A Clearer Vision from Fuzzy Logic:

Metrics for climate change sensitivity, exposure, and potential impacts in Utah and the Colorado Plateau

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2016.10.19

Conservation Biology Institute

National Park Service

Overview

- Fuzzy Logic
- The Models & Results
- Exploring Results
- Takeaways

Fuzzy Logic

From Binary Truth to Fuzzy Truth

From *Yes or No* to *How Much*

Start with a statement: Soil depth is high.

From Binary Truth to Fuzzy Truth

From *Yes or No* to *How Much*

Start with a statement: Soil depth is high.

False

True

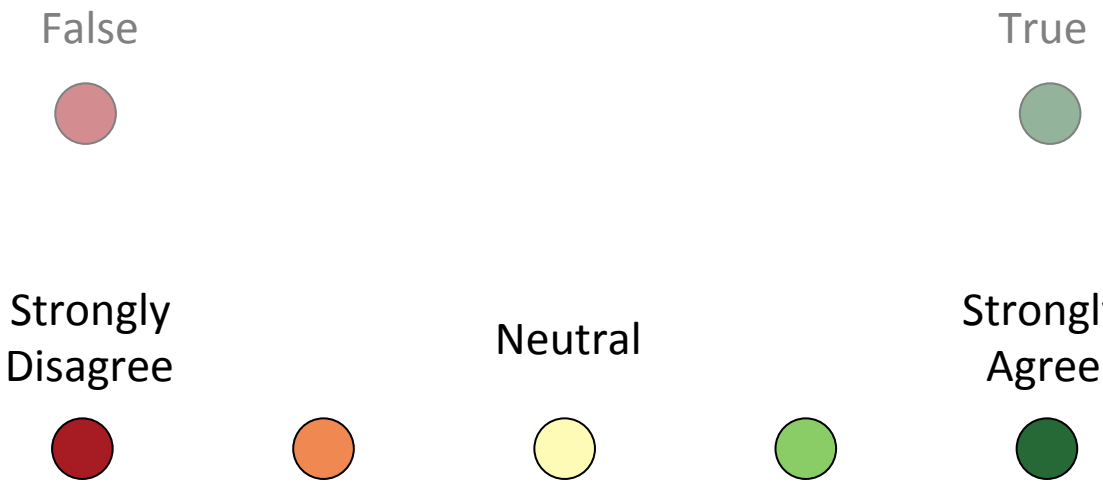
Binary logic:

- Either True or False

From Binary Truth to Fuzzy Truth

From *Yes or No* to *How Much*

Start with a statement: Soil depth is high.



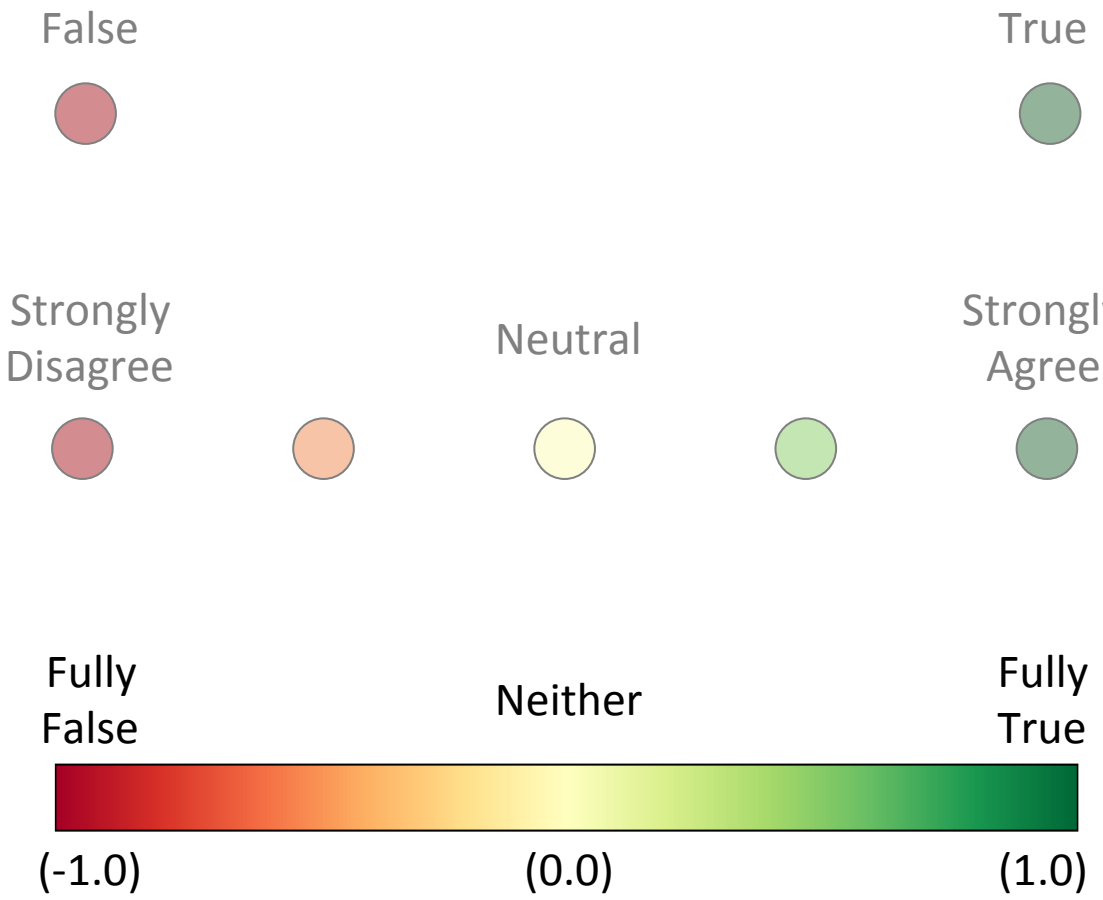
Agreement:

- Based on feeling / opinion
- Classes of trueness and falseness

From Binary Truth to Fuzzy Truth

From *Yes or No* to *How Much*

Start with a statement: Soil depth is high.

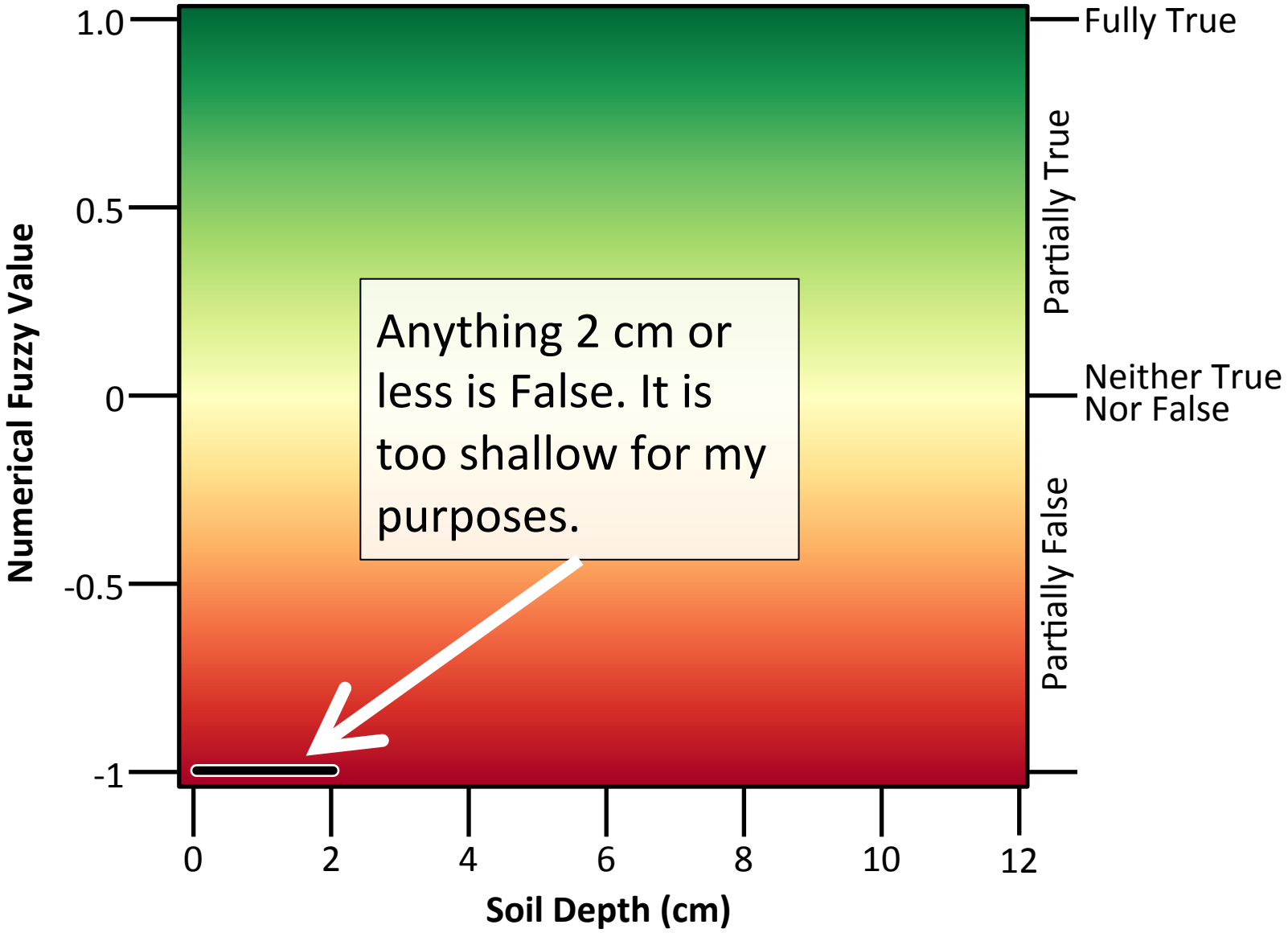


Fuzzy Truth:

- Based on degree
- Continuum from Fully False to Fully True
- Think of it as an index

From Data to Fuzzy Truth

Conversion function for *Soil Depth is High*



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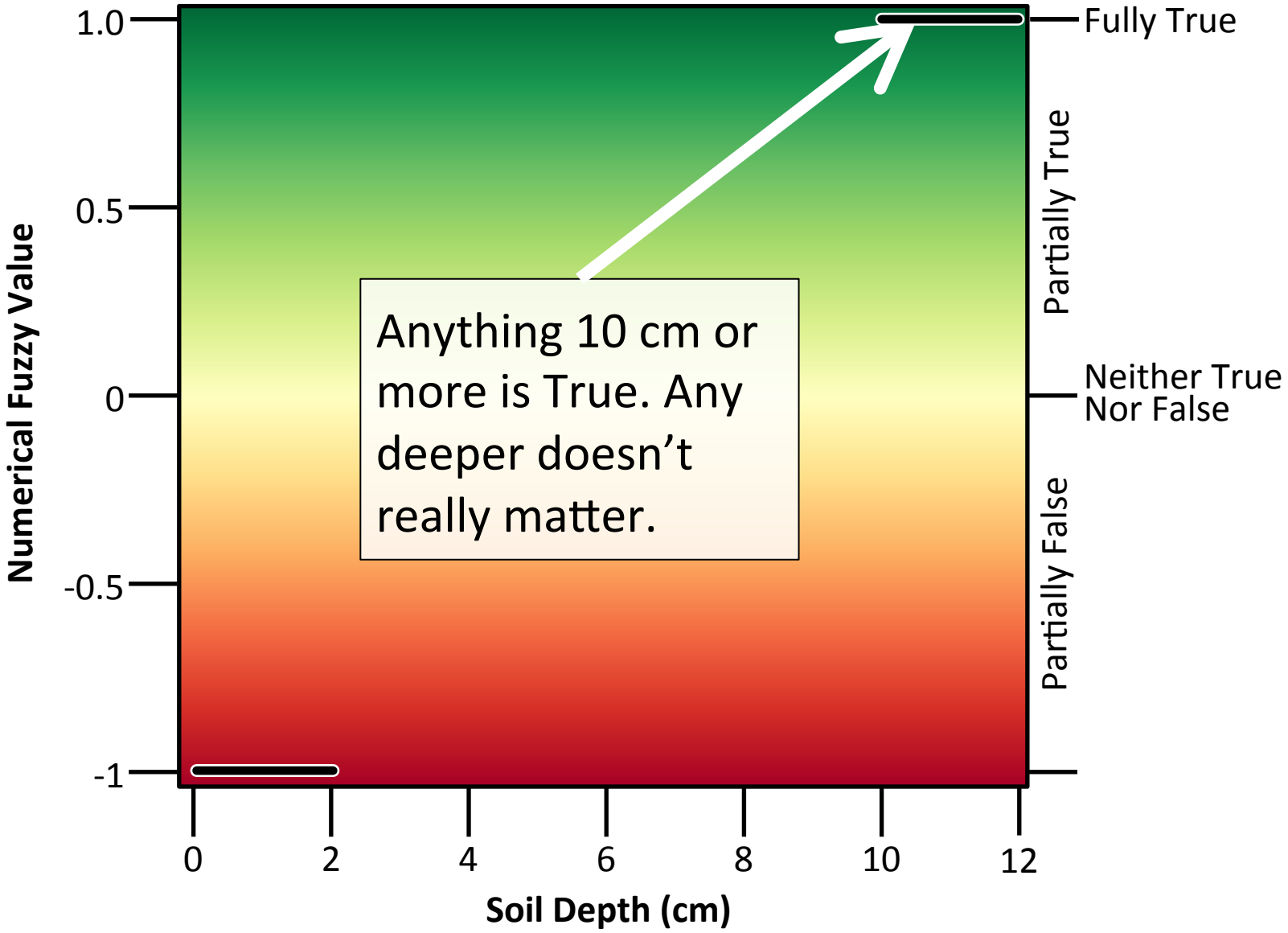

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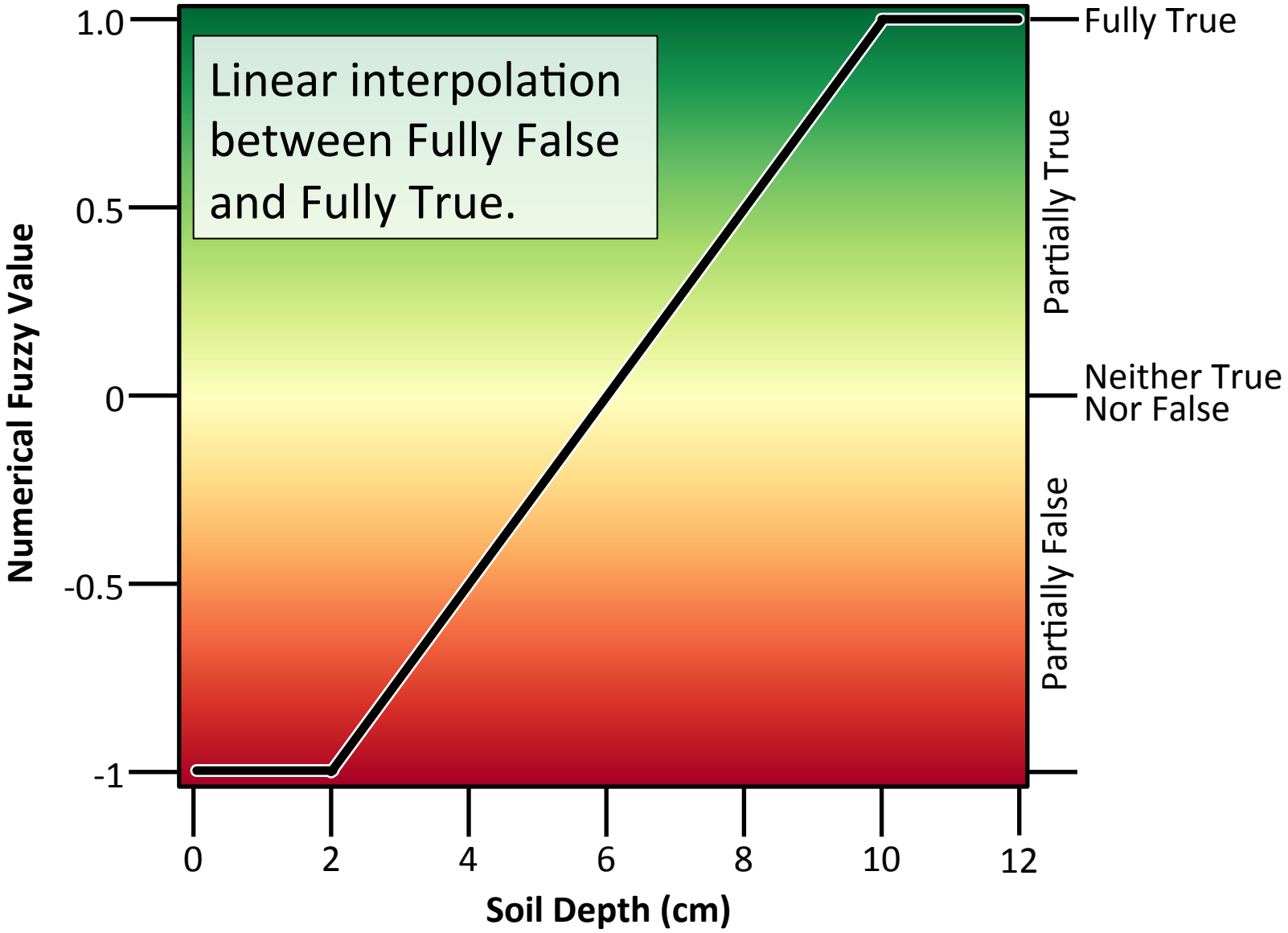


