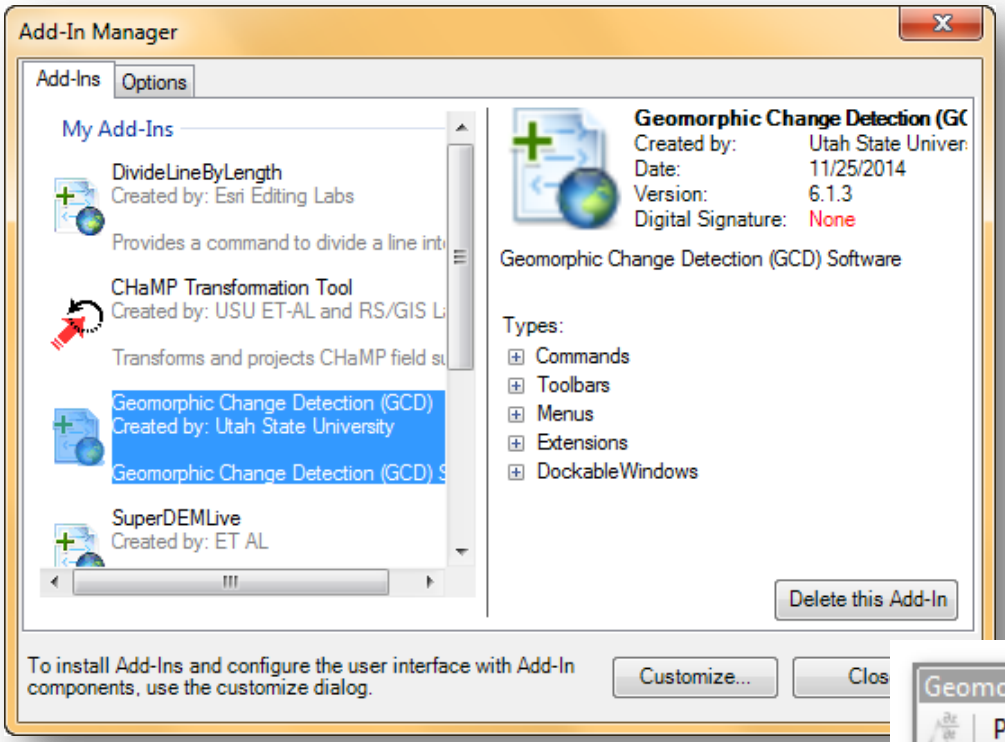

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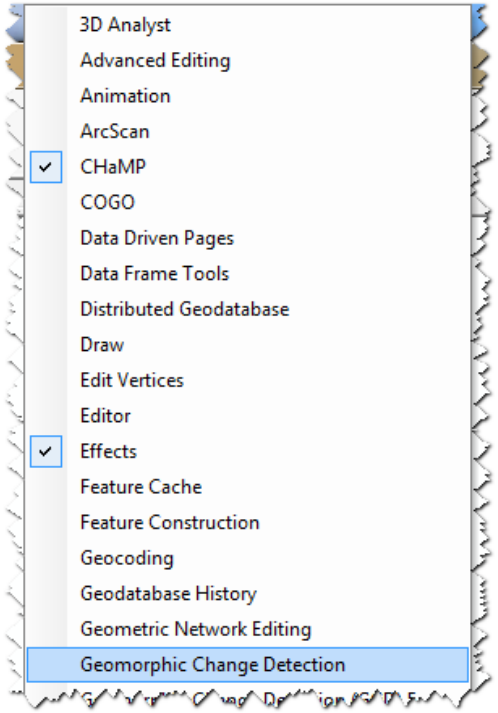
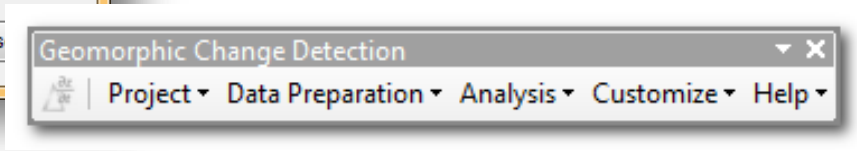




INTERSPERSE LECTURES WITH… HANDS-ON EXERCISES

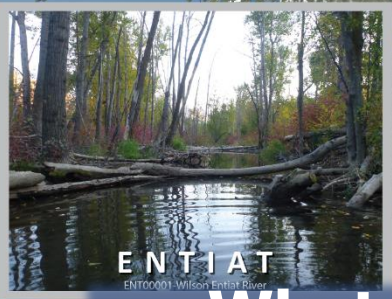
To Make Exercises Efficient:

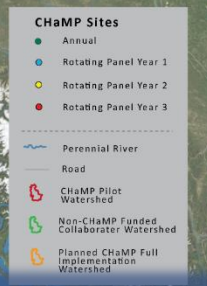
- Start up ArcGIS (leave idle in blank document)
- Make sure extensions are on
- Make sure GCD 6 toolbar is loaded
- Make sure exercise data is copied to: `c:\0_Worskhop\` or similarly easy place to find…

COLUMBIA HABITAT MONITORING PROGRAM
MONITORING SITE LOCATIONS, COLUMBIA RIVER WATERSHED

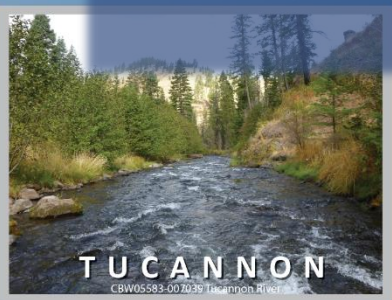
CHaMP Columbia Habitat Monitoring Program

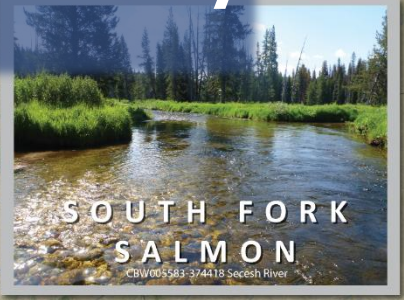
Funding Entities

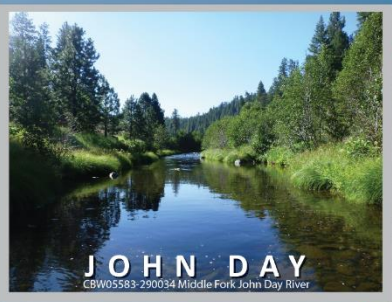


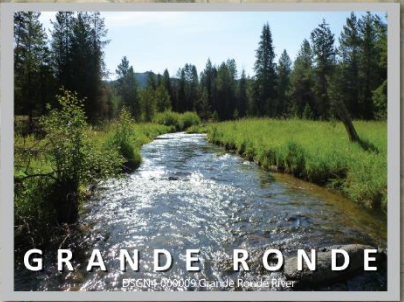


What can geomorphic change tell us about habitat conditions for fish across a huge diversity of reach types?







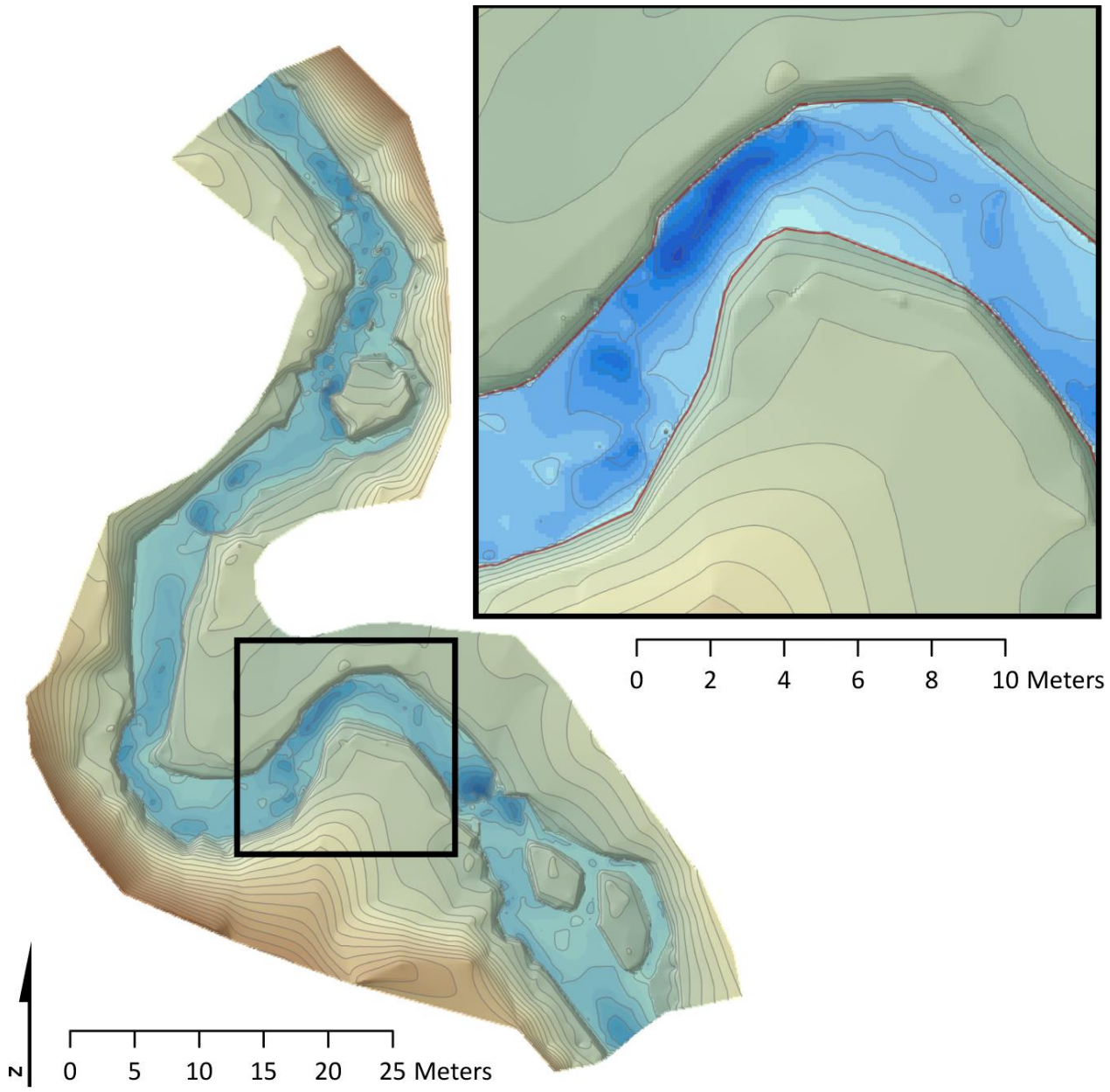


Development Team:

Other Collaborators:

champmonitoring.org

A TYPICAL CHaMP TOPO SURVEY



CHaMP TOPO SANDBOX

CHaMP | Columbia Habitat Monitoring Program

BONNEVILLE POWER ADMINISTRATION

~~Pilot~~ Phase

- 11 Watersheds throughout the Columbia Basin
- Roughly 45-55 sites in each basin (10-15 annual): +700 Total

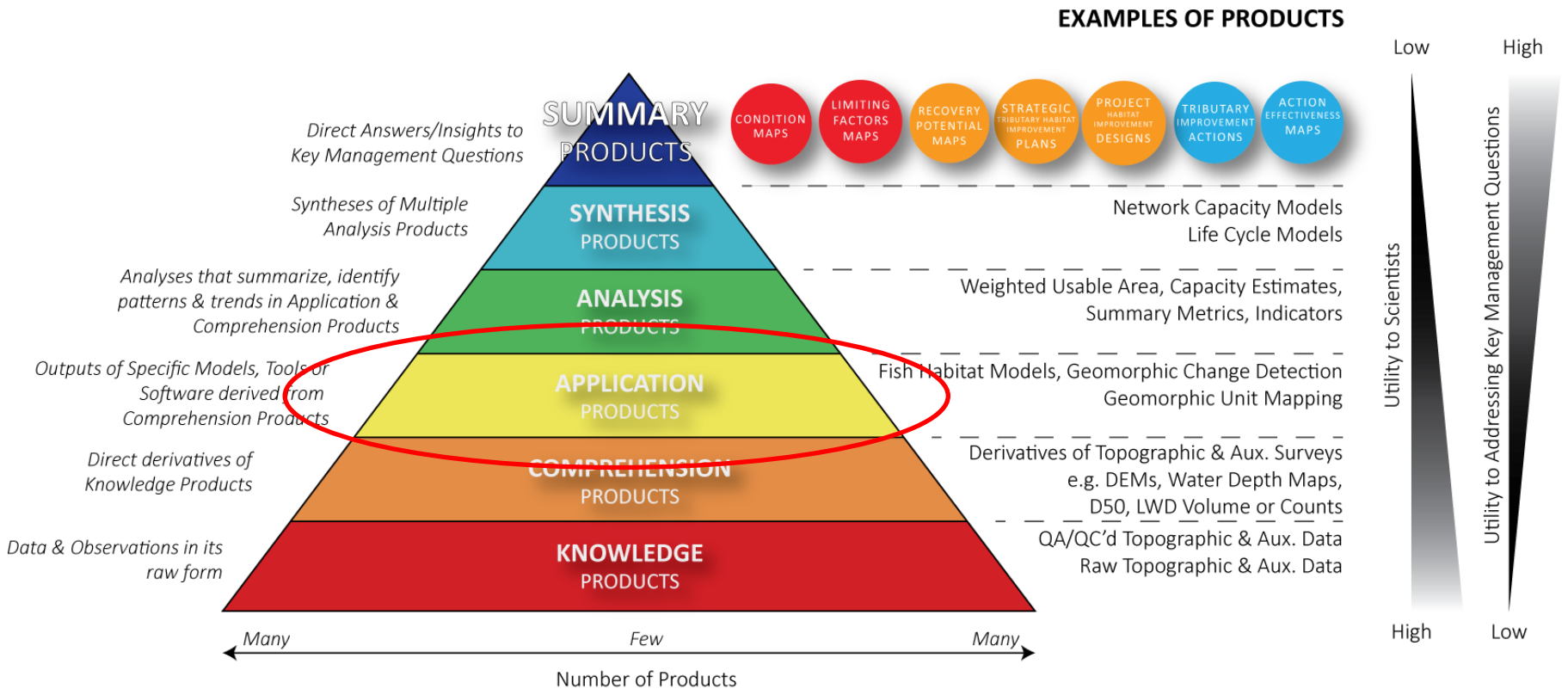
Full Implementation?

- Up to 26 Watersheds
- ~1200 sites

Map by Martha Jensen
See http://champmonitoring.org

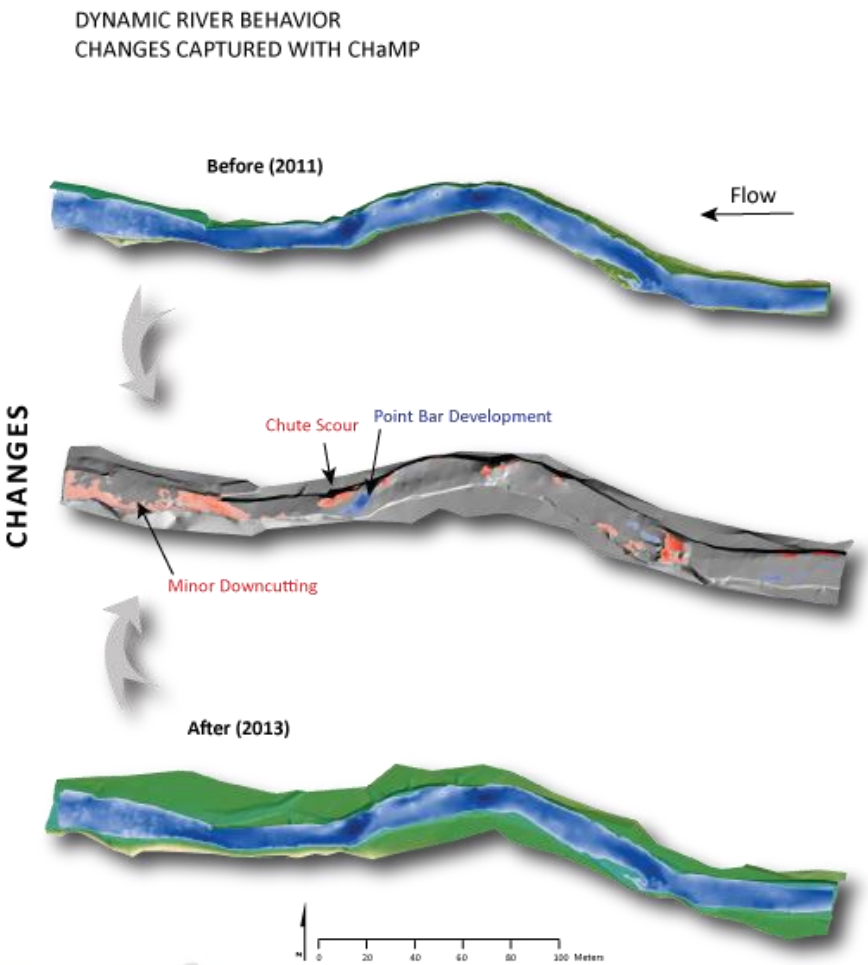
Utah State University
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY

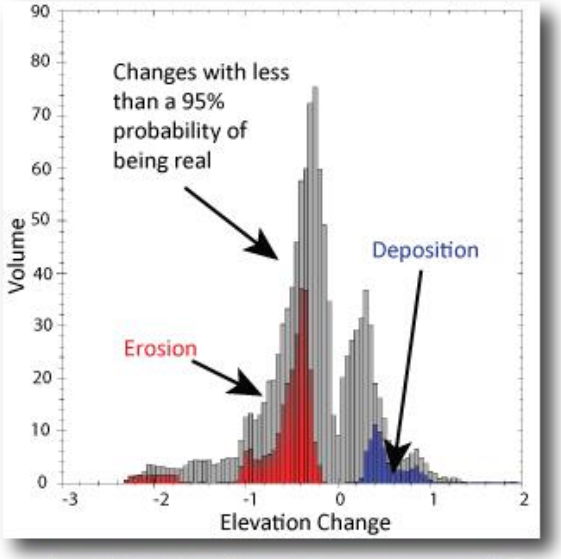
WHERE GCD FITS IN PRODUCT FAMILY



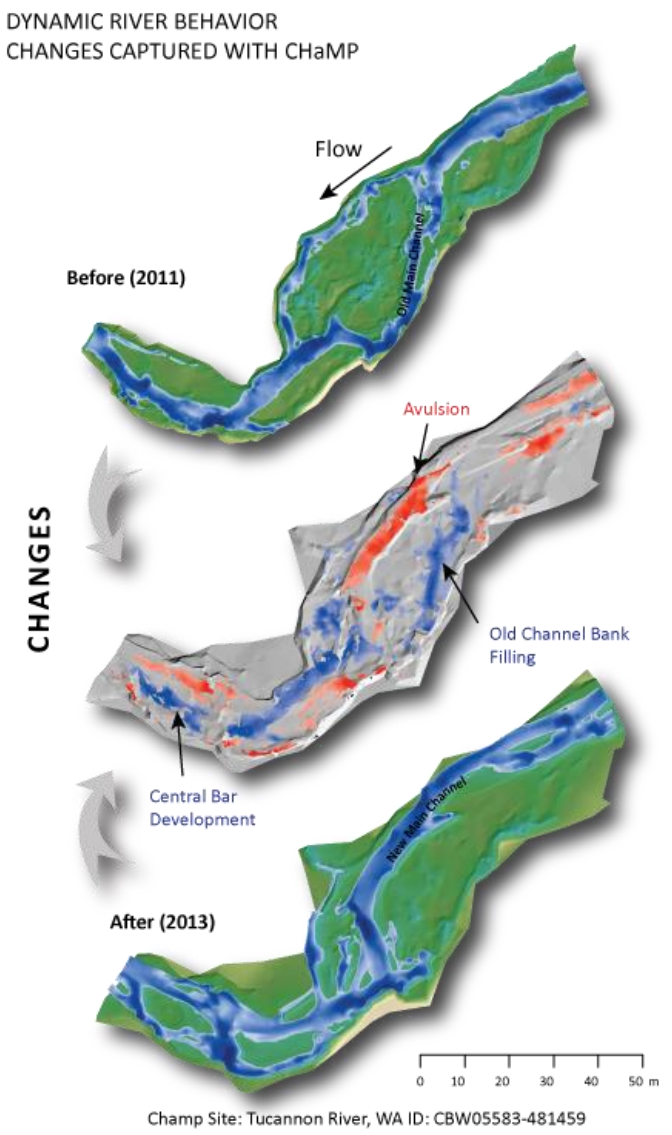
An *application product* that uses repeat surveys of DEMs (*comprehension products*) to quantify **trends** (i.e. geomorphic changes)

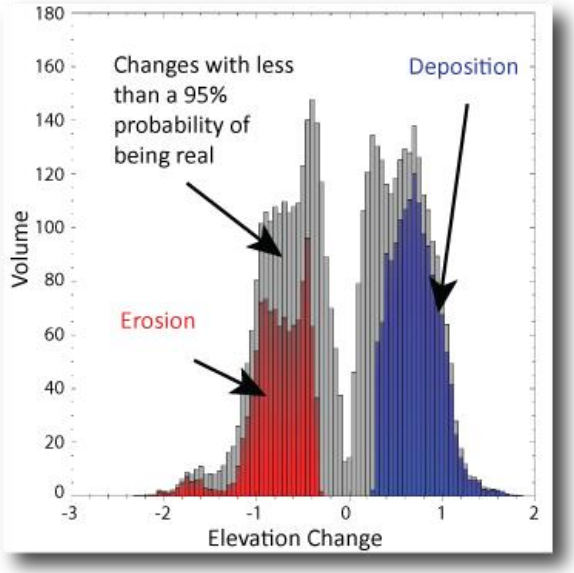
GCD TO DESCRIBE BEHAVIOR… IN A POOR CONDITION VARIANT





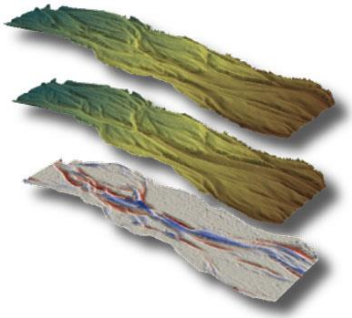
GCD TO DESCRIBE BEHAVIOR… IN A GOOD CONDITION VARIANT





GEOMORPHIC CHANGE DETECTION

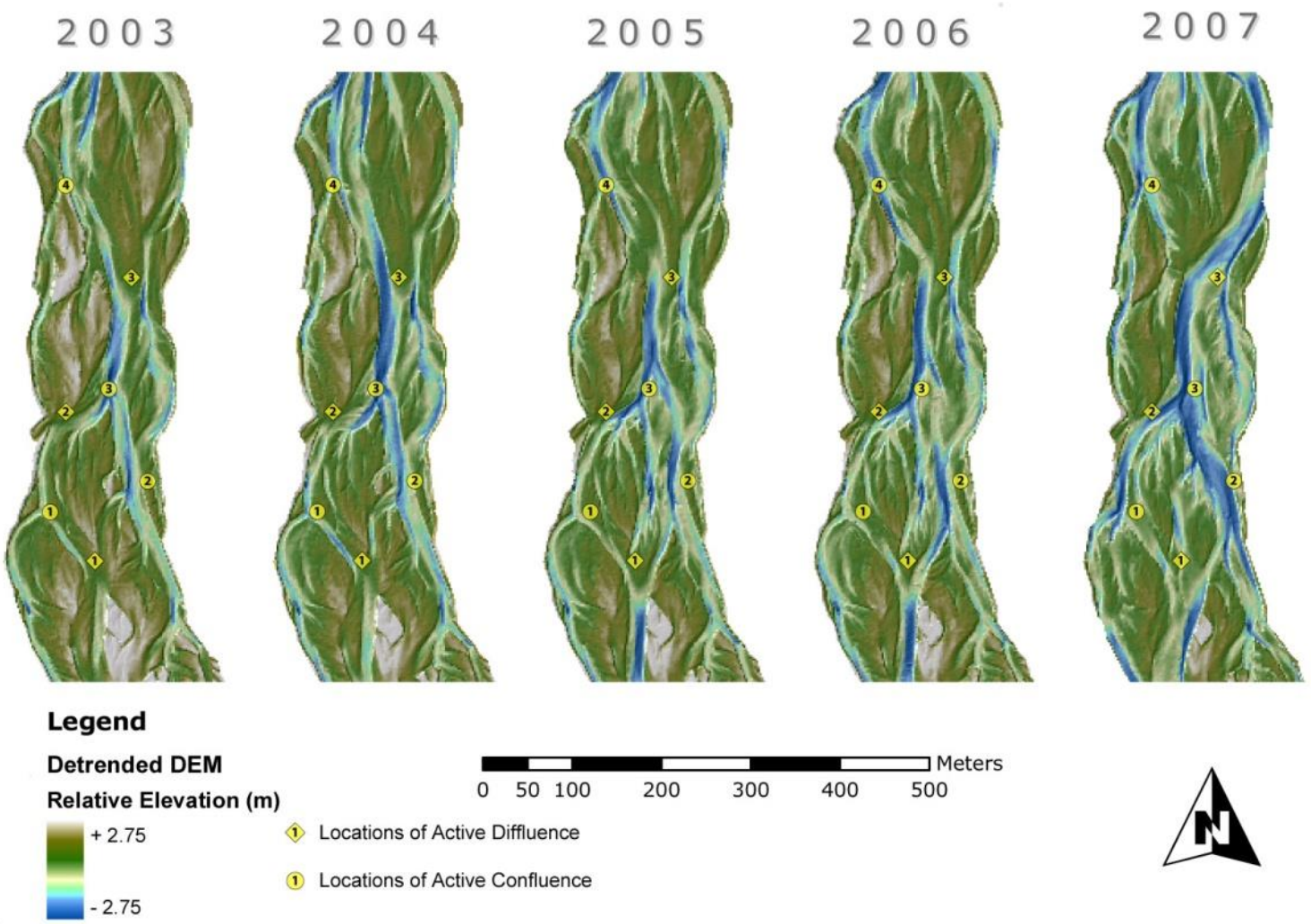
TRADITIONAL APPROACHES TO GEOMORPHIC CHANGE DETECTION



NORTH ARROW RESEARCH

HOW CAN WE CALCULATE CHANGE?

- Given these DEMs through time, what could we use to calculate change?



DETAIL PLAN

TRADITIONAL APPROACHES TO GEOMORPHIC CHANGE DETECTION

1. Background Problem

2. Basic DEM Differencing

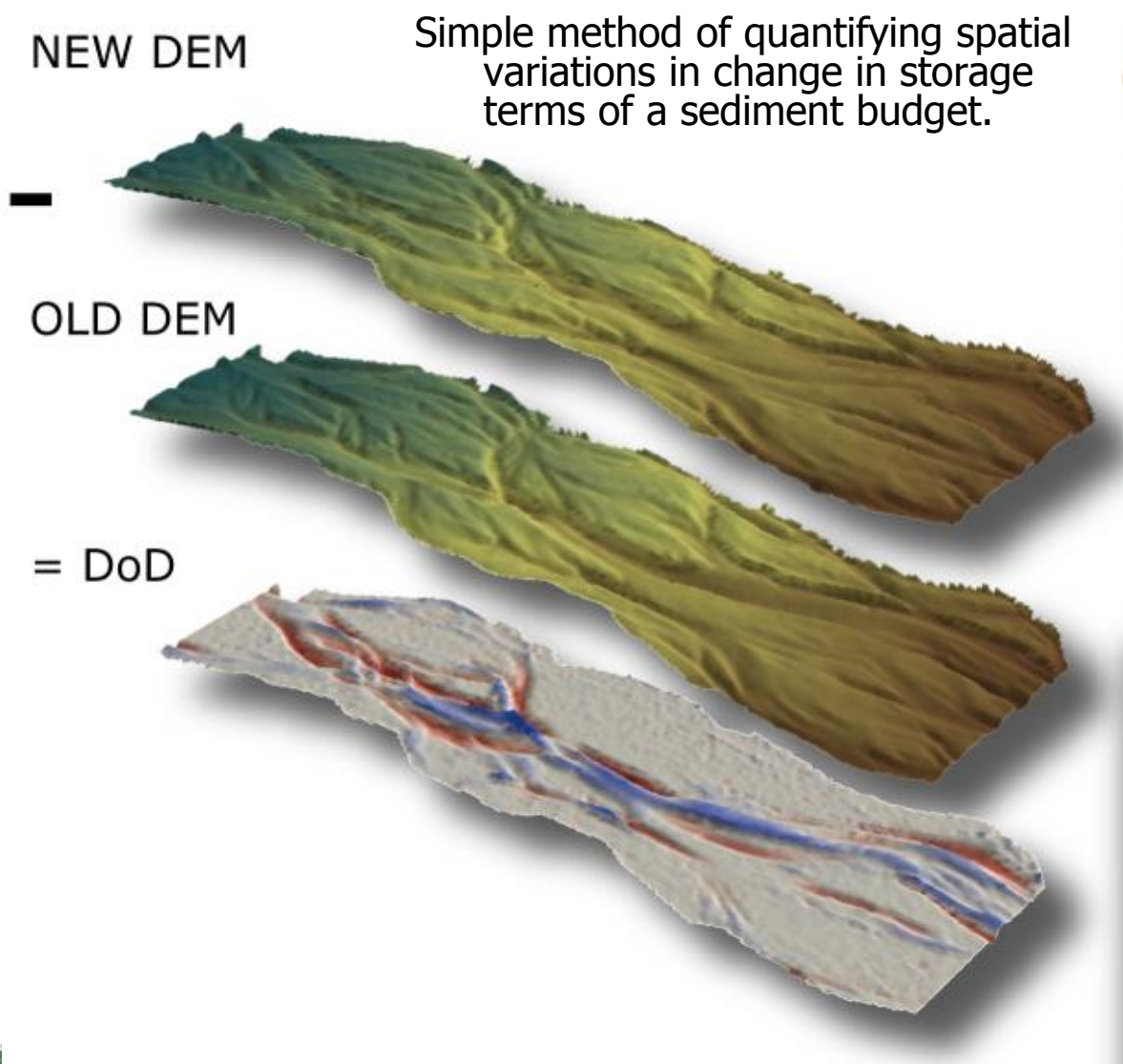
3. Raster Calculator DoD Example

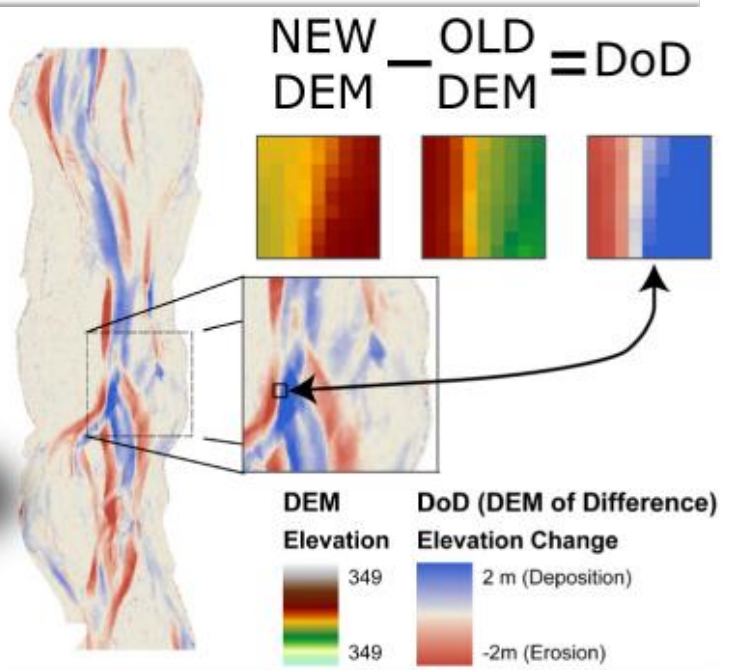
4. Simple Thresholding

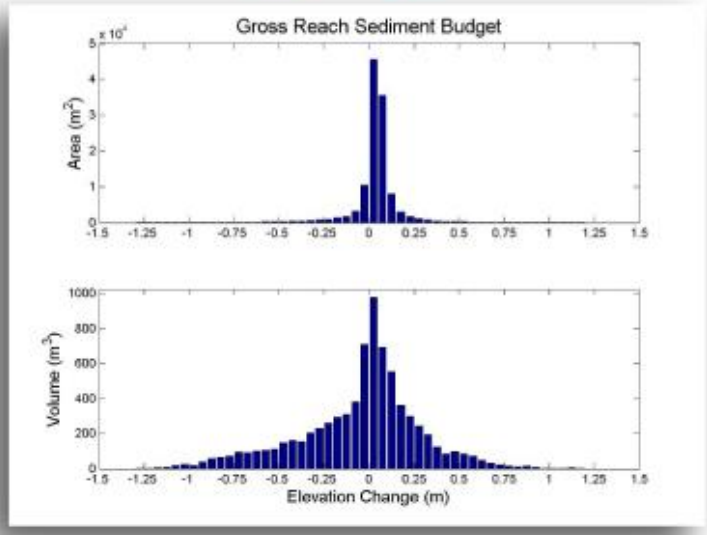
5. Raster Calculator Threshold Example

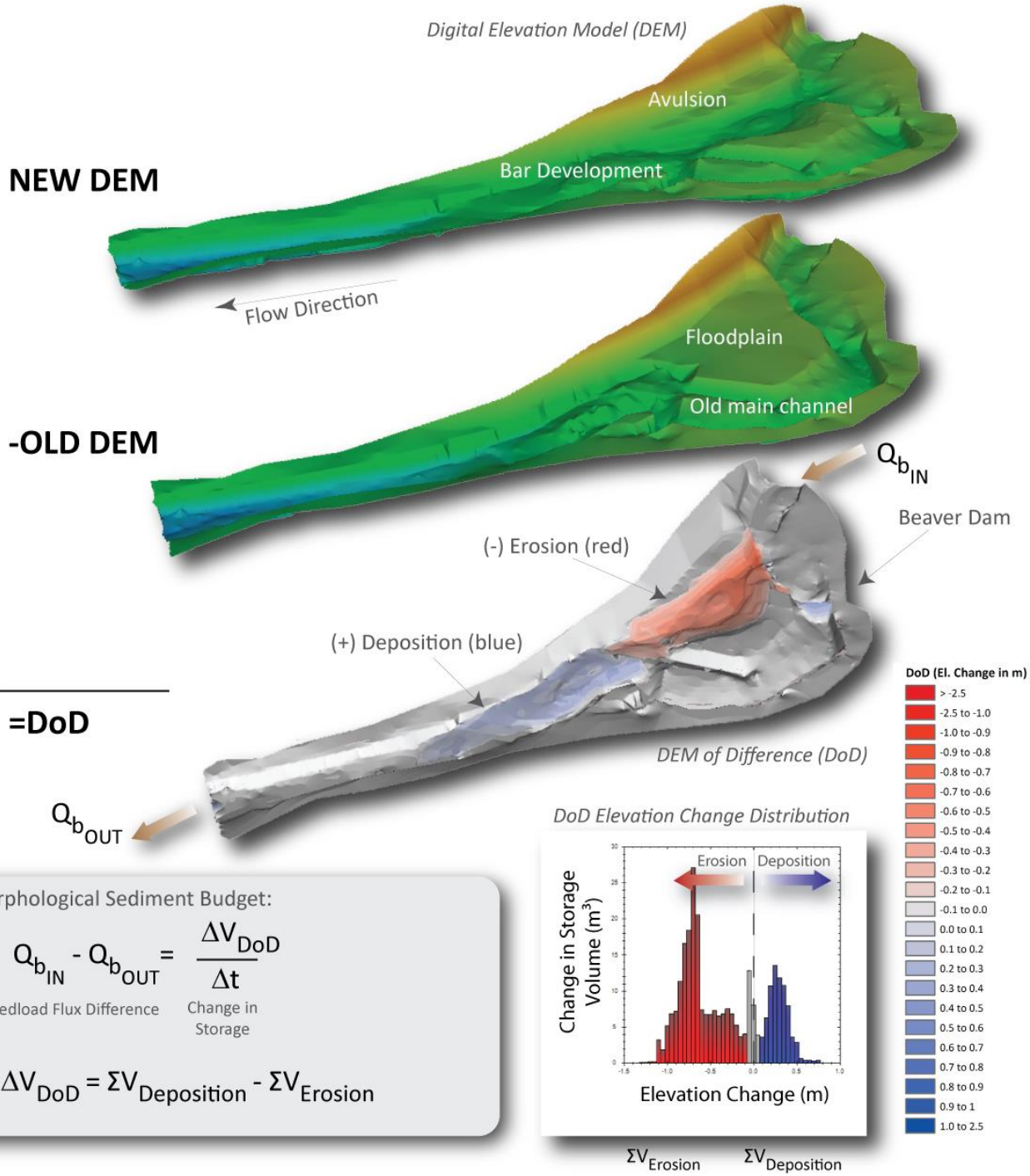
DEM DIFFERENCING

Simple method of quantifying spatial variations in change in storage terms of a sediment budget.









