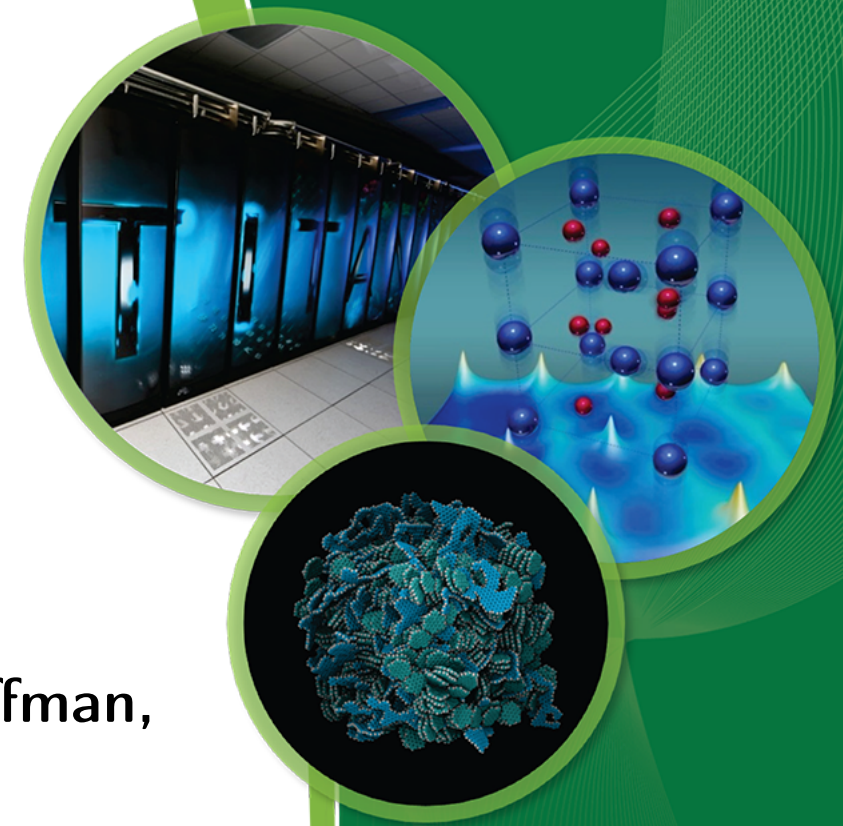
Landscape structure and heterogeneity controls on ecohydrological processes in Arctic tundra ecosystem



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Oak Ridge, TN, USA

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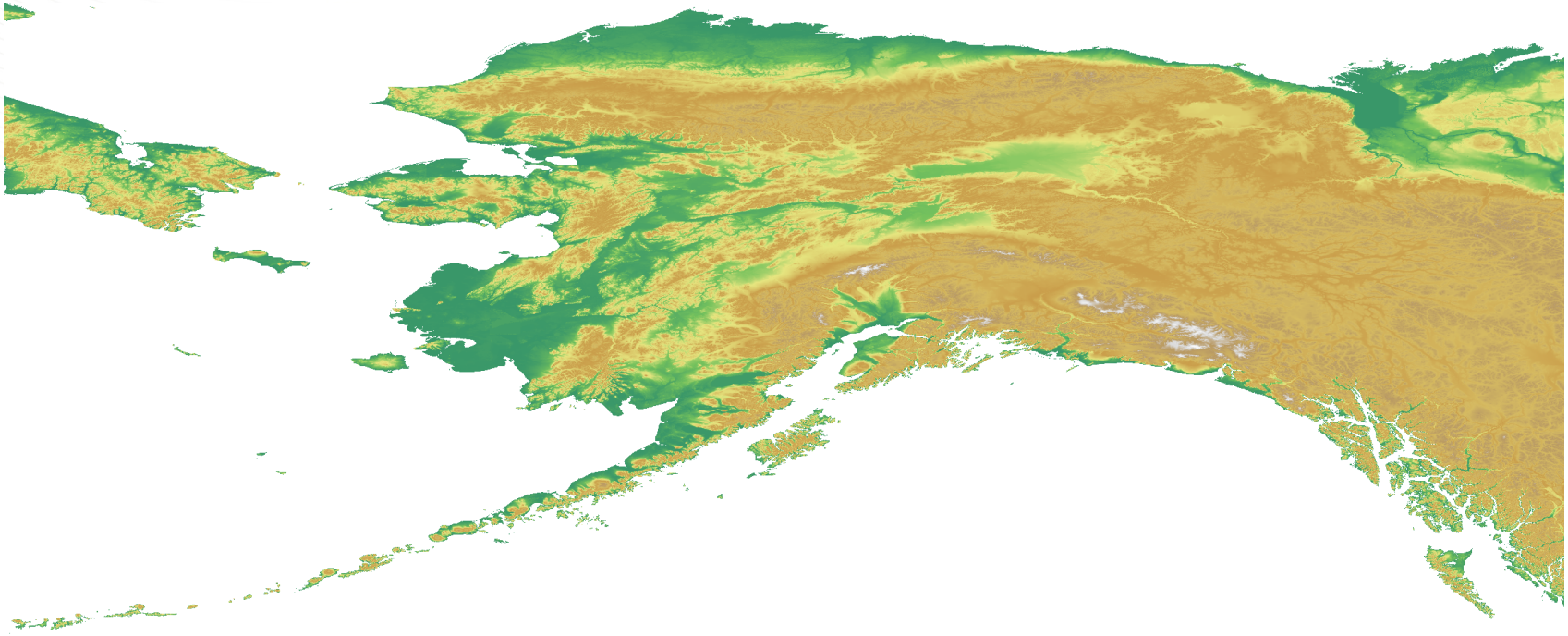
Introduction

- Biotic and abiotic complexity and heterogeneity of the landscape plays critical role in governing and influencing the ecohydrological processes on the landscape.