Building a Fuzzy Logic Model

Combine values from the bottom up

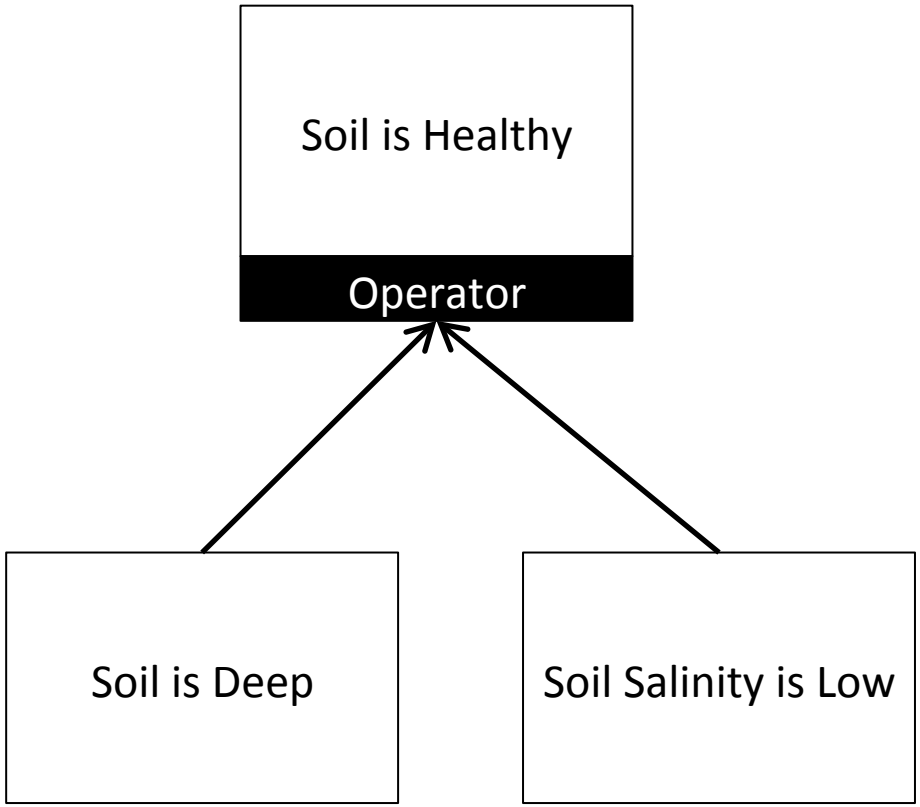
Soil is Healthy

We want to determine if *Soil is Healthy* (i.e. How healthy is the soil).

National Park Service

Building a Fuzzy Logic Model

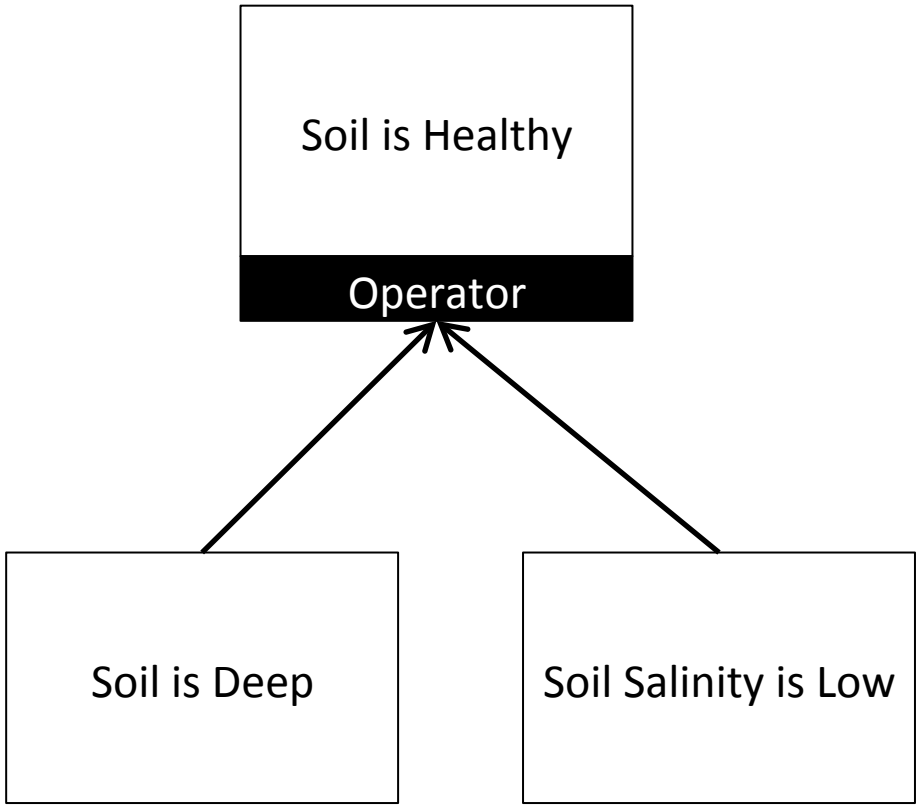
Combine values from the bottom up



Soil depth and soil salinity both contribute to soil health.

Building a Fuzzy Logic Model

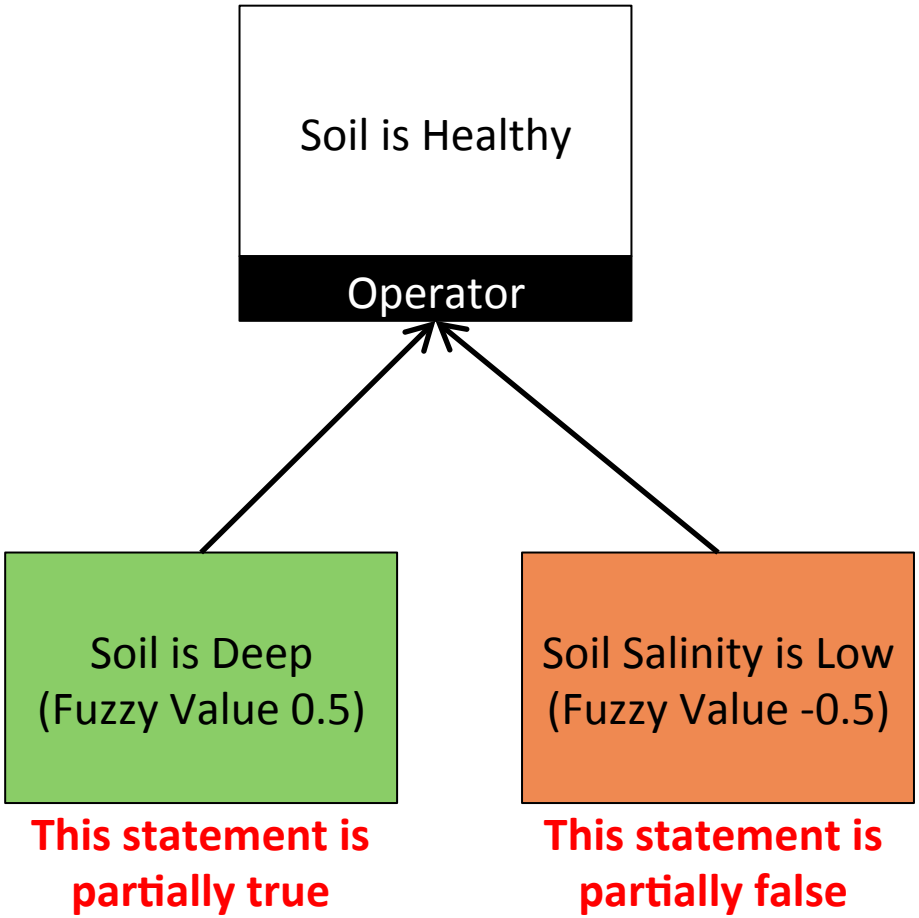
Combine values from the bottom up



Let's say we have an 8 cm deep soil that has bit of salt in it.

Building a Fuzzy Logic Model

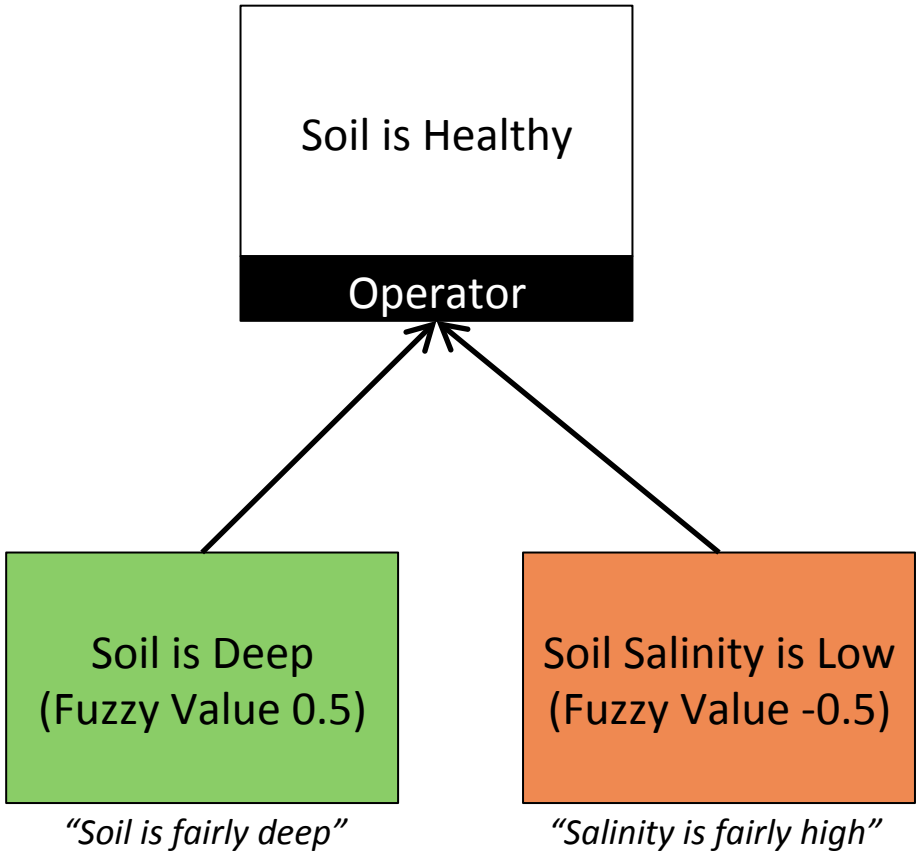
Combine values from the bottom up



The fuzzy value represents how True or False the statement is. (How much of the characteristic is there.)

Building a Fuzzy Logic Model

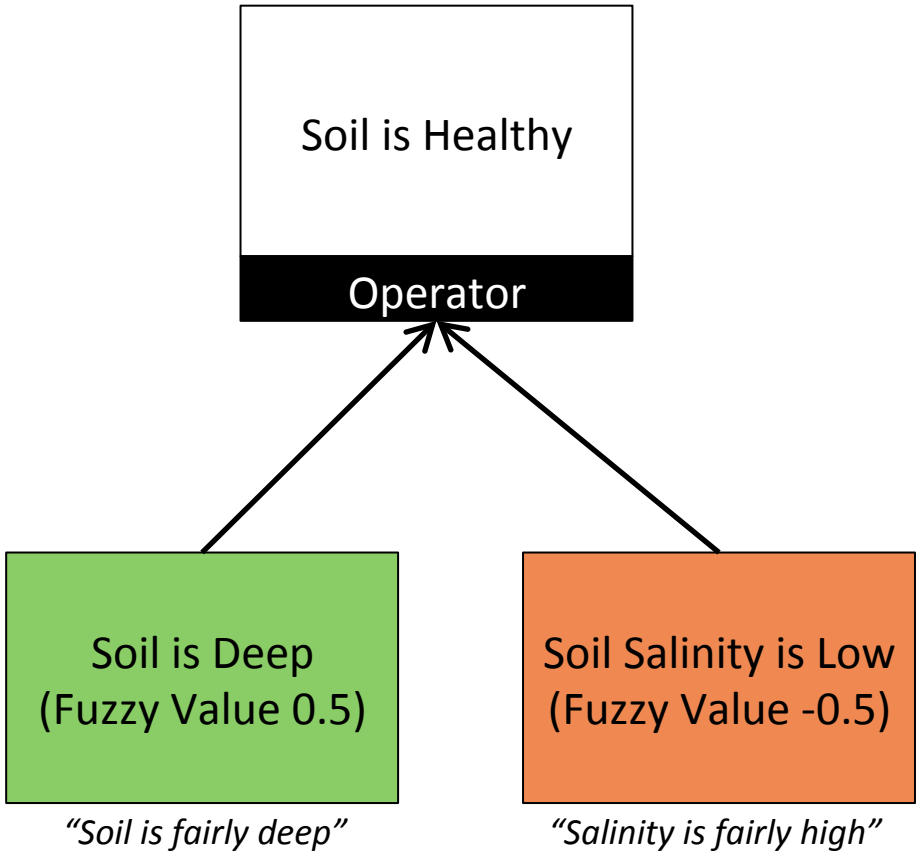
Combine values from the bottom up



We can describe the meaning of those values in plain English.