Morphological Sediment Budget:

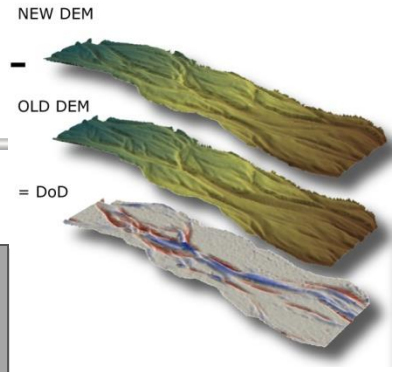
$$Q_{b_{IN}} - Q_{b_{OUT}} = \frac{\Delta V_{DoD}}{\Delta t}$$

Bedload Flux Difference

Change in Storage

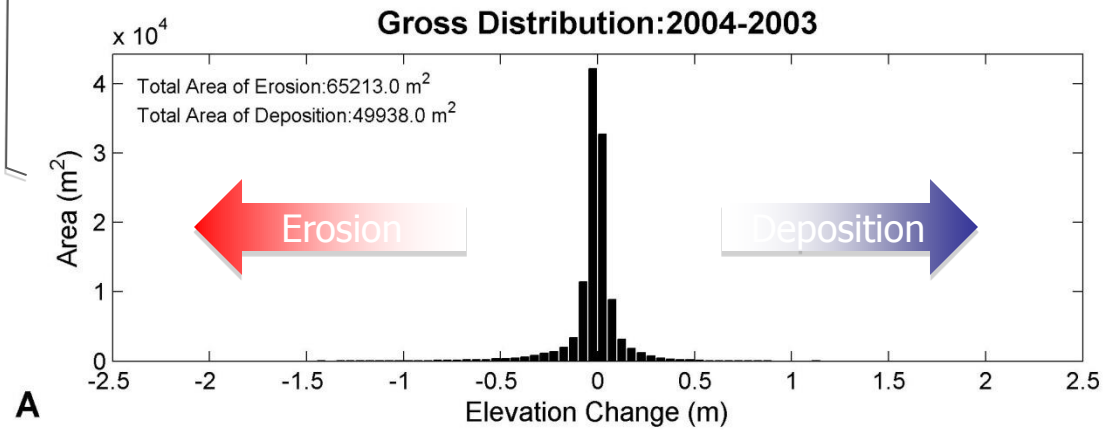
$$\Delta V_{DoD} = \Sigma V_{Deposition} - \Sigma V_{Erosion}$$

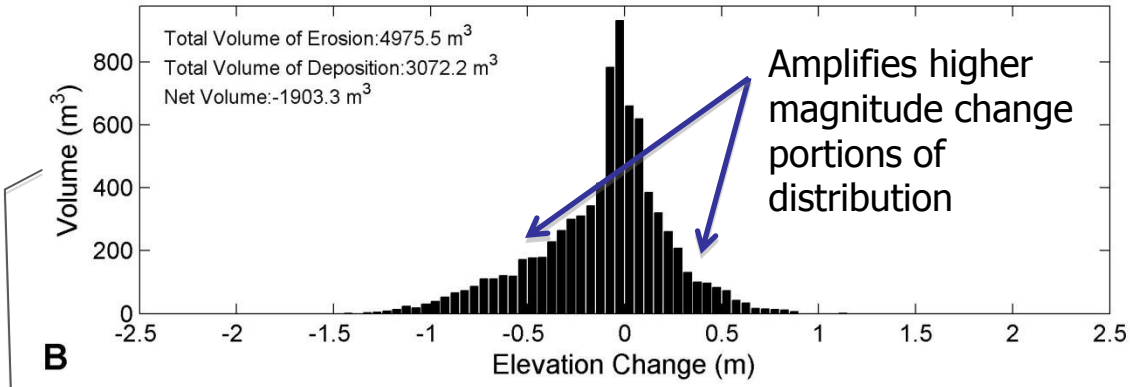
WHAT'S THE HISTOGRAM OF?



- What about the DoD?
- Values on vertical derived in different ways
- Same information revealed differently…

Multiply count by cell size^2 to get area

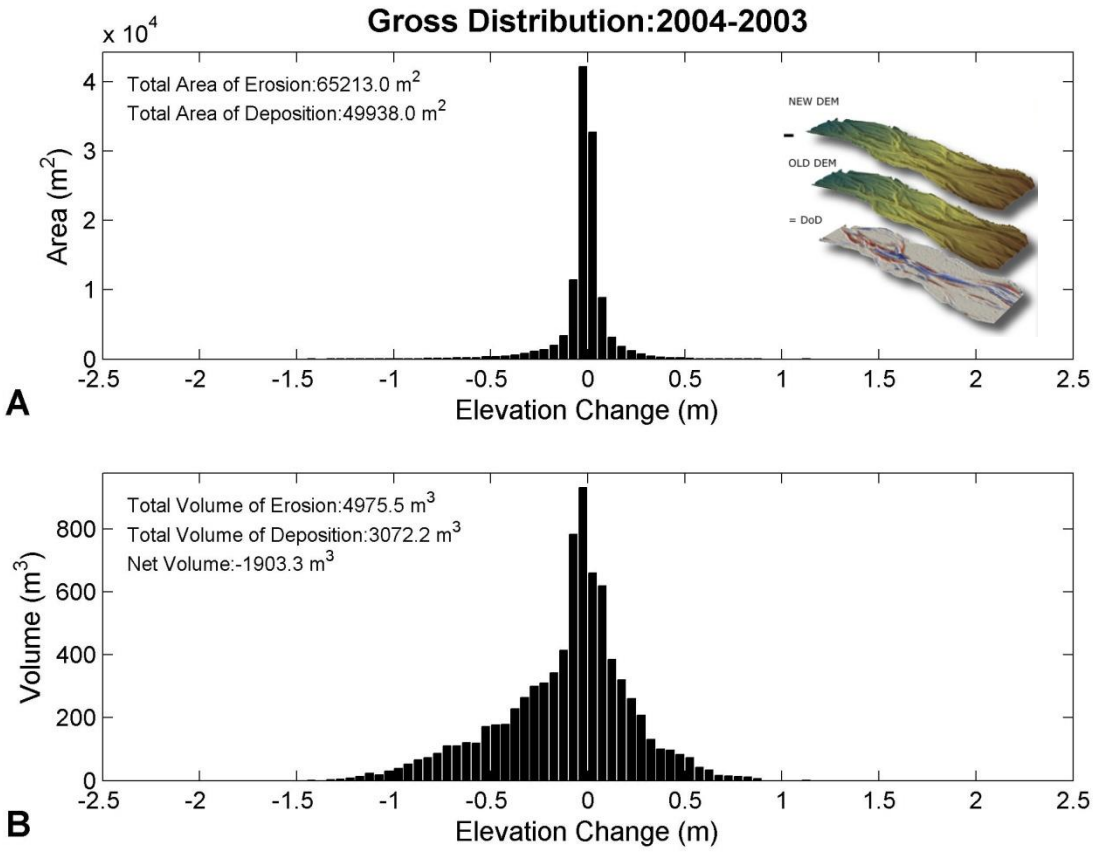




Multiply area by elevation change to get volume

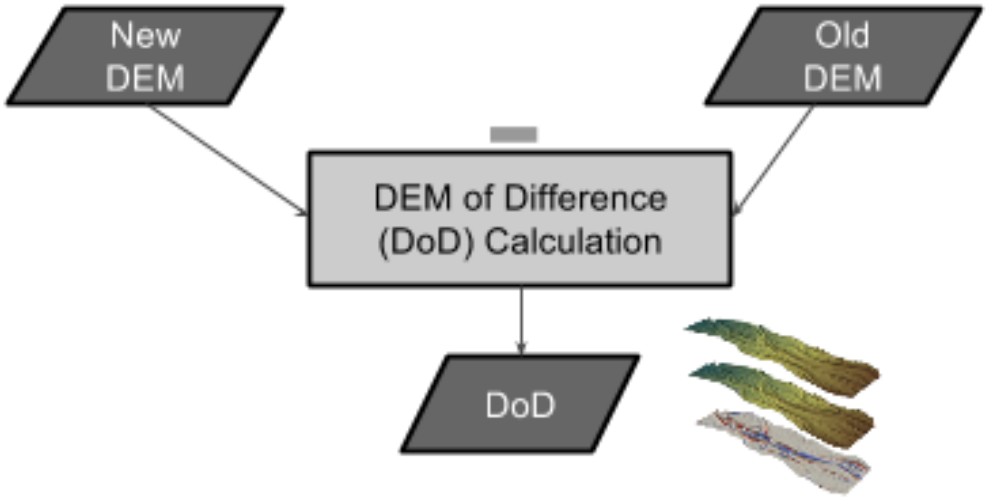
WHY IS SO MUCH OF DoD DISTRIBUTION CENTERED AROUND ZERO?

- Is it real?
- Are there just a lot of small changes?
- What needs to happen to get NO change?
- What is likelihood of measuring exact same value?



'SO… THIS IS *JUST* A SIMPLE SUBTRACTION PROBLEM?'

- $DoD = DEM_{new} - DEM_{old}$



DETAIL PLAN

TRADITIONAL APPROACHES TO GEOMORPHIC CHANGE DETECTION


1. Background Problem


2. Basic DEM Differencing

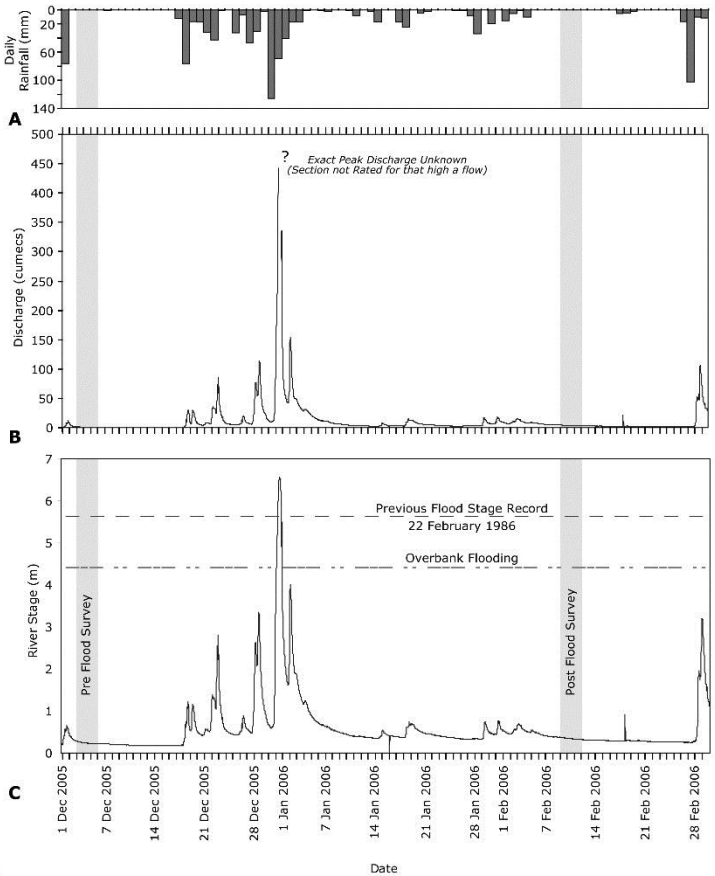

3. Raster Calculator DoD Example


4. Simple Thresholding

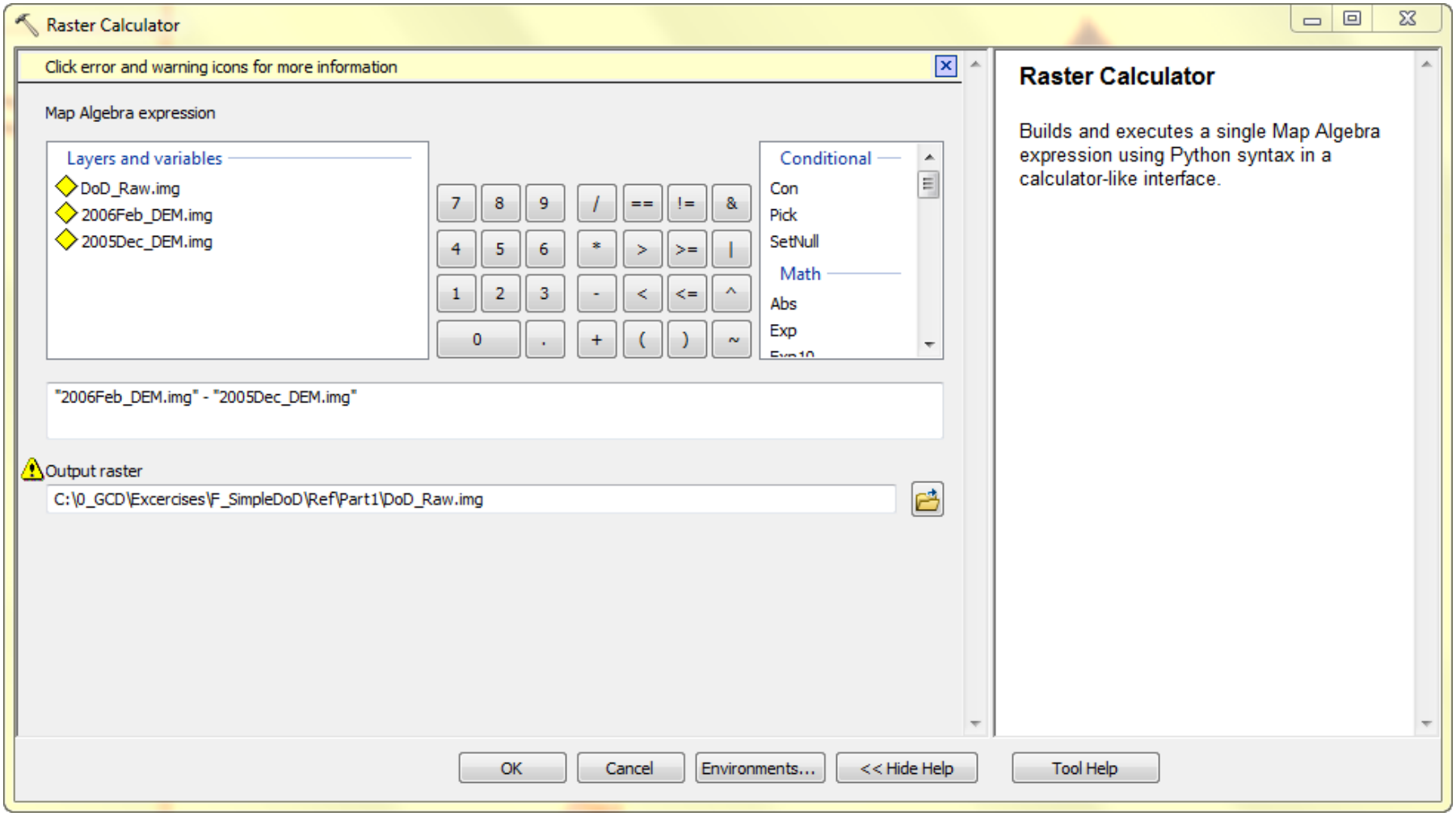

5. Raster Calculator Threshold Example

5 MINUTES…

- DoD w/ Sulphur Creek, CA



WHAT TO DO…


Raster Calculator
Click error and warning icons for more information
Map Algebra expression
Layers and variables
DoD_Raw.img
2006Feb_DEM.img
2005Dec_DEM.img
7 8 9 / == != &
4 5 6 * > >= |
1 2 3 - < <= ^
0 . + ( ) ~
Conditional
Con
Pick
SetNull
Math
Abs
Exp
"2006Feb_DEM.img" - "2005Dec_DEM.img"
Output raster
C:\0_GCD\Excercises\F_SimpleDoD\Ref\Part1\DoD_Raw.img
Raster Calculator
Builds and executes a single Map Algebra expression using Python syntax in a calculator-like interface.
OK
Cancel
Environments...
<< Hide Help
Tool Help

EXERCISE G – PART 1.A: RASTER CALC.

`C:\CHaMPWorkshop\Exercises\GCD\G_SimpleDoD\CA_SulphurCreek\Raw_OrthoInputs`

1. Load 2005 & 2006 DEMs
2. Start Raster Calculator
3. Subtract old (2005) from new (2006)
4. Import layer symbology from: `DoD_Raw.img.lyr` and apply to DOD

DETAIL PLAN

TRADITIONAL APPROACHES TO GEOMORPHIC CHANGE DETECTION


1. Background Problem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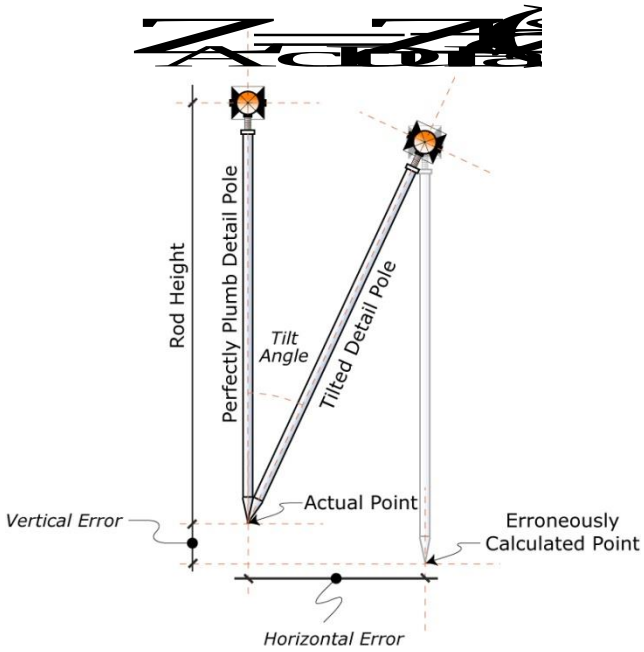
THE CRUX OF THE PROBLEM…

Reliability Uncertainty: Of the predicted changes, what can we actually distinguish from noise?

We want: $\delta(z) < \frac{\partial z}{\partial t}$

But, $\delta(z) \approx \frac{\partial z}{\partial t}$

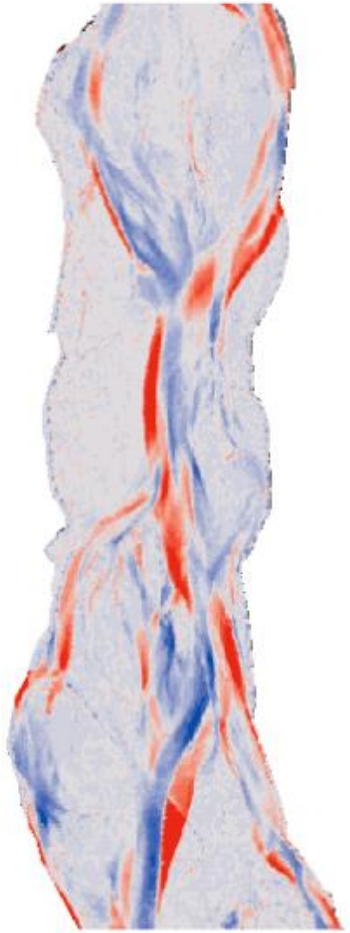


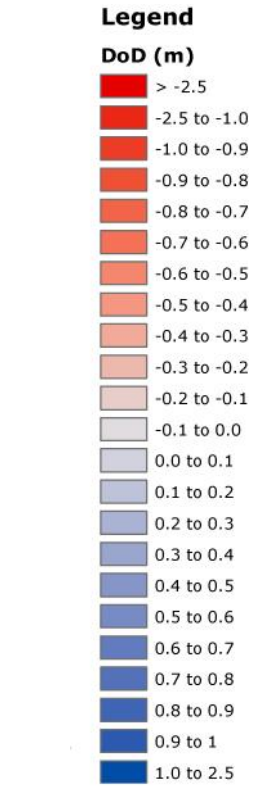
© Wheaton (2008)

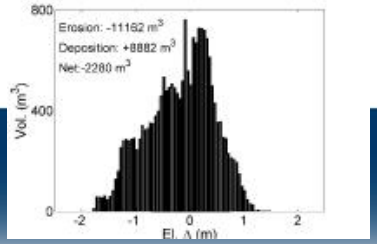
MINIMUM LEVEL OF DETECTION

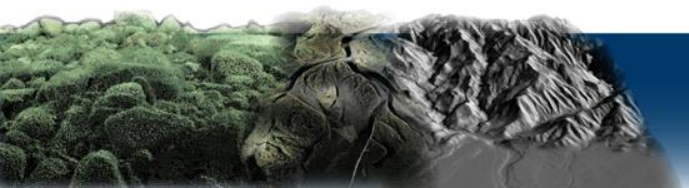
- Should there be change everywhere?

- Distinguish those changes that are real from noise
- Error assumed to be unbiased (toward erosion or deposition)



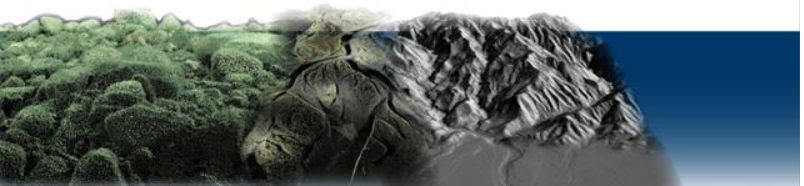


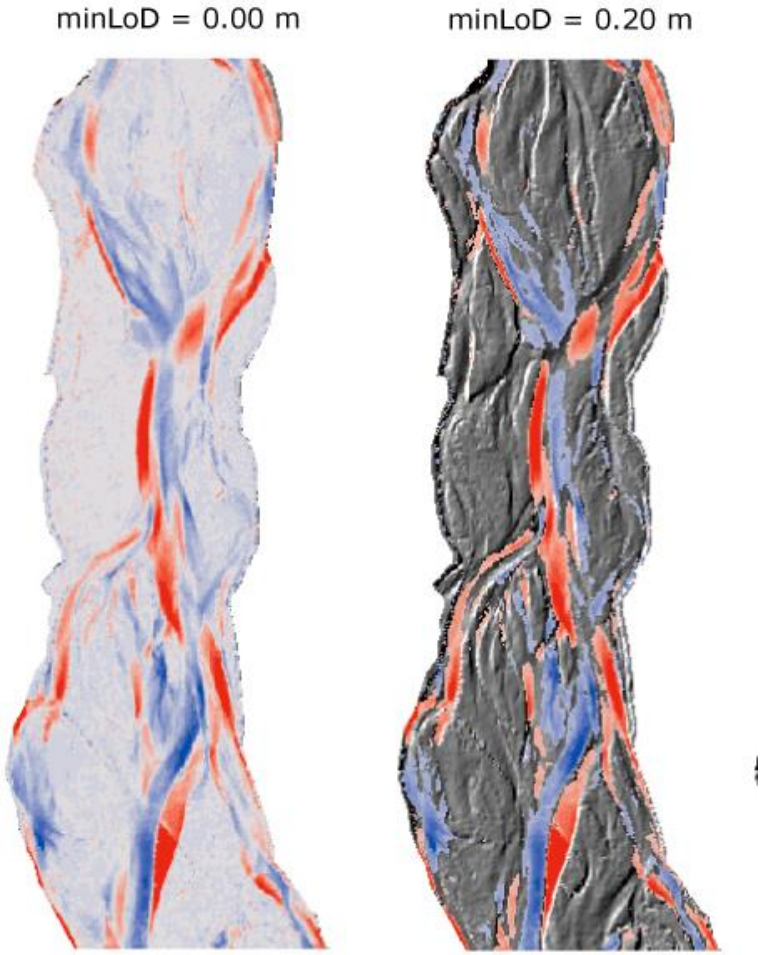


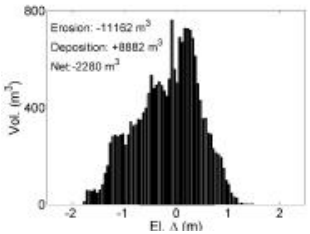


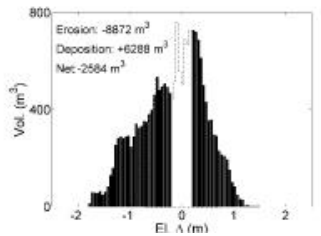
HOW DOES A $_{MIN}$LoD GET APPLIED?

- You take original DoD, and remove all changes <= $_{min}$LoD
- For example +/- 20 cm
- How would you do that?
- What is the assumption here?









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TRADITIONAL APPROACHES TO GEOMORPHIC CHANGE DETECTION


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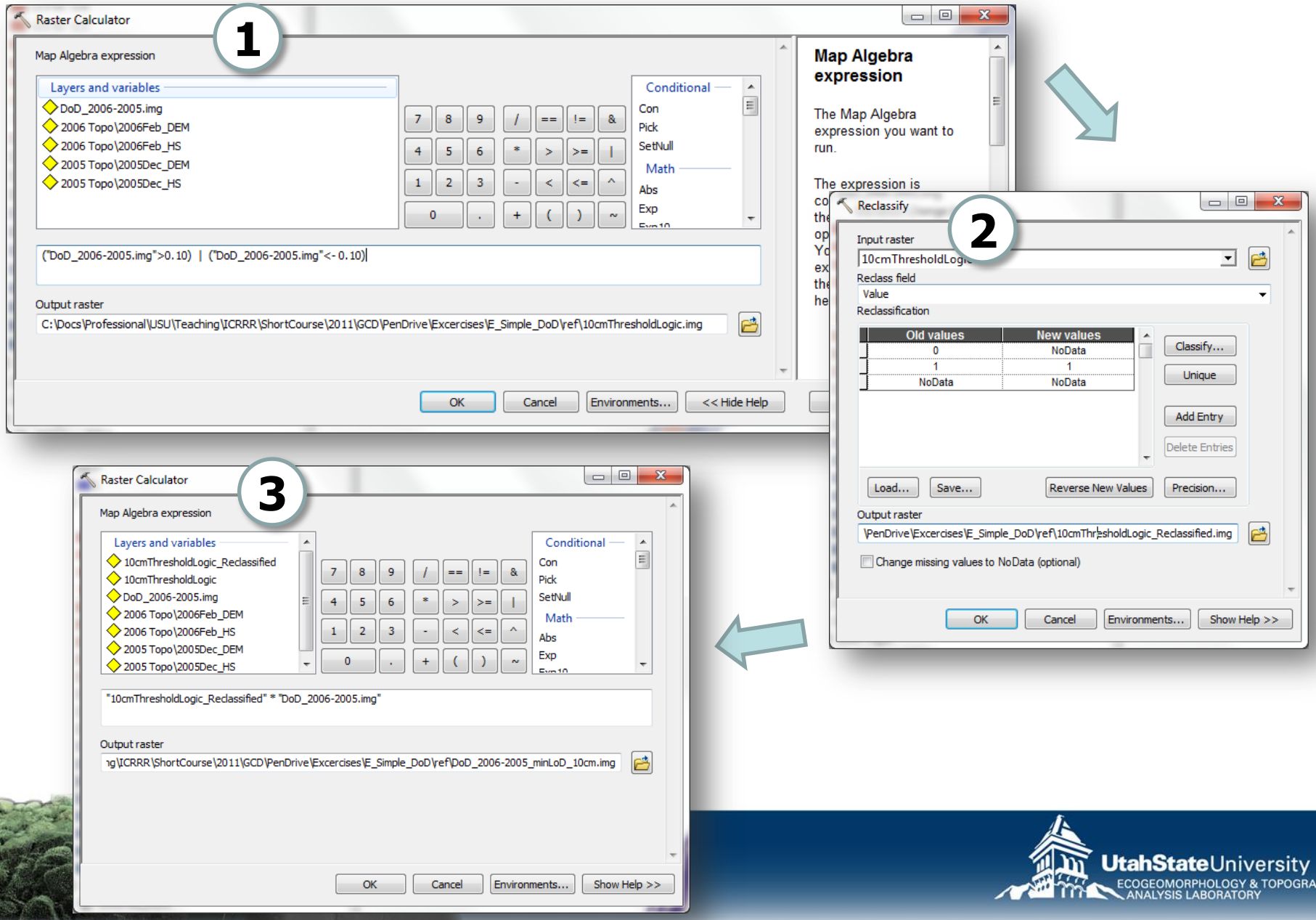
5. Raster Calculator Threshold Example

EXERCISE G – PART 1.B: THRESHOLD

C:\CHaMPWorkshop\Exercises\GCD\G_SimpleDoD\

1. Using Raster Calculator, apply conditional logic to identify mask for areas above a 10 cm threshold
2. Reclassify the mask such that 1s remain 1s, 0s turn to NoData and NoData remains NoData.
3. Using Raster Calculator, apply the Reclass Mask to DoD to 'threshold'
4. Apply DoD Symbology to thresholded DoD for direct visual comparison.

THRESHOLD THE DoD



EXERCISE G – PART 2: SAME THING IN GCD

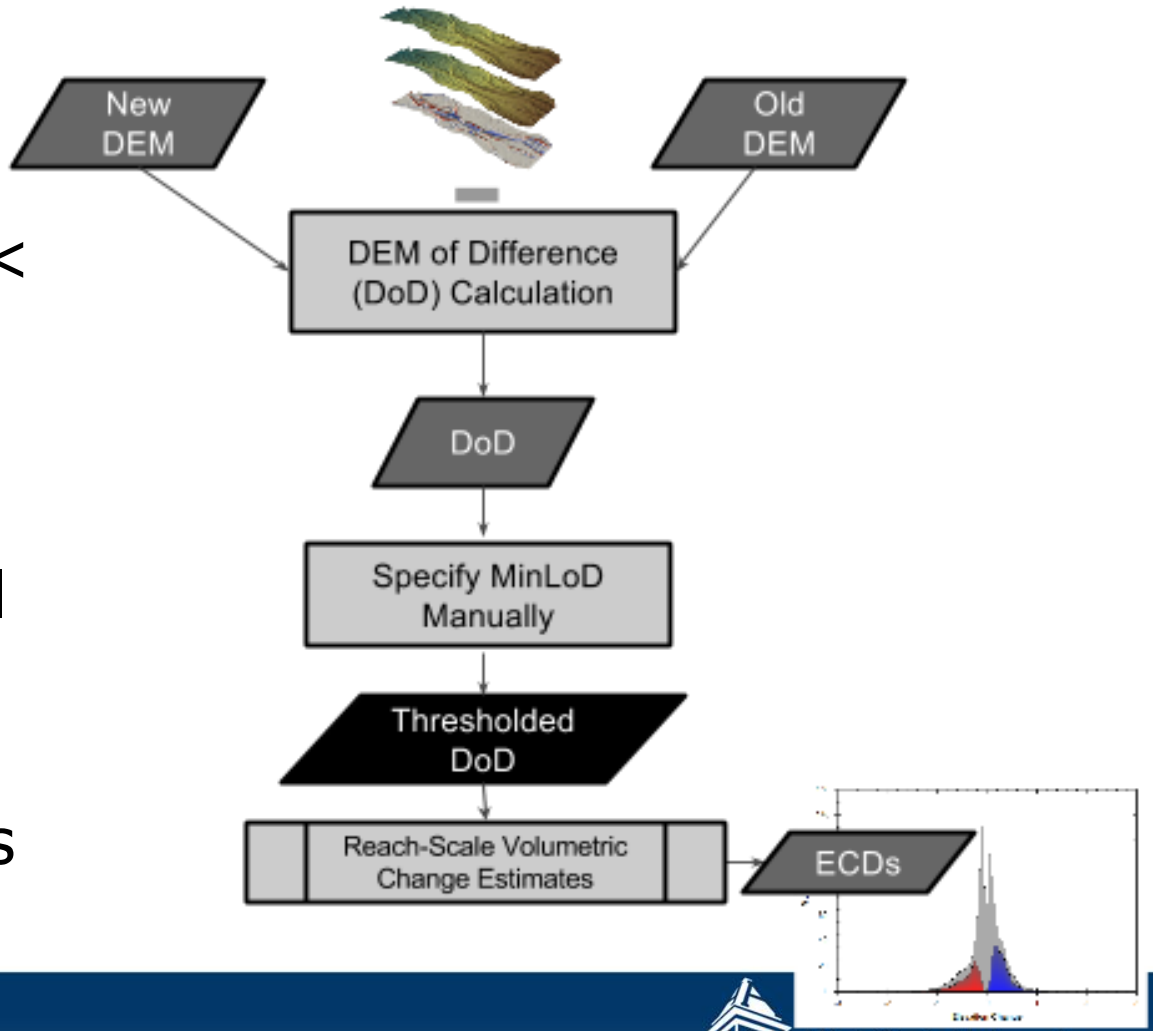
C:\CHaMPWorkshop\Exercises\GCD\G_SimpleDoD\

No real explanation… just follow steps.