- These processes operate at a range of spatial and temporal scales.
- Capturing the subgrid heterogenity and their affects across scales is important for understand the current and future state of the landscape in changing climate.
- Characterizing and modeling these processes are especially difficult in data limited and ungauged landscapes like Arctic tundra landscape.

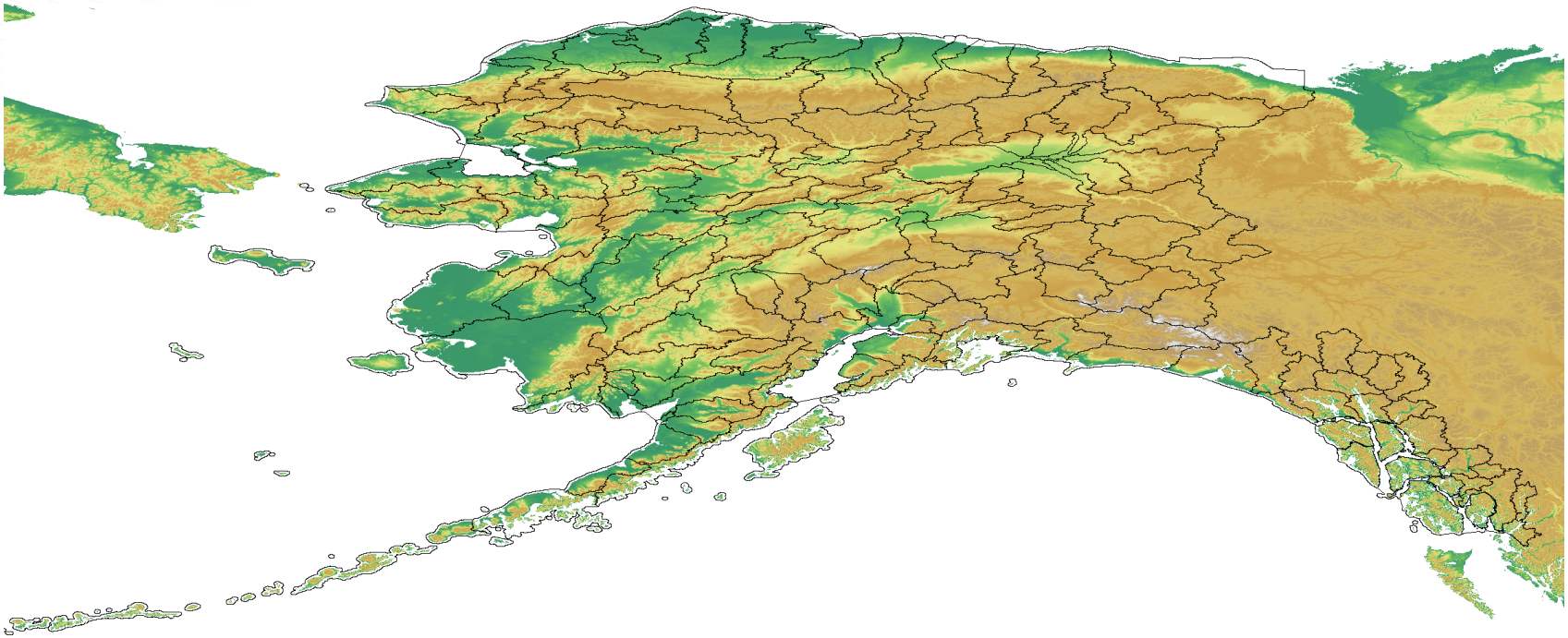
Objectives

- Characterize the heteogeneity of the landscape using multi-variate approach across spatial scales.