Building a Fuzzy Logic Model

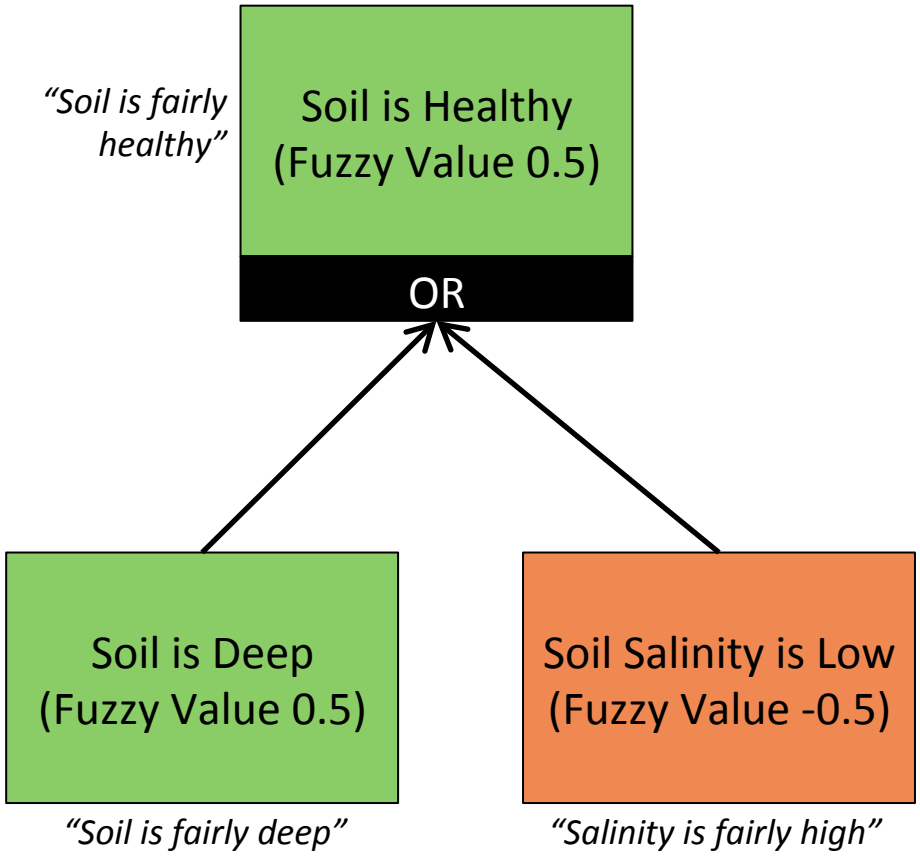
Combine values from the bottom up



But what about that operator. Let's look at the three most common ones.

Building a Fuzzy Logic Model

Combine values from the bottom up

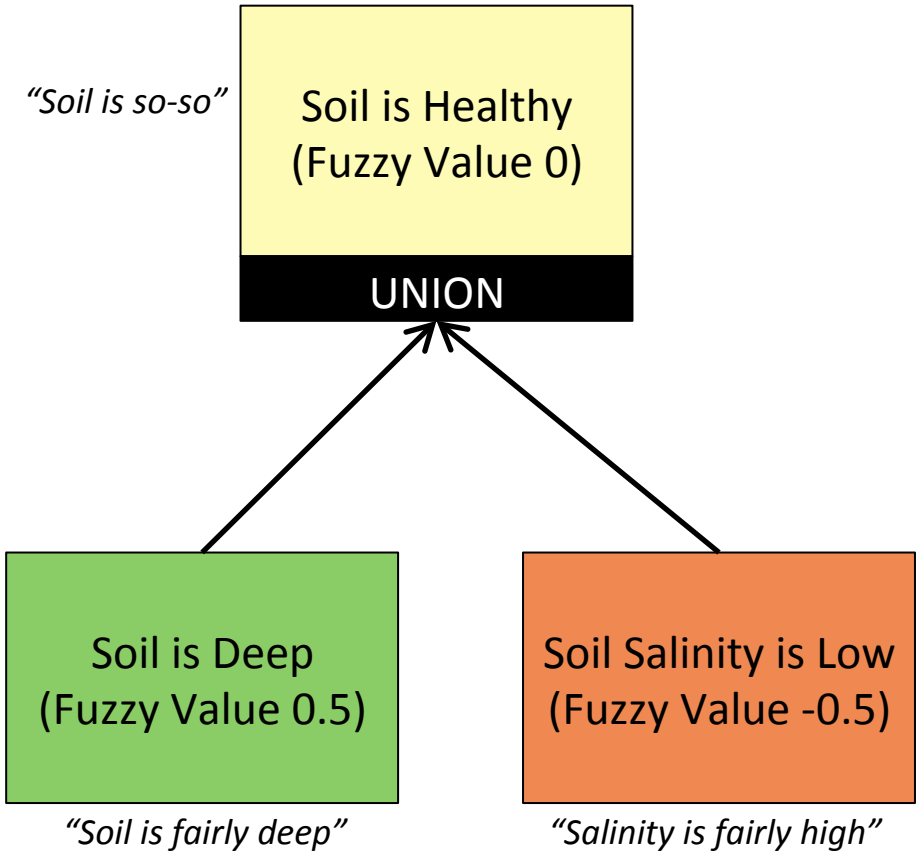


The **OR** operator takes the highest (Truest) of the inputs. So *Soil is Healthy* gets a fuzzy value of 0.5.

- Either is sufficient.

Building a Fuzzy Logic Model

Combine values from the bottom up

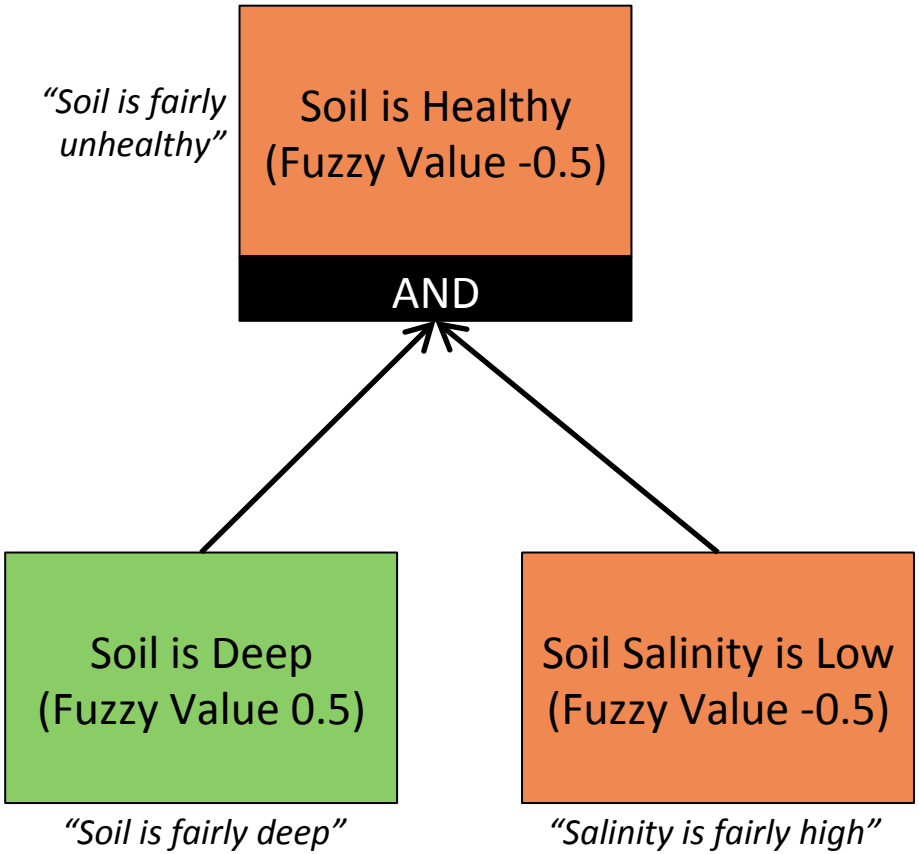


The **UNION** operator takes the mean of the inputs, so *Soil is Healthy* gets a fuzzy value of 0.0 (neither False nor True).

- Both contribute.

Building a Fuzzy Logic Model

Combine values from the bottom up

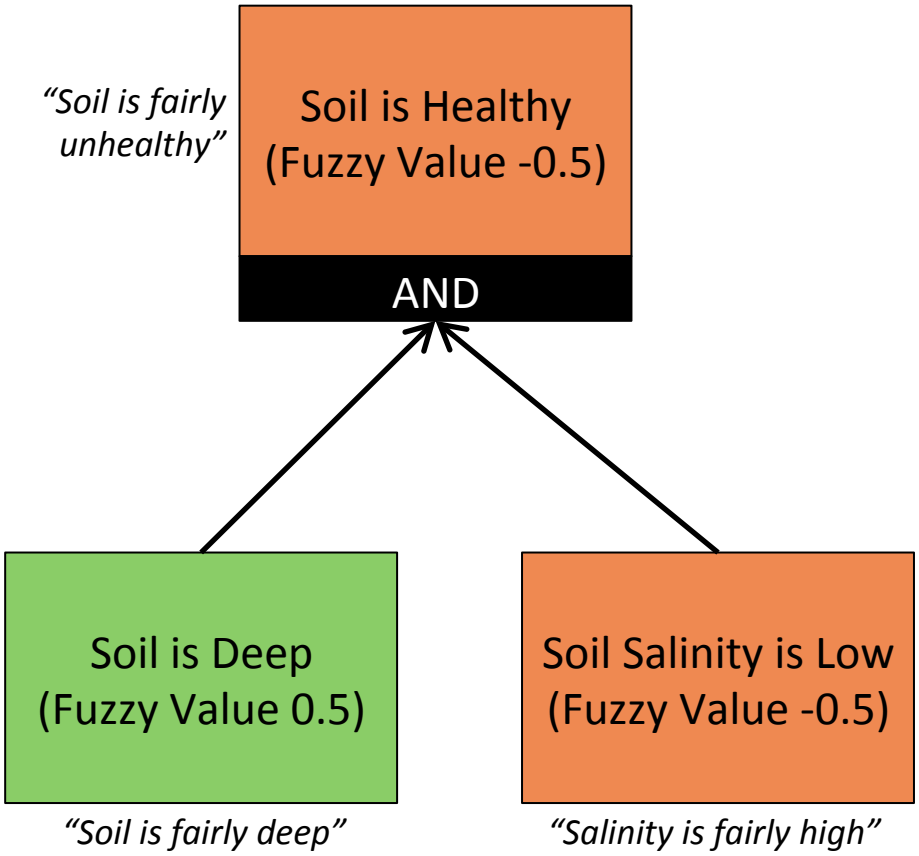


The **AND** operator takes the lowest (Falsest) of the inputs, so *Soil is Healthy* gets a fuzzy value of -0.5.

- Both are necessary

Building a Fuzzy Logic Model

Combine values from the bottom up

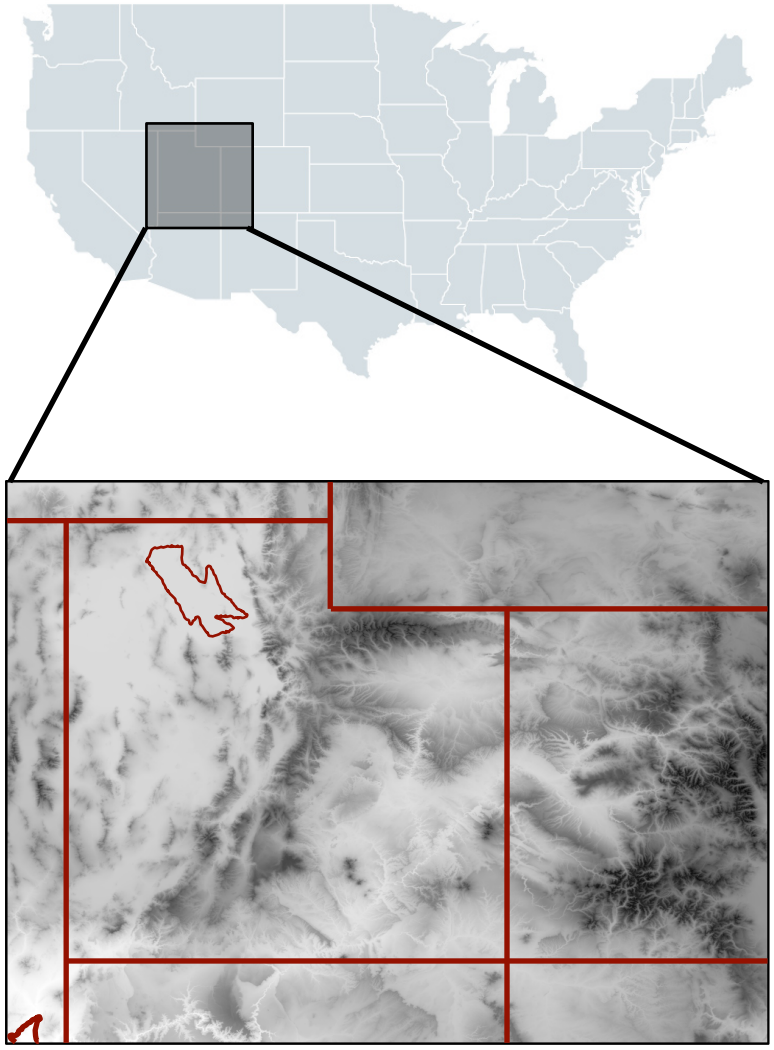


In effect, the fuzzy value can be thought of as an index. For example: *How Healthy is the Soil* on a scale from -1 to +1.

Models and Results

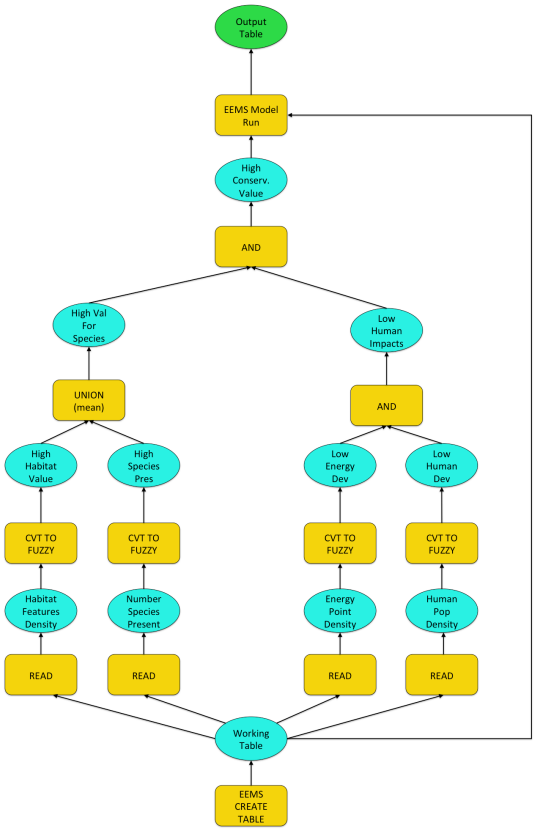
Overview

- Study region
  - Utah and the Colorado Plateau
  - 30 arc second resolution
- Software: EEMS
  - Environmental Evaluation Modeling System
    (Based on Keith Reynolds' EMDS)
- Models
  - Site sensitivity
  - Climate vulnerability
  - Potential impacts