1. Load Blank New Map Document… Save.
2. Create Project
3. Load 2005 and 2006 DEMs as Surveys
4. Calculate Change Detection using simple minLoD and specify
5. Explore and visualize output

WHAT WE'RE DOING TO SIMPLE SUBTRACTION PROBLEM

- Just specifying a minimum level of detection ($_{min}$LoD)
- Throwing away DoD < $_{min}$LoD
- Calculating some summary statistics
- Multiplying cell by cell DoD by cell area to get volumes
- Looking at histograms of change (ECD)



DETAIL PLAN

TRADITIONAL APPROACHES TO GEOMORPHIC CHANGE DETECTION


1. Background Problem


2. Basic DEM Differencing

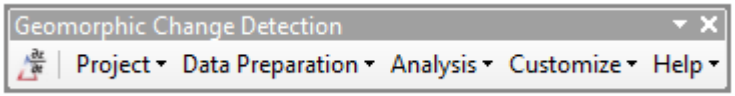

3. Raster Calculator DoD Example

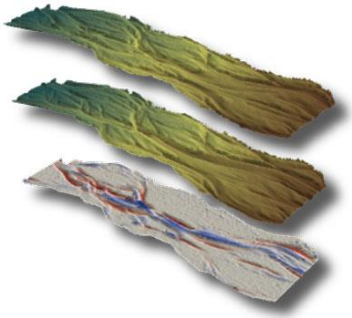

4. Simple Thresholding


5. Raster Calculator Threshold Example

GEOMORPHIC CHANGE DETECTION

THRESHOLDING ALTERNATIVES IN GCD





NORTH ARROW RESEARCH

DETAIL PLAN

THRESHOLDING ALTERNATIVES FOR GCD

1. **Three Types in GCD 6**

2. Recall minLoD

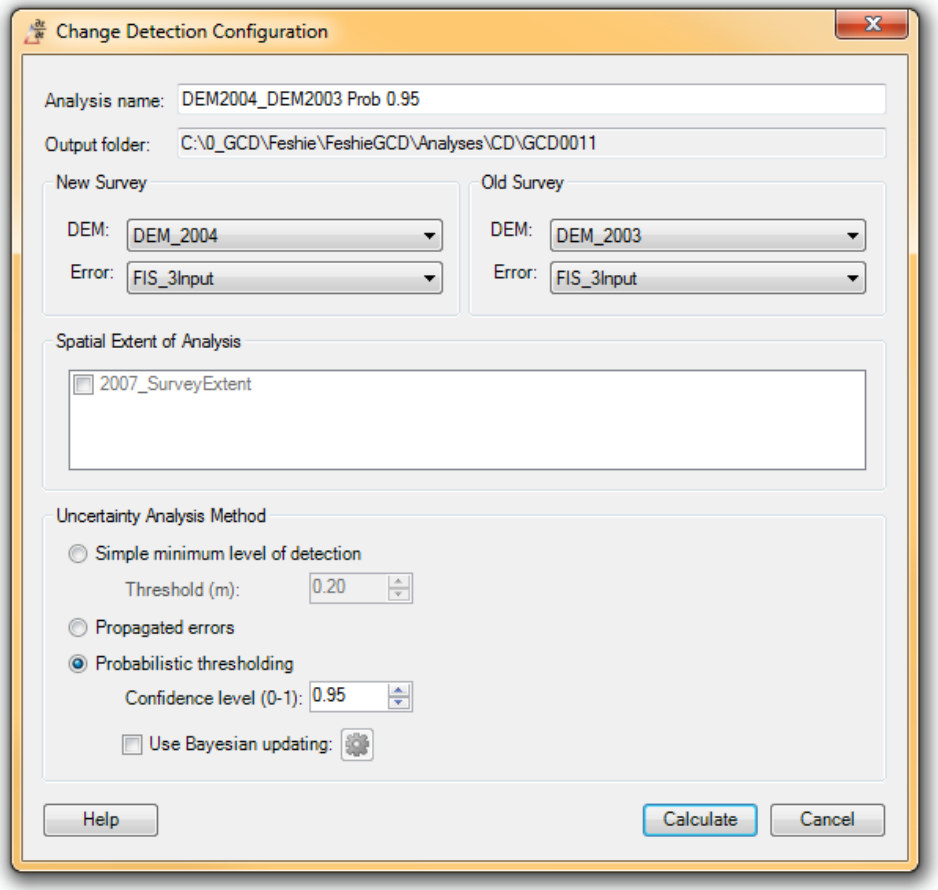
3. Error Propagation

4. Probabilistic Thresholding

5. Tutorial

GCD 6 THRESHOLDING

- Simple defined $_{min}$LoD
- Propagated Errors
- Probabilistic Confidence Interval



DETAIL PLAN

THRESHOLDING ALTERNATIVES FOR GCD

1. Three Types in GCD 5

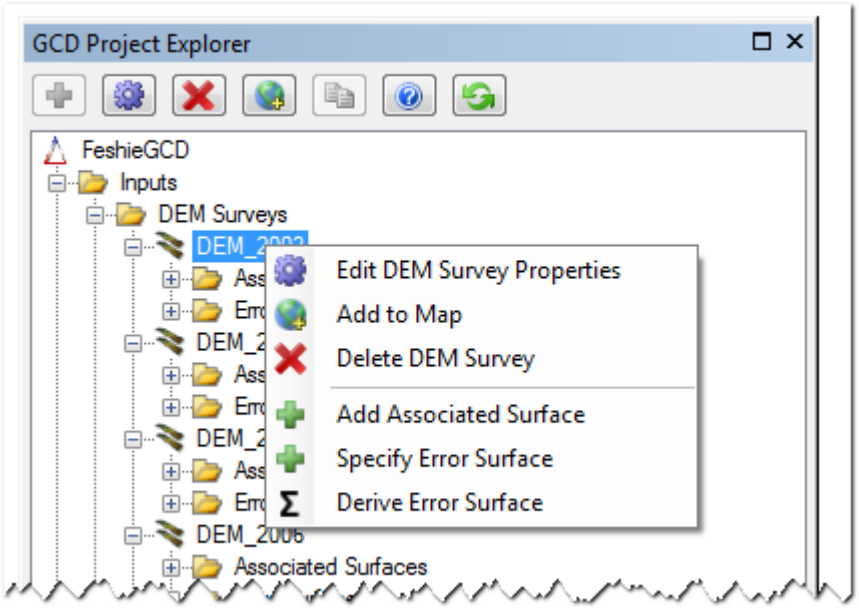
2. Recall minLoD

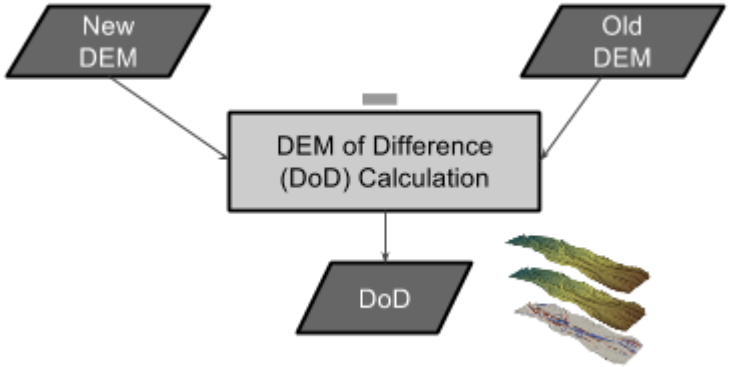
3. Error Propagation

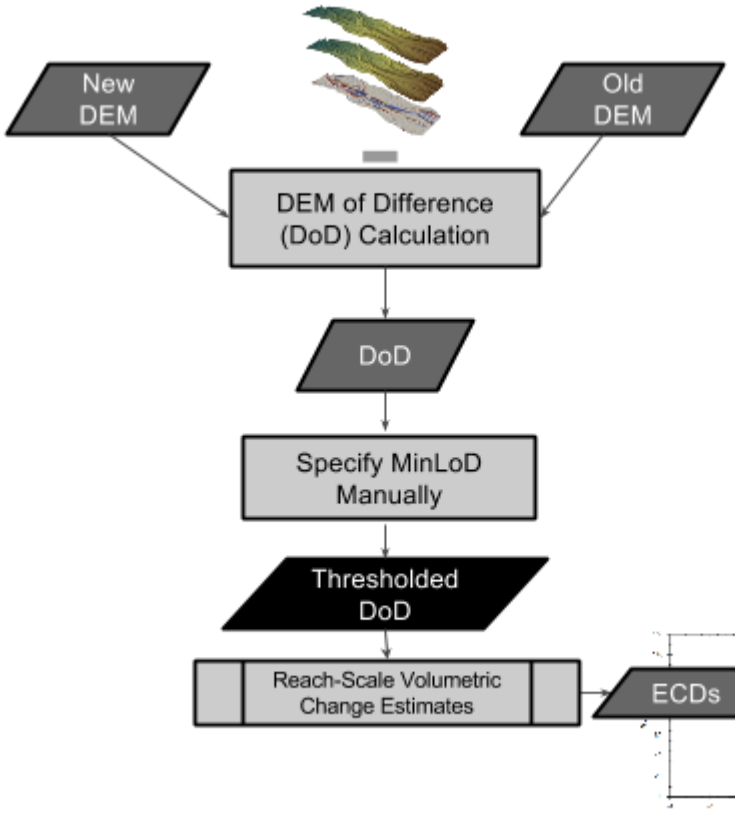
4. Probabilistic Thresholding

5. Tutorial

WE'VE JUST DONE THE SIMPLE $_{MIN}$LoD

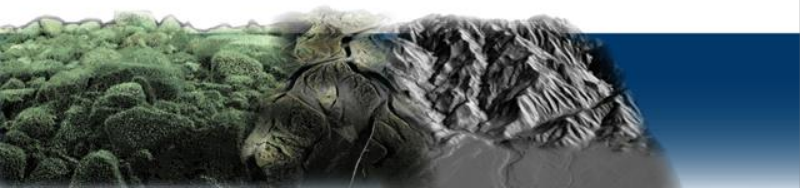


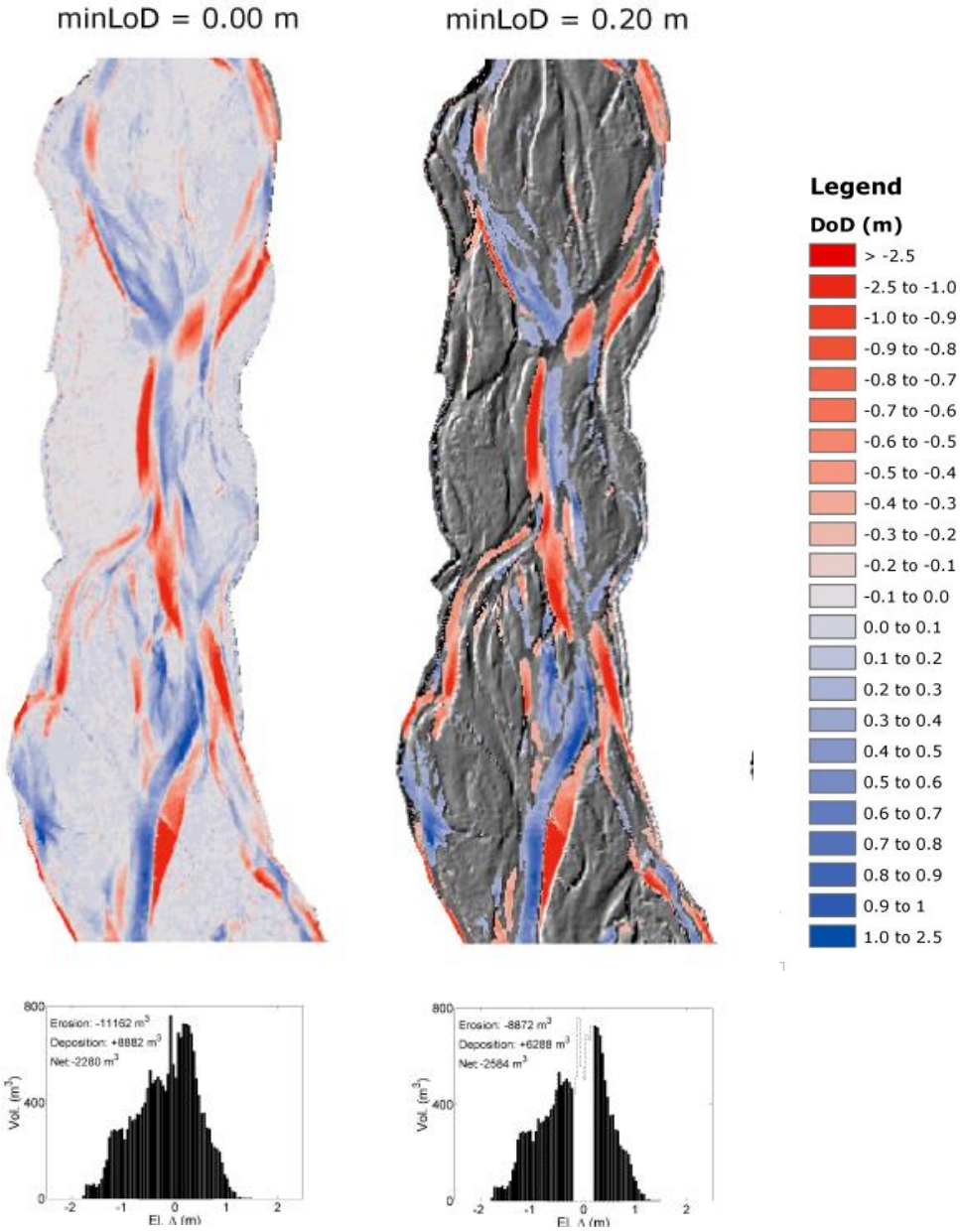




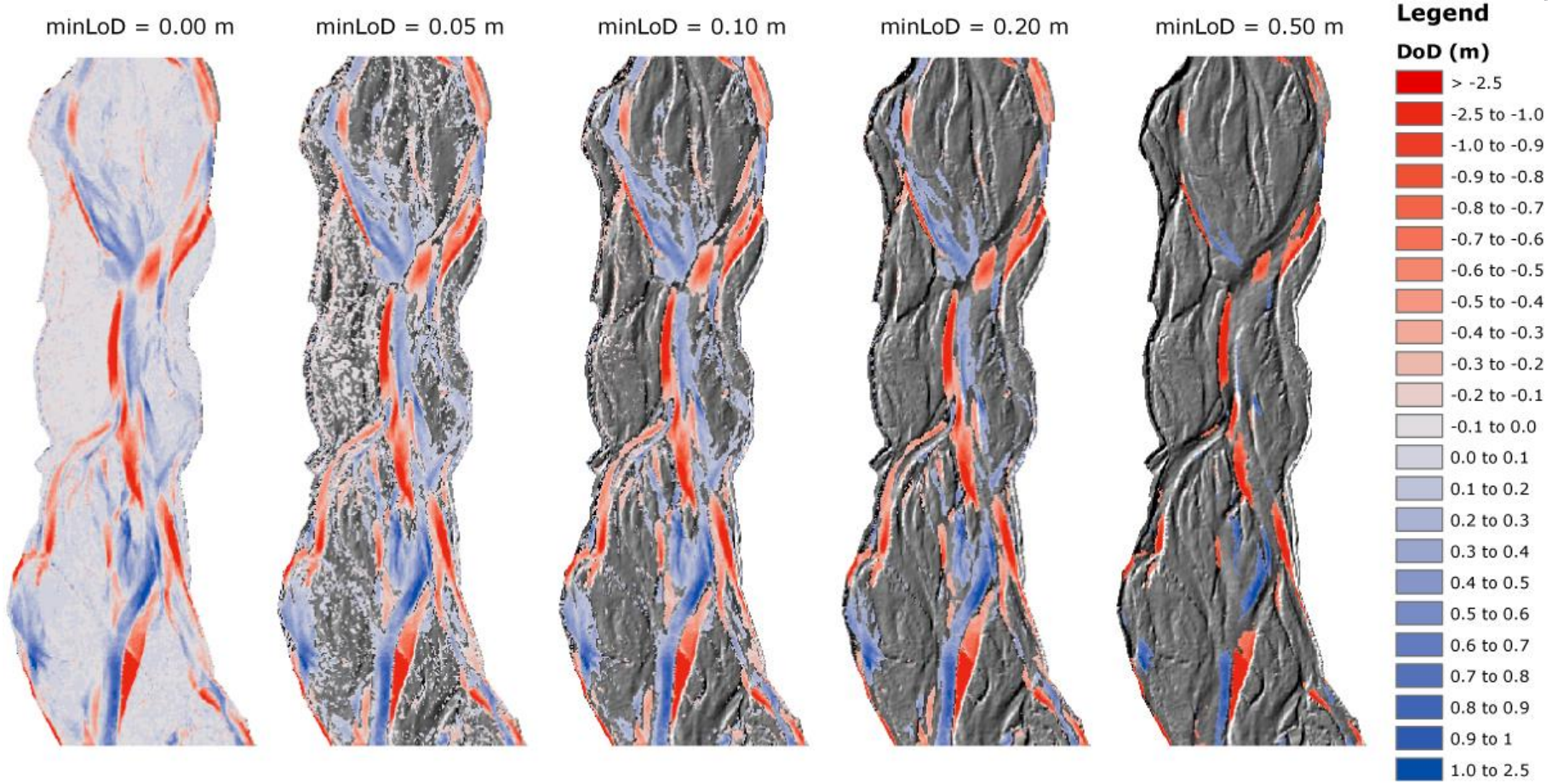
APPLICATION OF A $_{MIN}$LoD

- You take original DoD, and remove all changes <= $_{min}$LoD
- For example +/- 20 cm





VARYING $_{min}$LoD THRESHOLDS



EXERCISE I – PART 1 : VARYING $_{MIN}$LOD

C:\CHaMPWorkshop\Exercises\GCD\I_Thresholding

1. Start new ArcMap Document
2. Create new GCD Project called 'Feshie_Threshold' in I
3. Load 2 DEMs provided as surveys
4. Do Change Detections with following minLoDs:
   - 0 cm, 5 cm, 10 cm, 20 cm, 50 cm
5. Compare the outputs (maps, summaries, elevation change distributions)…

DETAIL PLAN

THRESHOLDING ALTERNATIVES FOR GCD

1. Three Types in GCD 5

2. Recall minLoD

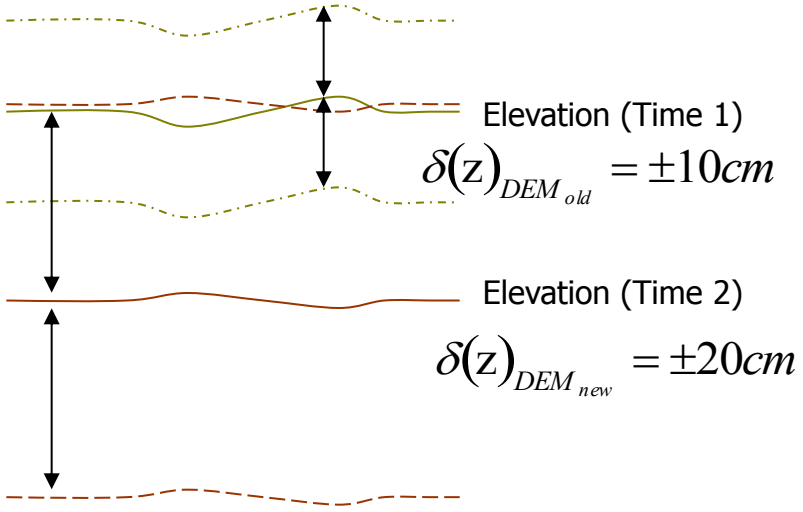
3. Error Propagation

4. Probabilistic Thresholding

5. Tutorial

$_{MIN}$LoD USING ERROR PROPAGATION

- Distinguish those changes that are real from noise
- Use standard Error Propagation
- DEM Errors can vary temporally and spatially



$$\delta(z) = \sqrt{\left(\delta(z)_{DEM\ old}\right)^2 + \left(\delta(z)_{DEM\ new}\right)^2}$$

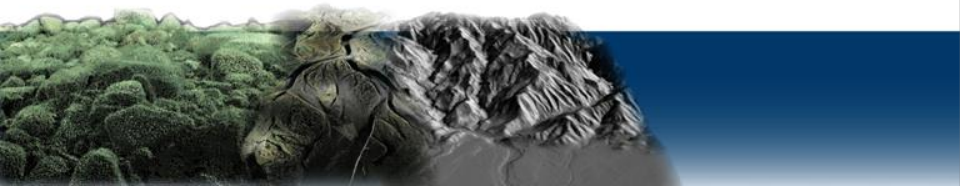
e.g. $\delta(z) = \sqrt{(10)^2 + (20)^2} = 22.36$

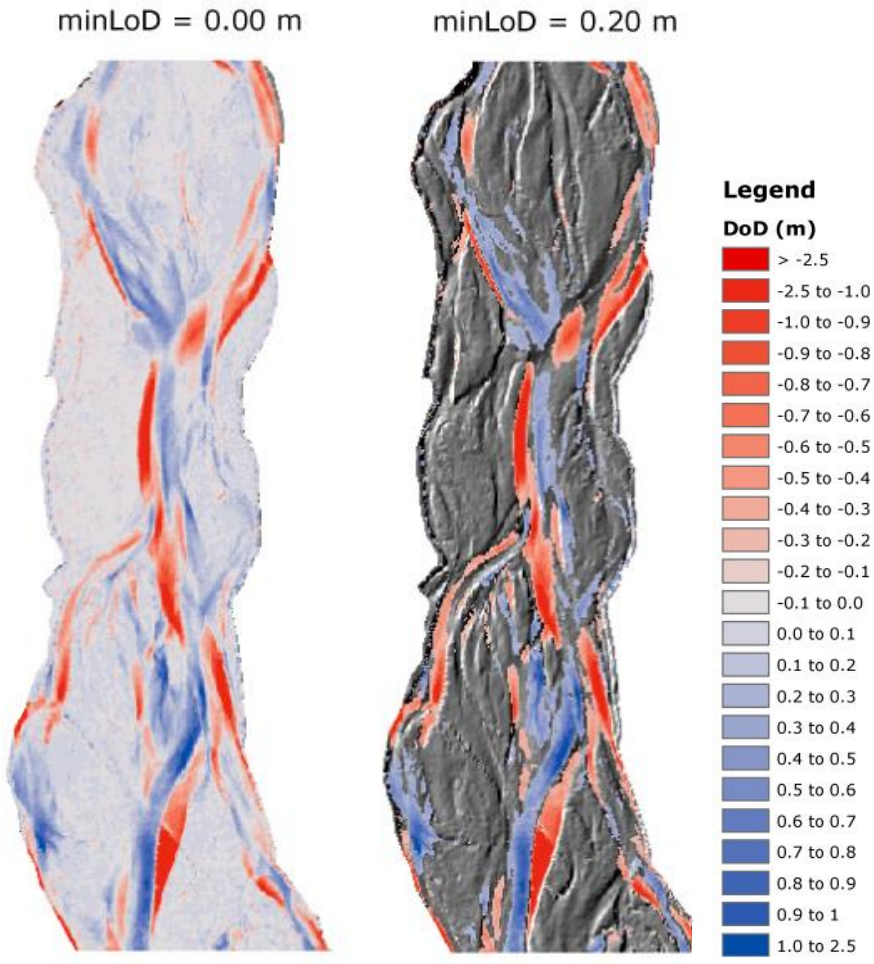
22.36 cm ≈ 8.8 in

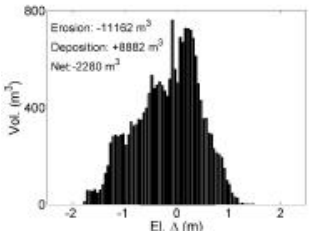
See
- Brasington et al (2000): *ESPL*
- Lane et al (2003): *ESPL*
- Brasington et al (2003): *Geomorphology*

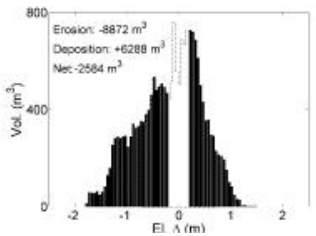
ERROR PROPAGATION GETS APPLIED SAME WAY AS $_{MIN}$LoD

- Does not matter whether the $_{min}$LoD is specified, or calculated from error propagation
- Just on a cell-by-cell basis!
- In background a perror grid is produced



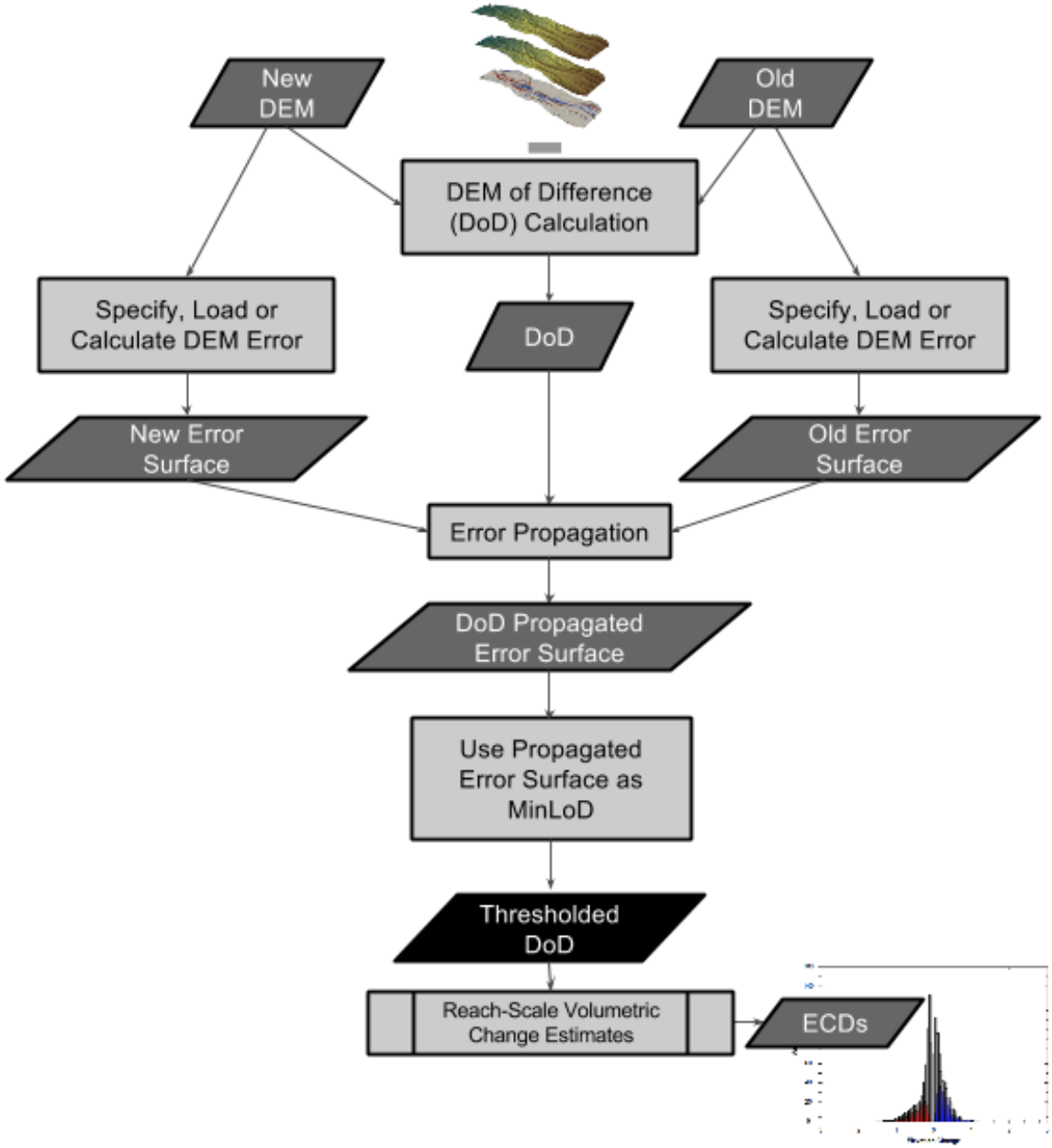






OUR REVISED WORKFLOW: PROPAGATED

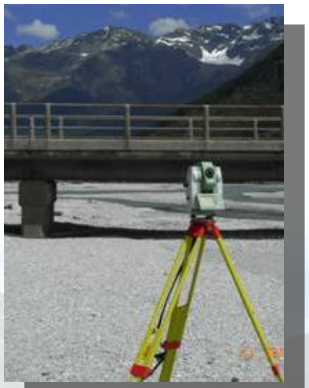
- Just *come up with* separate estimates of error for DEM_{new} & DEM_{old} & propagate using square root of the sum of the square of the errors in quadrature…

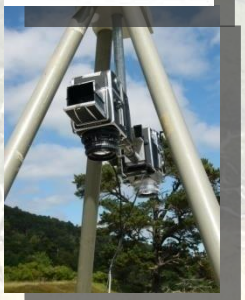


WHAT ARE TYPICAL ERRORS?

Remotely Sensed or Aerial Surveys

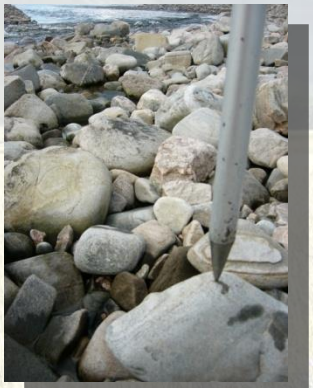
- LiDaR : +/- 12 to 25 cm
- Aerial Photogrammetry : +/- 10 to 15 cm

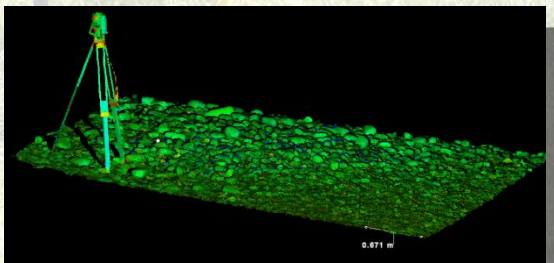


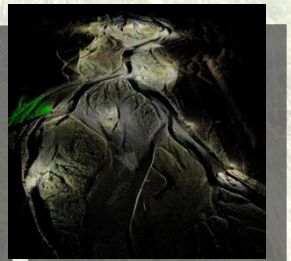


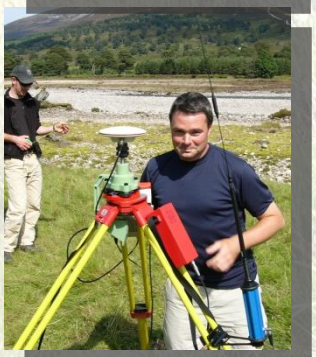
Ground-Based Surveys

- Total Station Surveys : +/- 2 to 10 cm
- GPS: : +/- 3 to 12 cm
- Terrestrial Laser Scanning: +/- 0.5 to 4 cm

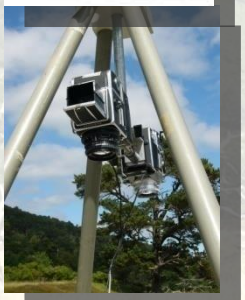






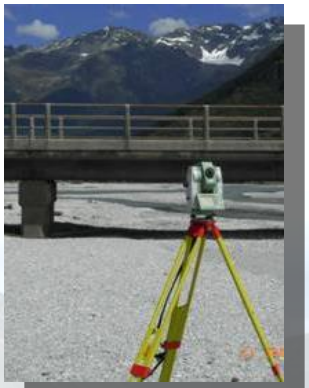


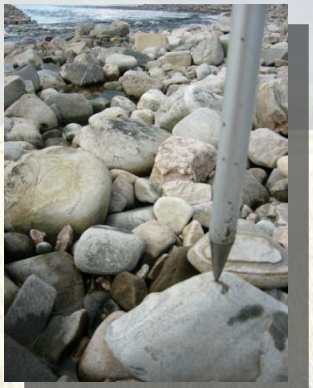
SO WHAT WOULD PROPAGATED ERRORS BE?