- Understand the landscape organization and their role and influence in modulating the ecohydrological processes.

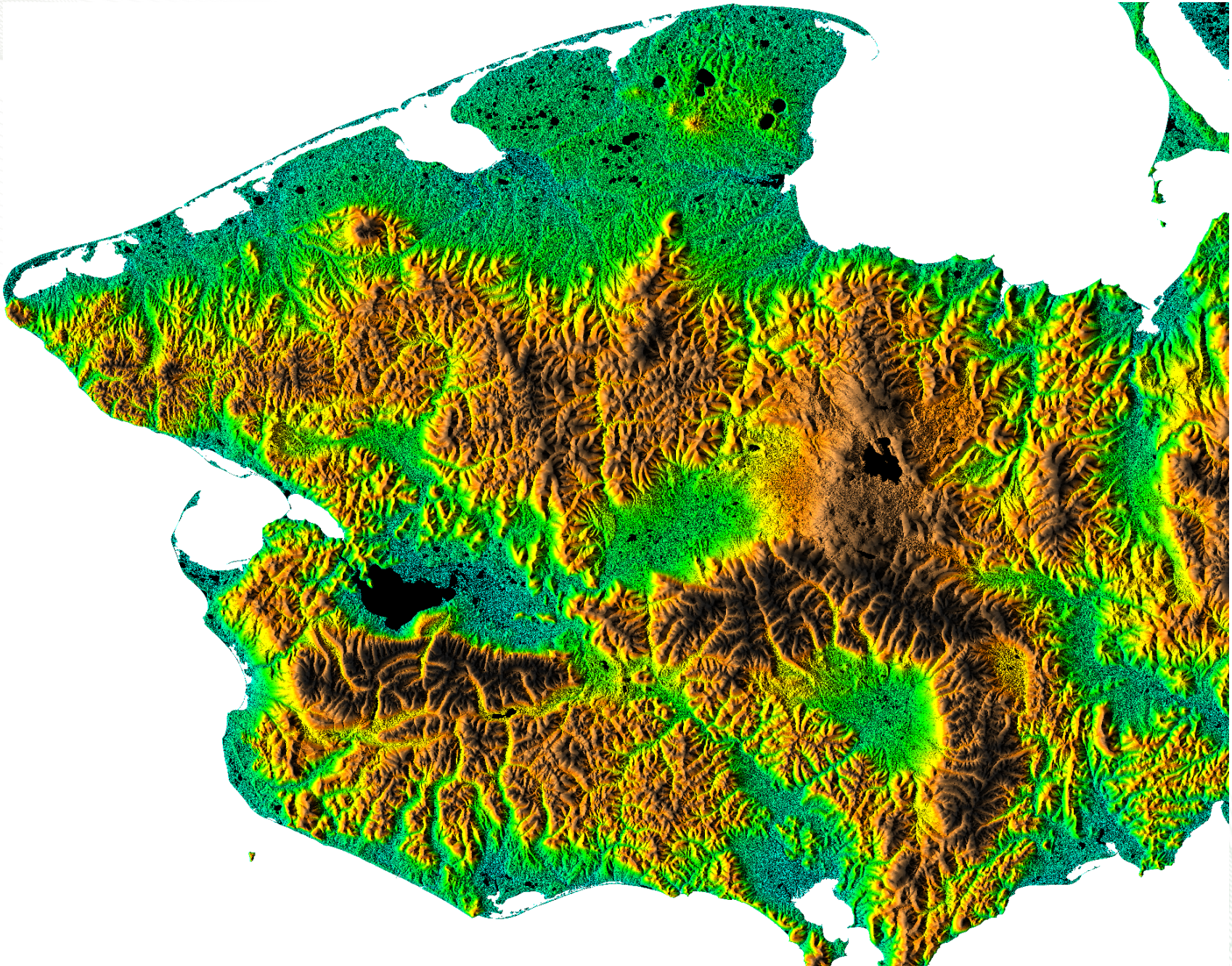
Study Region: Alaska