EEMS

Environmental Evaluation Modeling System



ArcGIS ModelBuilder Interface

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   InFieldName = anom,
   NewFieldName = MaxTempAnnAnomaly,
   OutFileName = /MyData/CAClimateExposure.nc
   )
                                                    . . .
HighPrecipAnnExposureFz = CVTTOFUZZYCURVE(
   InFieldName = PrecipAnnAnomaly,
   RawValues =   [-8, -4,   -2, -1,  -0.5, .5, 1,   2, 4,     8],
   FuzzyValues = [1, 0.5, 0,  -0.5, -1,    -1,  -0.5, 0, 0.5, 1.0 ],
   OutFileName = /MyData/CAClimateExposure.nc
   )
```

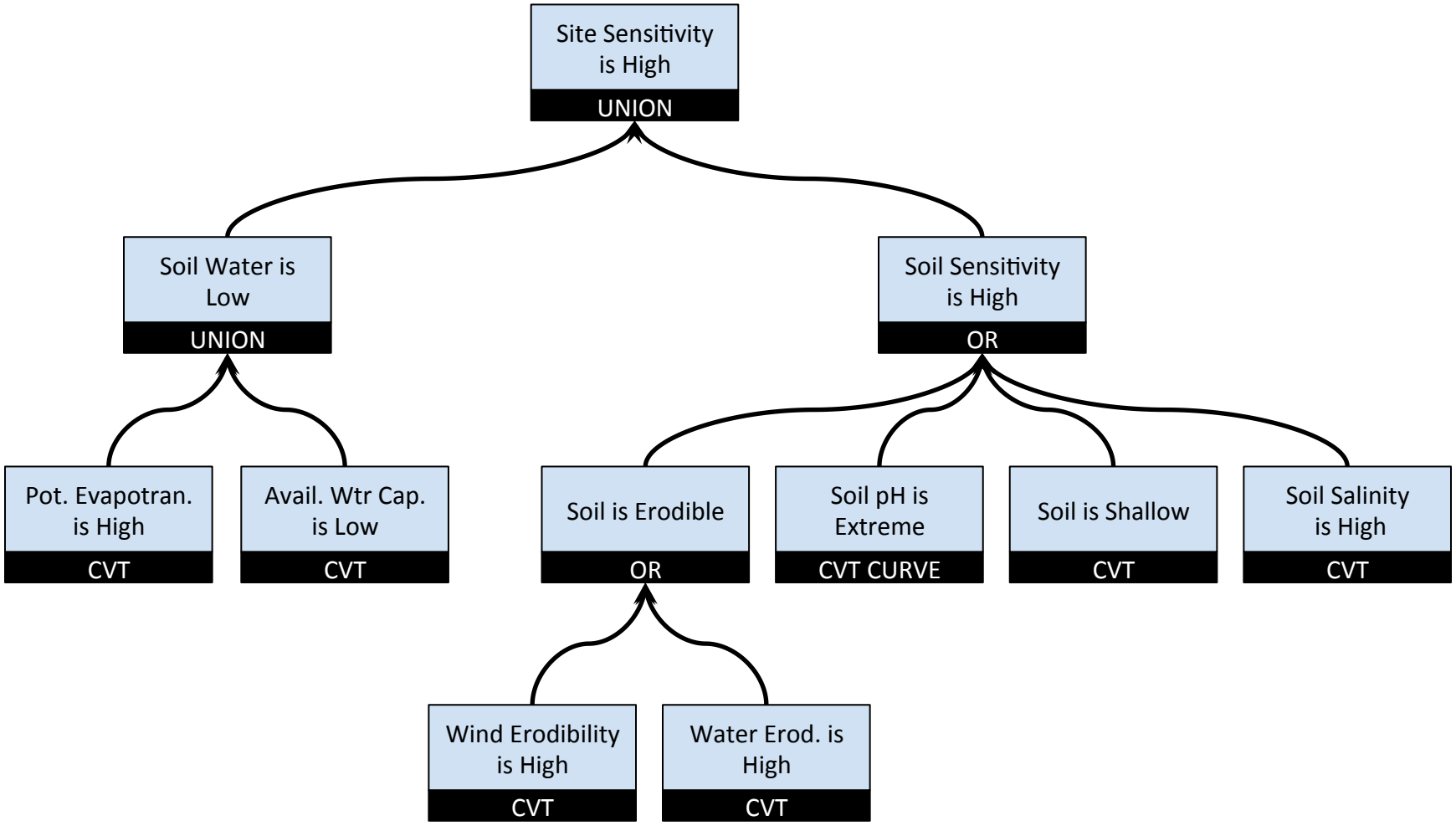
. . .

Scripting Language for NetCDF and CSV

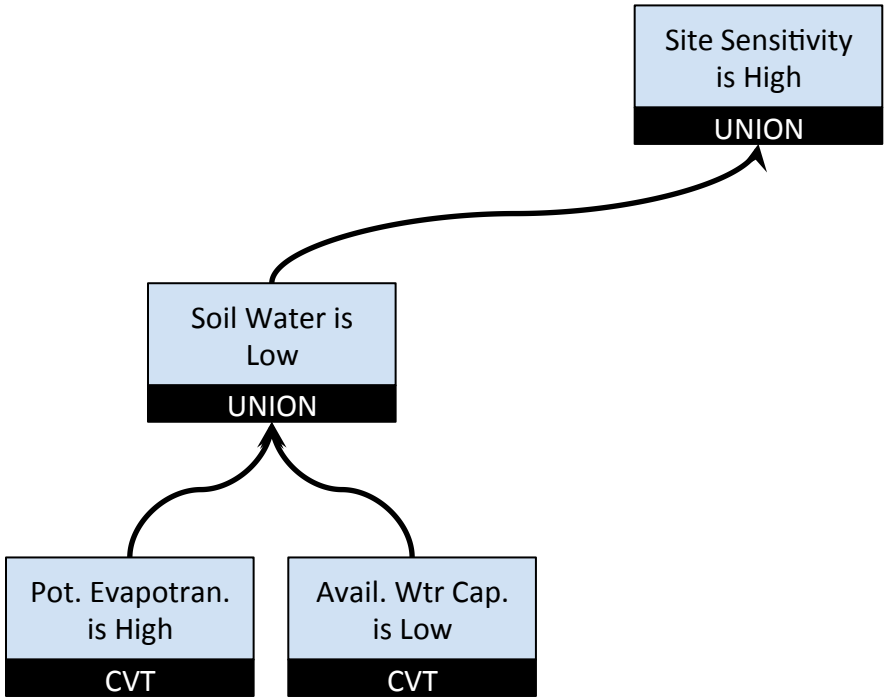
Watch This Space

Web Version Coming Soon

Site Sensitivity Model



Site Sensitivity Model



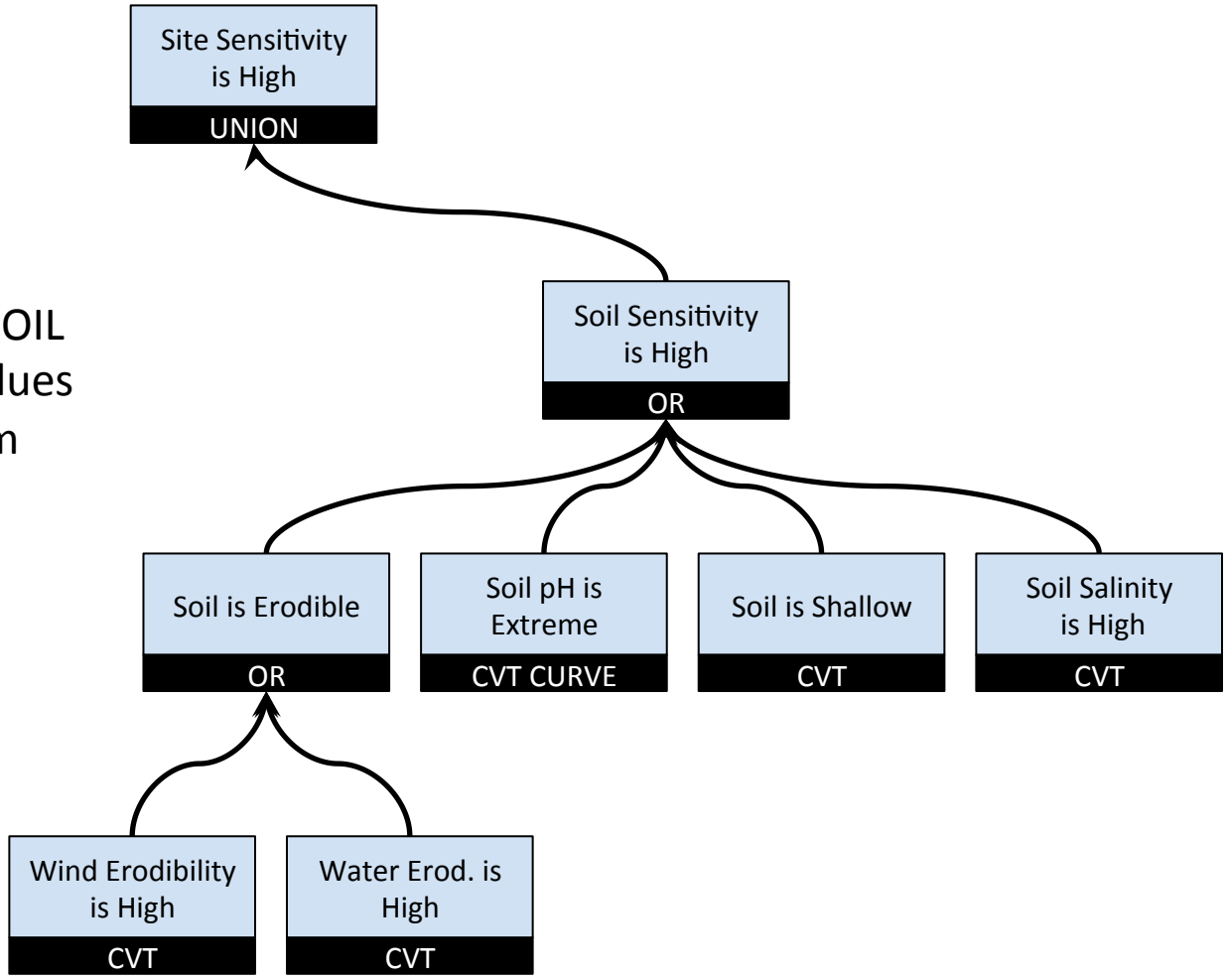
Soil Water Branch

- Potential evapotranspiration (Hargreaves and Allen, 2003)
- Available water capacity (CONUS-SOIL database, Penn. State)