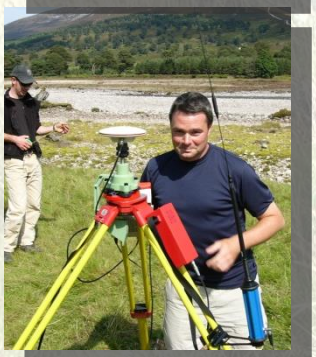


Remotely Sensed or Aerial Surveys

- LiDaR : +/- 12 to 25 cm (17 to 36 cm $_{min}$LoD)
- Aerial Photogrammetry : +/- 10 to 15 cm(14 to 22 cm $_{min}$LoD)

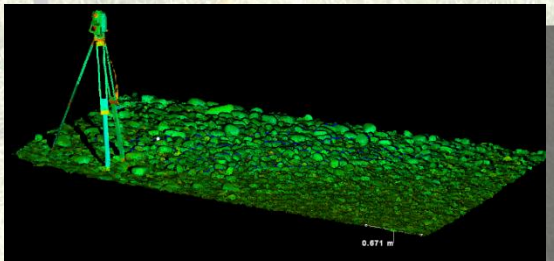


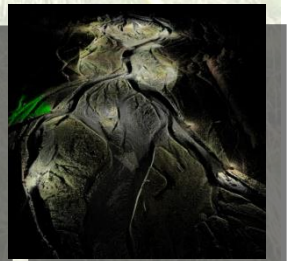




Ground-Based Surveys

- Total Station Surveys : +/- 2 to 10 cm (3 to 14 cm $_{min}$LoD)
- GPS: : +/- 3 to 12 cm (4 to 17 cm $_{min}$LoD)
- Terrestrial Laser Scanning: +/- 0.5 to 4 cm (0.7 to 6 cm $_{min}$LoD)





EXERCISE I – PART 2 : VARYING $_{MIN}$LOD

C:\CHaMPWorkshop\Exercises\GCD\I_Thresholding

1. In Same ArcMap Document
2. Go to each DEM Survey, and derive spatially uniform error surface for rtkGPS
3. Do Change Detections with Propagated Error
4. Compare the outputs (maps, summaries, elevation change distributions)…

DETAIL PLAN

THRESHOLDING ALTERNATIVES FOR GCD

1. Three Types in GCD 5

2. Recall minLoD

3. Error Propagation

4. Probabilistic Thresholding

5. Tutorial

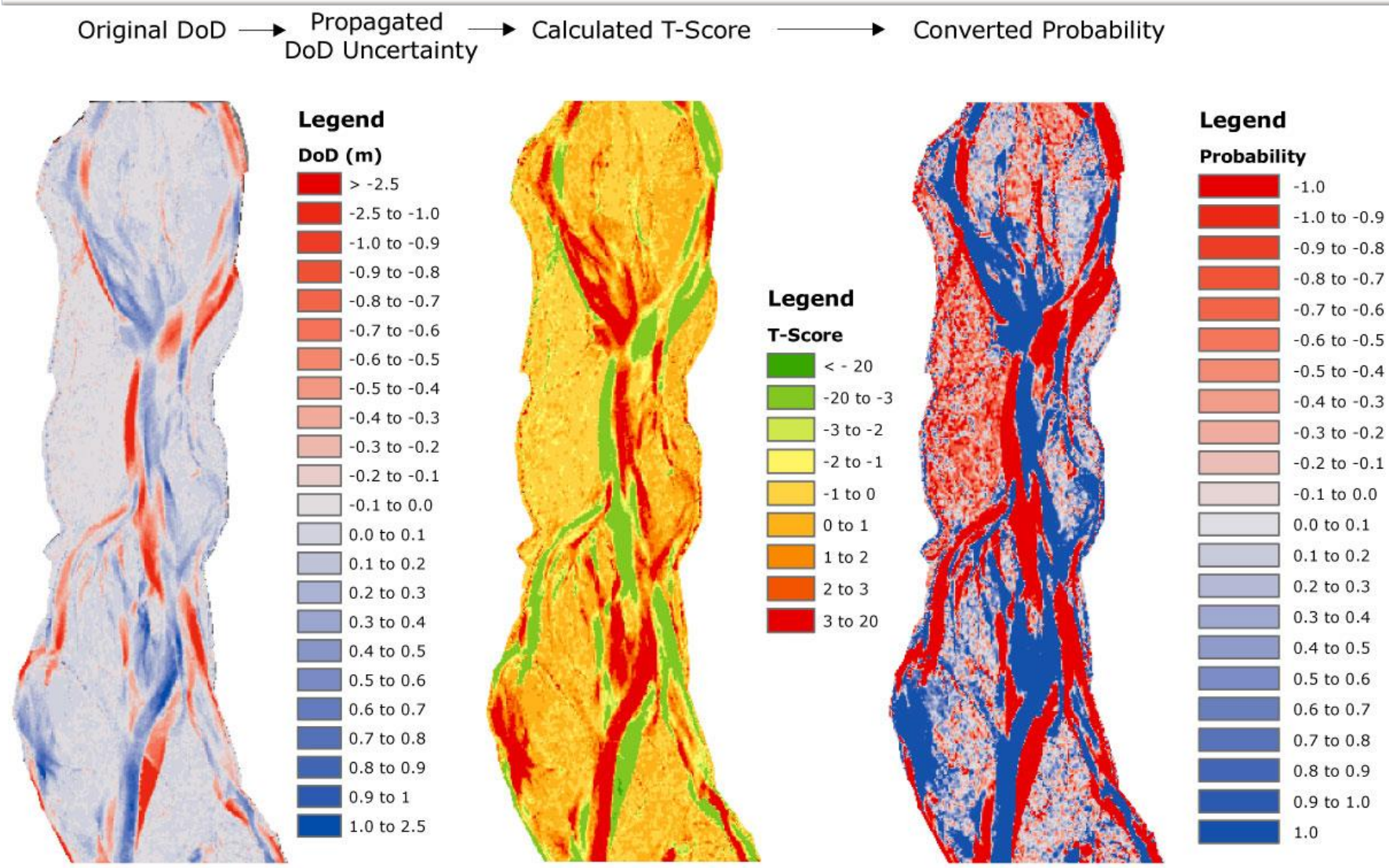
HOW COULD I REPRESENT AS PROBABILITY?

- Using inferential statistics, we'll calculate a t-score
- σ_{DoD} is the characteristic uncertainty
  - In this case σ_{DoD} = $_{min}$LoD

$$t = \frac{\left| z_{DEM_{new}} - z_{DEM_{old}} \right|}{\sigma_{DoD}}$$

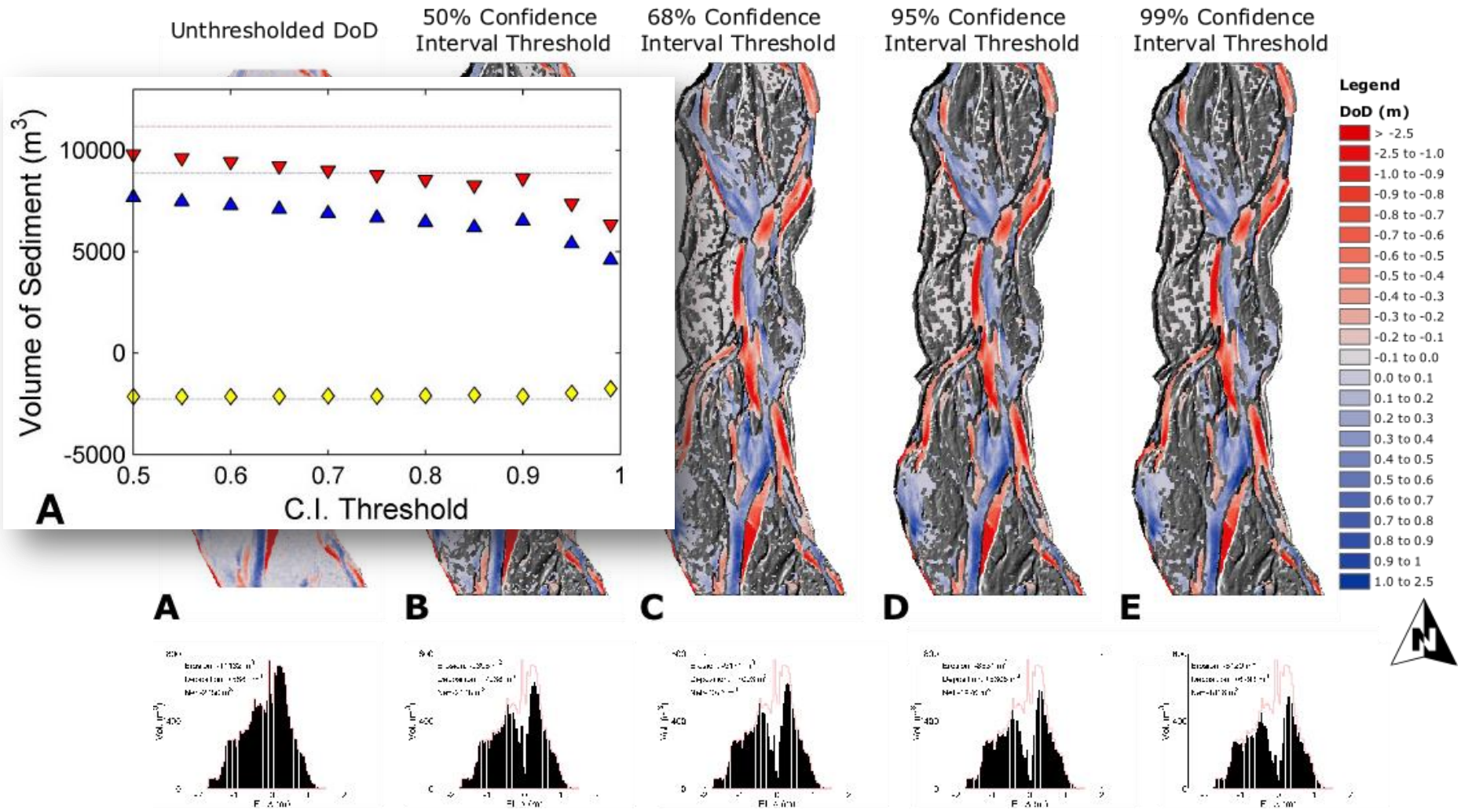
- Just the ratio of actual change to $_{min}$LoD change
- Assuming two-tailed test, t is significant at:
  - 68% confidence limit when t= 1
  - 95% confidence limit when t=1.96

PROBABILITY THAT CHANGE IS REAL

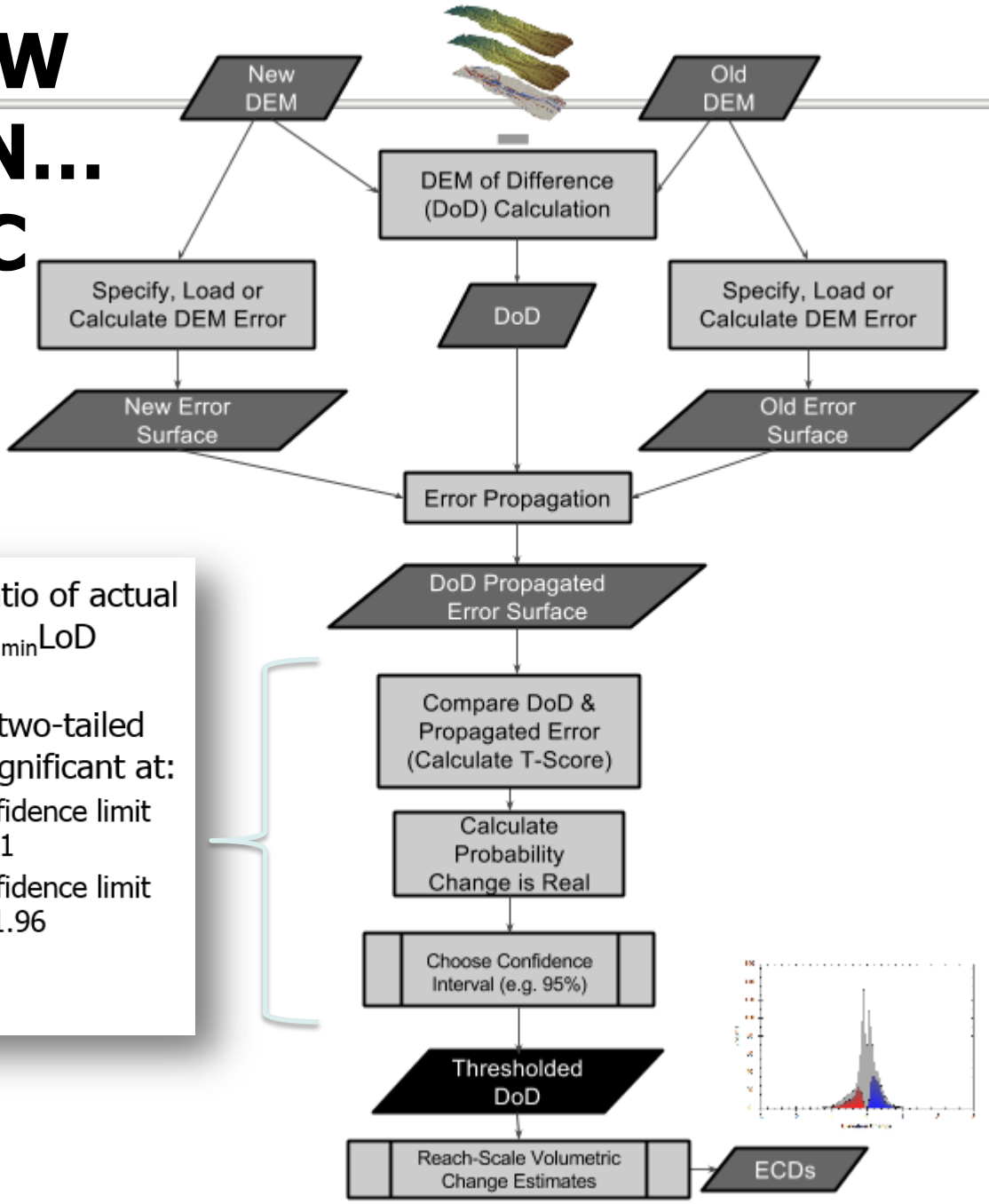


Even when $_{min}$LoD is spatially constant, probability varies in space… why?

SENSITVITY OF THRESHOLD?



OUR WORKFLOW REVISED AGAIN… PROBABILISTIC



- Using inferential statistics, we'll calculate a t-score
- σ_{DoD} is the characteristic uncertainty
  - In this case σ_{DoD} = $_{min}$LoD

$$t = \frac{\left| z_{DEM_{new}} - z_{DEM_{old}} \right|}{\sigma_{DoD}}$$

- Just the ratio of actual change to $_{min}$LoD change
- Assuming two-tailed test, t is significant at:
  - 68% confidence limit when t= 1
  - 95% confidence limit when t=1.96

DETAIL PLAN

THRESHOLDING ALTERNATIVES FOR GCD

1. Three Types in GCD 5

2. Recall minLoD

3. Error Propagation

4. Probabilistic Thresholding

5. Tutorial

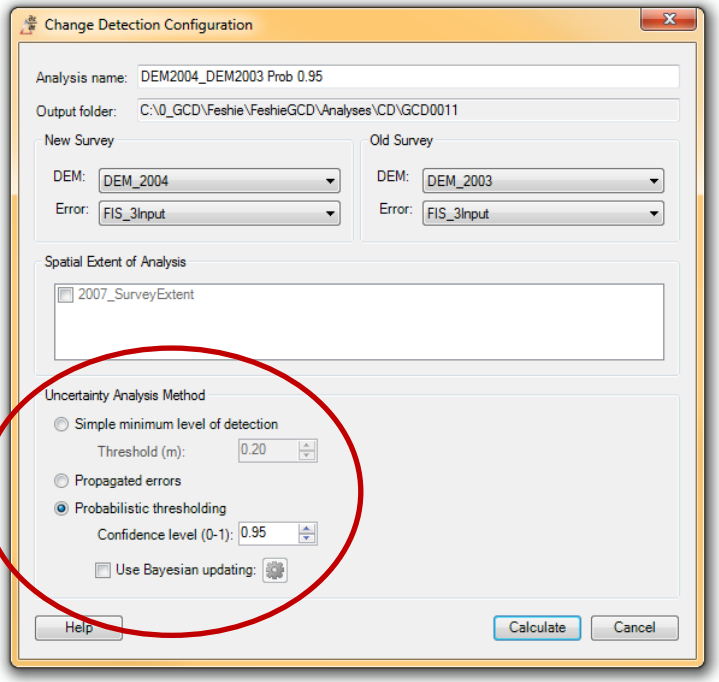
EXERCISE I – PART 3 : VARYING PROB.

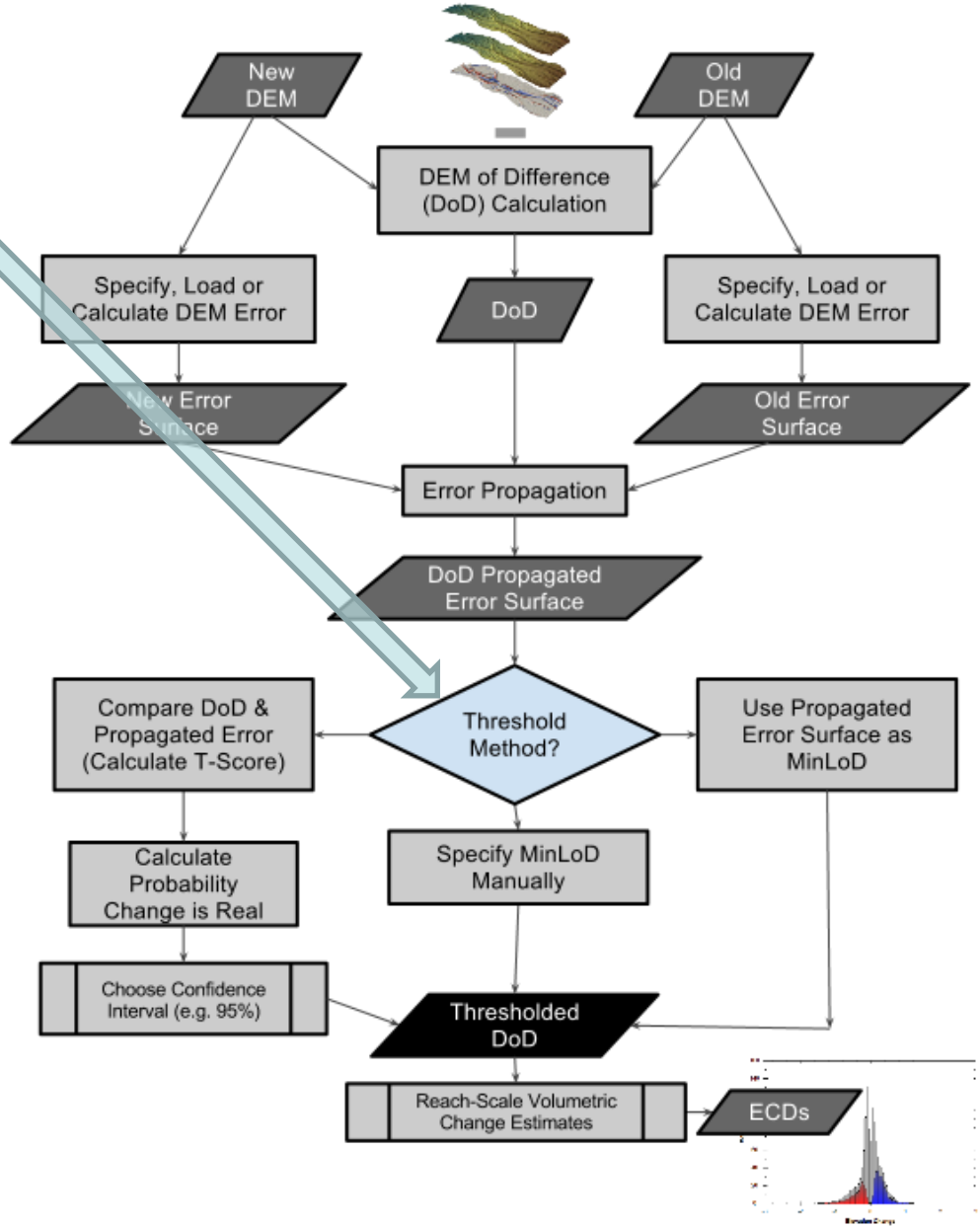
C:\CHaMPWorkshop\Exercises\GCD\I_Thresholding

1. In Same ArcMap Document
2. Do Change Detections with Propagated Error for following probabilities:
    1. 99%, 95%, 90%, 80%, 66% and 50%
3. Compare the outputs (maps, summaries, elevation change distributions)…

WHERE DOES THIS FIT IN GCD?

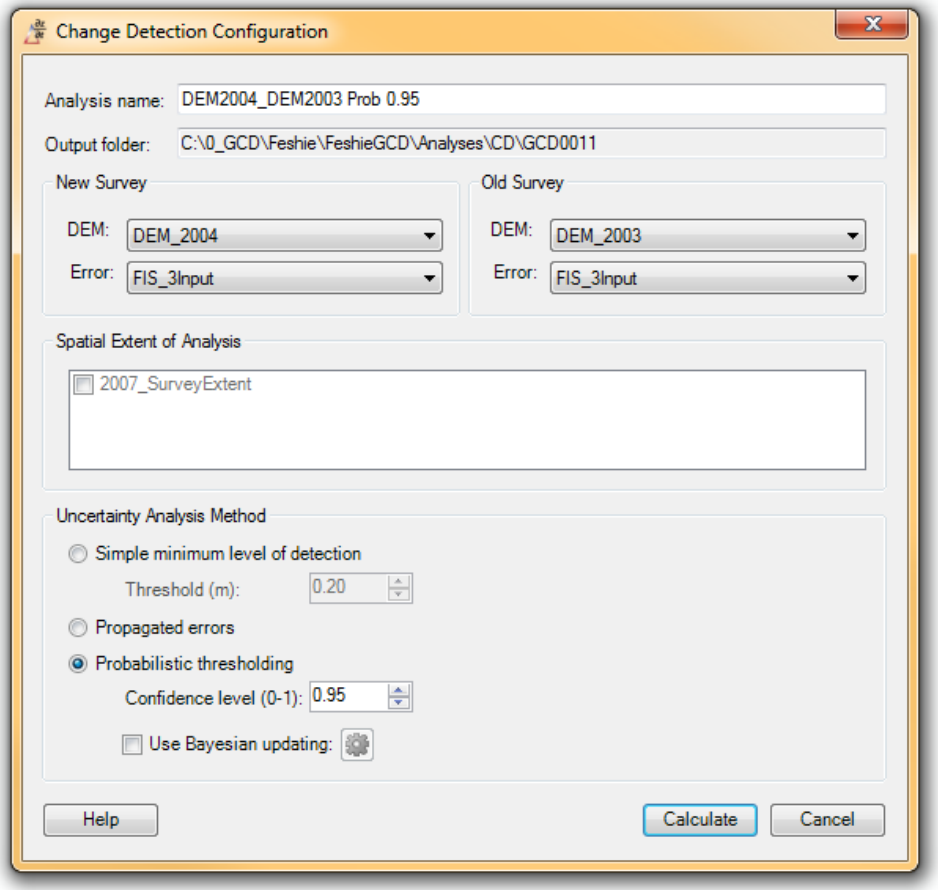
- Choosing the Threshold Method is a choice:





GCD 6 THRESHOLDING - TUTORIAL

- Simple defined $_{min}$LoD
- Propagated Errors
- Probabilistic Confidence Interval

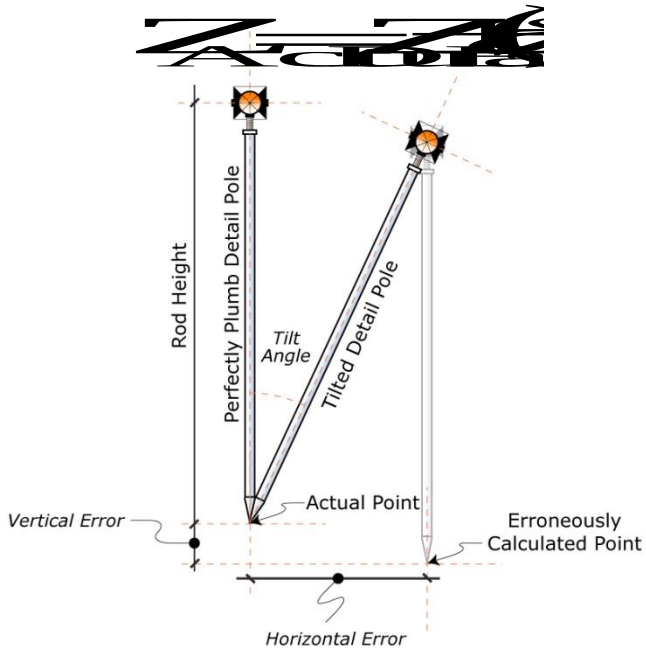


GEOMORPHIC CHANGE DETECTION

ERROR MODELLING & ESTIMATION

WHAT ARE SOURCES OF POINT ERROR?

- From Sensor
  - Instrument precision
  - Positional error of instrument/sensor
  - Orientation errors
  - Network occupation error
  - Range errors
- At sample point
  - Footprint
  - Angle of incidence
  - Range distance
  - Swath angle
  - What part of surface is being sampled

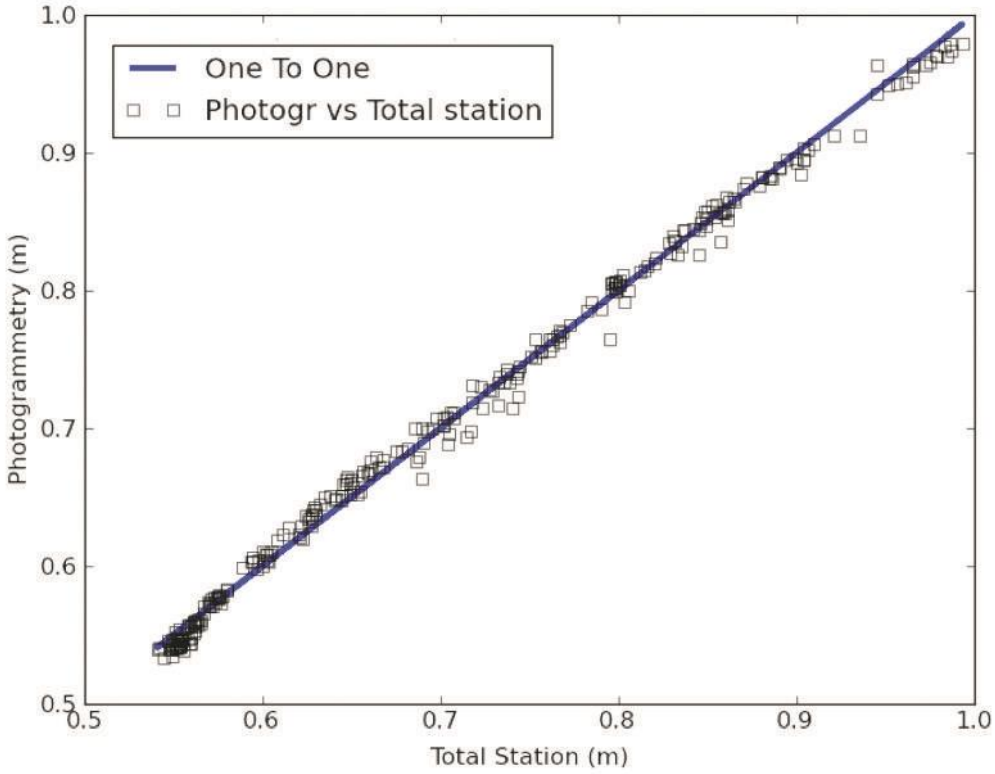


- User Errors
  - Incorrect rod-heights, offsets, settings
  - What part of surface is being sampled
  - Tilt errors

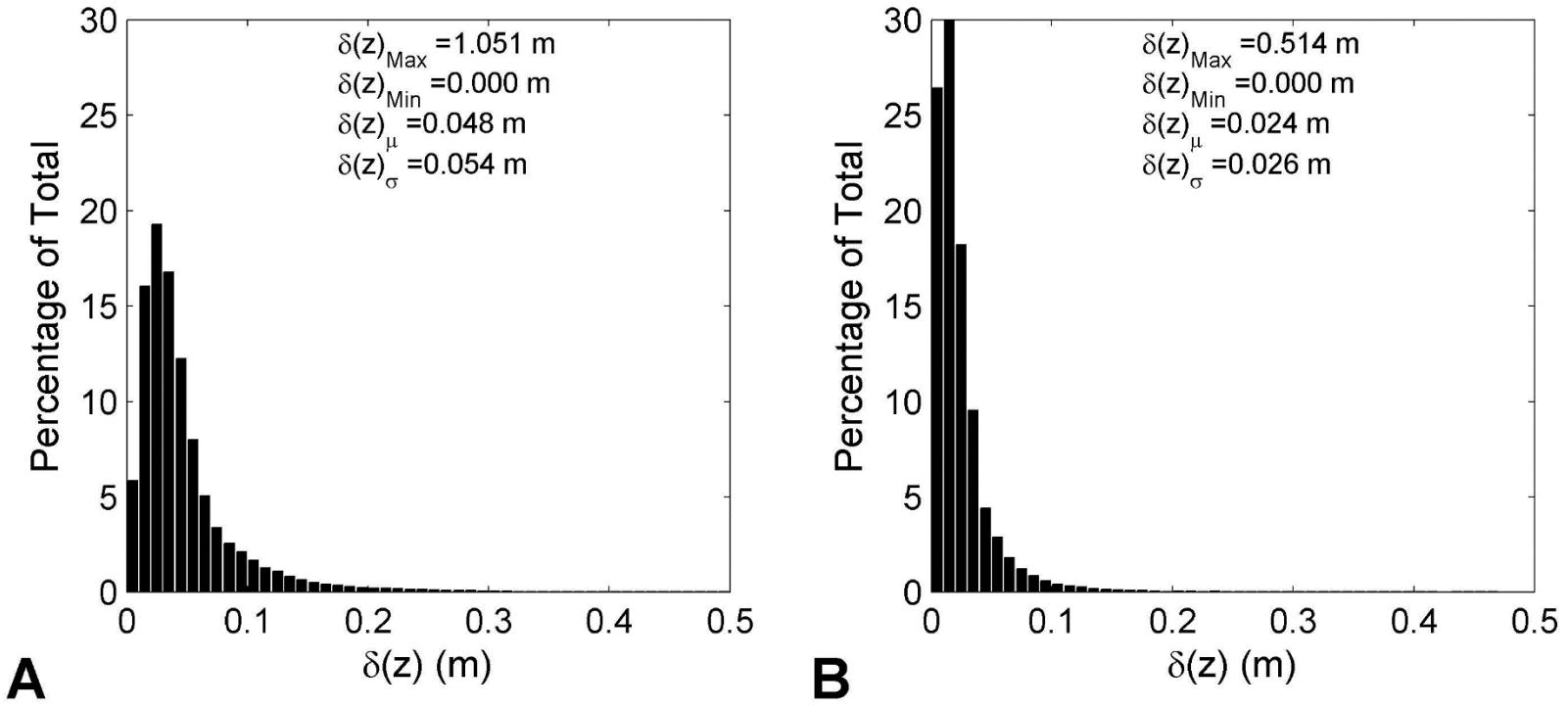
WHEN WE SAY ERROR…

- In statistics, an error is defined as the difference between a *computed*, *estimated*, or *measured value* and the *accepted true*, *specified*, or *theoretically correct value*

- In practice, we often treat the more precise method as '*theoretically correct*'



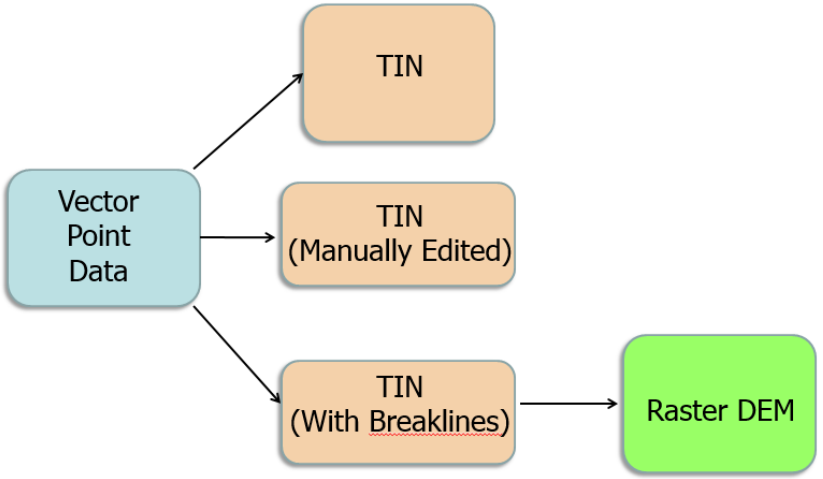
DISTRIBUTIONS OF ERROR



How do I get something like this?

WHAT DO WITH UNCERTAIN XYZ POINTS?

- We interpolate them to a TIN
- We then further interpolate them to a raster

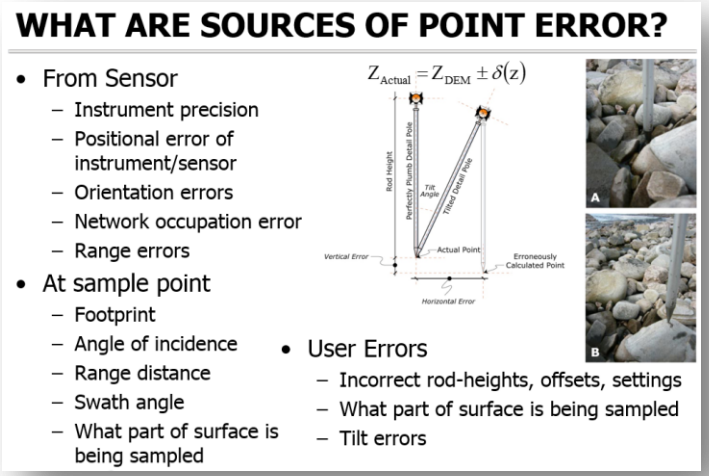


WHAT IS DEM ERROR?

- A measure of how uncertain DEM is?
- The DEM is a raster model of elevation, so error is only considered in vertical (i.e. elevation)
- If horizontal accuracy >> cell resolution, this is okay (if not… we're in trouble)

WHAT ARE SOURCES OF DEM UNCERTAINTY?