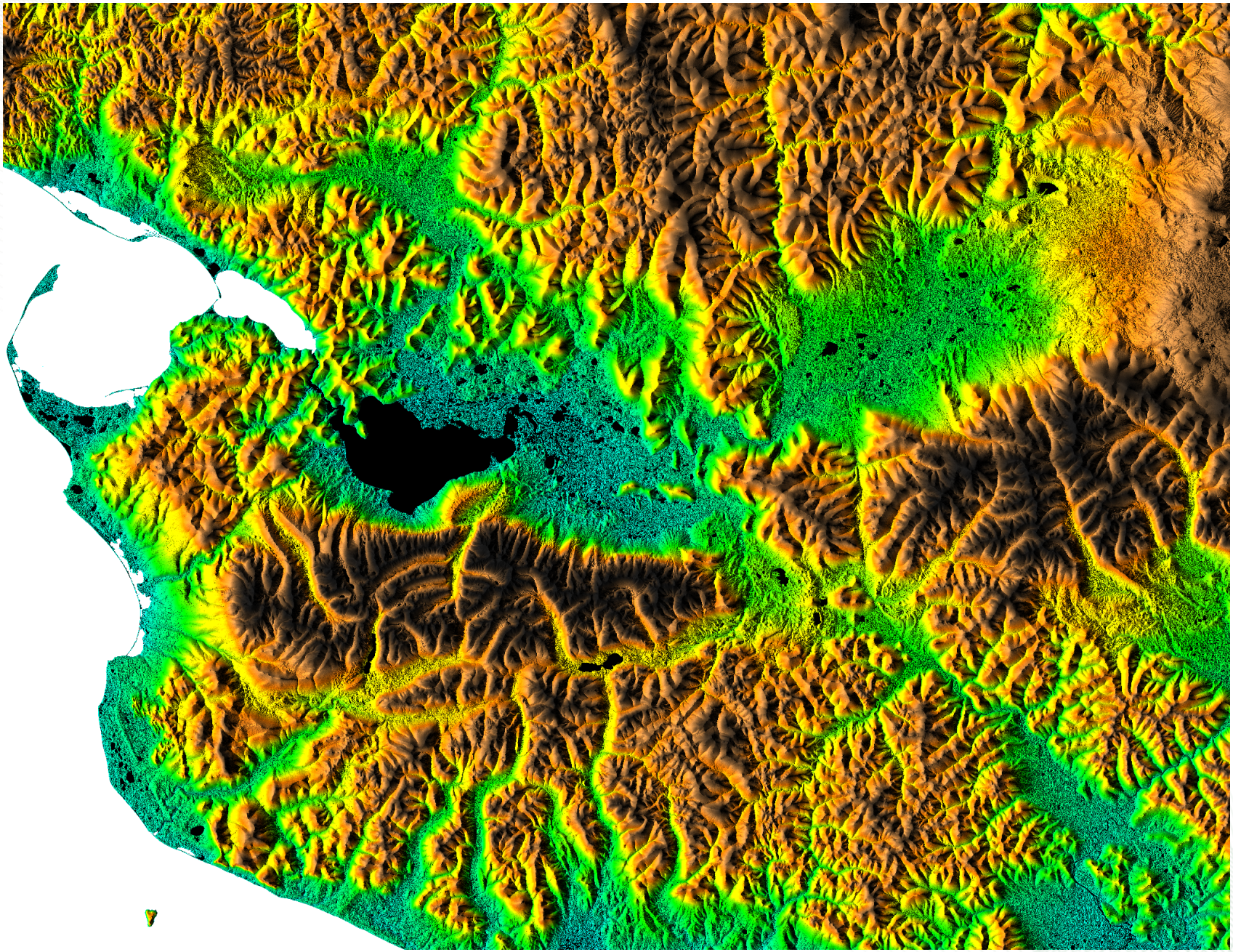
HUC 8 basins in Alaska



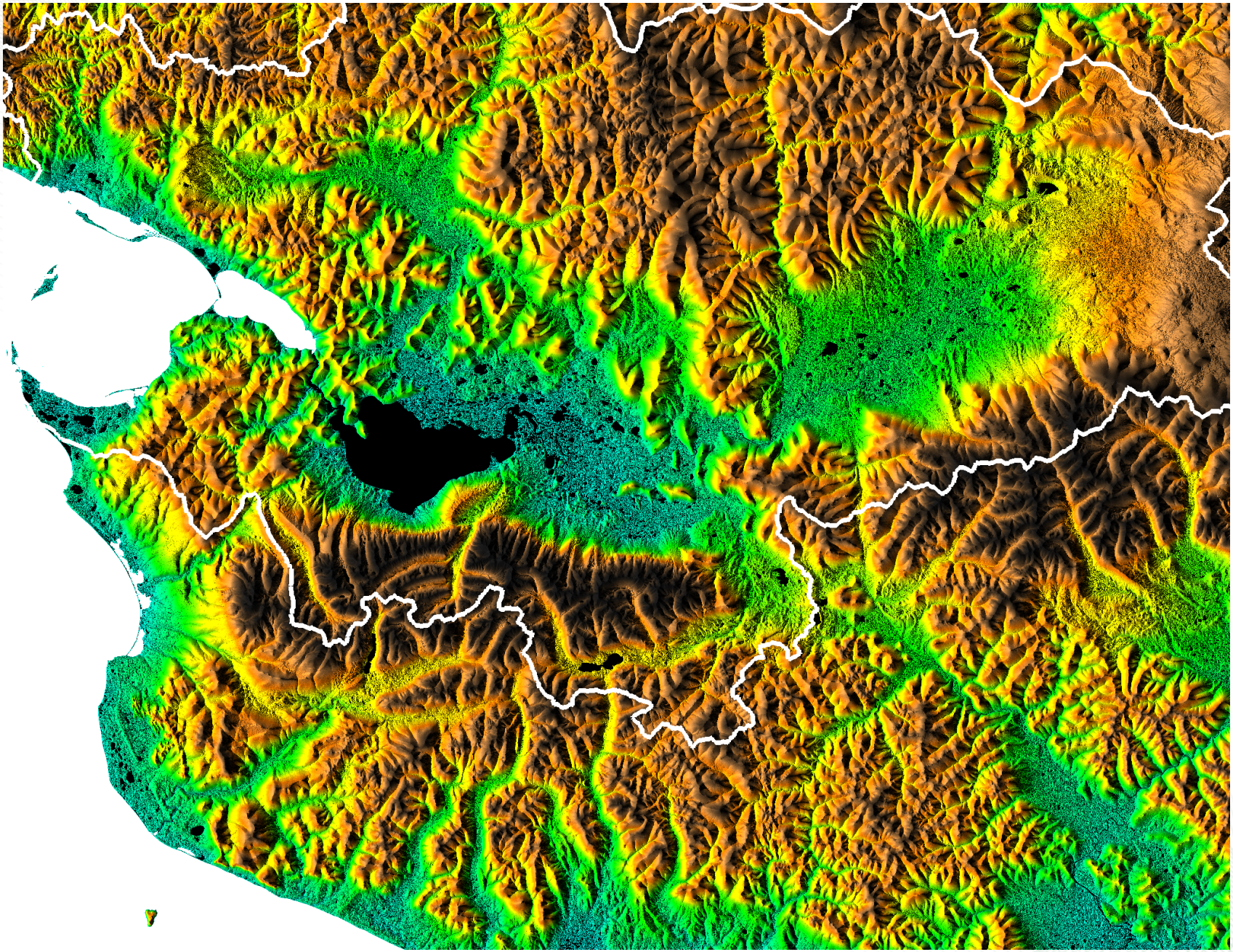