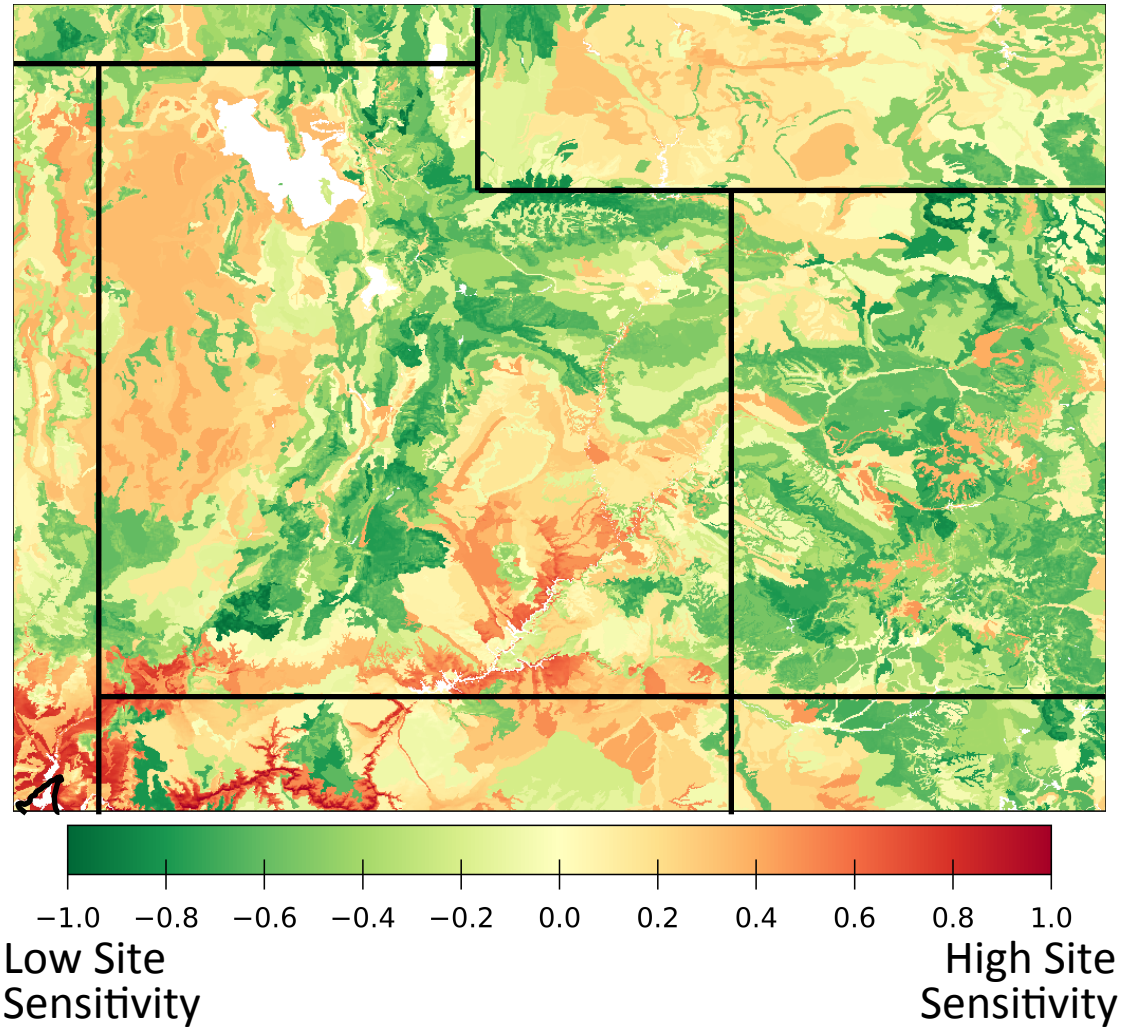
Site Sensitivity Model

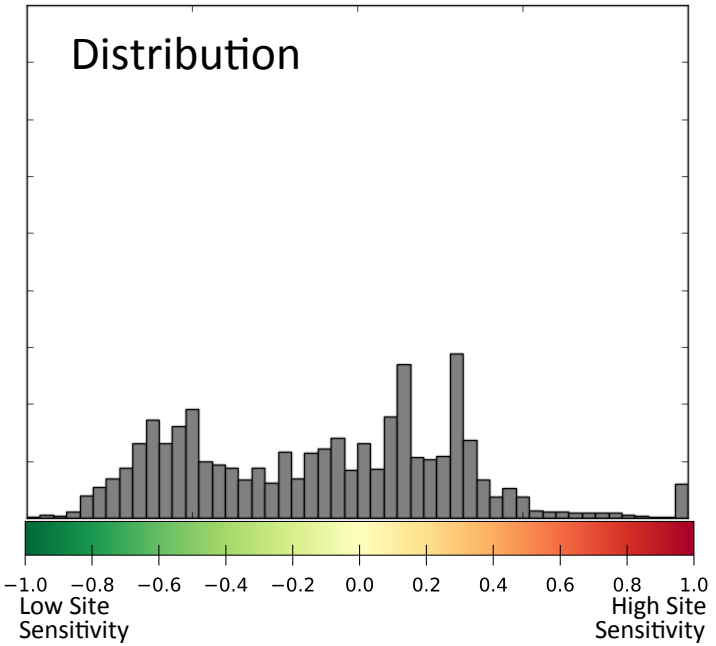
Soil Sensitivity Branch

- Input values from STATSGO and CONUS-SOIL
- Thresholds for fuzzy values based on feedback from BLM.



Site Sensitivity Results

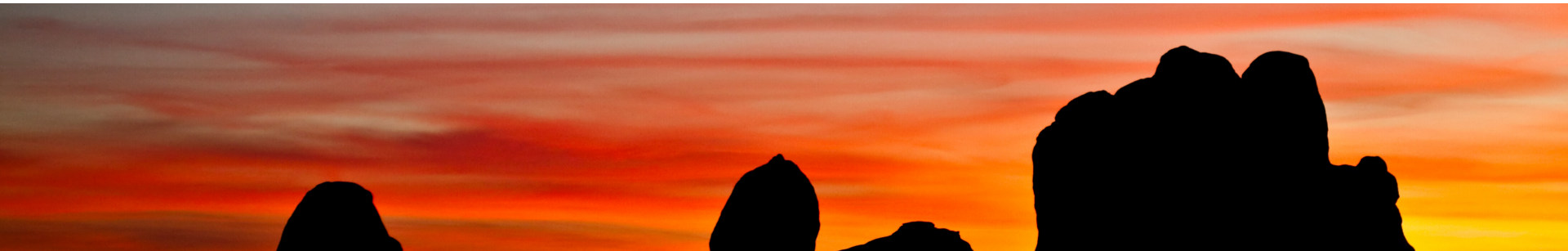




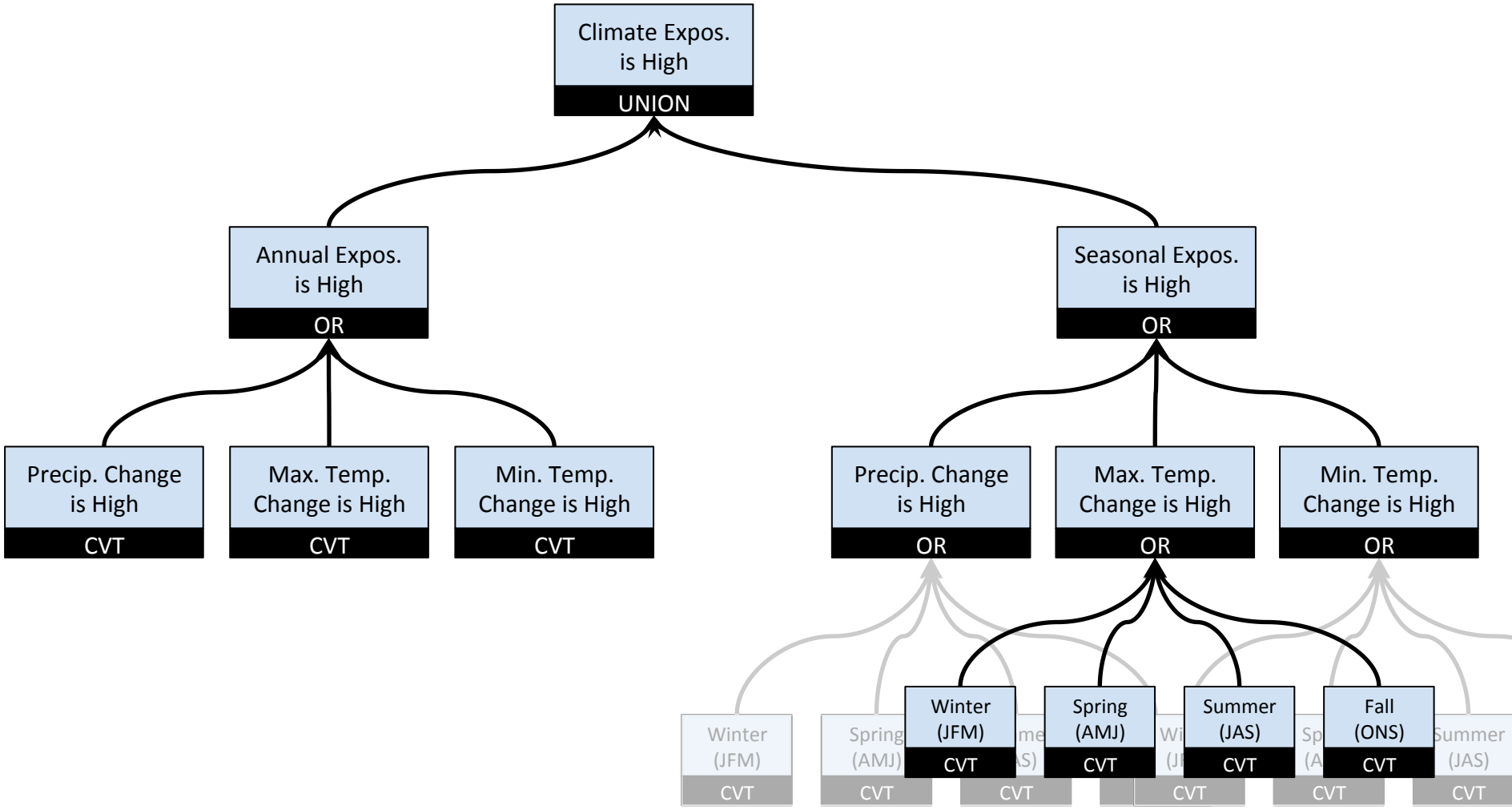
Driven by different factors in different locations.

Climate Exposure Model

- Four climate projections and **ensemble**
  - CanESM2 (Canadian Centre for Climate Modelling and Analysis)
  - CCSM4 (National Center for Atmospheric Research, USA)
  - CNRM5 (National Centro for Meteorological Research, France)
  - HadGEM2-ES (Met Office Hadley Centre, UK)
- 2016-2045 and 2046-2075 vs 1968-1999 (PRISM)
- Change normalized by historical std. dev.
  - Precip., monthly min. temp., max. monthly temp.

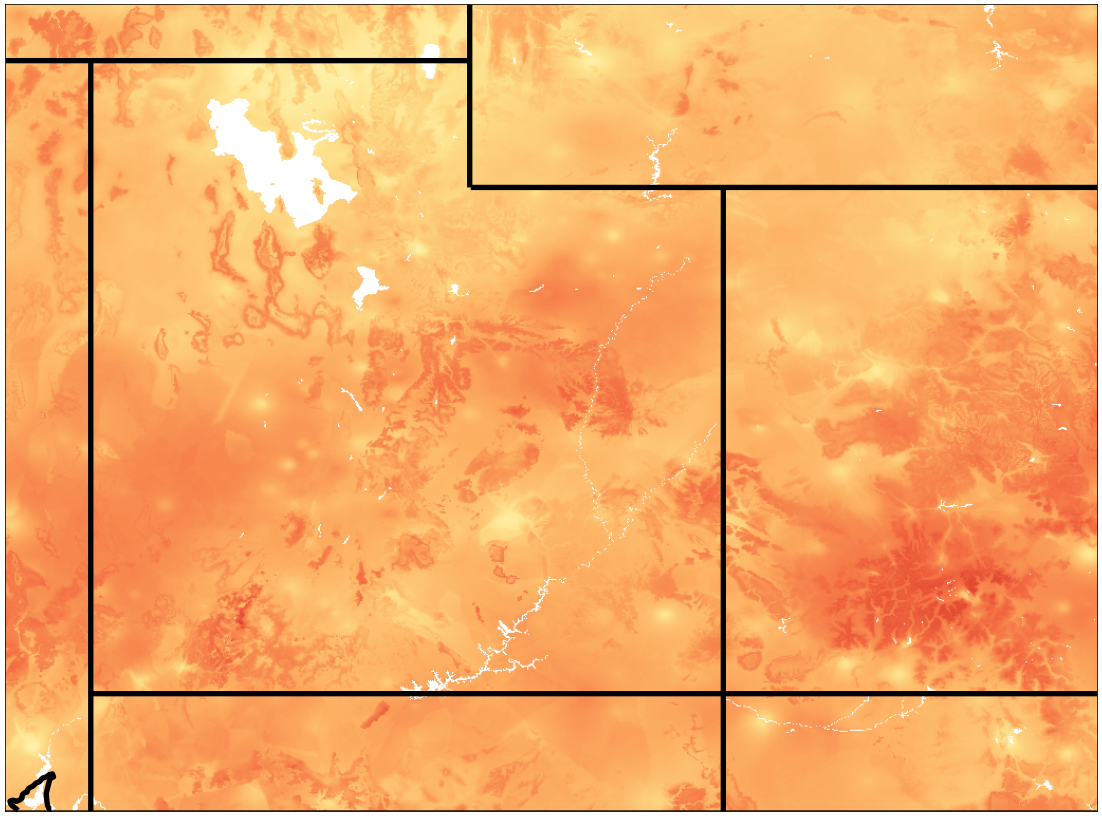


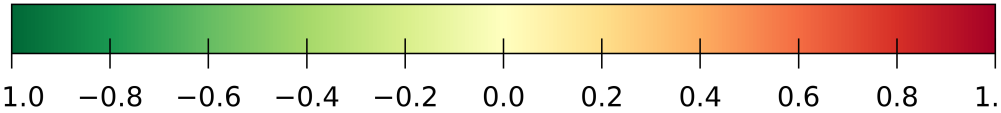
Climate Exposure Model

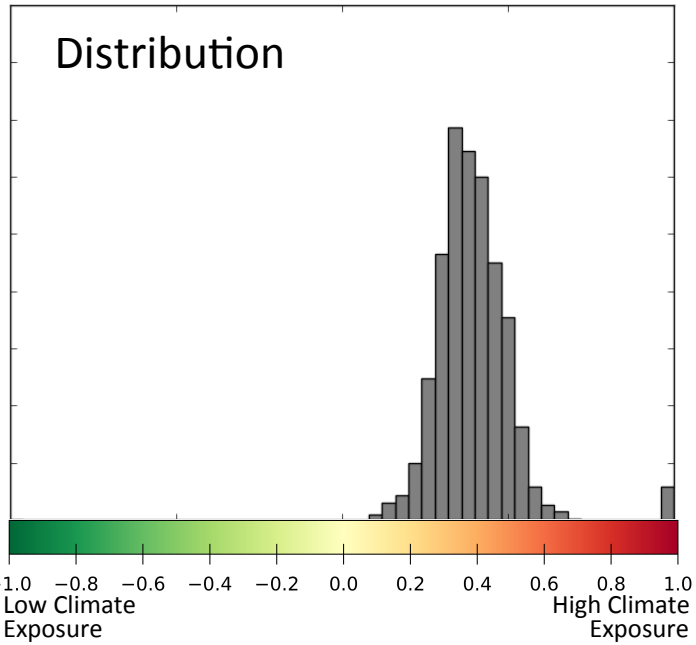