- Point-Based
  - Total Propagated Uncertainty at each point?
  - Horizontal accuracy
  - Vertical accuracy
  - Busts & Blunders
- Interpolation-Based
  - Interpolation models used (e.g. TIN & TIN to Raster vs. IDW, Kriging)
  - Cell Resolution used
  - Resampling errors!



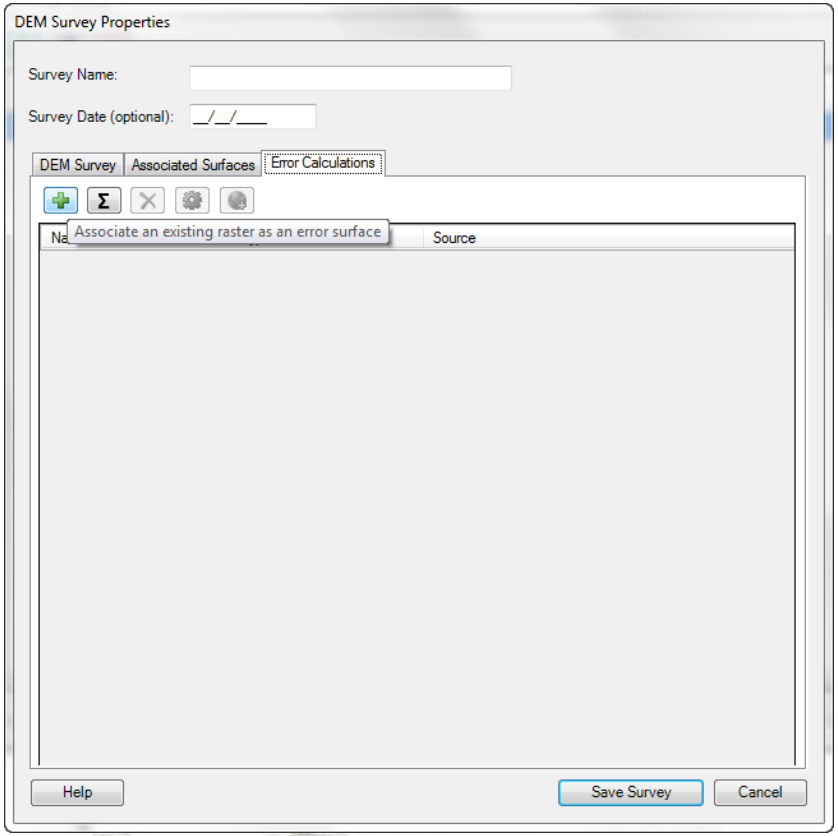
- User Choices (Structural Uncertainty)
  - Projections…
  - Methods for interpolation
  - Methods for cleaning
  - Sampling

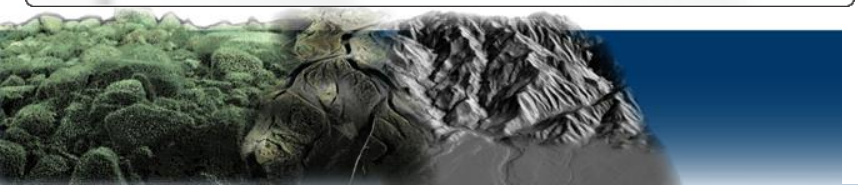
DEM ERROR

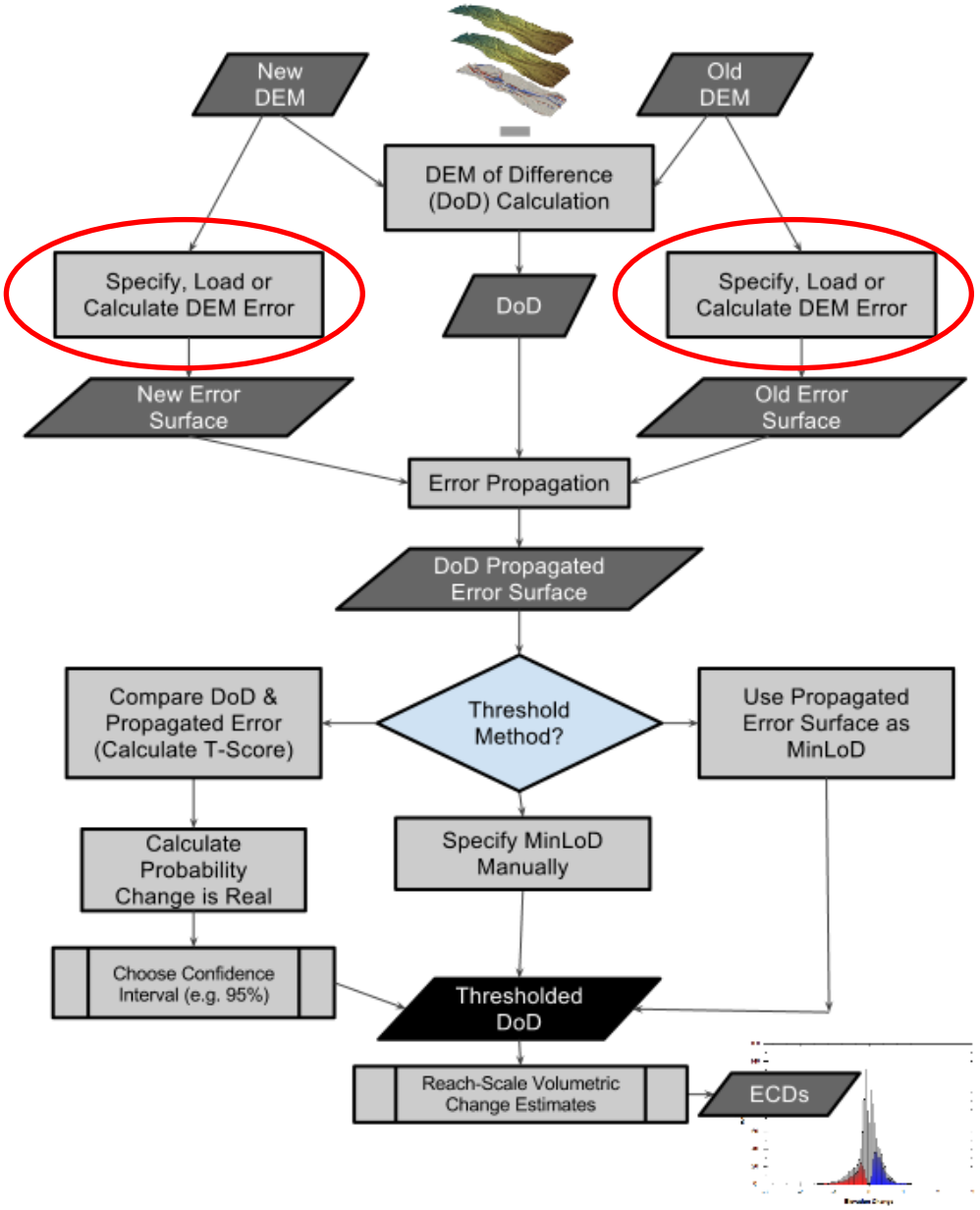
- Most common approach is to use one value everywhere! i.e. $const. \approx \delta(z) \neq f(x, y)$
- WRONG thing to do is to use manufacture reported instrument precision (way too liberal)
- Probably too conservative to use full error budgeting or TPU (total propagated uncertainty)
- What to use for that one value?

WHERE DOES THIS FIT IN GCD WORKFLOW?

- New DEM Error
- Old DEM Error

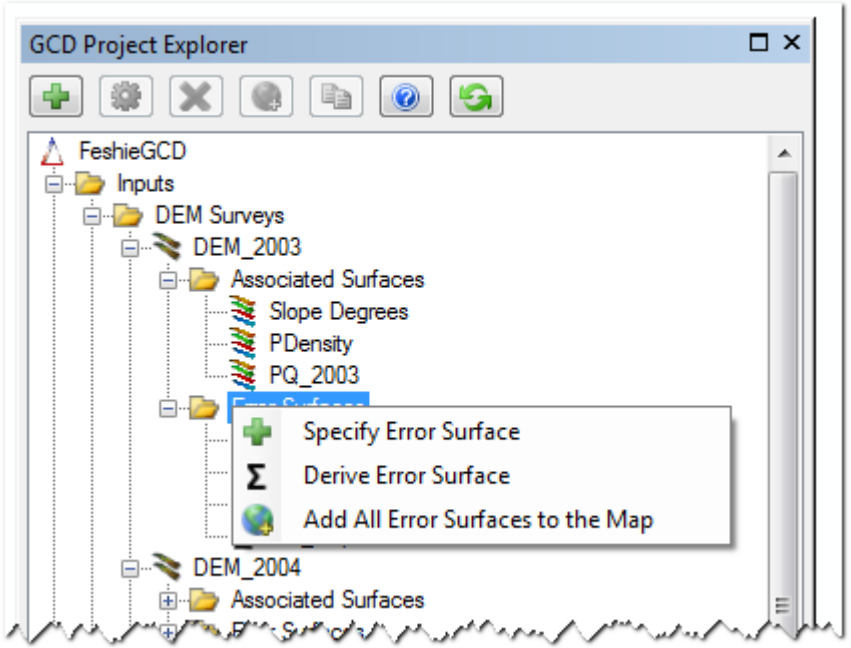


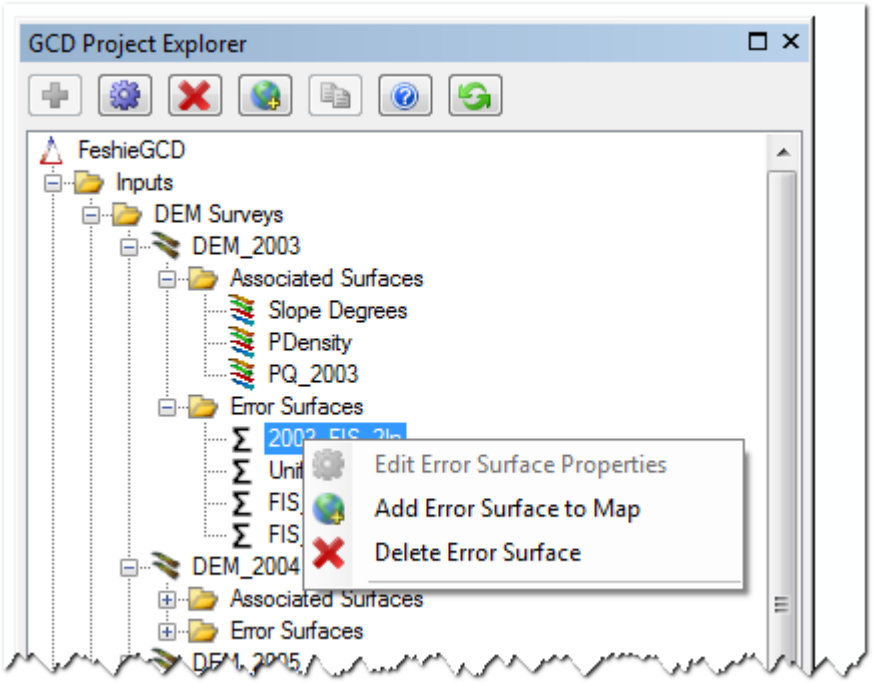




IN GCD, DEM ERRORS ARE PART OF SURVEY

- Each survey can have multiple DEM Errors

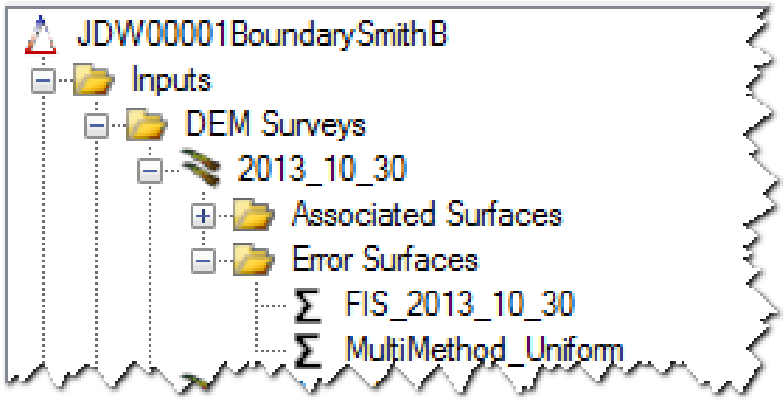


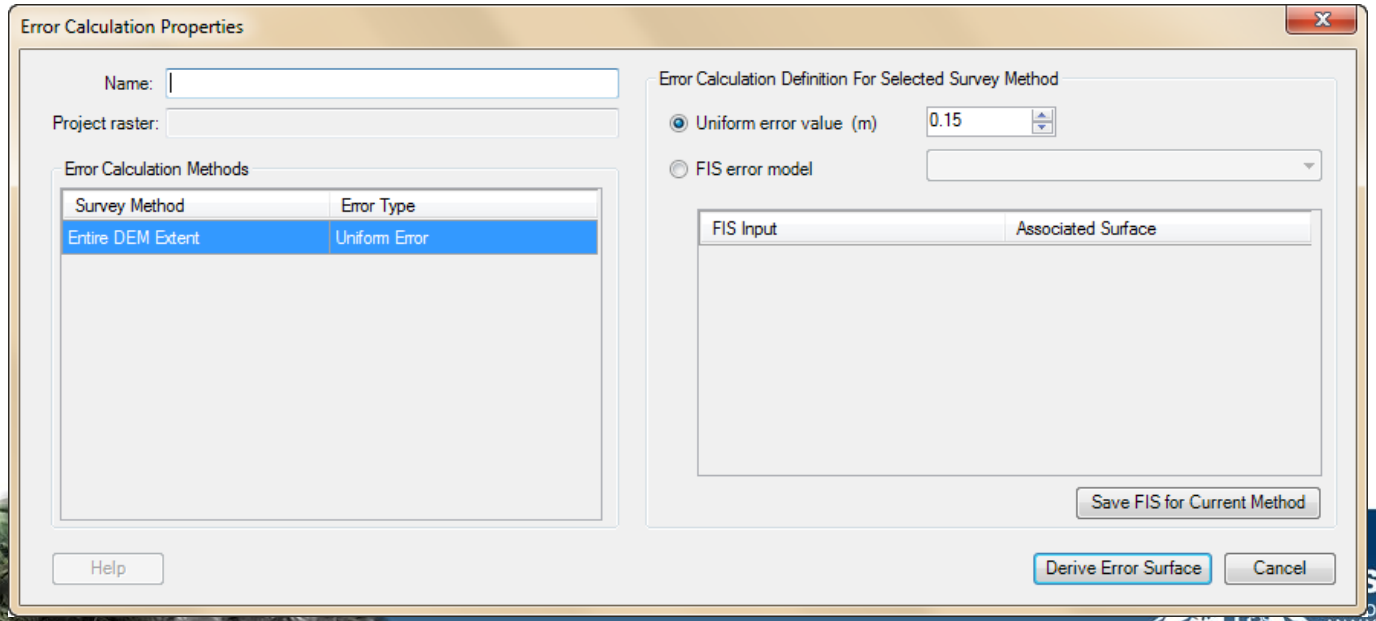


- 'Specify' means to load an existing
- 'Derive' means to build your own

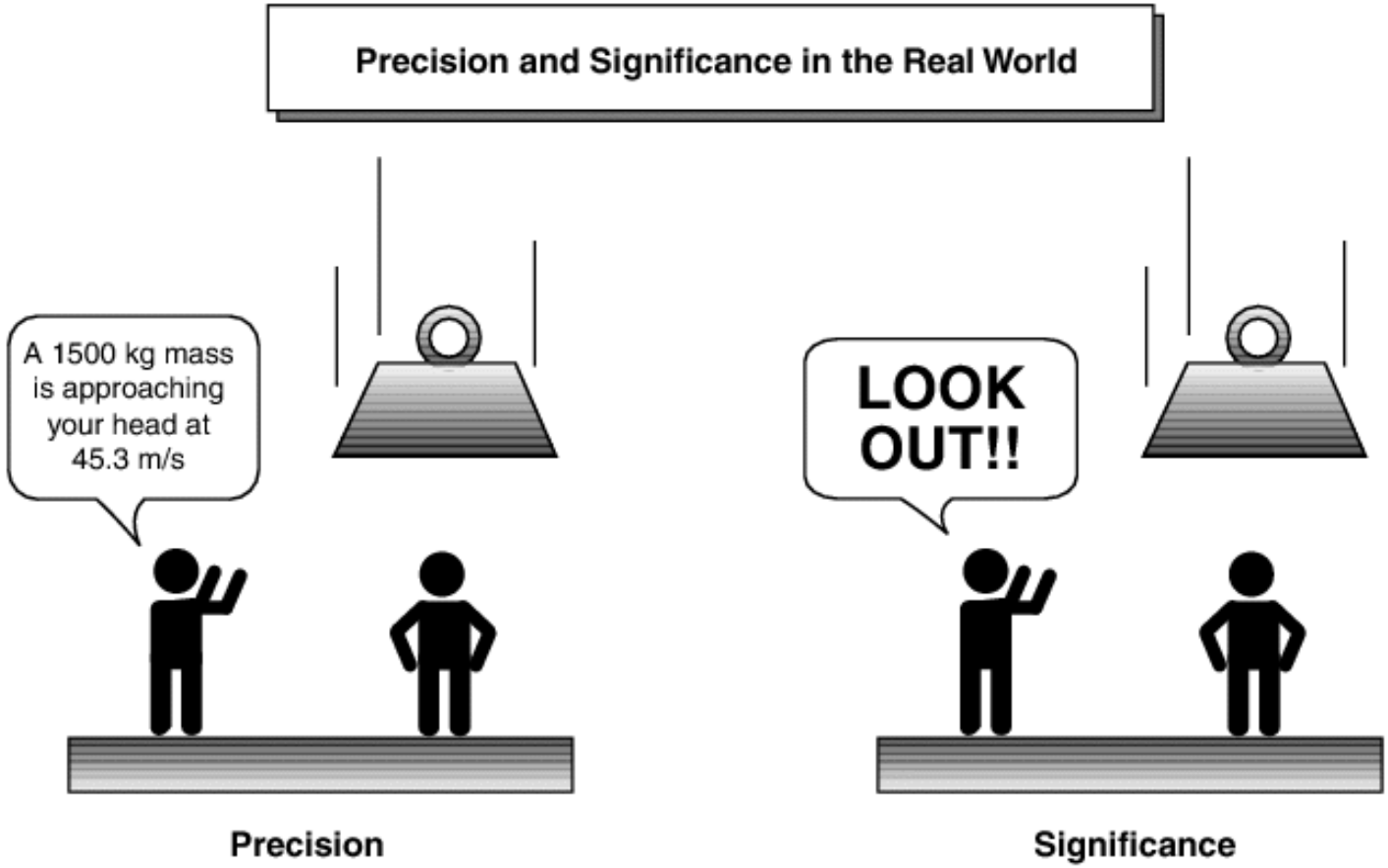
PART OF POINT OF HAVING A PROJECT IS TO EXPLORE IMPACT OF DIFFERENT ERROR MODELS

- GCD allows you to have multiple Error models for every DEM survey



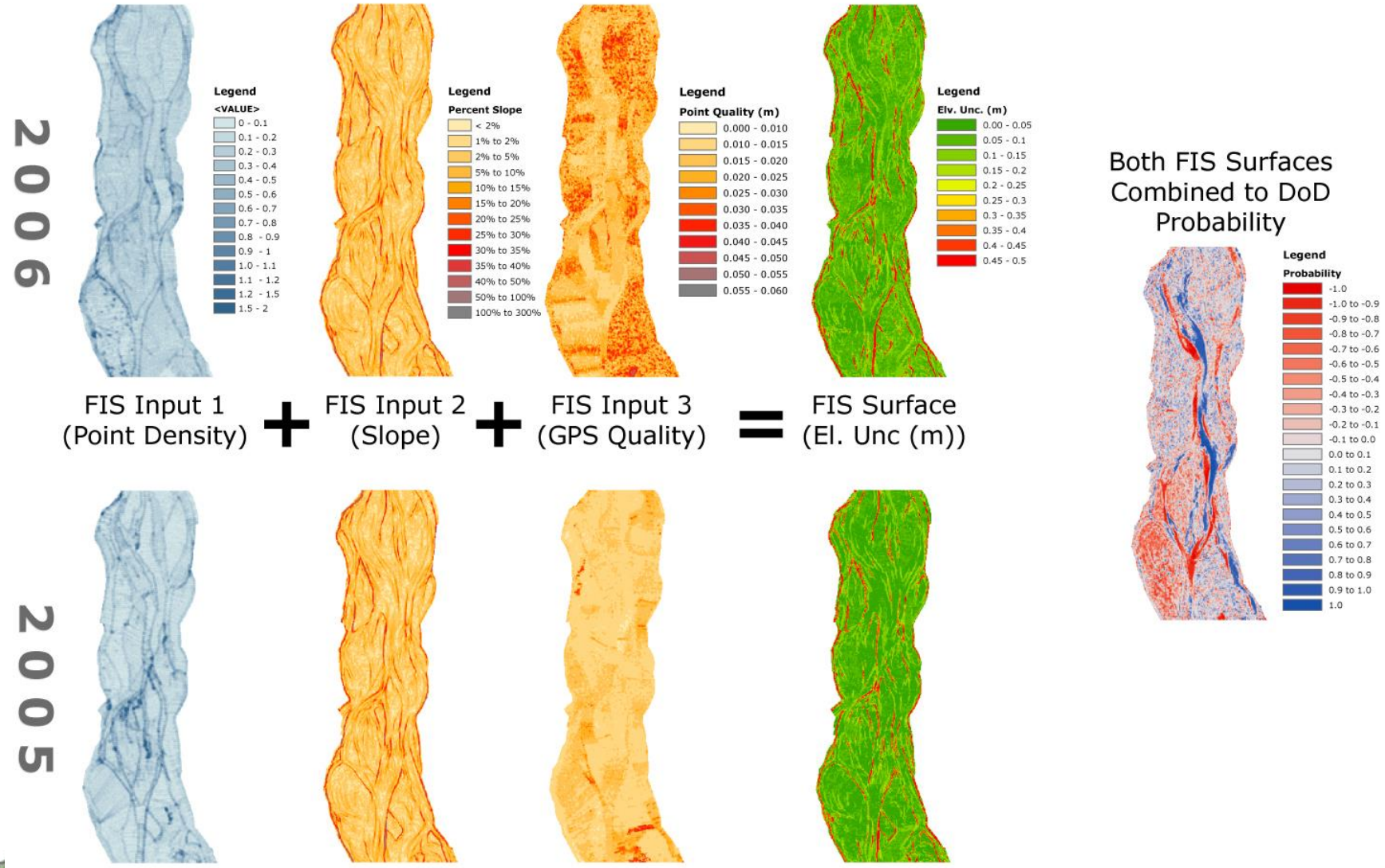


ARGUMENT FOR FUZZY LOGIC



"Fuzzy logic is all about the relative importance of precision: How important is it to be exactly right when a rough answer will do?"

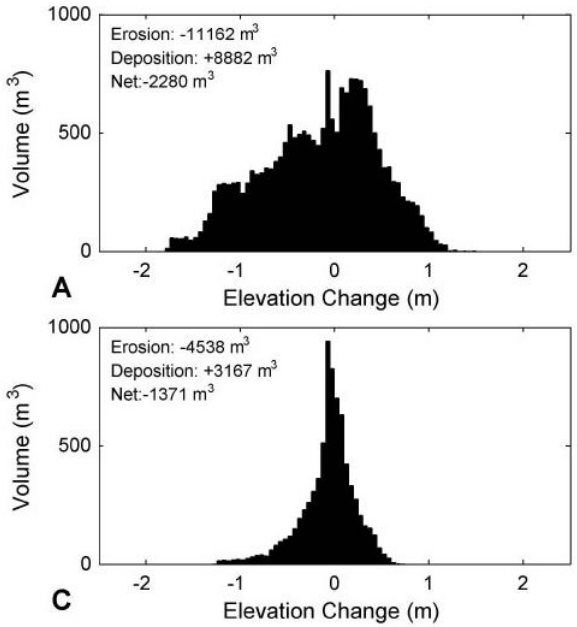
APPLY FIS ON CELL BY CELL BASIS



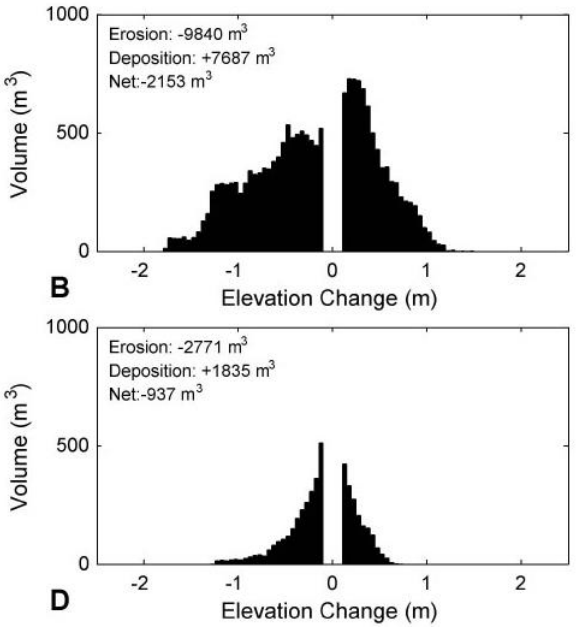
Both FIS Surfaces Combined to DoD Probability

WHAT DOES FIS DO TO ECD?

- Recovers some low magnitude change & discards some higher magnitude change
- More realistic bimodal distribution…

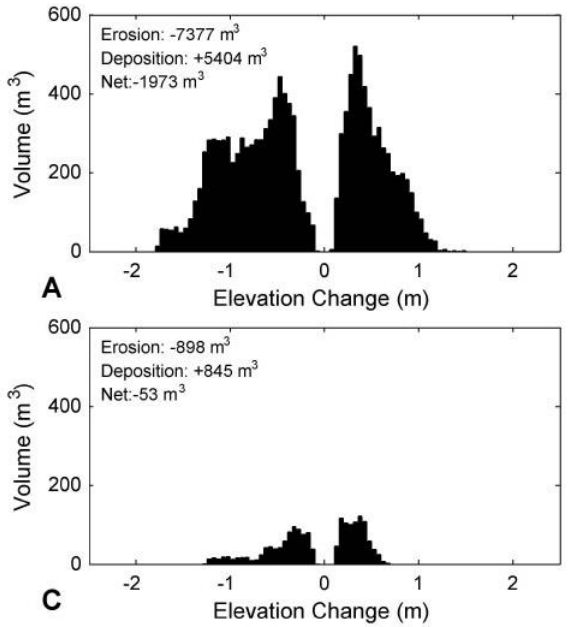


Unthresholded



Spatailly-Uniform

$_{min}$LoD =+/- 10cm



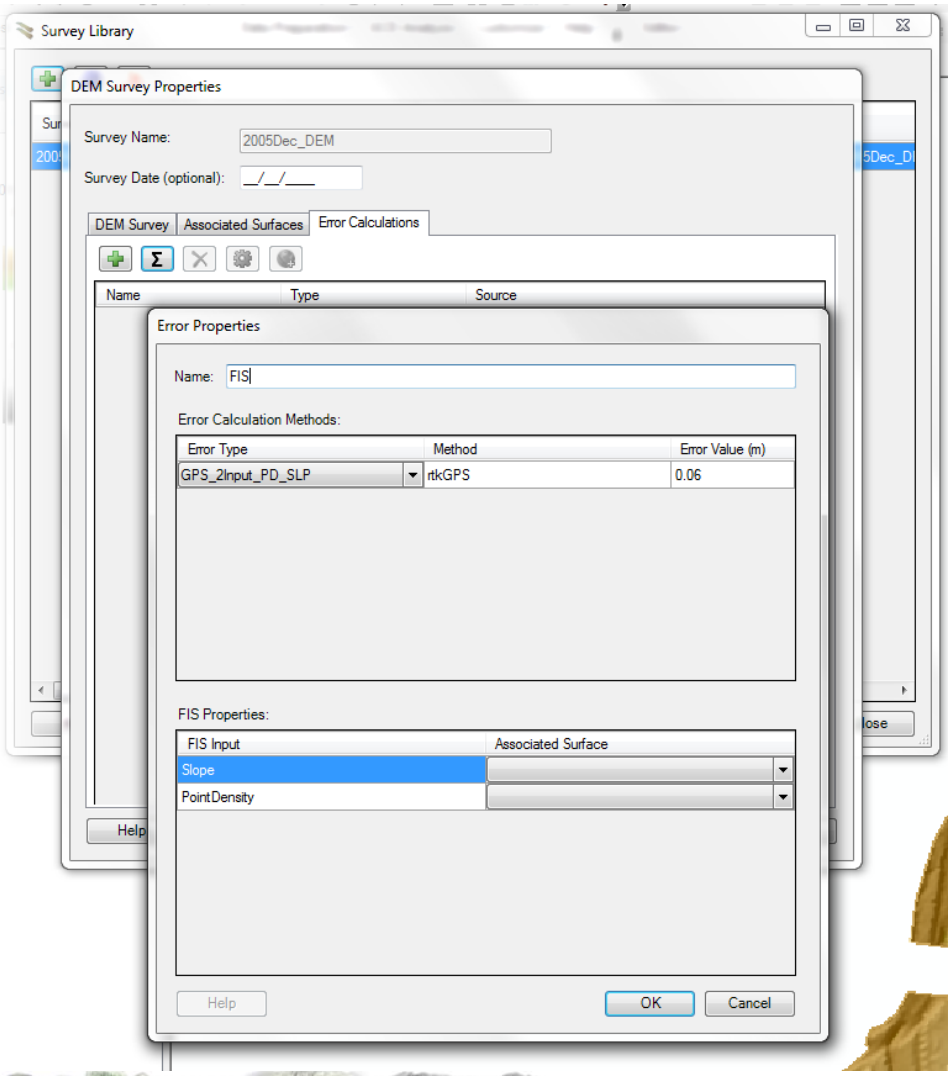
FIS

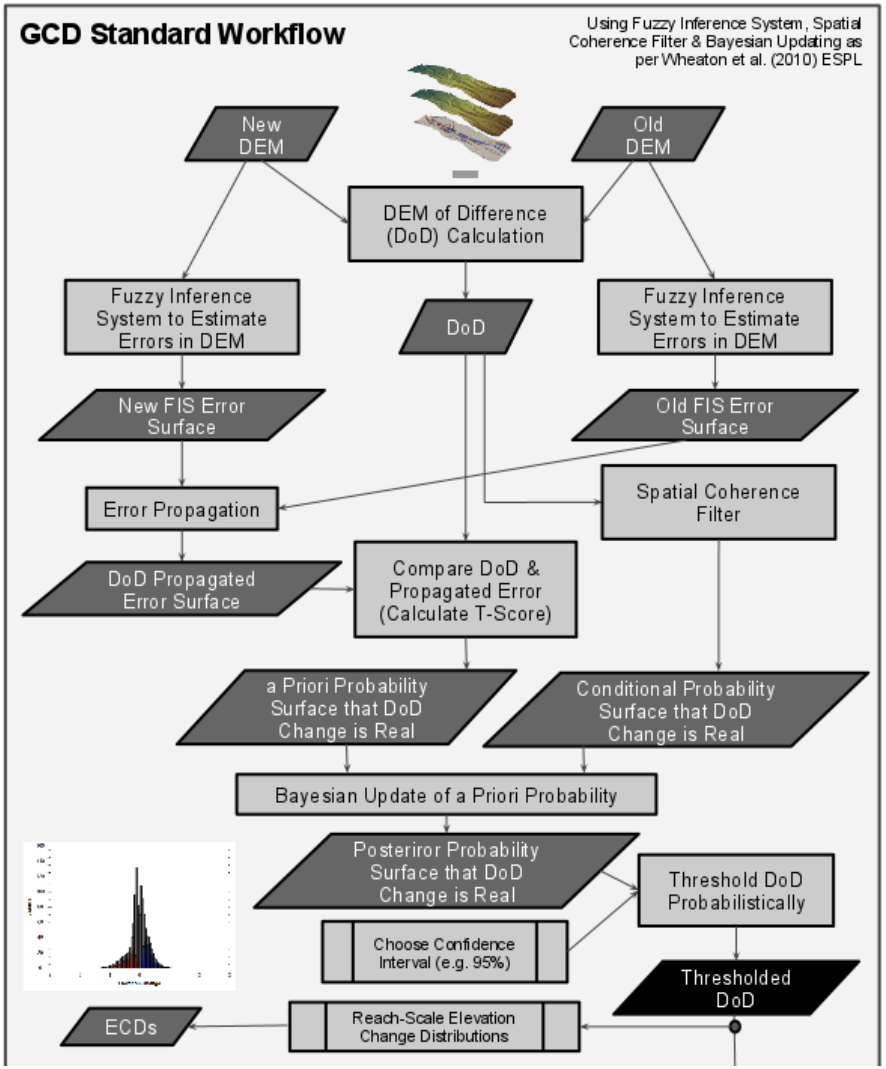
95% C.I.