Topography of Seward Peninsula



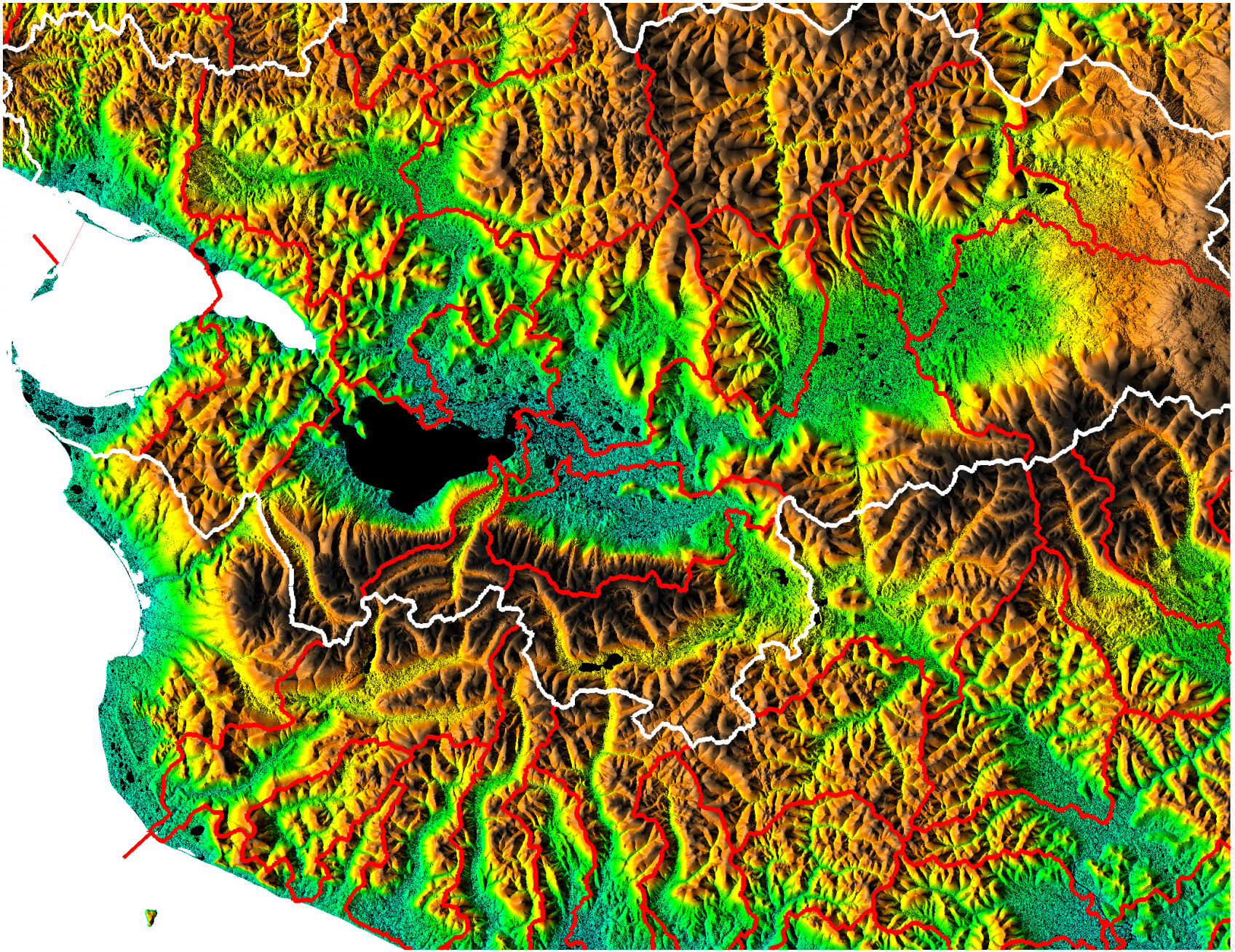