Climate Exposure Results

2016-2045





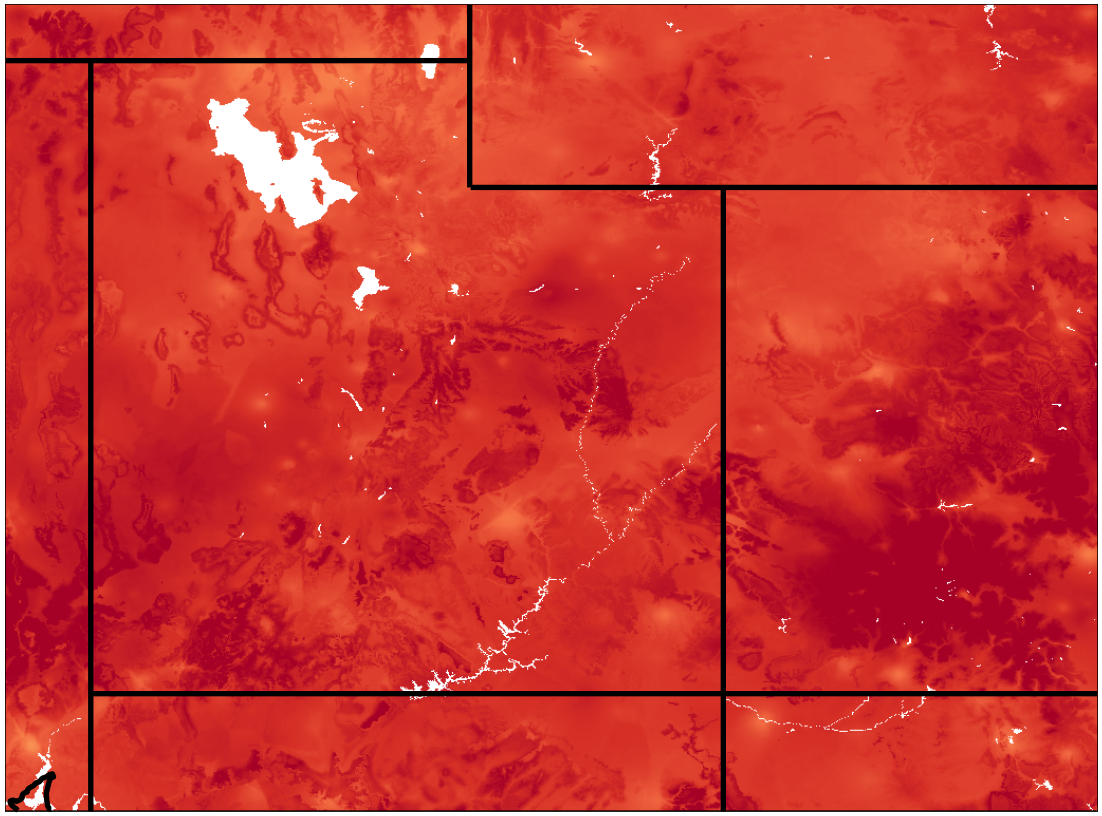


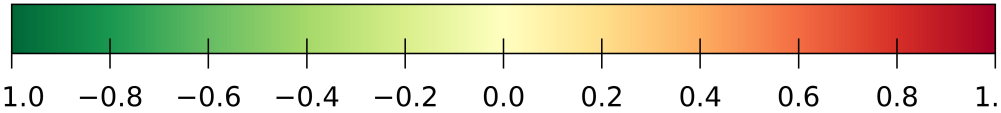
Driven by annual and seasonal temp. change.

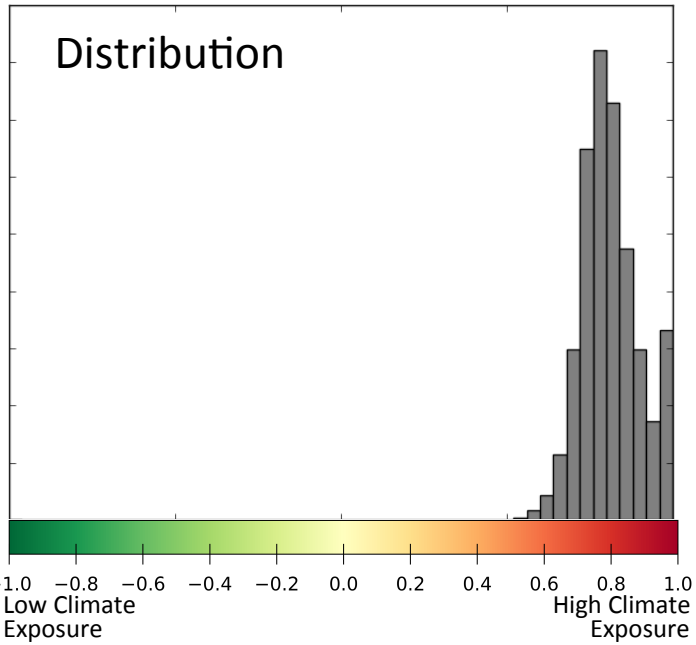
- Up to 4.5 SD.

Climate Exposure Results

2046-2075



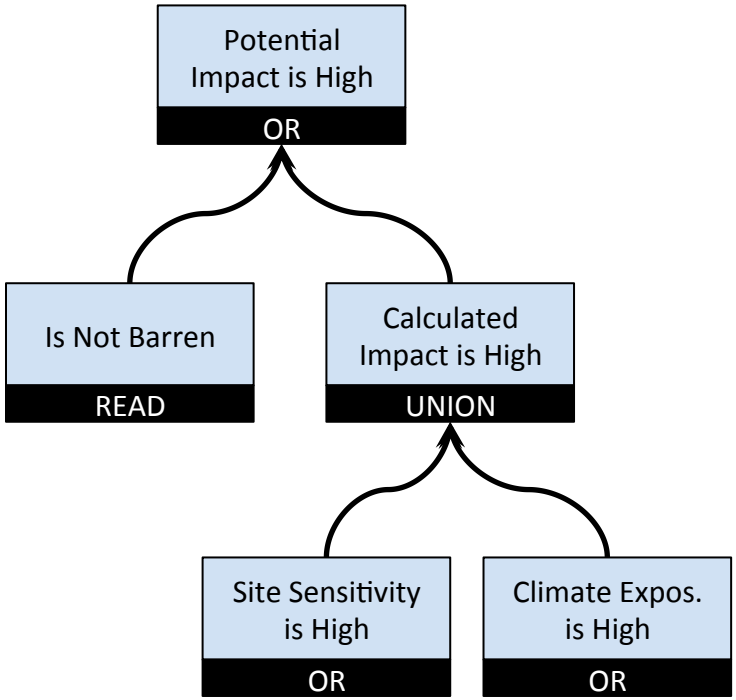




Driven by annual and seasonal temp. change.

- Up to 8.5 SD.

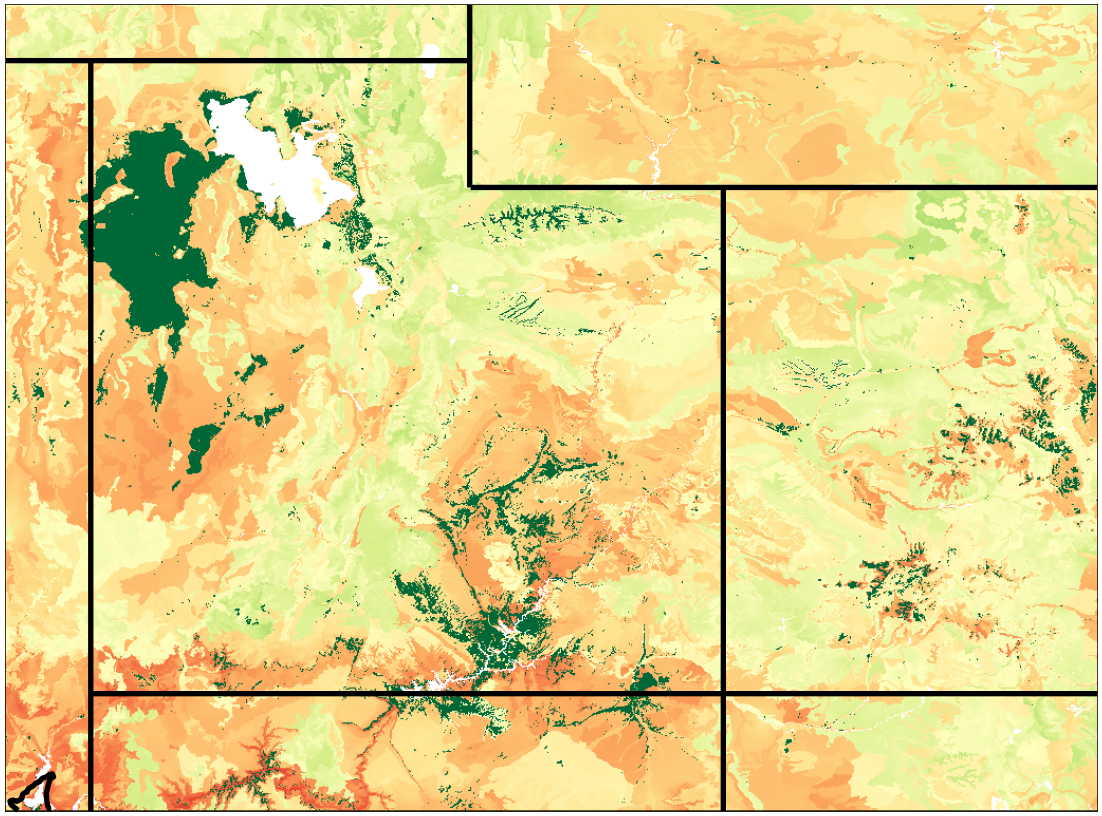
Potential Impact Model

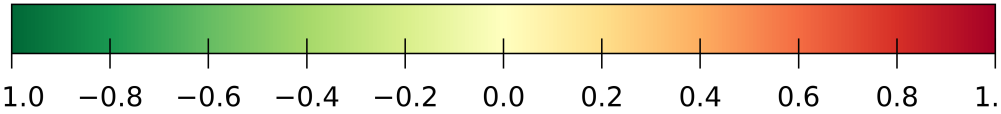


- Combines site sensitivity and climate exposure
- Maps out barren areas (cannot be impacted)

Potential Impact Results

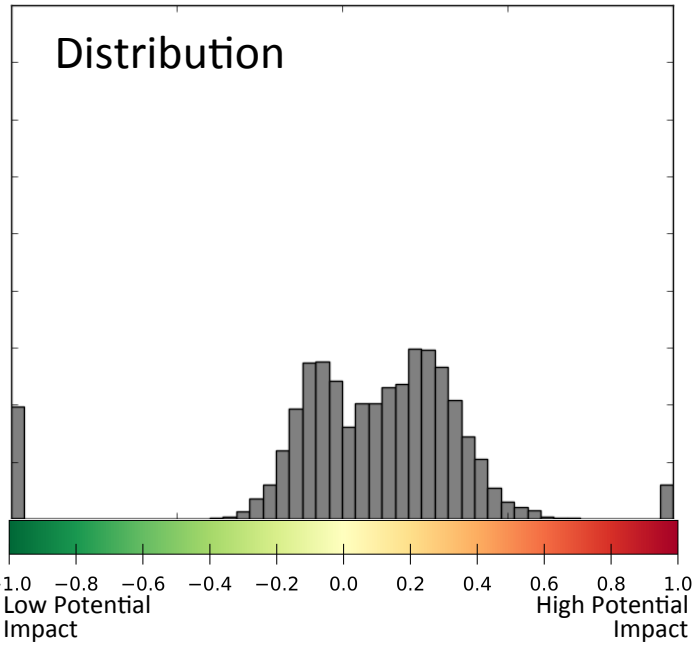
2016-2045





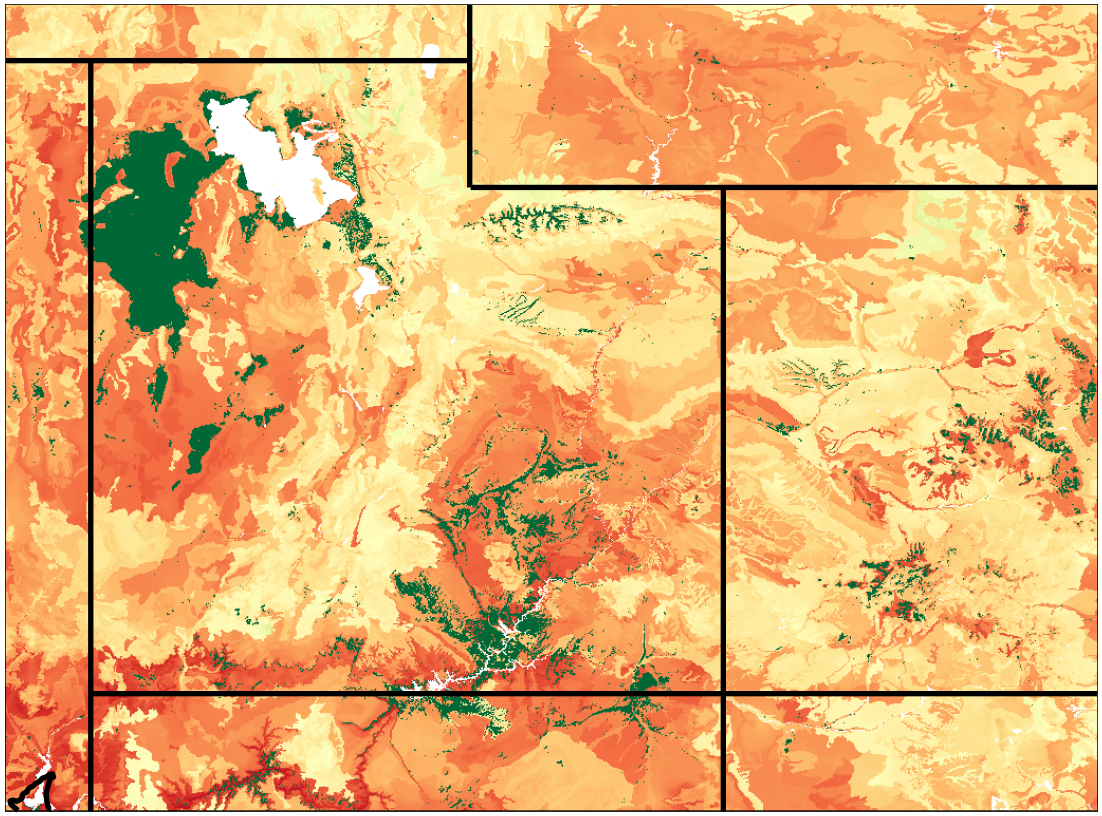
Low Potential Impact

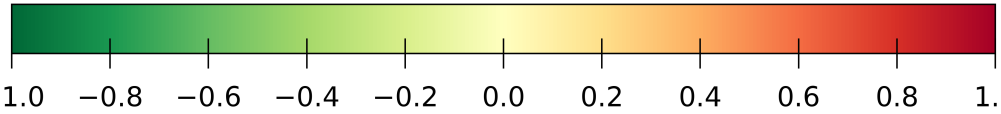
High Potential Impact

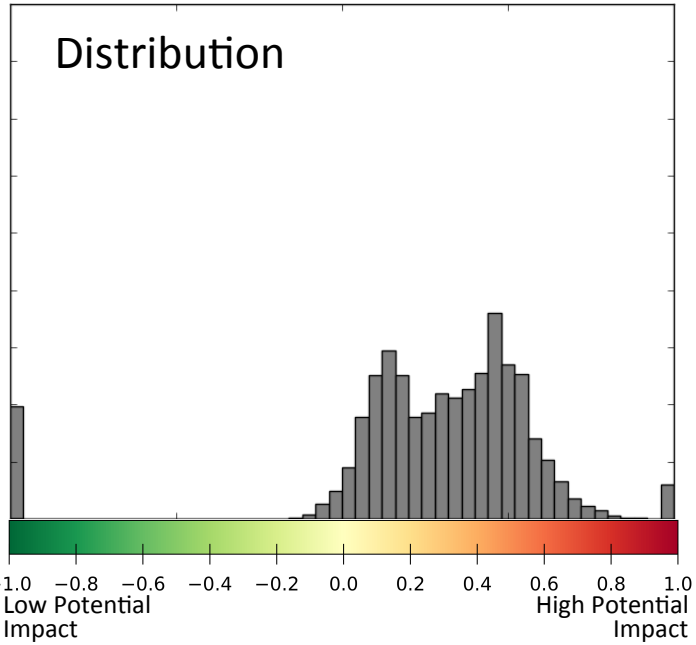


Potential Impact Results

2046-2075





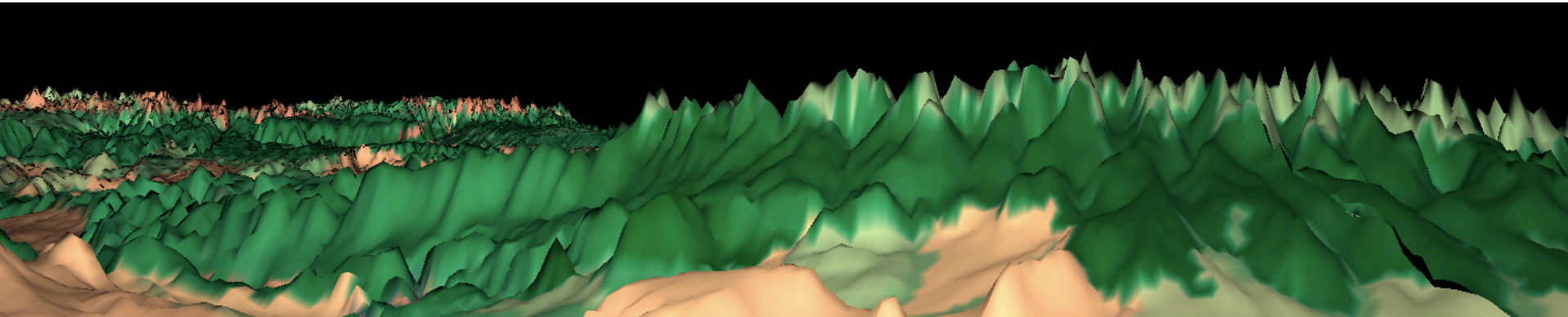


Digging Deeper

Drilling Down

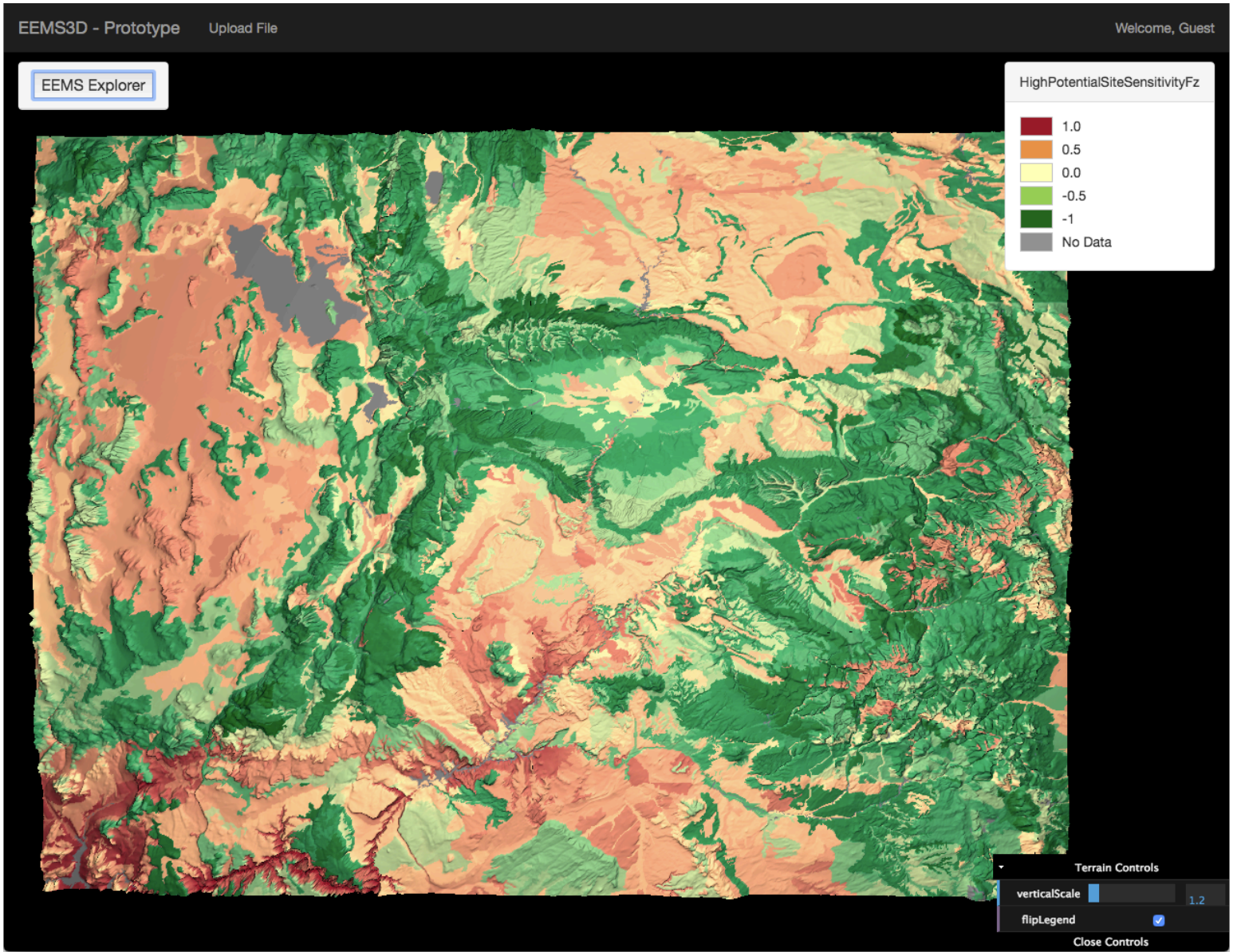