Wet Year

Dry Year

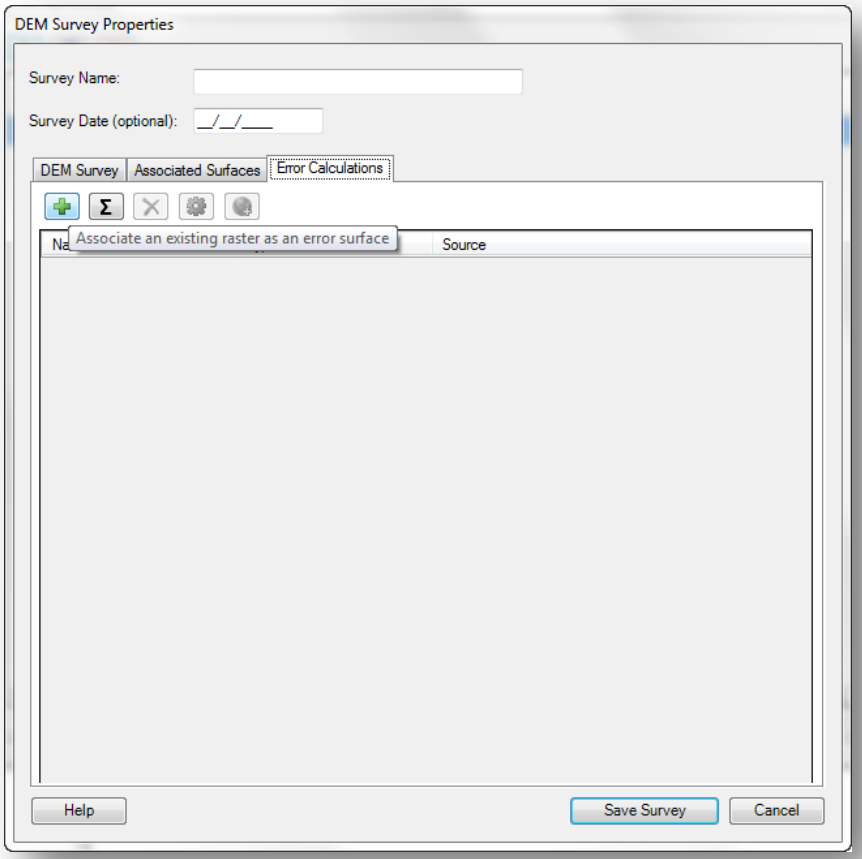
USING THE GCD SOFTWARE… FIS





YOU RUN FIS IN ERROR SURFACES TAB

- Error surfaces created in Survey Library
- Inputs to FIS loaded in Associated Surfaces Tab



WHAT IS AN INFERENCE SYSTEM

- AKA:
  - Rule table
  - Look up Table
- Given inputs a, b, …. N -> output is?

AN INFERENCE SYSTEM OR RULE TABLE

- All Words…
  - E.g. Rule 1: 'If suitability of streamside vegetation is *unsuitable* **and** suitability of riparian/upland vegetation is *unsuitable*, then the dam density capacity is NONE
- How many inputs?
- How many categories for each input?
- How many output categories?
- Why 25 rules?

		INPUTS				OUTPUT
	IF	Suitability of Streamside Vegetation		Suitability of Riparian/Upland Vegetation		Dam Density Capacity
RULES	1	Unsuitable	&	Unsuitable	, then	None
	2	Barely Suitable	&	Unsuitable	, then	Occasional
	3	Moderately Suitable	&	Unsuitable	, then	Occasional
	4	Suitable	&	Unsuitable	, then	Occasional
	5	Preferred	&	Unsuitable	, then	Frequent
	6	Unsuitable	&	Barely Suitable	, then	Occasional
	7	Barely Suitable	&	Barely Suitable	, then	Occasional
	8	Moderately Suitable	&	Barely Suitable	, then	Occasional
	9	Suitable	&	Barely Suitable	, then	Frequent
	10	Preferred	&	Barely Suitable	, then	Frequent
	11	Unsuitable	&	Moderately Suitable	, then	Occasional
	12	Barely Suitable	&	Moderately Suitable	, then	Occasional
	13	Moderately Suitable	&	Moderately Suitable	, then	Frequent
	14	Suitable	&	Moderately Suitable	, then	Frequent
	15	Preferred	&	Moderately Suitable	, then	Frequent
	16	Unsuitable	&	Suitable	, then	Occasional
	17	Barely Suitable	&	Suitable	, then	Occasional
	18	Moderately Suitable	&	Suitable	, then	Frequent
	19	Suitable	&	Suitable	, then	Frequent
	20	Preferred	&	Suitable	, then	Frequent
	21	Unsuitable	&	Preferred	, then	Occasional
	22	Barely Suitable	&	Preferred	, then	Frequent
	23	Moderately Suitable	&	Preferred	, then	Frequent
	24	Suitable	&	Preferred	, then	Pervasive
	25	Preferred	&	Preferred	, then	Pervasive

PROs & CONs of INFERENCE SYSTEM

Pros

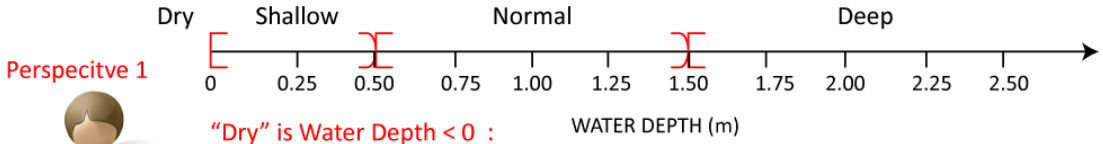
- Easy to apply and transparent
- Flexibility in number of inputs and categories

Cons

- Potentially subjective expert judgment
- Number of rules can grow... substantially

CRISP VS. FUZZY SETS

CRISP CATEGORIZATION OF CONTINUOUS VARIABLE



Perspecitve 1

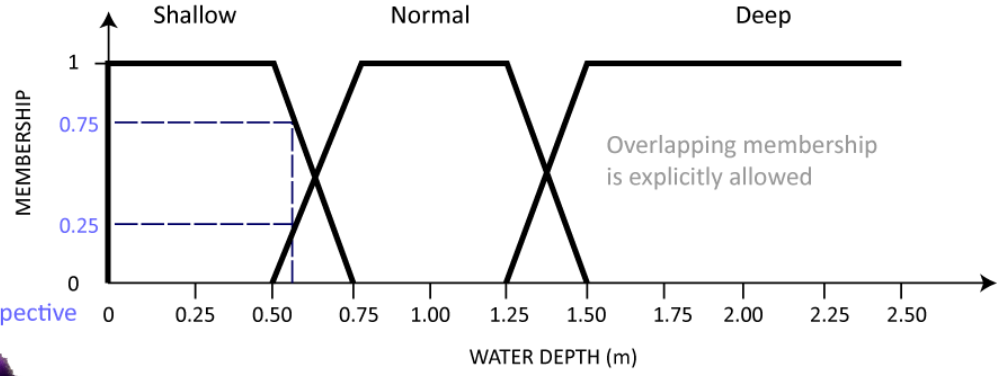
"Dry" is Water Depth < 0 :
"Shallow" is Water Depth from 0 to 0.5
"Normal" is Water Depth from 0.5 to 1.50
"Deep" is Water Depth > 1.50

CATEGORICAL AMBIGUITY BETWEEN PERSPECTIVES

Perspecitve 2

"Dry" is Water Depth < 0
"Shallow" is Water Depth from 0 to 0.75
"Normal" is Water Depth from 0.75 to 1.25
"Deep" is Water Depth > 1.25

FUZZY MEMBERSHIP IN CATEGORIES BASED ON AMBIGUITY/ UNCERTAINTY



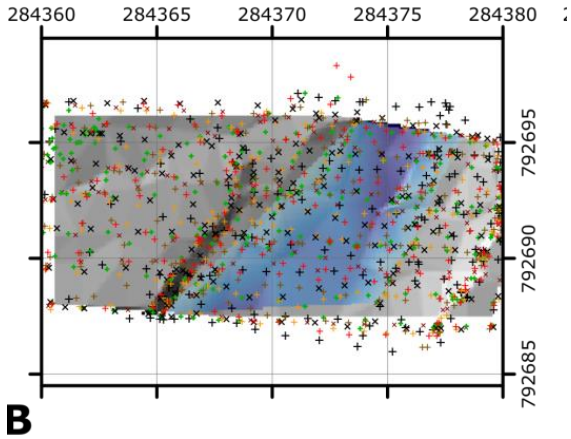
Fuzzy Perspective

A water depth of 0.60 m has a 75% membership in the "Shallow" category and a 25% membership in the "Normal" Category

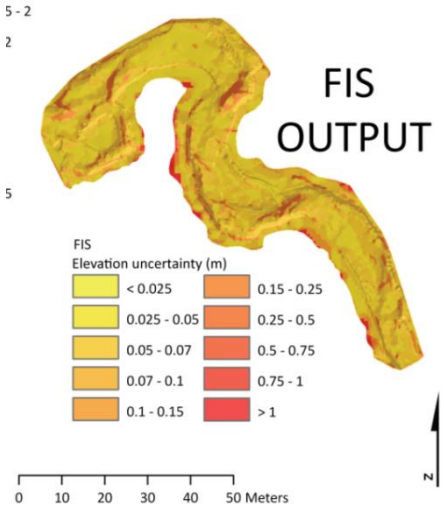
A SIMPLE TWO RULE SYSTEM…

- Given a point cloud
- Relationship between topographic complexity (slope) and sampling (point density)

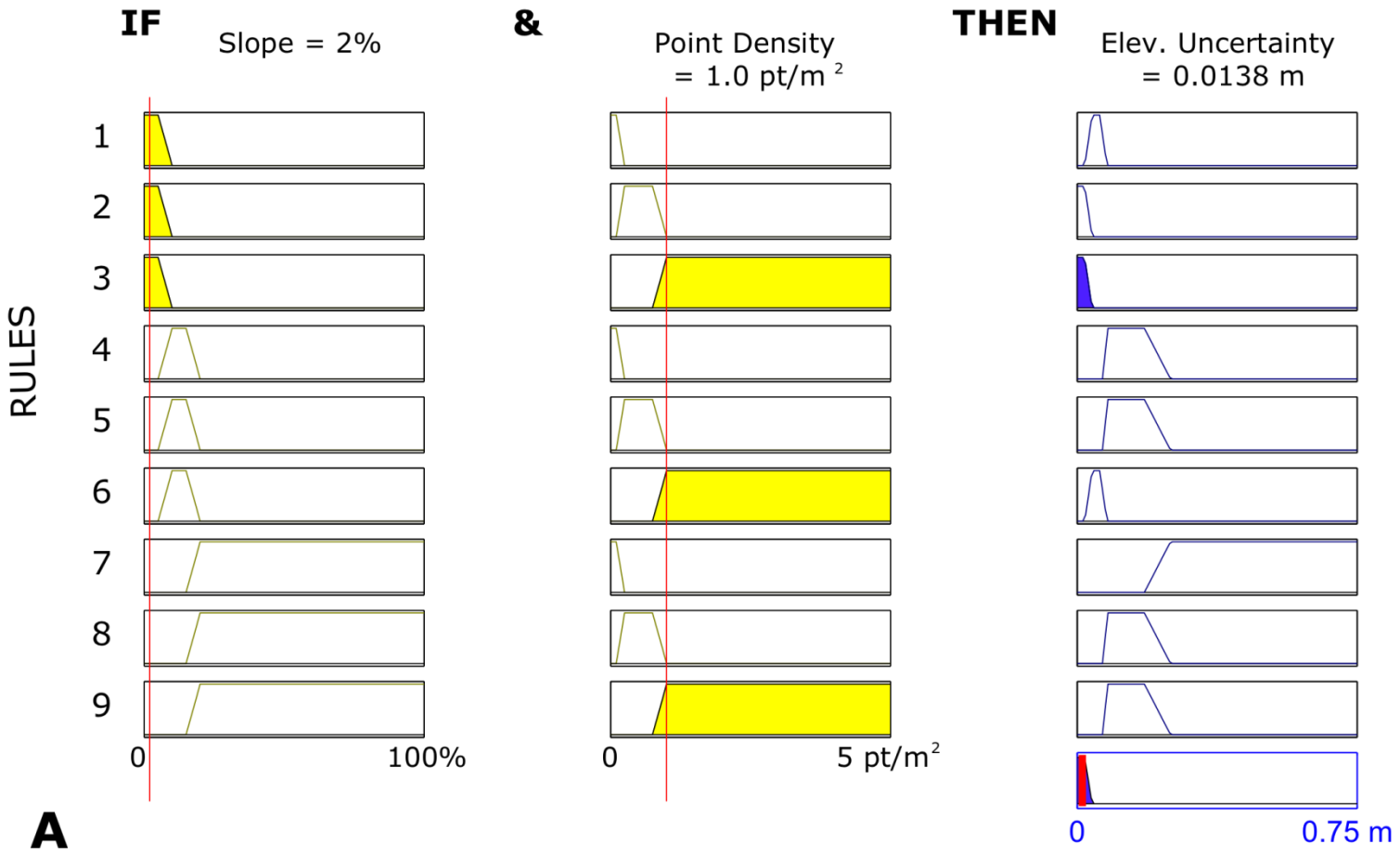
Rule:	Inputs		Output
	Slope %	Pt. ρ m/pts^2	$\delta(z)$ m
1	Low	Low	Average
2	Low	Medium	Low
3	Low	High	Low
4	Medium	Low	High
5	Medium	Medium	High
6	Medium	High	Average
7	High	Low	Extreme
8	High	Medium	High
9	High	High	High



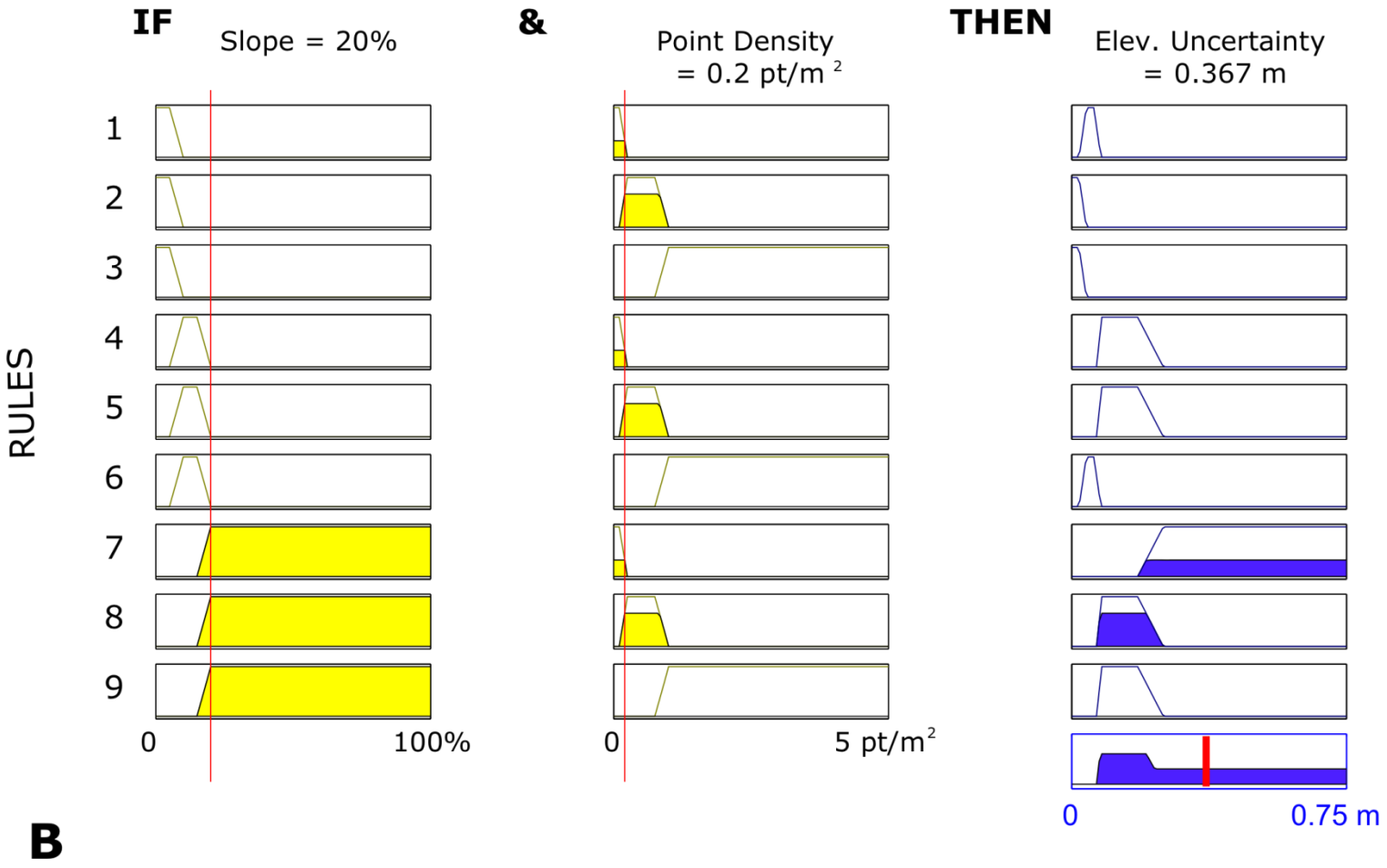
B



EXAMPLE IMPLEMENTATION (2-RULE)



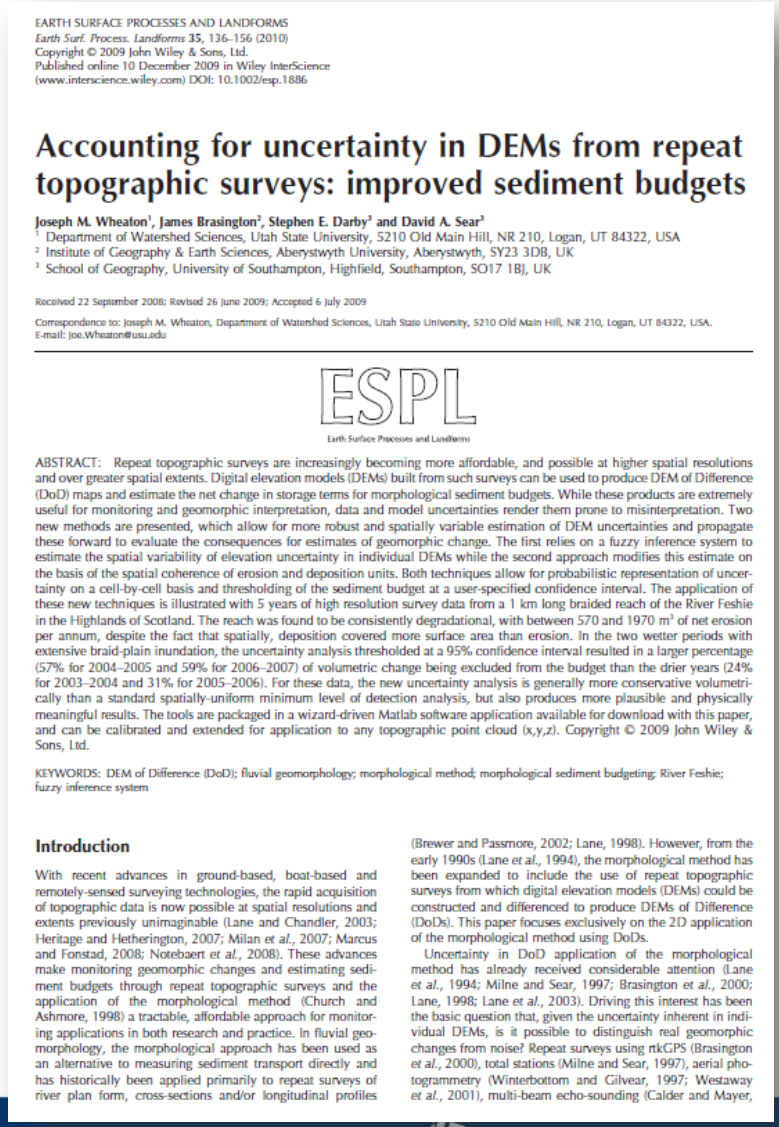
EXAMPLE IMPLEMENTATION



B

SOME BACKGROUND READING

- Two methodological advances
  1. **Fuzzy Inference Systems**
  2. Spatial Coherence Filter & Bayesian Updating



EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **35**, 136–156 (2010)

Published online 10 December 2009 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/esp.1886

Accounting for uncertainty in DEMs from repeat topographic surveys: improved sediment budgets

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Received 22 September 2008; Revised 26 June 2009; Accepted 6 July 2009

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ESPL
Earth Surface Processes and Landforms

ABSTRACT: Repeat topographic surveys are increasingly becoming more affordable, and possible at higher spatial resolutions and over greater spatial extents. Digital elevation models (DEMs) built from such surveys can be used to produce DEM of Difference (DoD) maps and estimate the net change in storage terms for morphological sediment budgets. While these products are extremely useful for monitoring and geomorphic interpretation, data and model uncertainties render them prone to misinterpretation. Two new methods are presented, which allow for more robust and spatially variable estimation of DEM uncertainties and propagate these forward to evaluate the consequences for estimates of geomorphic change. The first relies on a fuzzy inference system to estimate the spatial variability of elevation uncertainty in individual DEMs while the second approach modifies this estimate on the basis of the spatial coherence of erosion and deposition units. Both techniques allow for probabilistic representation of uncertainty on a cell-by-cell basis and thresholding of the sediment budget at a user-specified confidence interval. The application of these new techniques is illustrated with 5 years of high resolution survey data from a 1 km long braided reach of the River Feshie in the Highlands of Scotland. The reach was found to be consistently degradational, with between 570 and 1970 m^3 of net erosion per annum, despite the fact that spatially, deposition covered more surface area than erosion. In the two wetter periods with extensive braid-plain inundation, the uncertainty analysis thresholded at a 95% confidence interval resulted in a larger percentage (57% for 2004–2005 and 59% for 2006–2007) of volumetric change being excluded from the budget than the drier years (24% for 2003–2004 and 31% for 2005–2006). For these data, the new uncertainty analysis is generally more conservative volumetrically than a standard spatially-uniform minimum level of detection analysis, but also produces more plausible and physically meaningful results. The tools are packaged in a wizard-driven Matlab software application available for download with this paper, and can be calibrated and extended for application to any topographic point cloud (x,y,z).

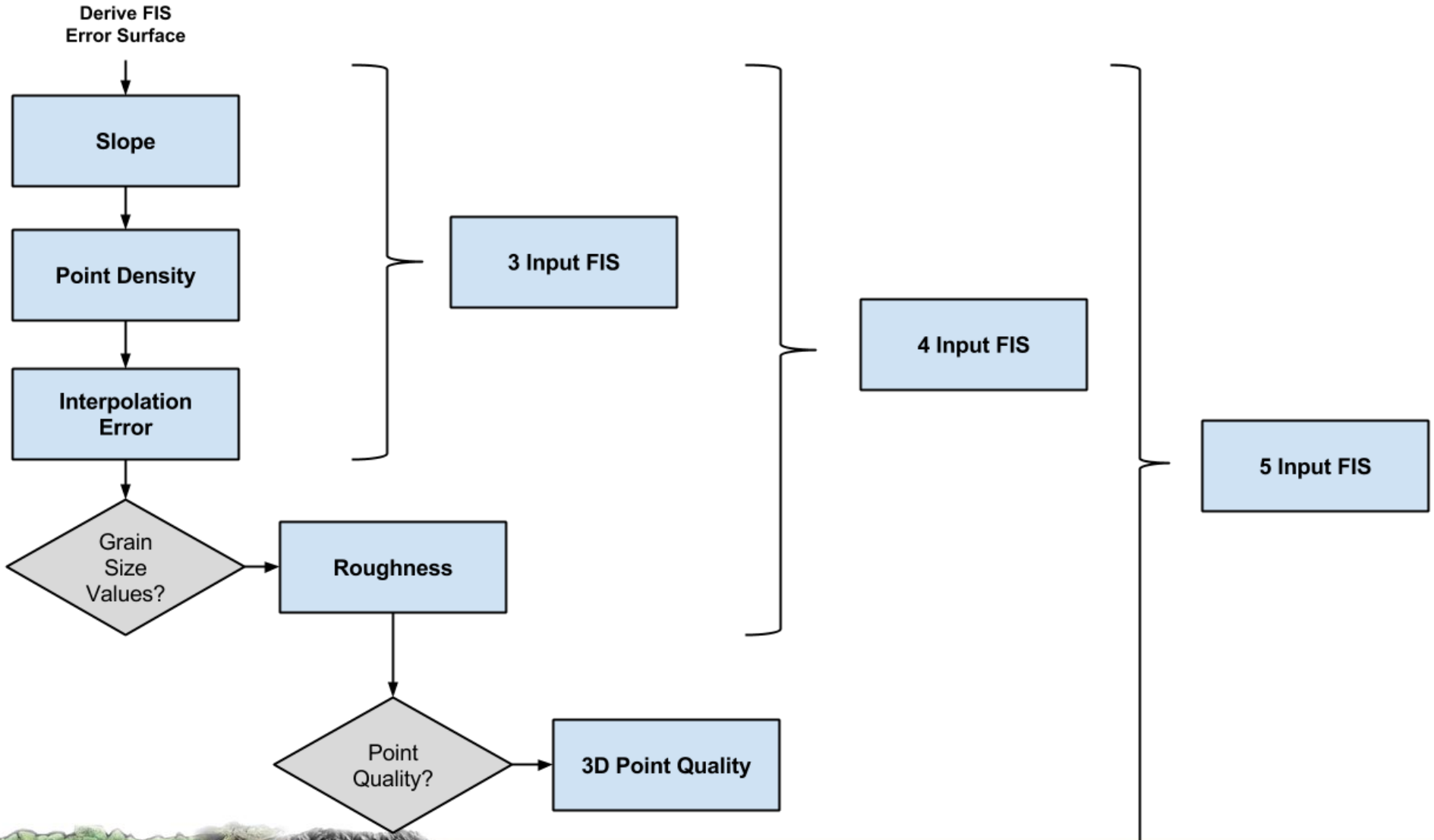
KEYWORDS: DEM of Difference (DoD); fluvial geomorphology; morphological method; morphological sediment budgeting; River Feshie; fuzzy inference system

Introduction

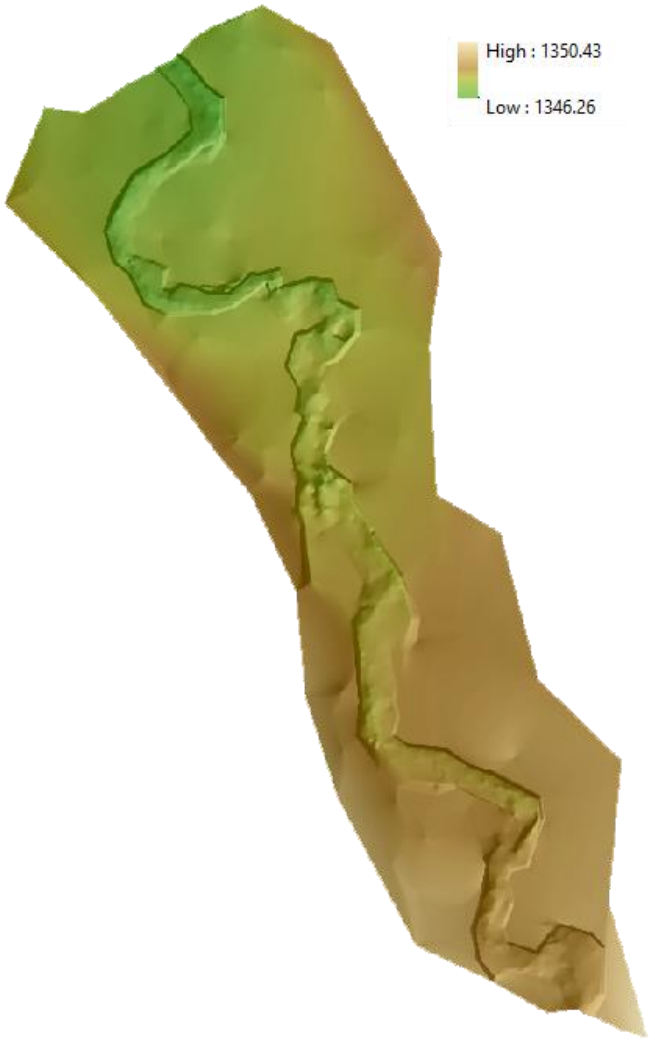
With recent advances in ground-based, boat-based and remotely-sensed surveying technologies, the rapid acquisition of topographic data is now possible at spatial resolutions and extents previously unimaginable (Lane and Chandler, 2003; Heritage and Hetherington, 2007; Milan *et al.*, 2007; Marcus and Fonstad, 2008; Notebaert *et al.*, 2008). These advances make monitoring geomorphic changes and estimating sediment budgets through repeat topographic surveys and the application of the morphological method (Church and Ashmore, 1998) a tractable, affordable approach for monitoring applications in both research and practice. In fluvial geomorphology, the morphological approach has been used as an alternative to measuring sediment transport directly and has historically been applied primarily to repeat surveys of river plan form, cross-sections and/or longitudinal profiles (Brewer and Passmore, 2002; Lane, 1998). However, from the early 1990s (Lane *et al.*, 1994), the morphological method has been expanded to include the use of repeat topographic surveys from which digital elevation models (DEMs) could be constructed and differenced to produce DEMs of Difference (DoDs). This paper focuses exclusively on the 2D application of the morphological method using DoDs.

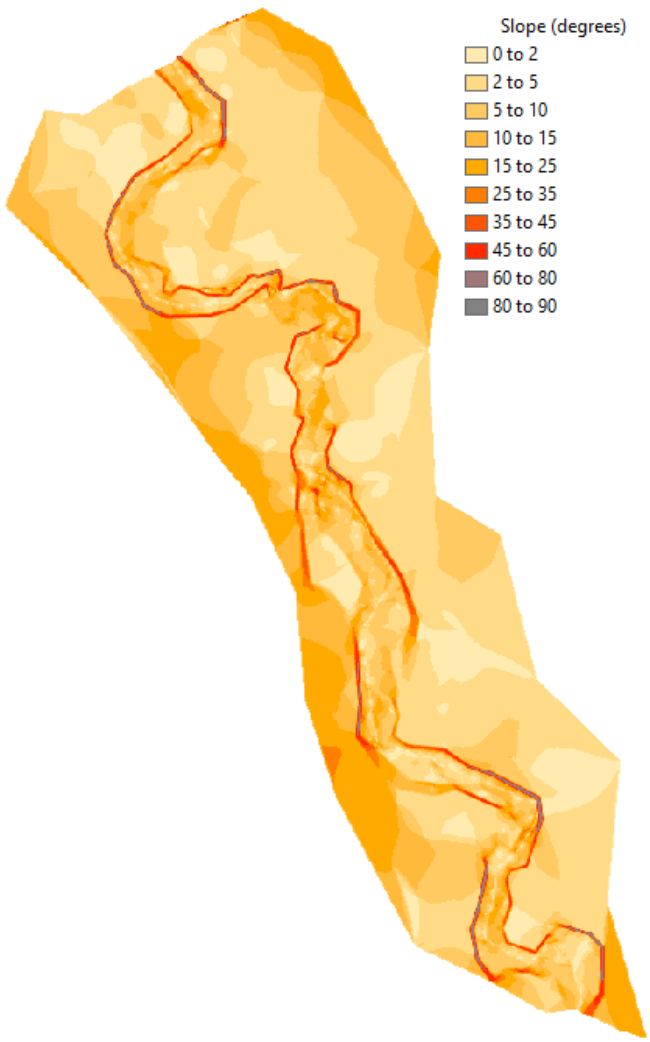
Uncertainty in DoD application of the morphological method has already received considerable attention (Lane *et al.*, 1994; Milne and Sear, 1997; Brasington *et al.*, 2000; Lane, 1998; Lane *et al.*, 2003). Driving this interest has been the basic question that, given the uncertainty inherent in individual DEMs, is it possible to distinguish real geomorphic changes from noise? Repeat surveys using rtkGPS (Brasington *et al.*, 2000), total stations (Milne and Sear, 1997), aerial photogrammetry (Winterbottom and Gilvear, 1997; Westaway *et al.*, 2001), multi-beam echo-sounding (Calder and Mayer,

METHOD

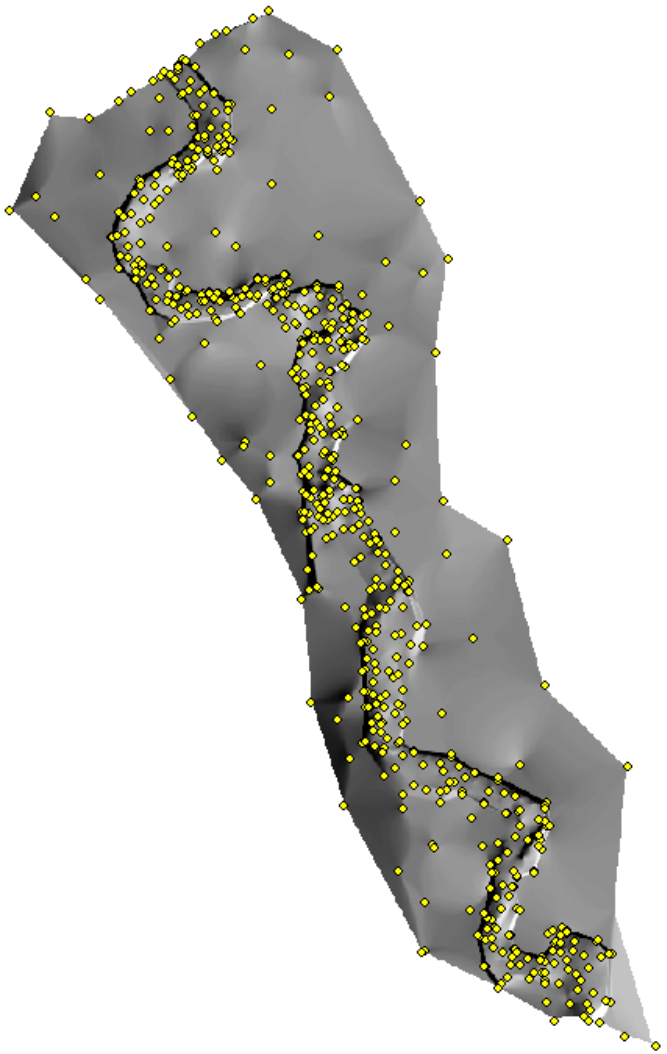

Derive FIS Error Surface
Slope
Point Density
Interpolation Error
Grain Size Values?
Roughness
Point Quality?
3D Point Quality
3 Input FIS
4 Input FIS
5 Input FIS