Southern Seward Peninsula



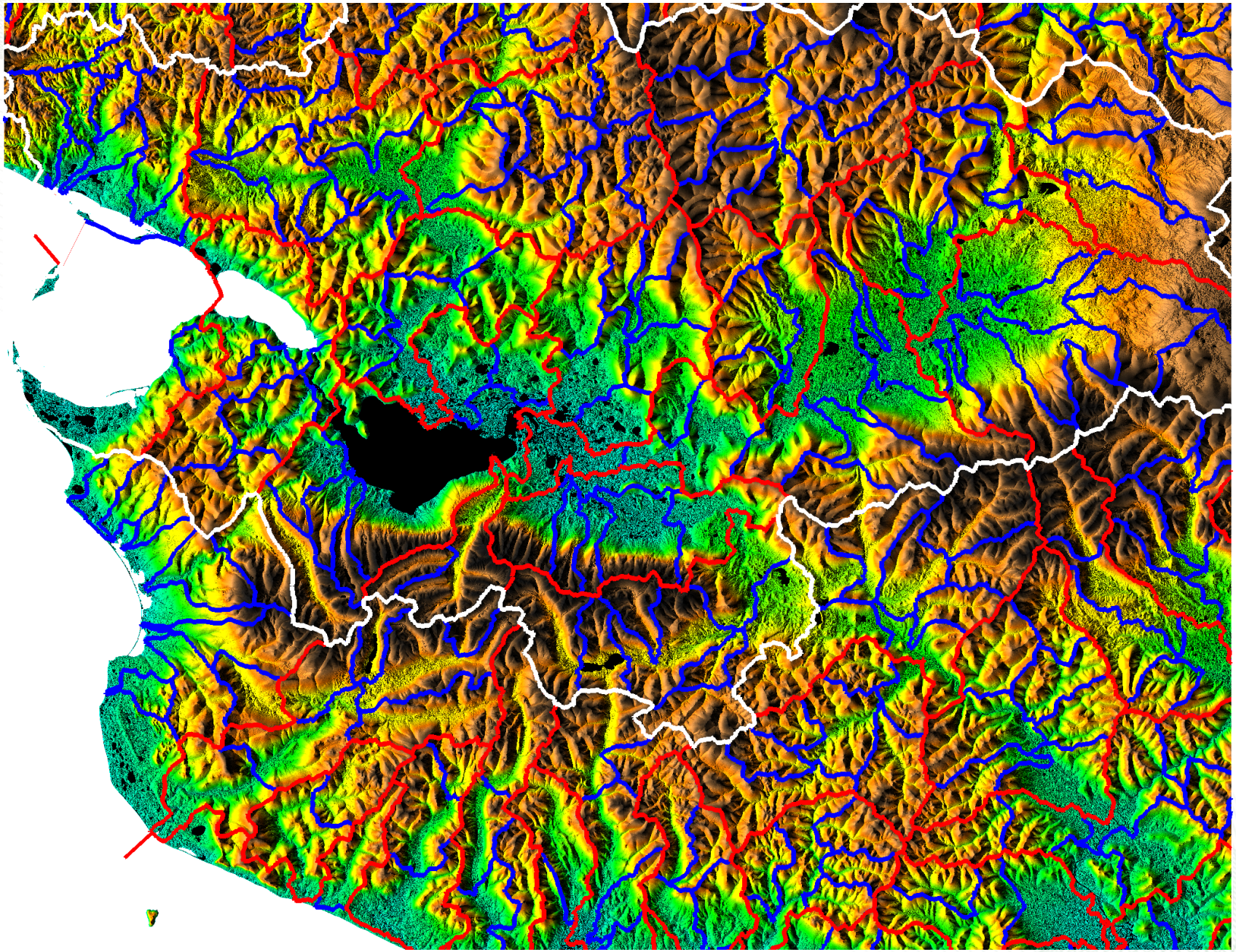
Southern Seward Peninsula: HUC8