What drives the final result?

- EEMS explorers (web-based)
  - Data Basin (Mike Lundin, www.databasin.org)
  - Climate Console (Mike Gough, www.climateconsole.org)
  - 3D Explorer (Taylor Mutch, prototype)
- Allow user to navigate model and examine result layers



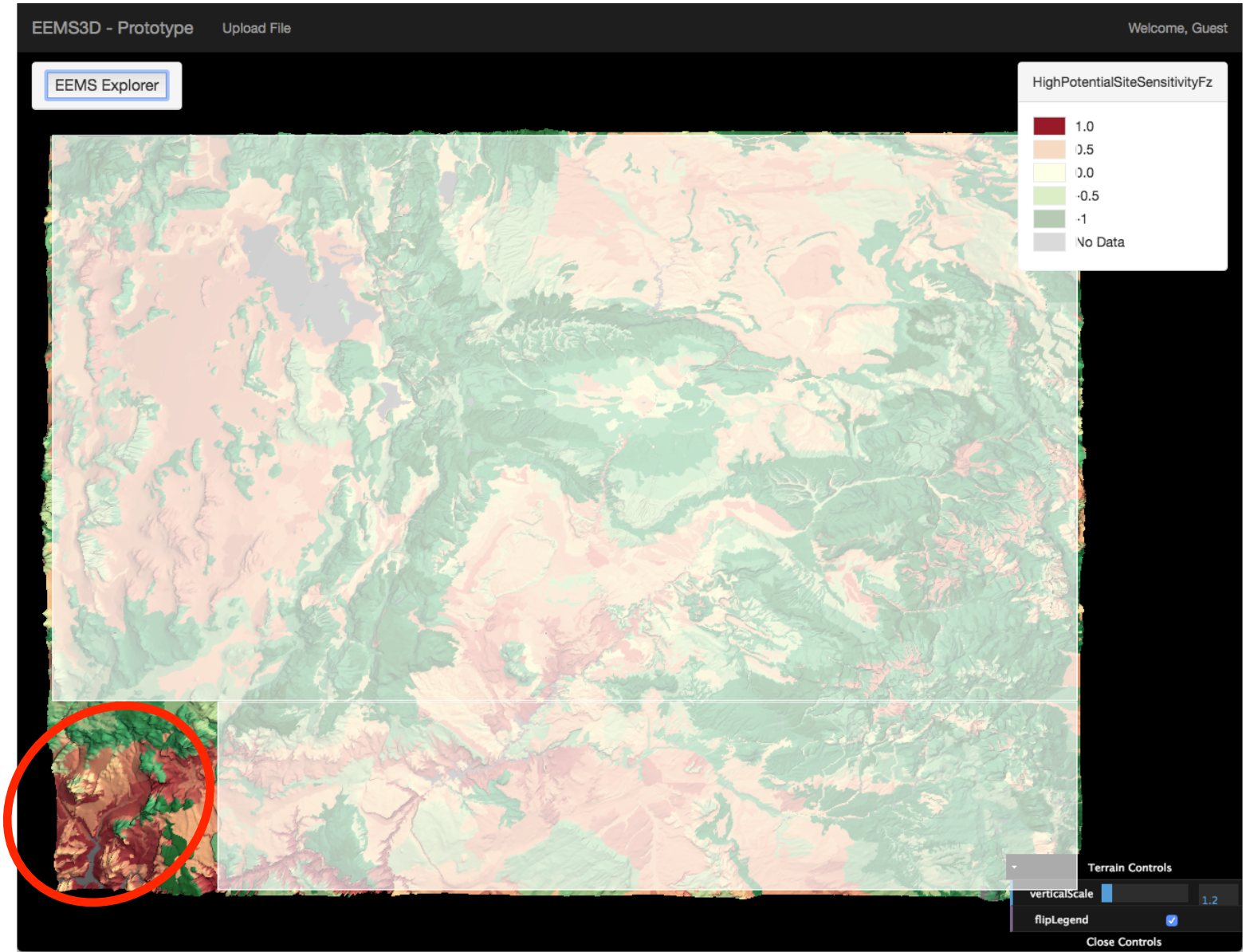
3D EEMS Explorer

Site Sensitivity is High for full Study Area



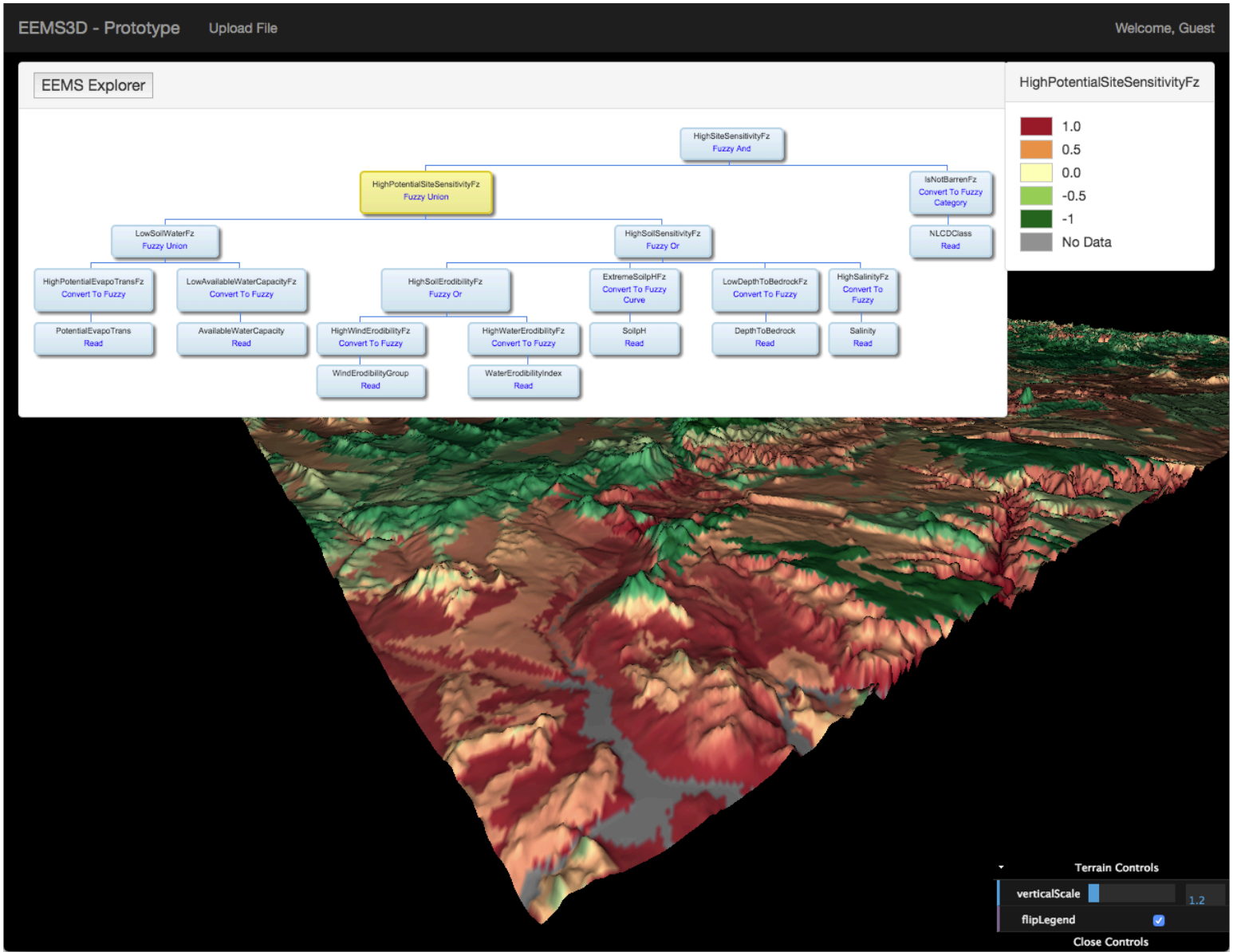
3D EEMS Explorer

Let's take a closer look at the SW corner.



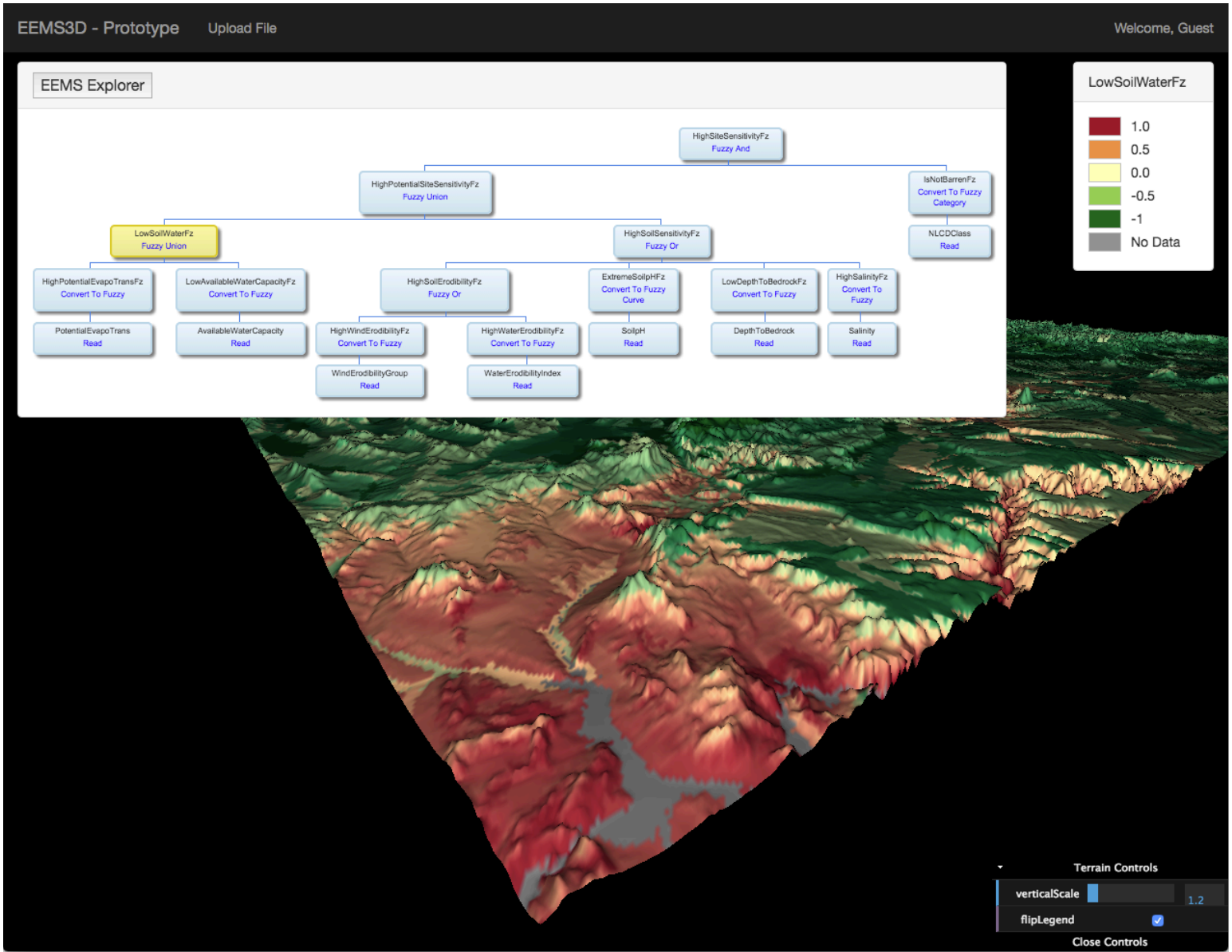
Site Sensitivity is High

Much of the area has high site sensitivity



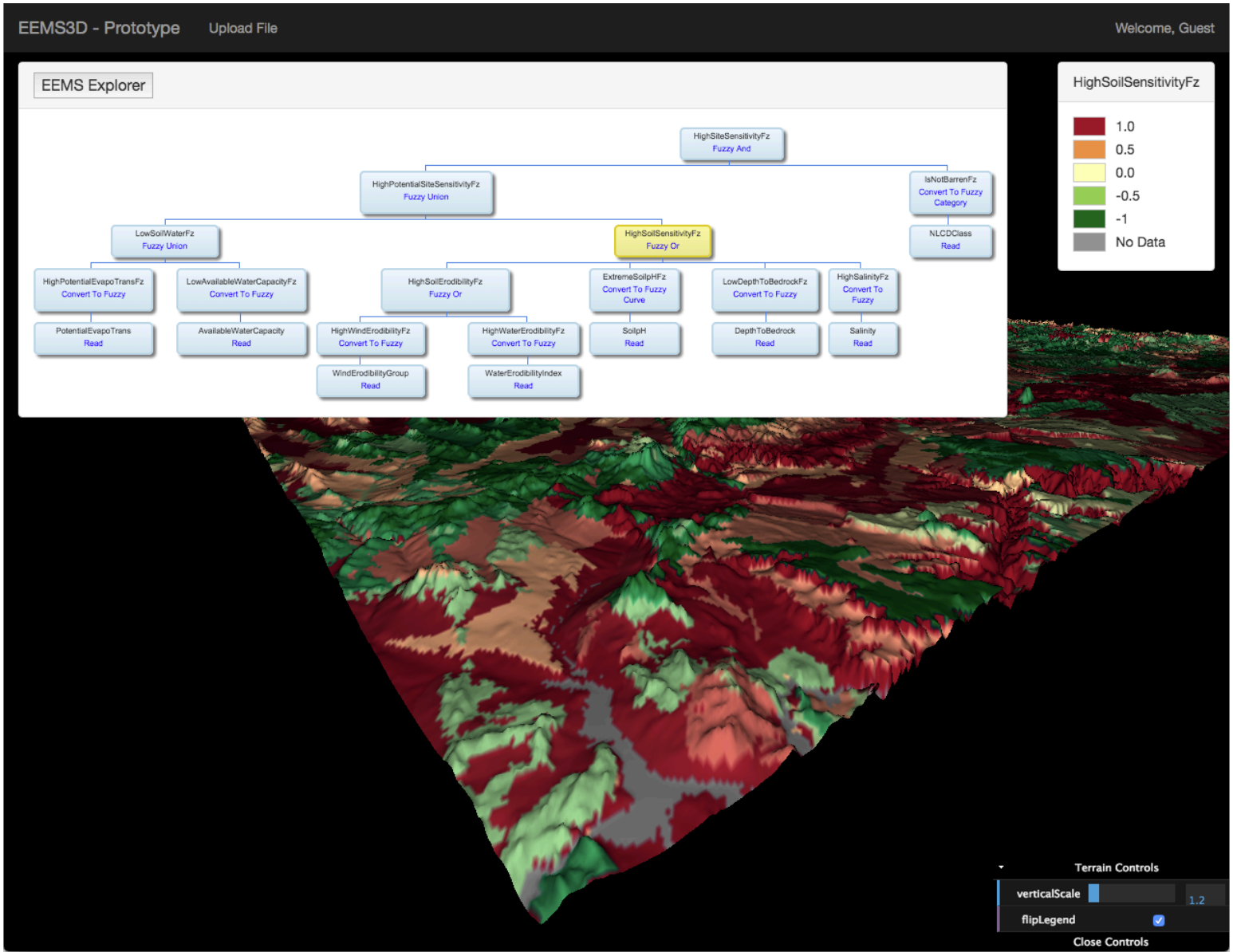
Soil Water is Low

A fairly high fuzzy value (i.e. fairly low soil water)



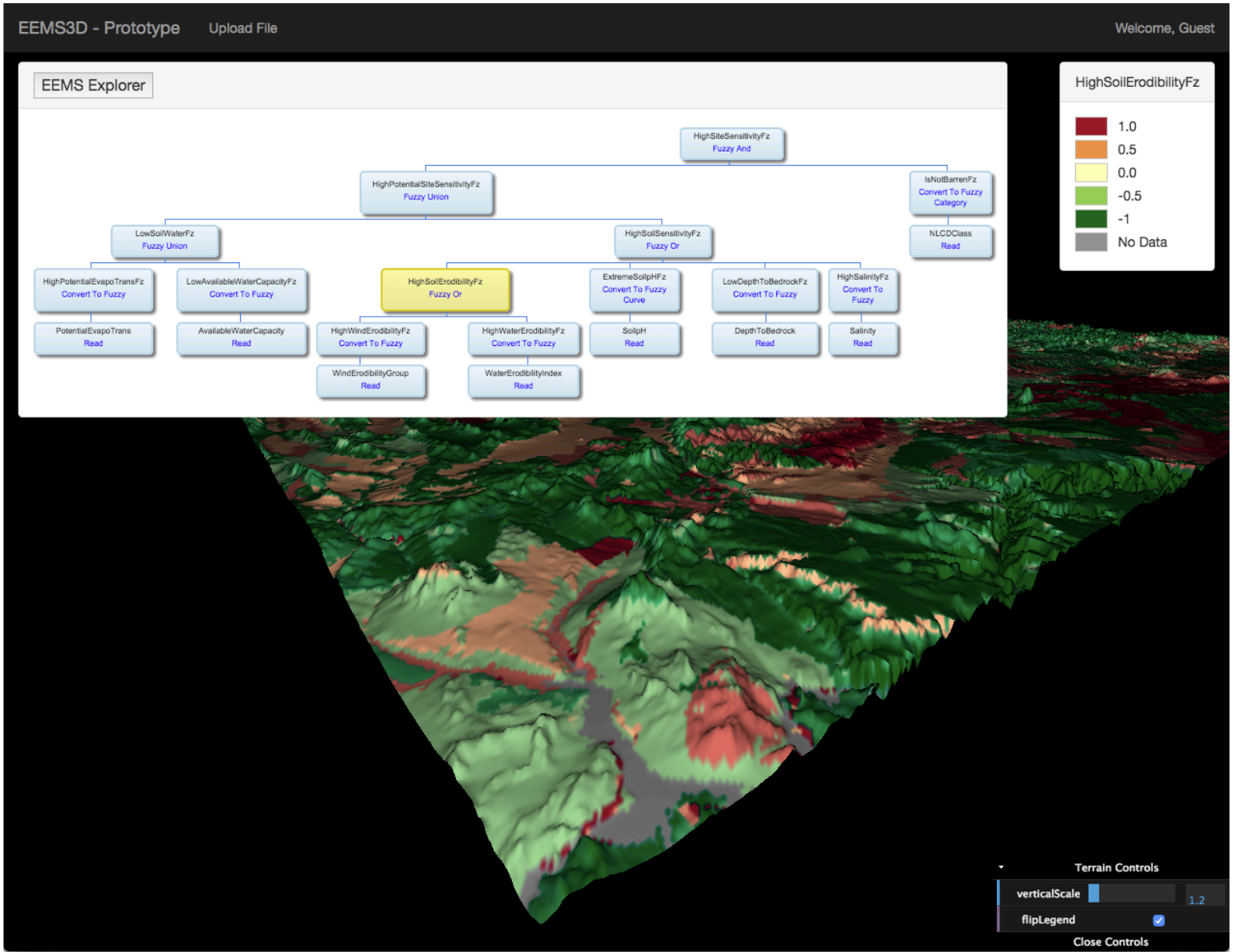
Soil Sensitivity is High

Much of the area has high soil sensitivity. But why?



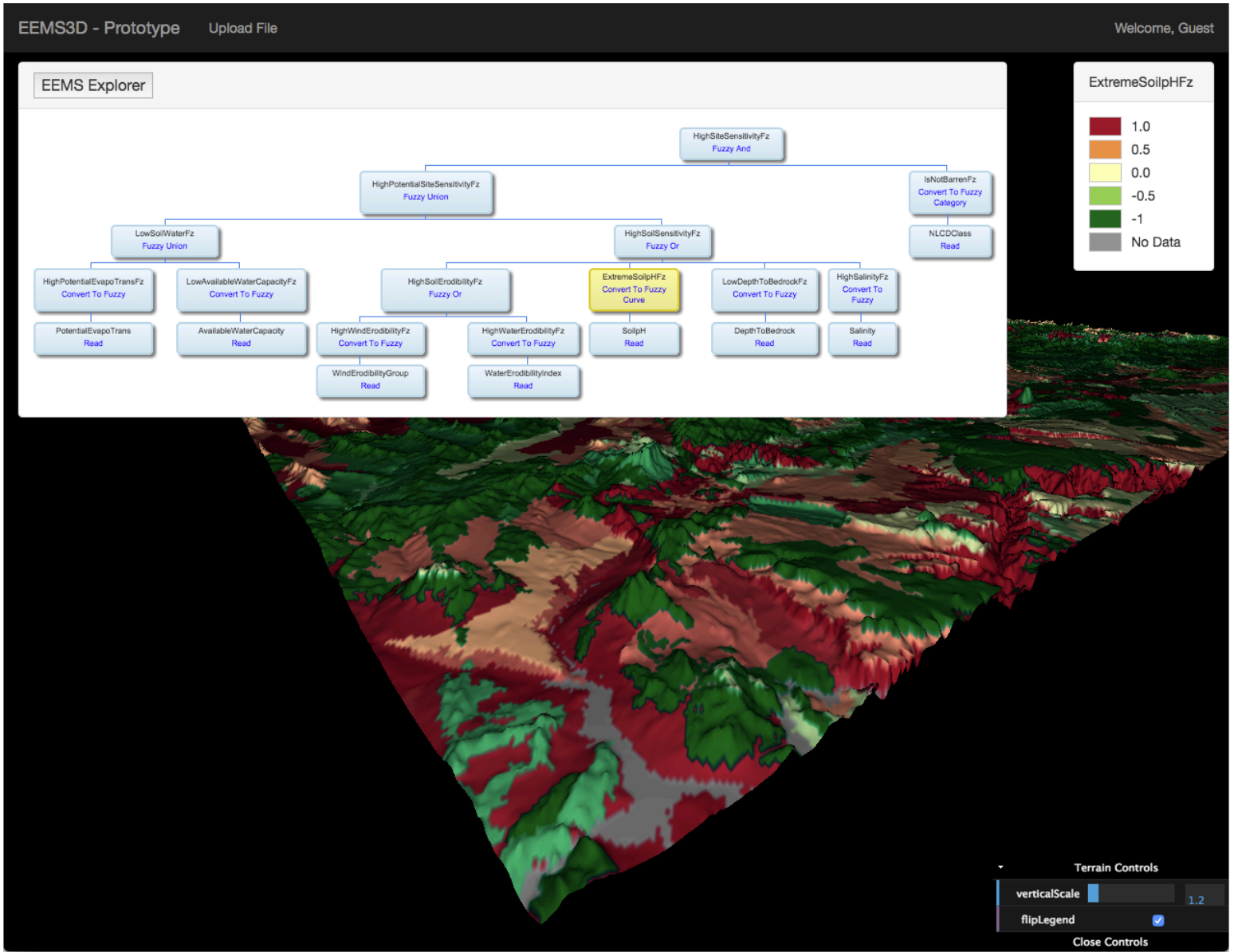
High Soil Erodibility

Low values indicate this is not THE driving characteristic.



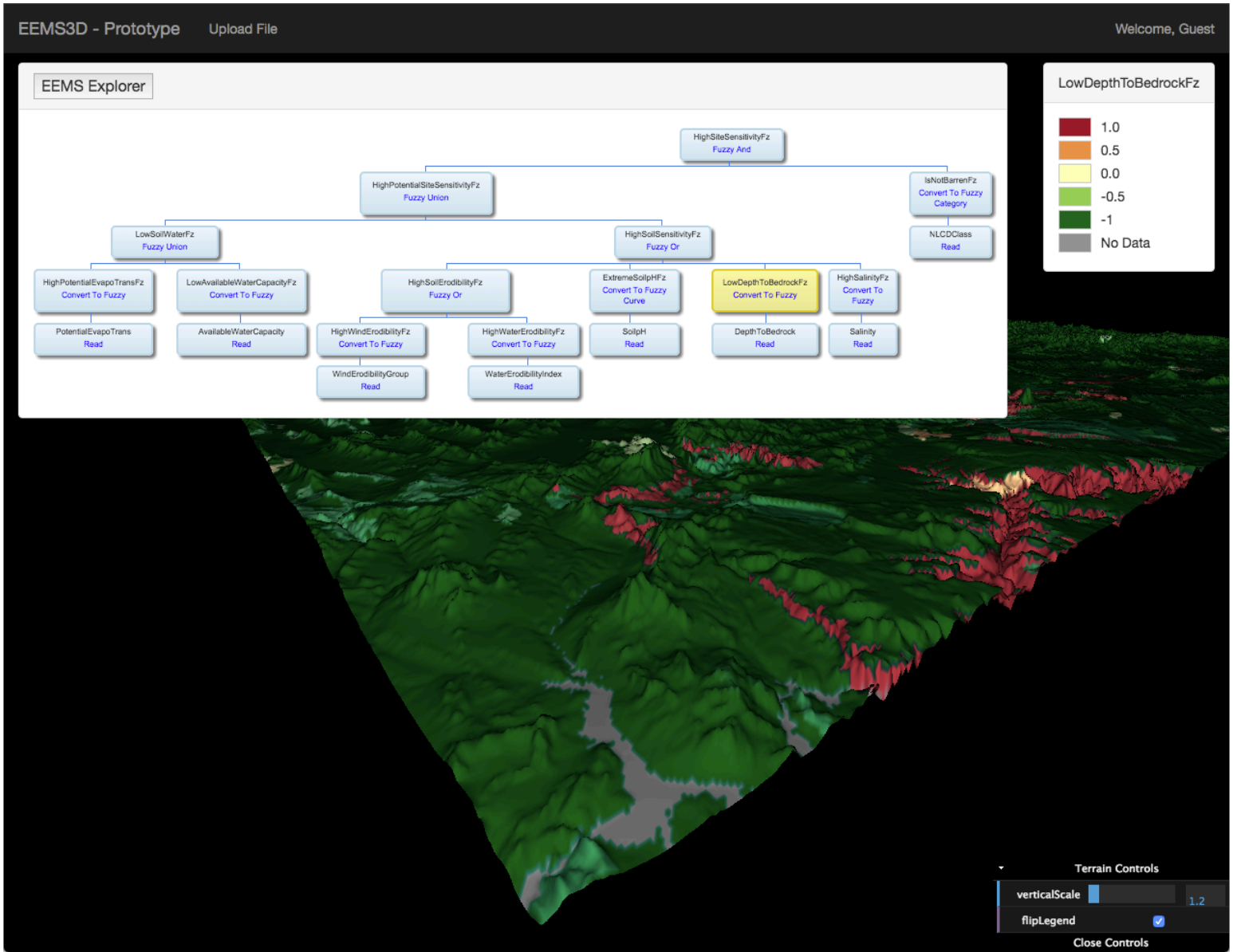