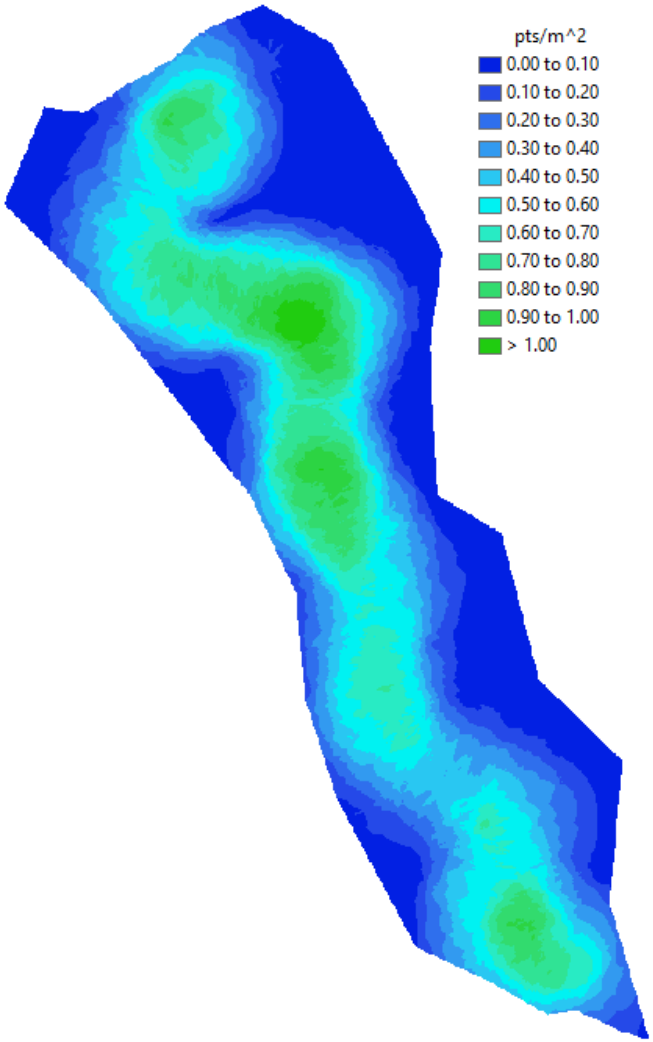
SLOPE


High : 1350.43
Low : 1346.26

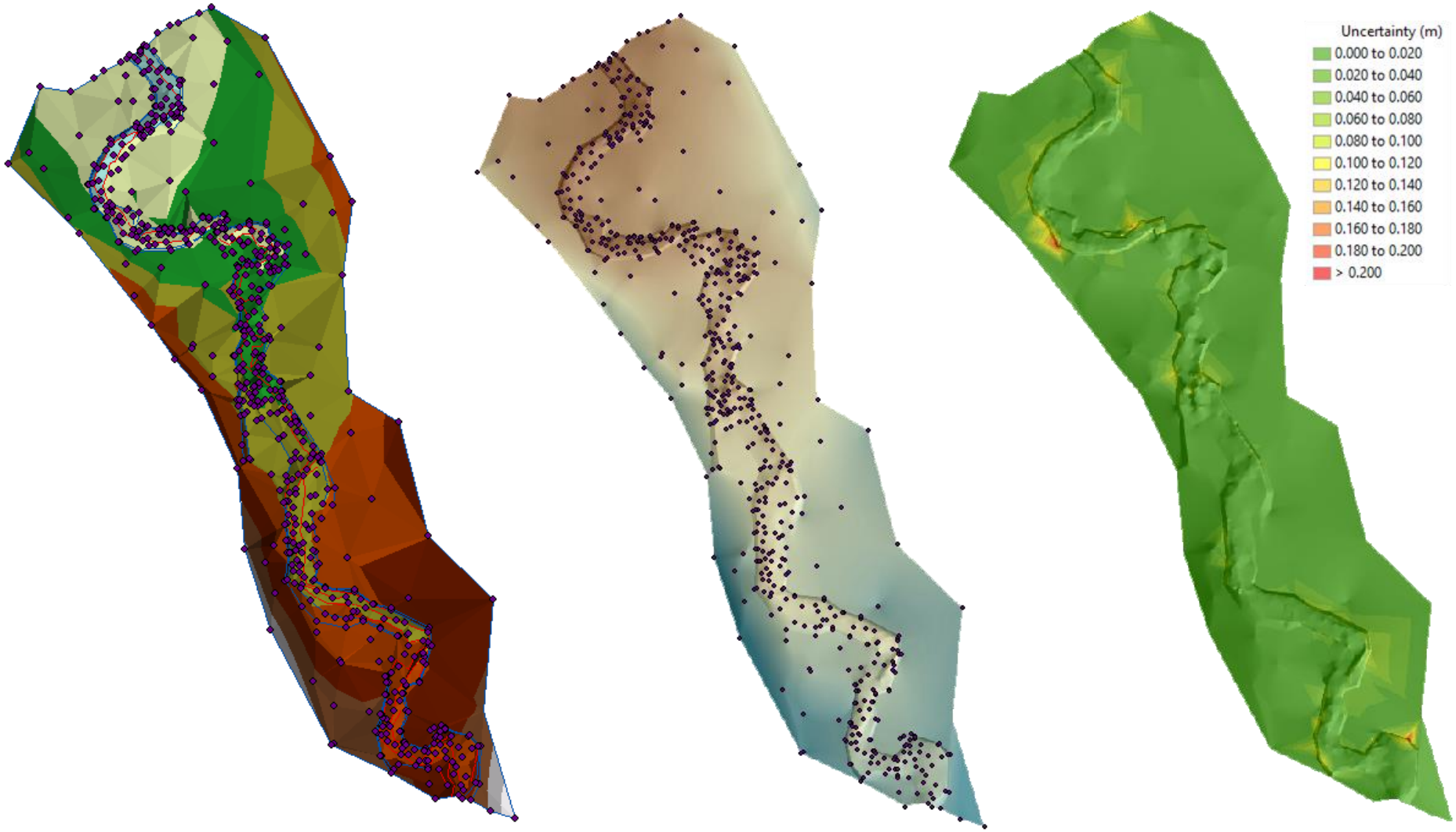

Slope (degrees)
0 to 2
2 to 5
5 to 10
10 to 15
15 to 25
25 to 35
35 to 45
45 to 60
60 to 80
80 to 90

POINT DENSITY

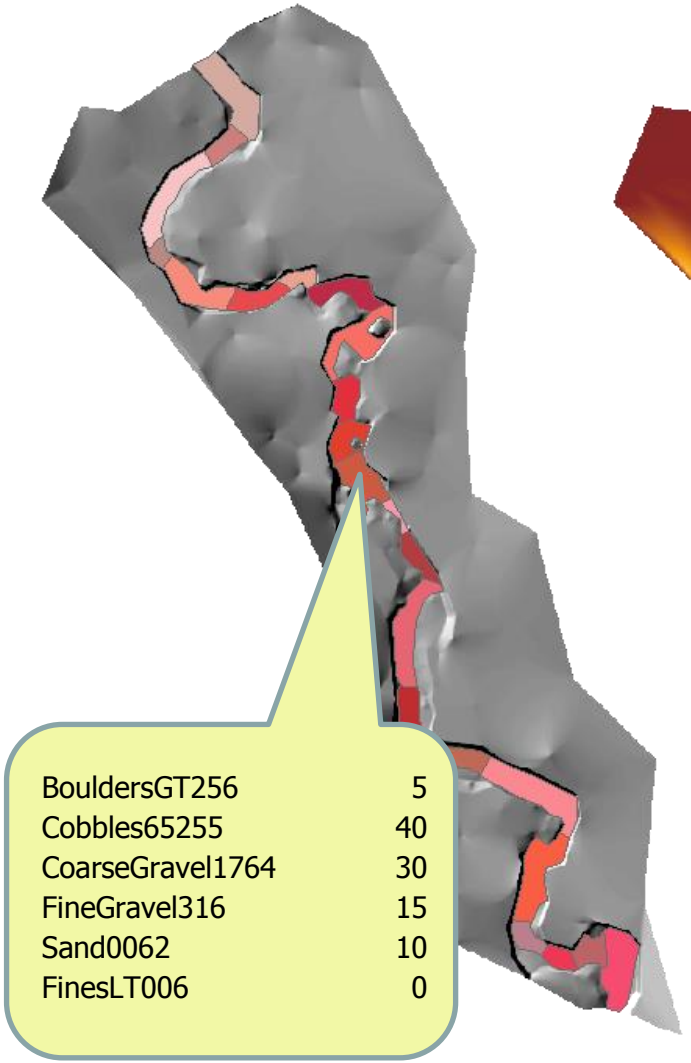




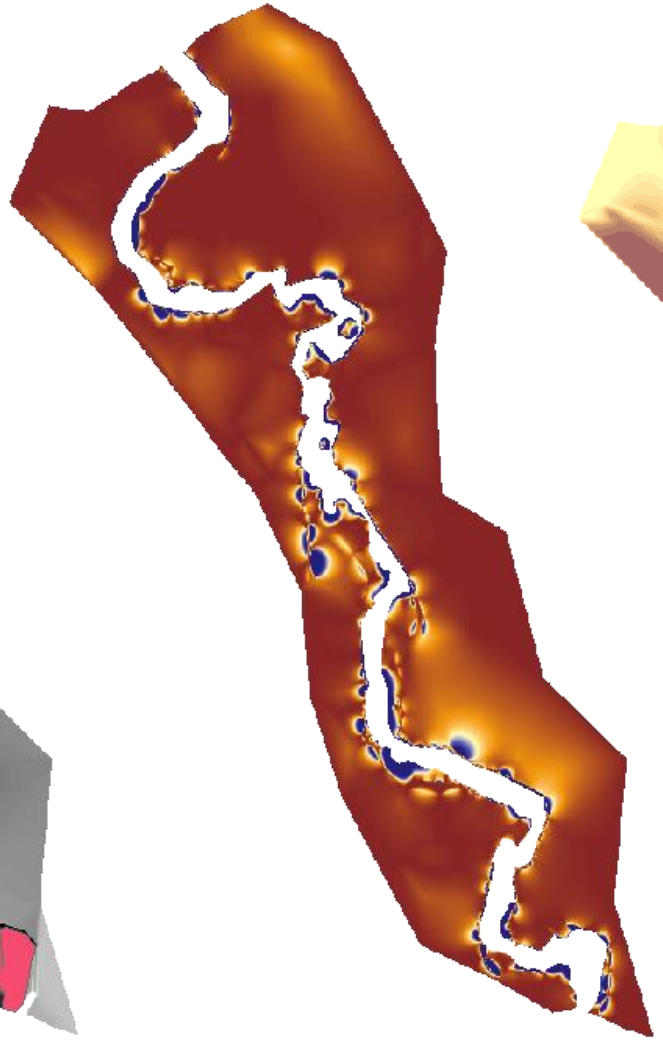
INTERPOLATION ERROR

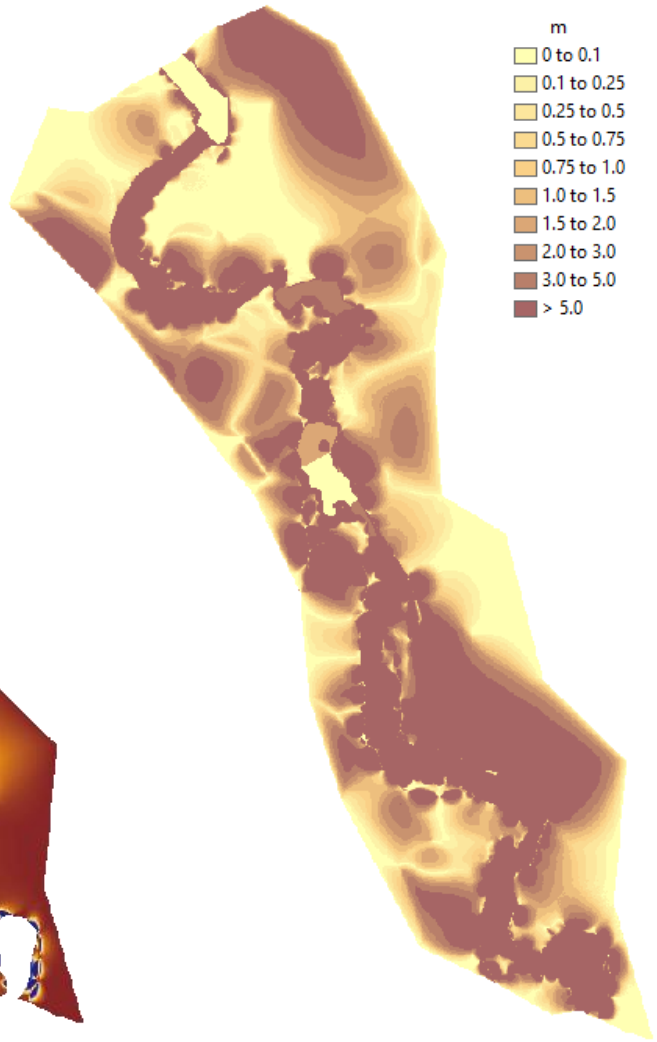


ROUGHNESS

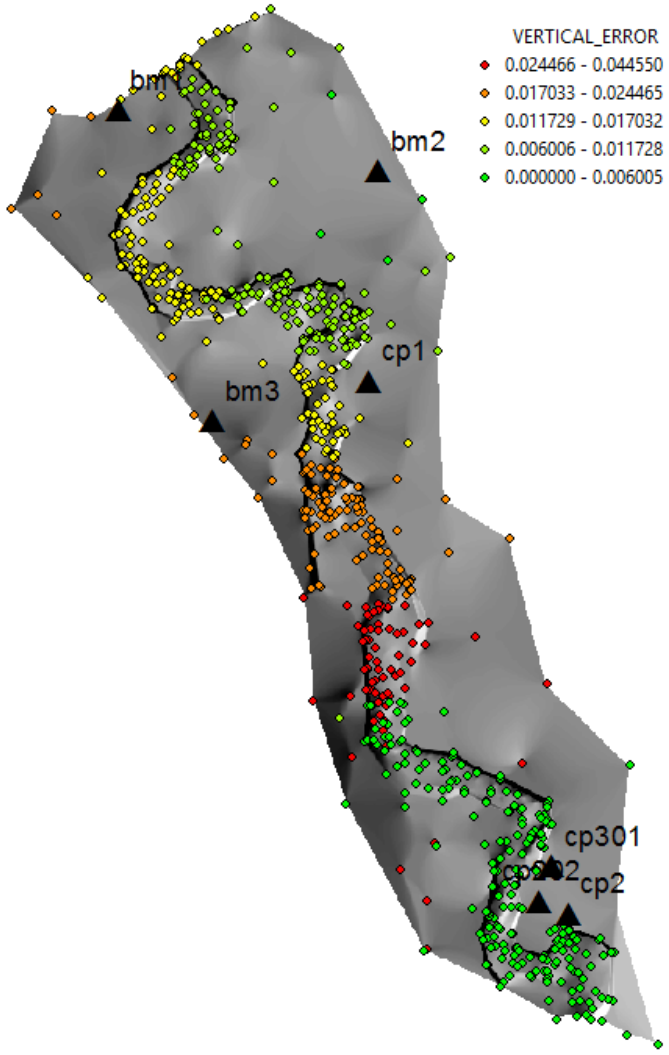


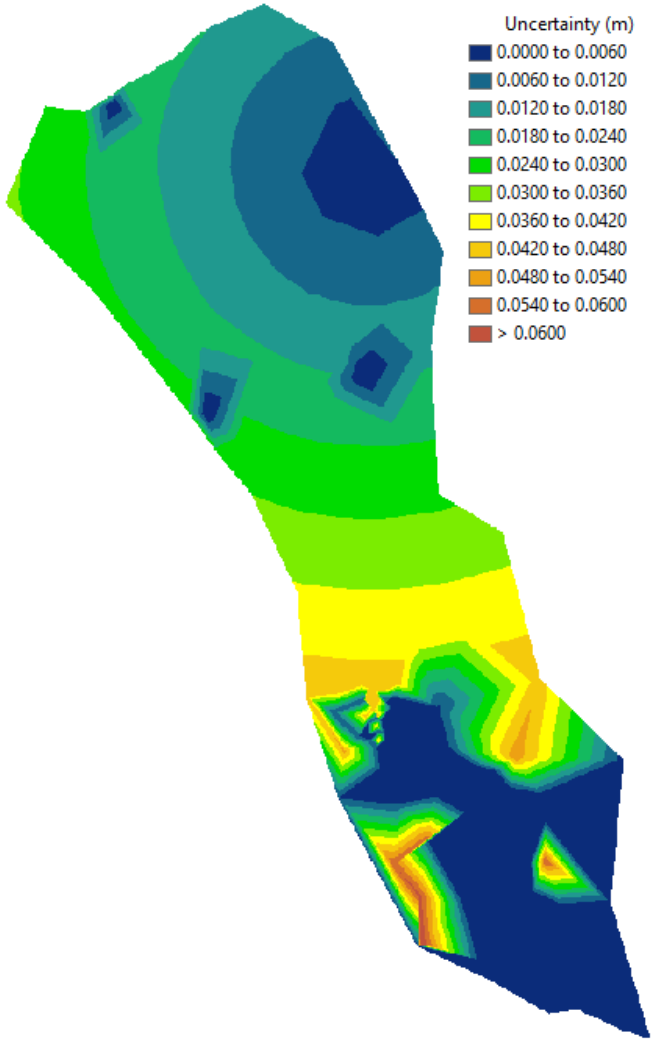
BouldersGT256	5
Cobbles65255	40
CoarseGravel1764	30
FineGravel316	15
Sand0062	10
FinesLT006	0



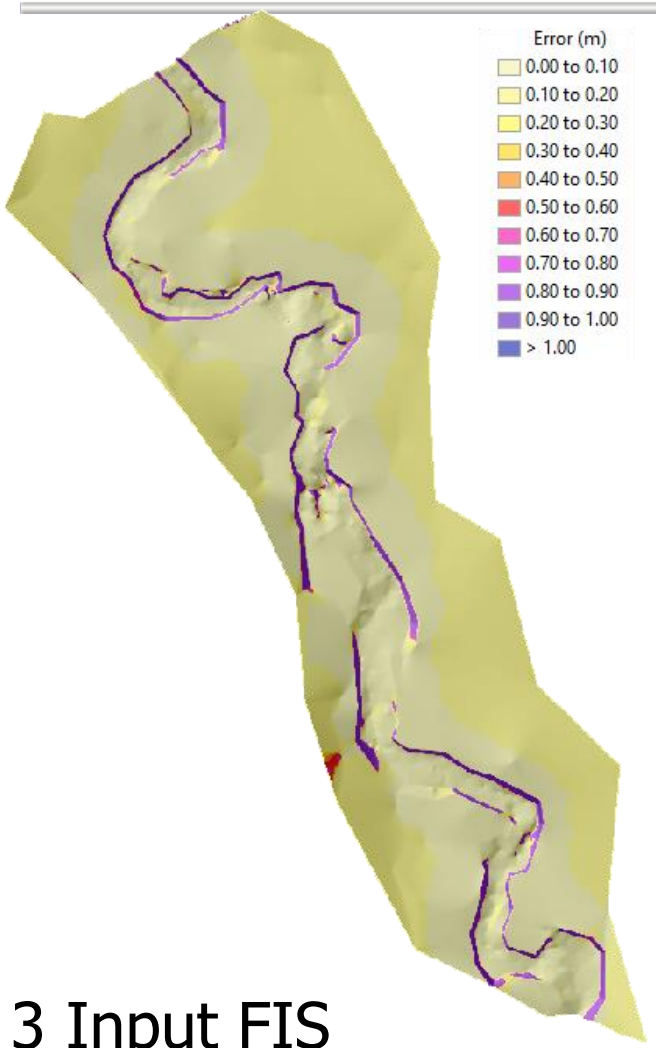


3D POINT QUALITY

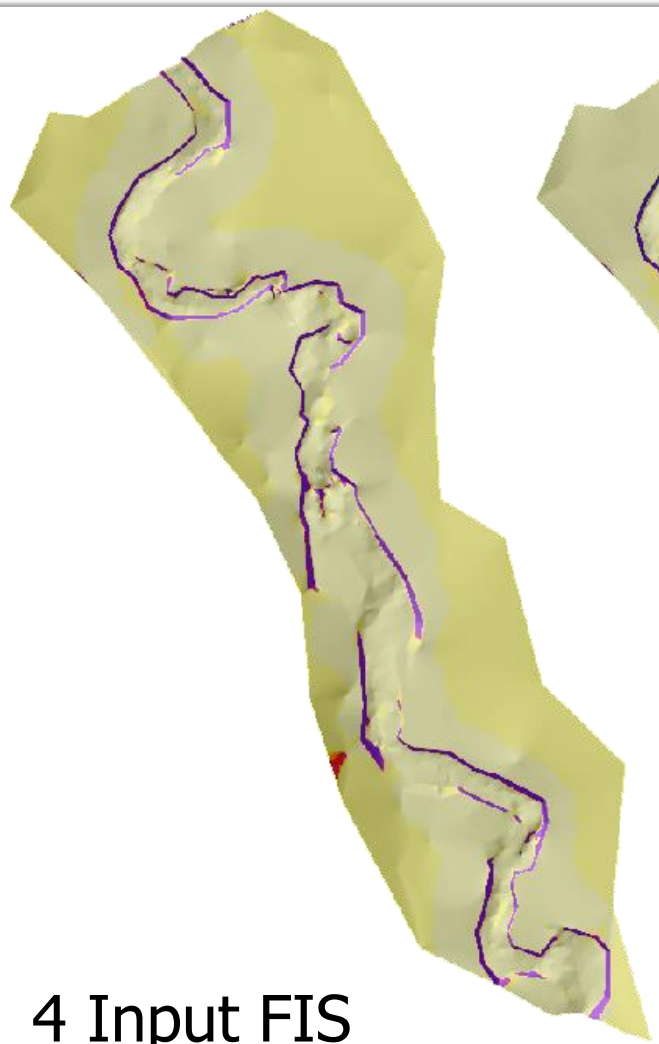




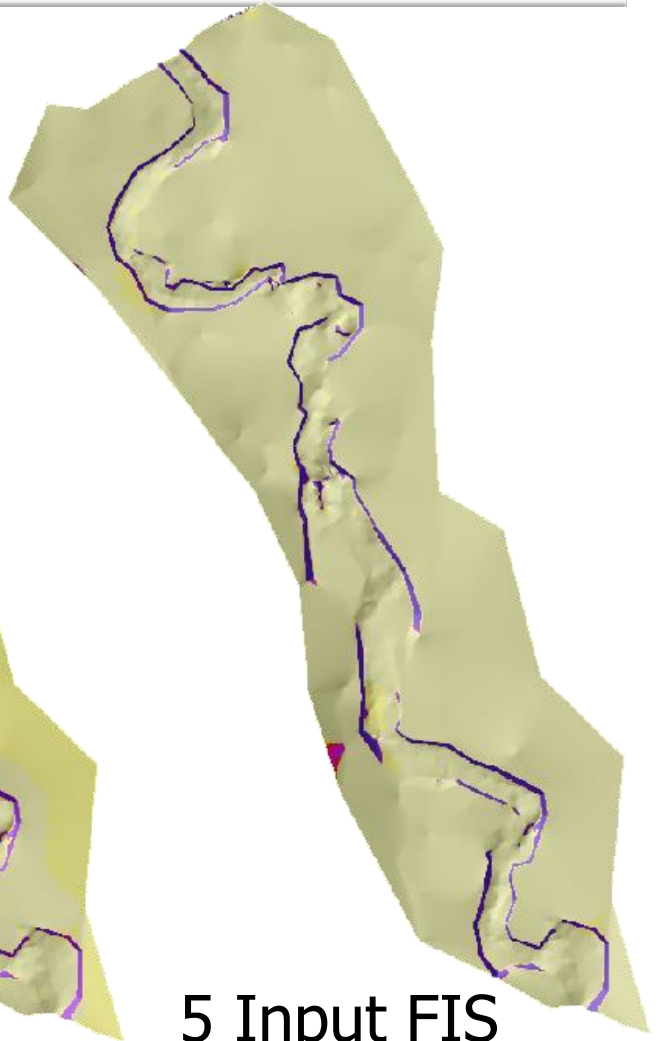
ERROR SURFACES



3 Input FIS



4 Input FIS



5 Input FIS

EXERCISE PIP: CHaMP FIS ERROR MODELS

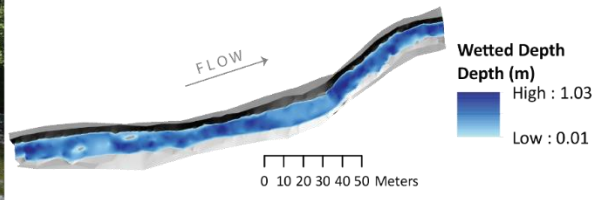
C:\CHaMPWorkshop\Exercises\GCD\O_CHaMPFIS

1. Start New ArcMap Document
2. Listen to Philip….

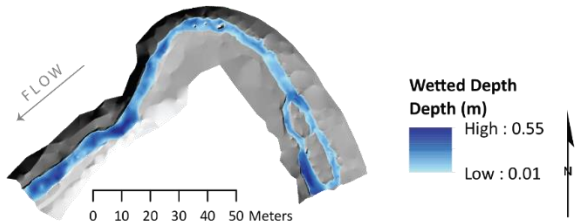
EXAMPLE OF TWO CONTRASTING SITES

Interior Columbia
River Basin
Location Map

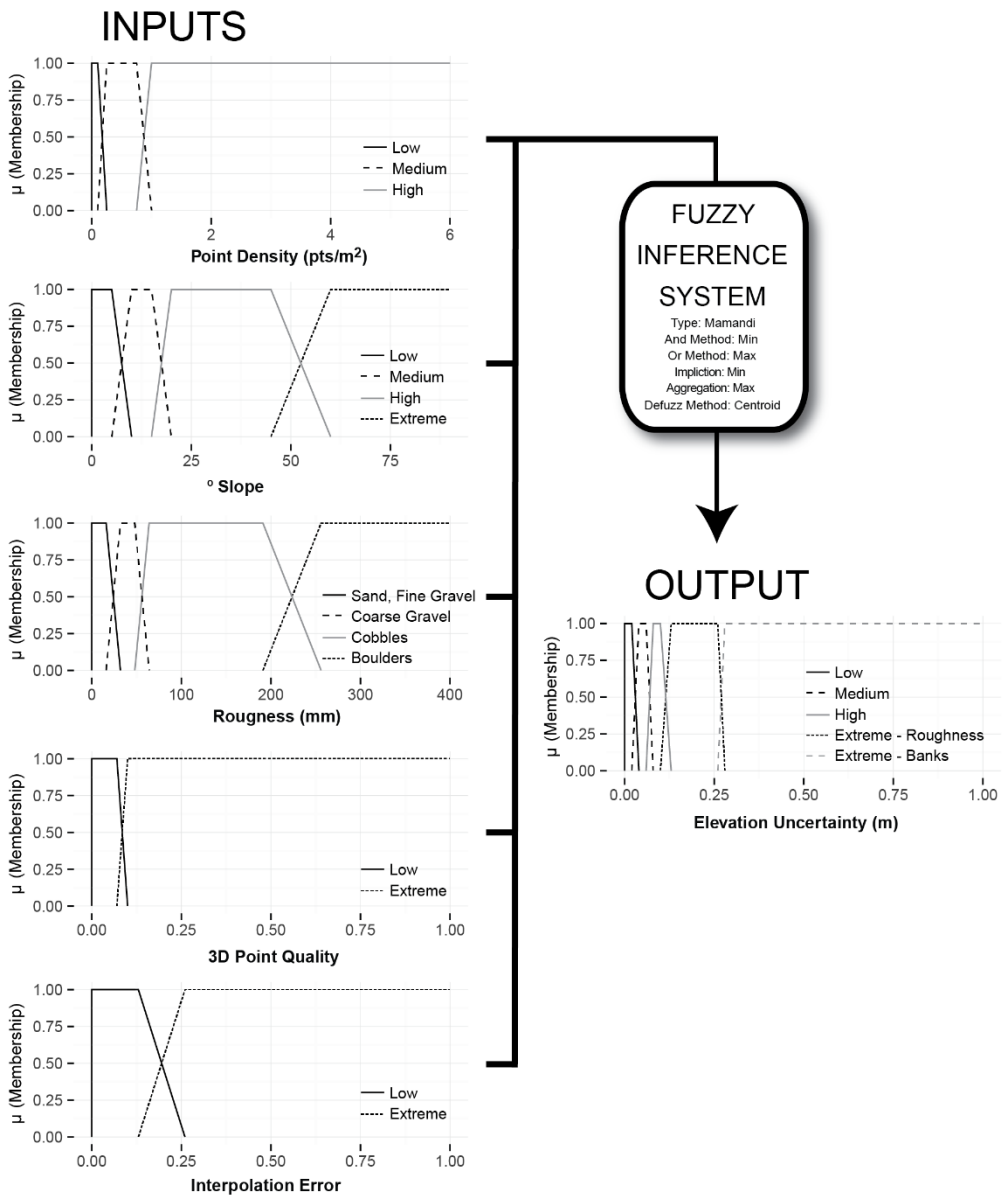
Mad River

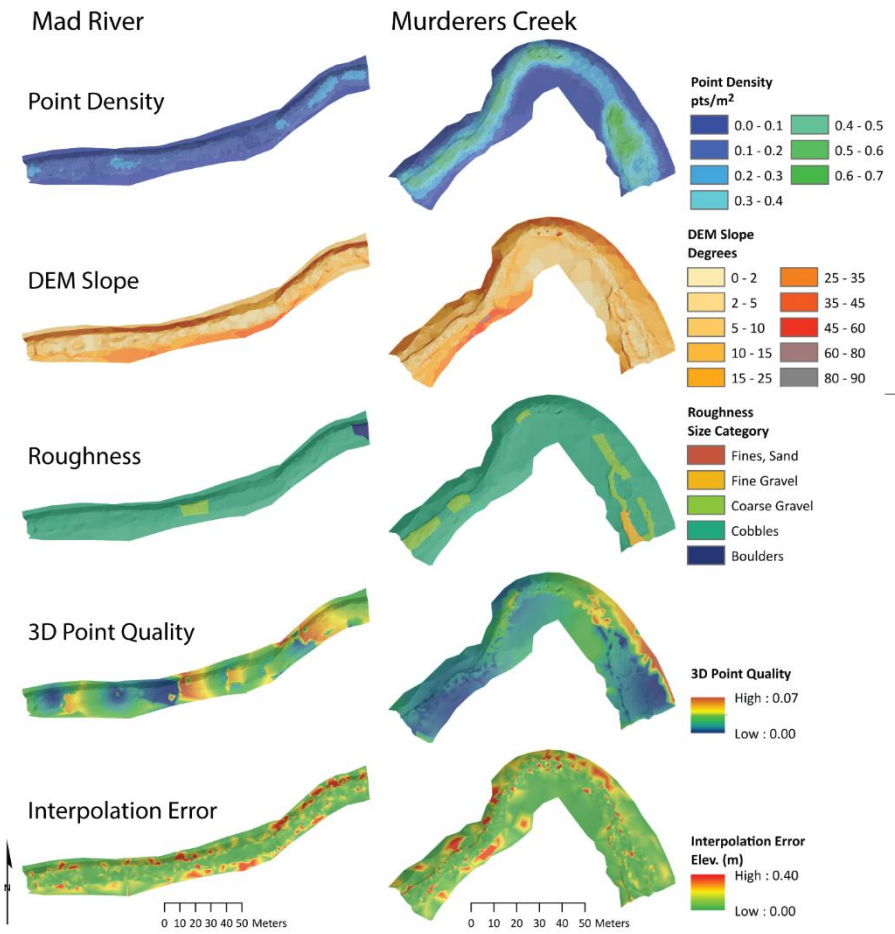


Murderers Creek

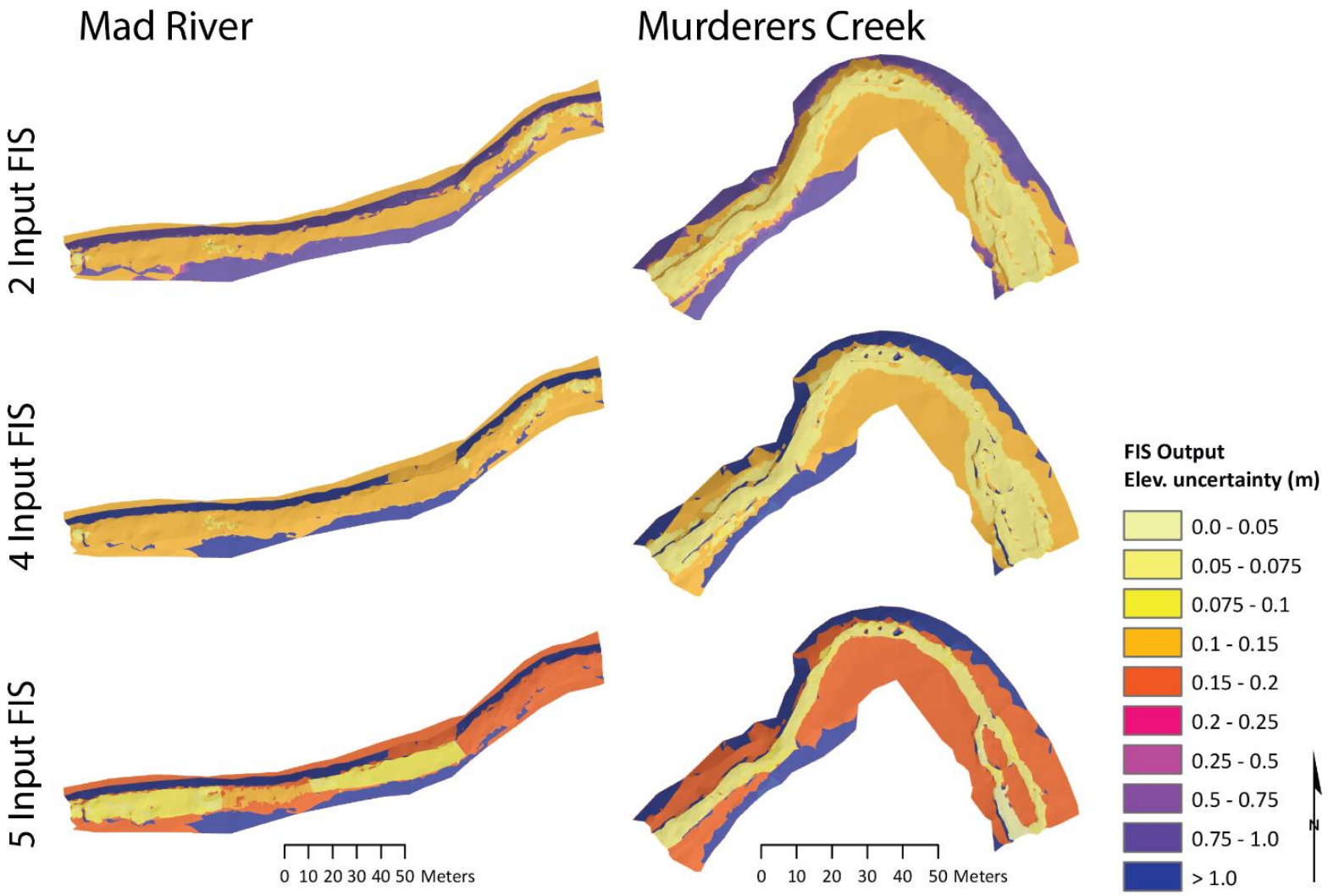


INPUTS...