Soil pH is Extreme

High values indicate soil pH is extreme



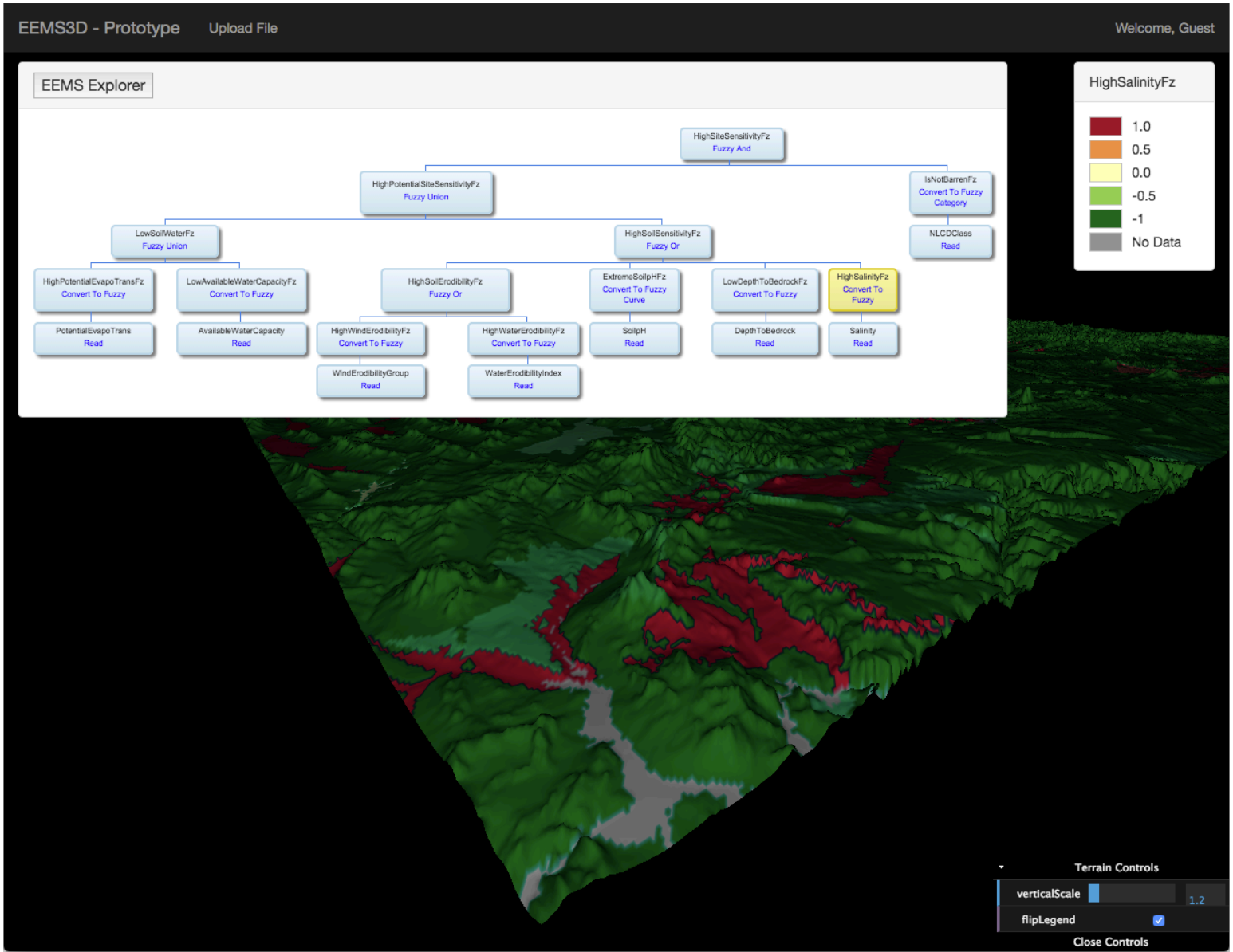
Soil Depth is Low

This is not the case for most of the area.



Soil Salinity is High

Very high soil salinity in much of the area.



Takeaways

Utah and Colorado Plateau Models

- Sensitivity locally driven by different factors
- Climate exposure
  - Driven by temperature
  - Increases with warming climate
- Lower site sensitivity dampens potential impact

Fuzzy Logic & EEMS

- Create metrics from diverse types of data
- Models are transparent and easily edited
- Exploring model and results together let's you determine what drives the model at every location

Acknowledgements

Bureau of Land Management and Utah Wildlife Resources for project funding



Mike Lundin, Mike Gough, and Taylor Mutch for the EEMS Explorers

National Park Service for all the cool photos in this presentation

Questions

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