INPUTS
μ (Membership)
Low
Medium
High
Point Density (pts/m²)
Extreme
° Slope
Sand, Fine Gravel
Coarse Gravel
Cobbles
Boulders
Rougness (mm)
3D Point Quality
Interpolation Error
FUZZY INFERENCE SYSTEM
Type: Mamandi
And Method: Min
Or Method: Max
Impliction: Min
Aggregation: Max
Defuzz Method: Centroid
OUTPUT
Extreme - Roughness
Extreme - Banks
Elevation Uncertainty (m)

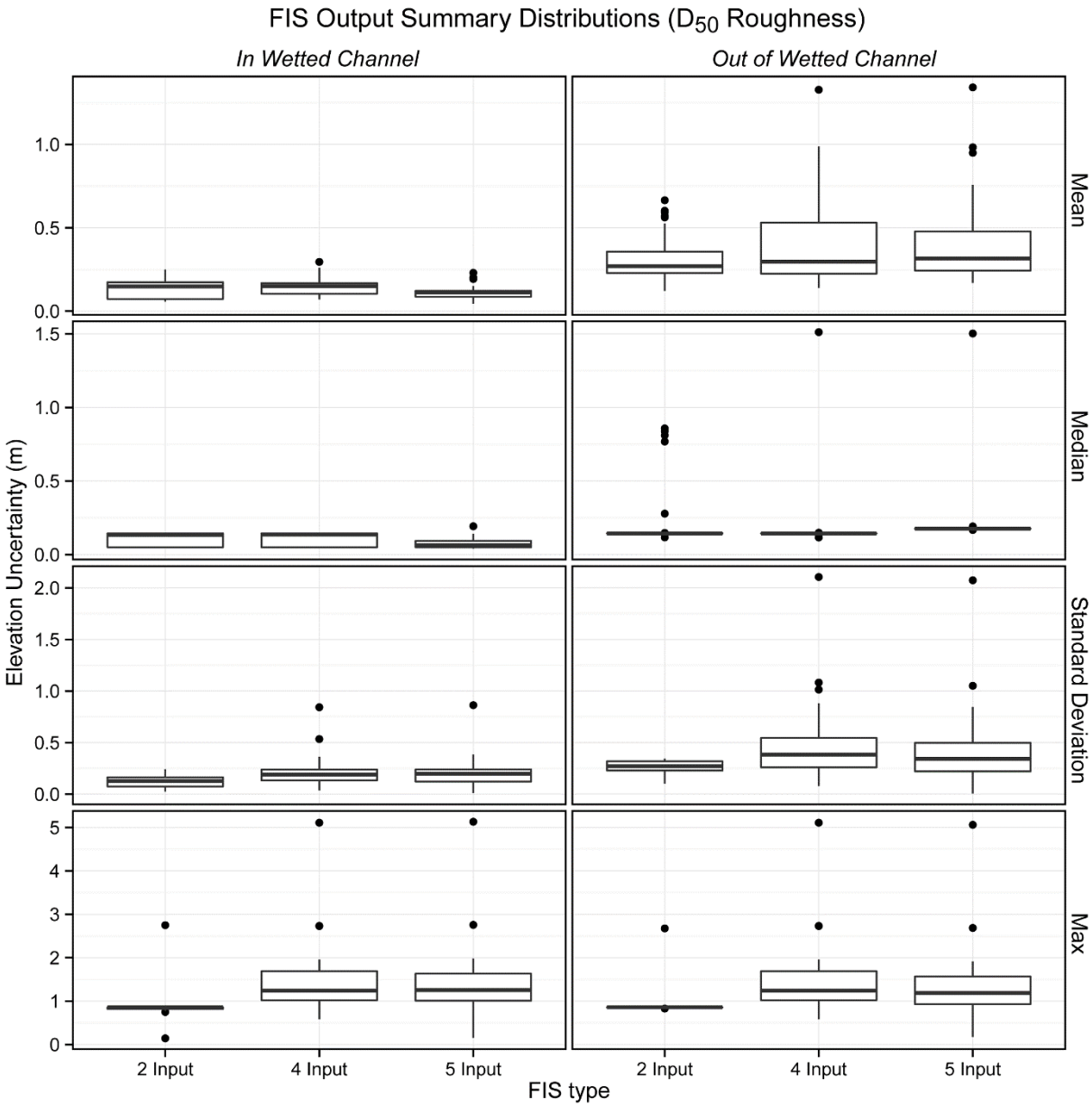

Mad River
Murderers Creek
Point Density
DEM Slope
Roughness
3D Point Quality
Interpolation Error
Point Density pts/m²
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
DEM Slope Degrees
0 - 2
2 - 5
5 - 10
10 - 15
15 - 25
25 - 35
35 - 45
45 - 60
60 - 80
80 - 90
Roughness Size Category
Fines, Sand
Fine Gravel
Coarse Gravel
Cobbles
Boulders
3D Point Quality
High : 0.07
Low : 0.00
Interpolation Error Elev. (m)
High : 0.40
Low : 0.00
0 10 20 30 40 50 Meters
0 10 20 30 40 50 Meters

OUTPUTS


Mad River
Murderers Creek
2 Input FIS
4 Input FIS
5 Input FIS
0 10 20 30 40 50 Meters
0 10 20 30 40 50 Meters
FIS Output
Elev. uncertainty (m)
0.0 - 0.05
0.05 - 0.075
0.075 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1.0
> 1.0
N

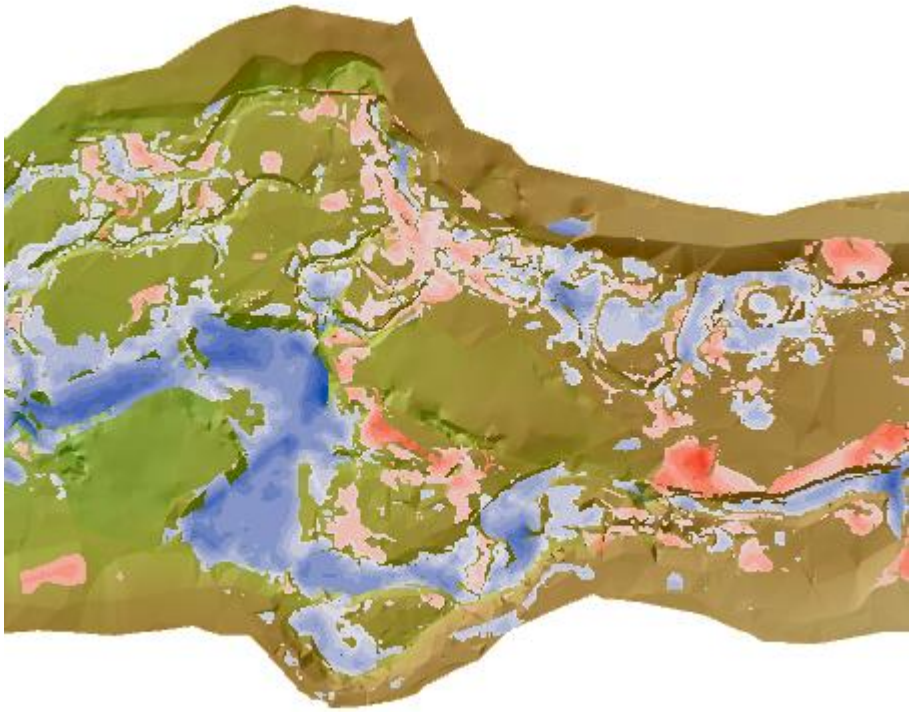
WHAT DOES ADDING MORE INPUTS DO?

- Minimal impact on mean
- Modest impact on standard deviation
- Biggest impact on outliers
- i.e. Its picking up localities with minor problems



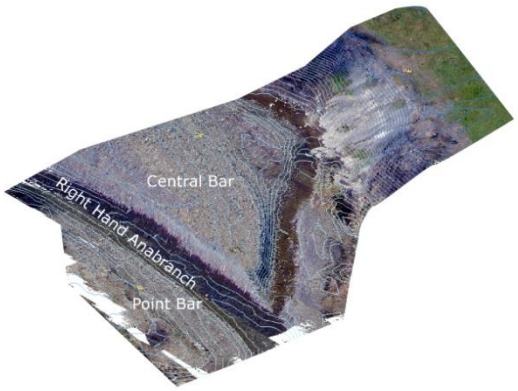
EXERCISE R – BRIDGE CREEK

- Create Project "Lower Owens D"
- Add two DEM Surveys (2010, 2014)
- Generate Associated Surfaces
  - Slope
  - Point Density (Topo_Points.shp)
  - Interpolation Error (XXXX_InterpError.tif)
- Generate 3 Input FIS error surfaces
- Change Detection using Probabilistic Threshold at 80% confidence level

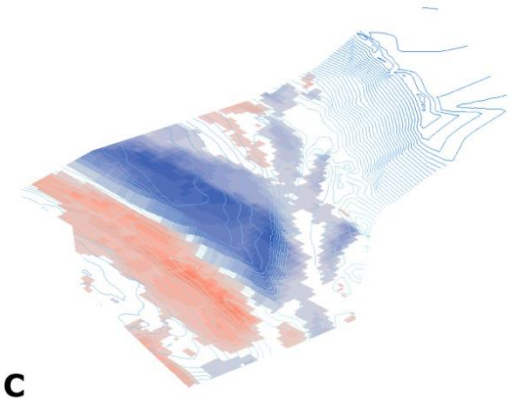


USE MASKS TO SEGREGATE DoD

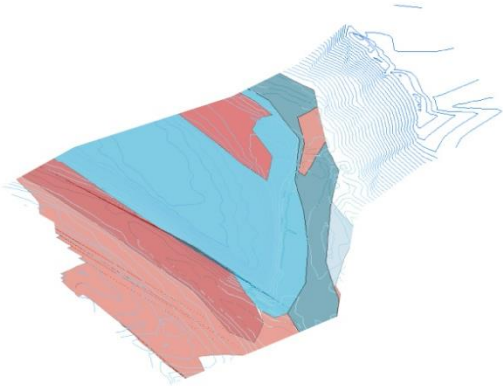
A



B



C



D

What are the individual mechanisms of net change?

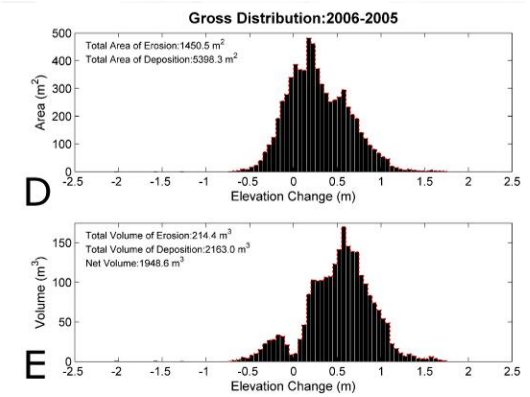
THREE TYPES OF MASKS

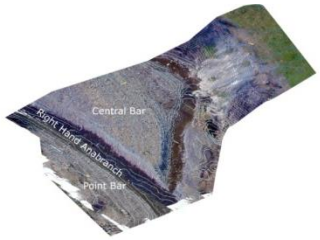
Just a way of spatially segregating budget to ask questions and query budget results.

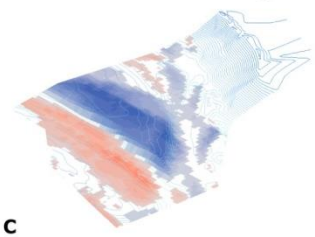
1. Standard Classification
2. Classification of Difference
3. Geomorphic Interpretation

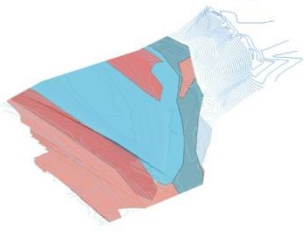
Just polygons…

Segregates both DoD & its Elevation Change Distribution…



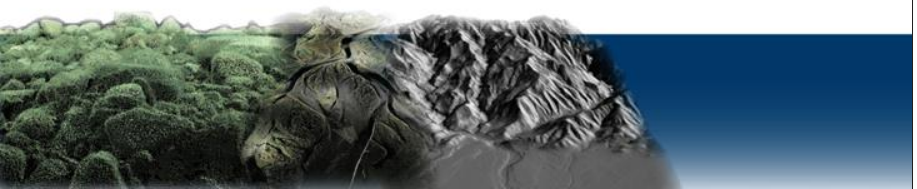


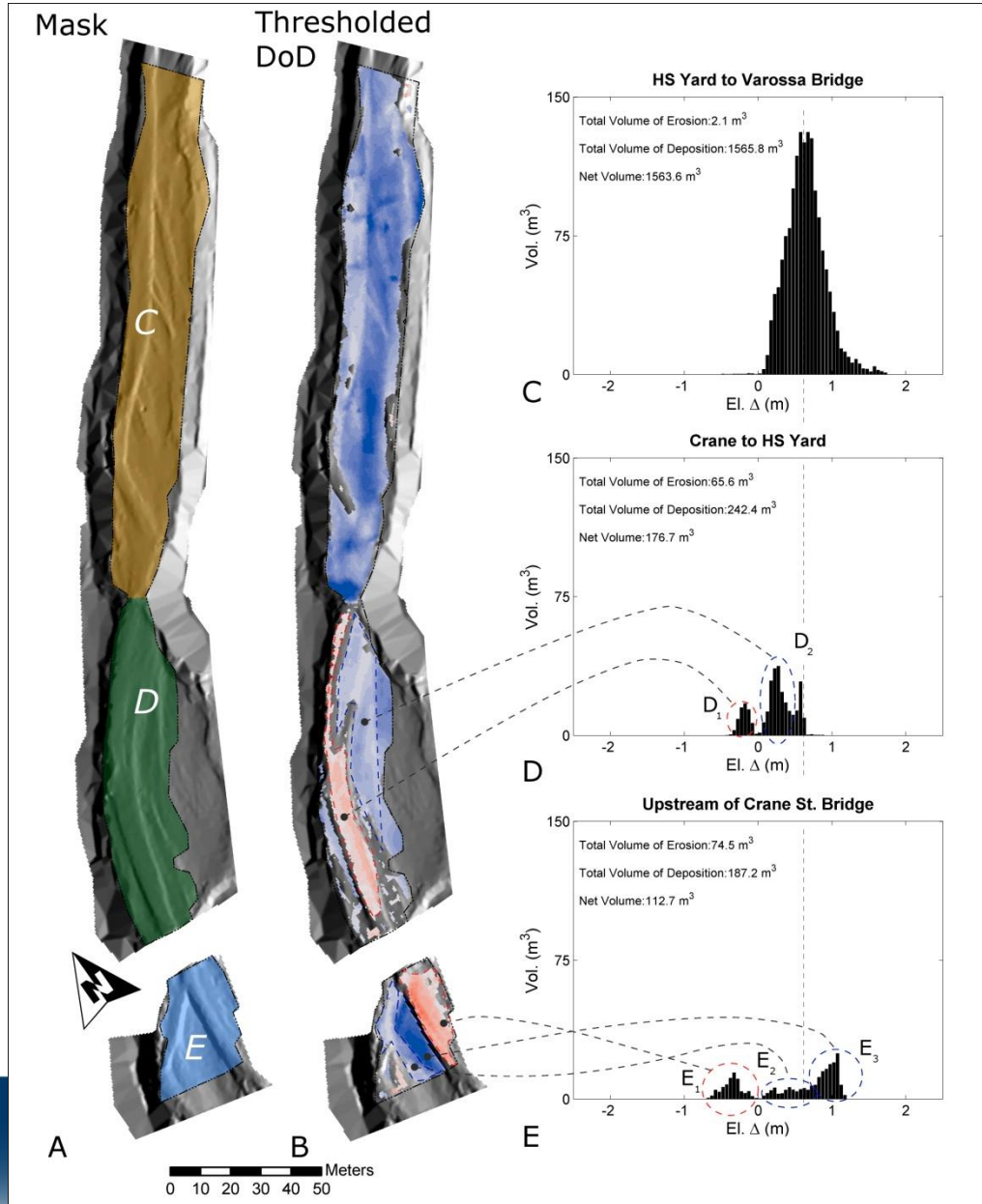




STANDARD CLASSIFCATION

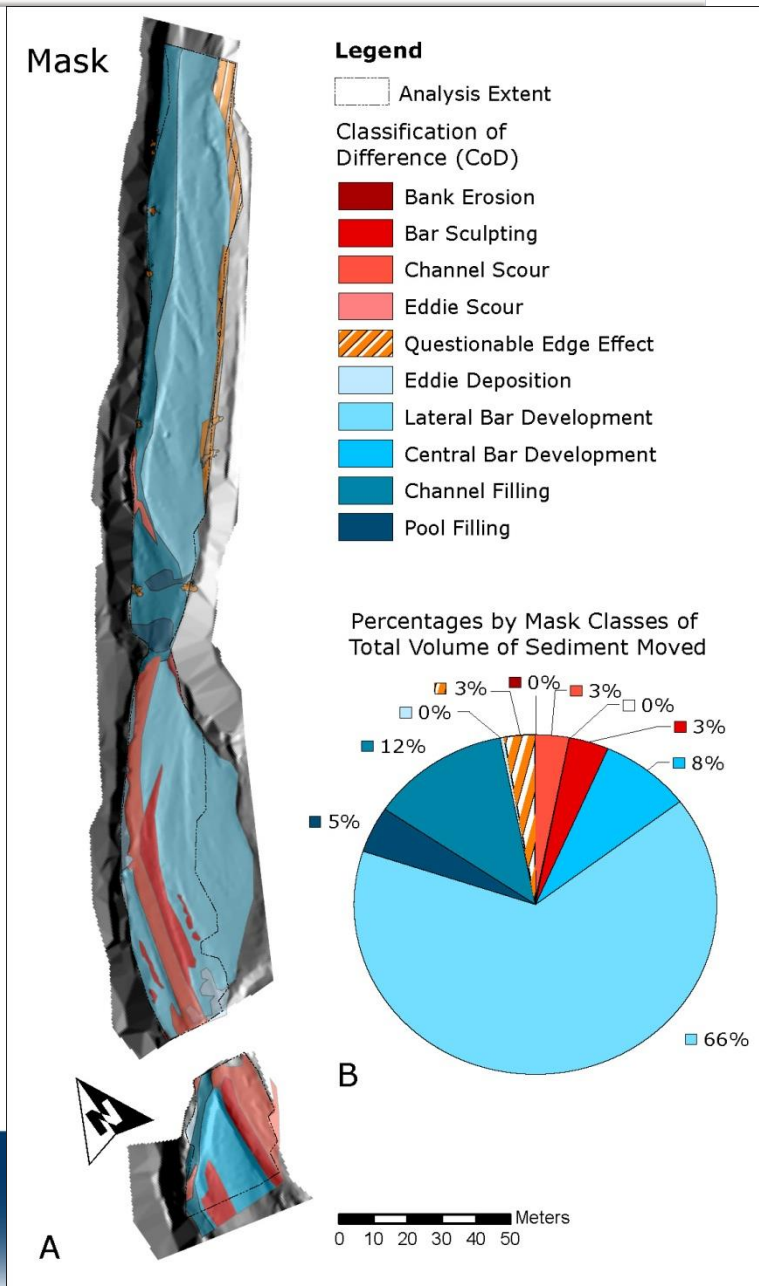
- Any classification that is of:
  - The pre-survey
  - The post-survey
  - Or Time Independent
- Examples:
  - Morphological Units
  - Habitat Classification
  - Administrative Bndys
  - Reaches



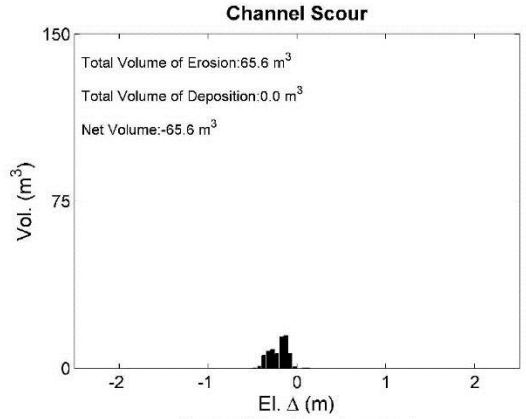


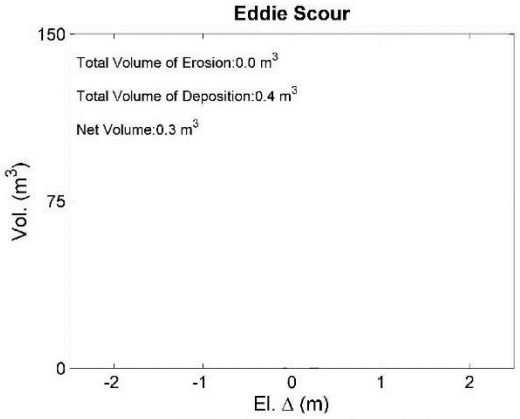
GEOMORPHIC INTERPRETATION

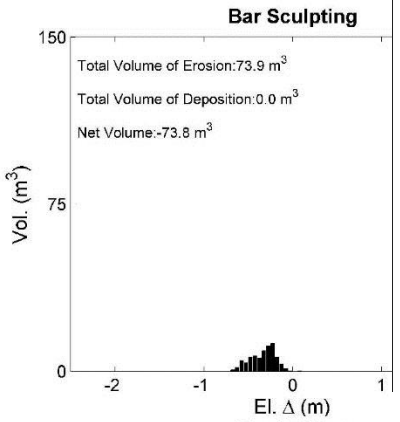
- Instead of mask being based on one point in time, this is based on the change surface itself (i.e. the DoD)
- Multiple lines of evidence can be used beyond DoD
- You define geomorphic processes of interest

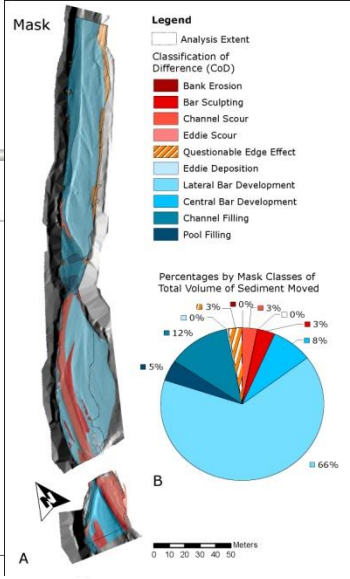


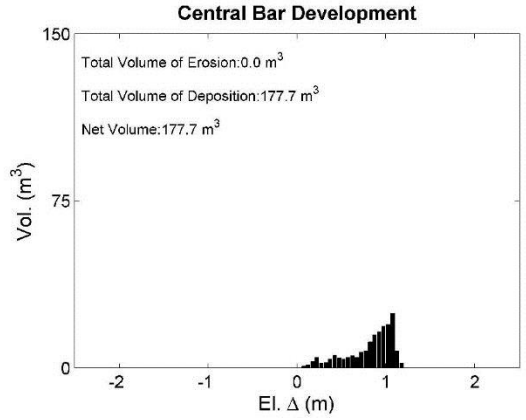
DOMINANT OR UNIQUE SIGNATURES?

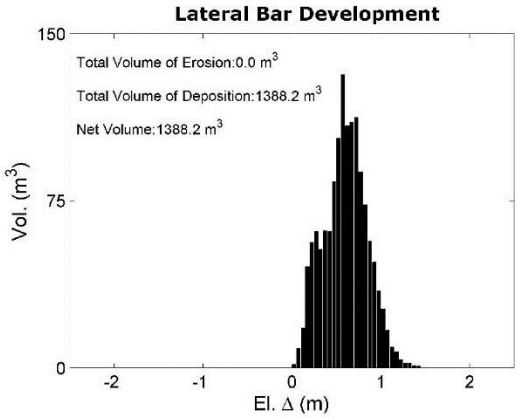


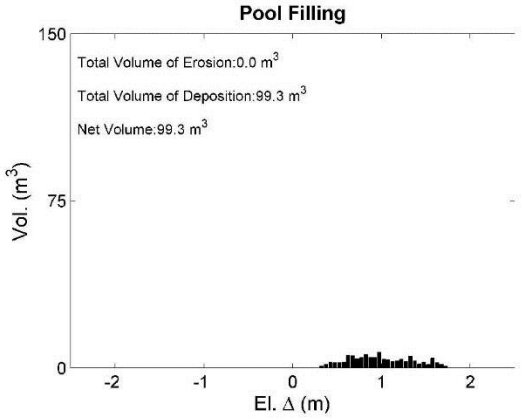


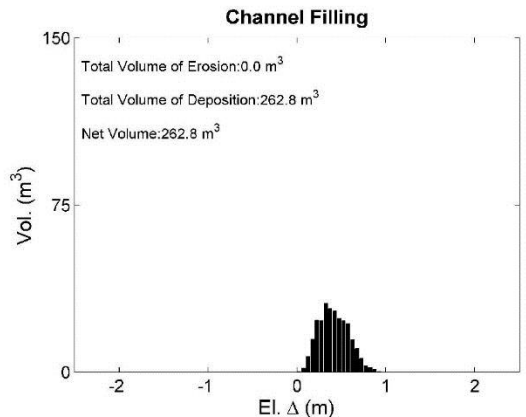


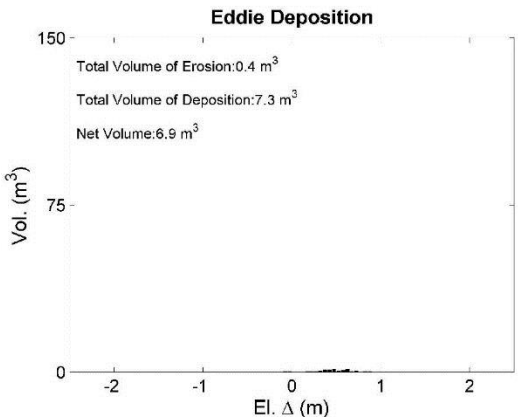


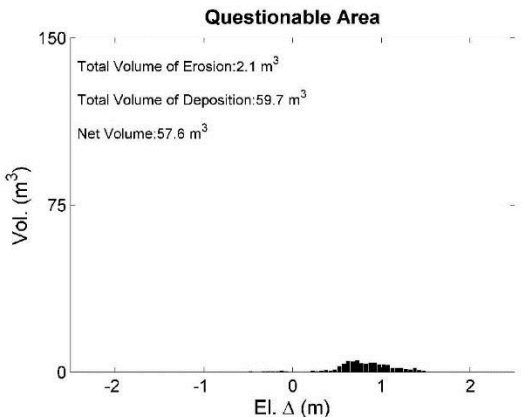




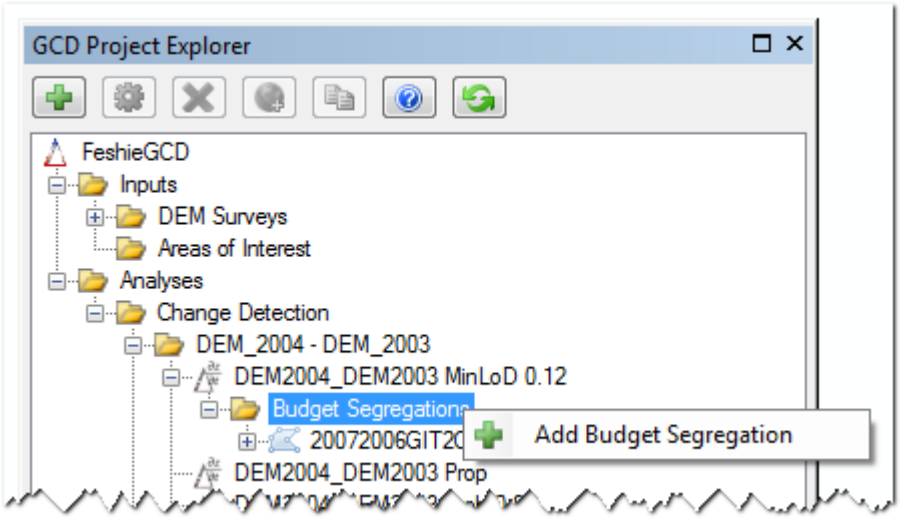


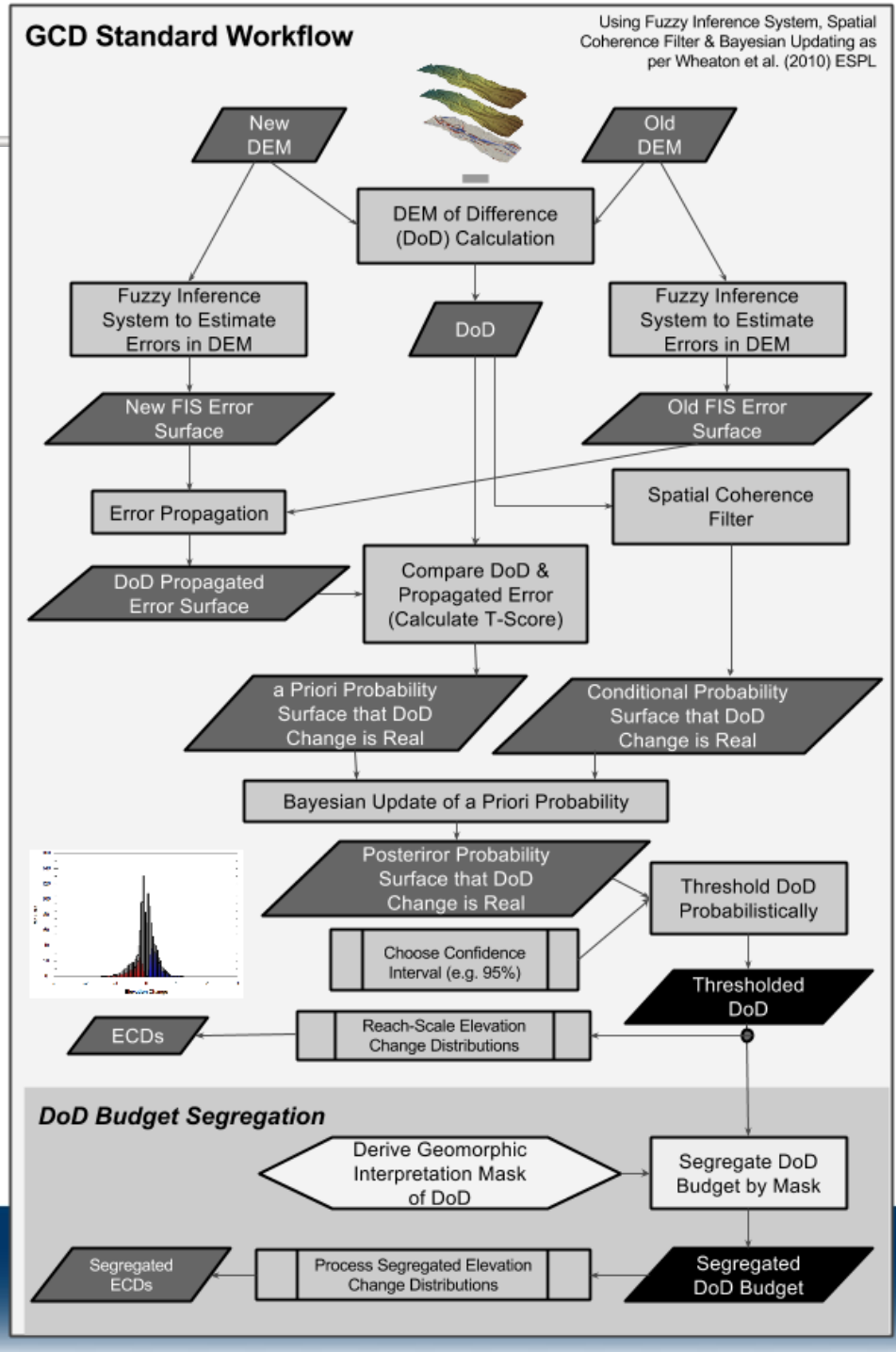






USING THE GCD SOFTWARE FOR BUDGET SEGREGATION…





EXERCISE V- PART 1: PERFORM BUDGET SEGREGATION C:\CHaMPWorkshop\Exercises\GCD\V_BudgetSeg

1. Start New ArcMap Document
2. Start New GCD Project – Sulphur Creek – In V
3. Add 2005 and 2006 DEMs, perform DoD with thresholding of your choosing…
4. Add a Budget Segregation using provided shapefile
5. Explore results

EXERCISE V : PART 2 DERIVE GI BUDGET SEGREGATION C:\CHaMPWorkshop\Exercises\GCD\V_BudgetSeg

1. Choose a GCD Project or Create a New One
2. Run raster calculator on thresholded DoD to get erosion and deposition areas
3. Convert integer raster output into polygon
4. Add text field(s) to polygon
5. Start classifying….
6. Use for budget segregation
7. Interrogate results

GCD ANALYSIS

- Get slide from PiP
  - Target Visit 2015
  - T-1 2014
  - T0 Visit 2011