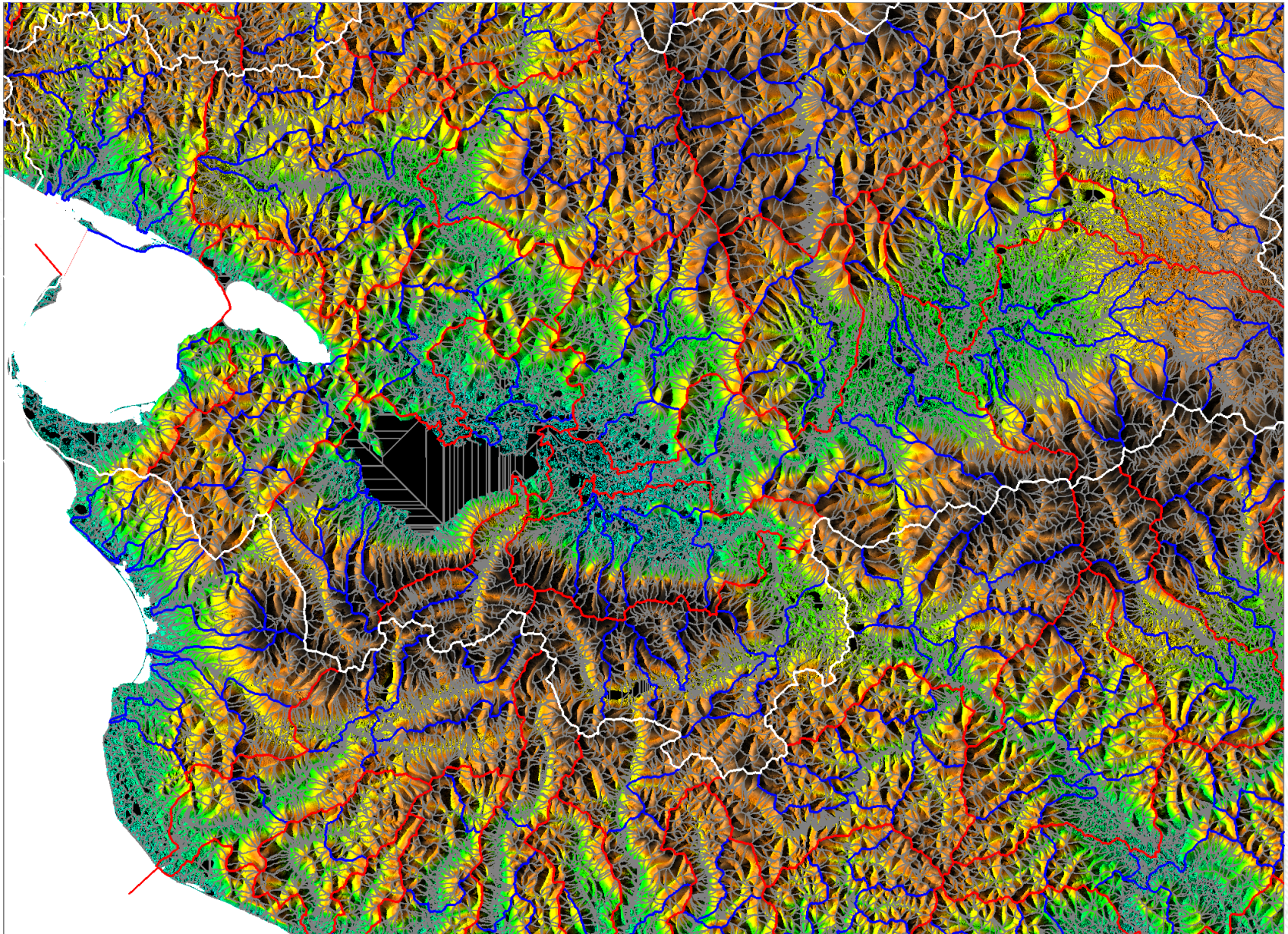
Southern Seward Peninsula: HUC8+HUC10



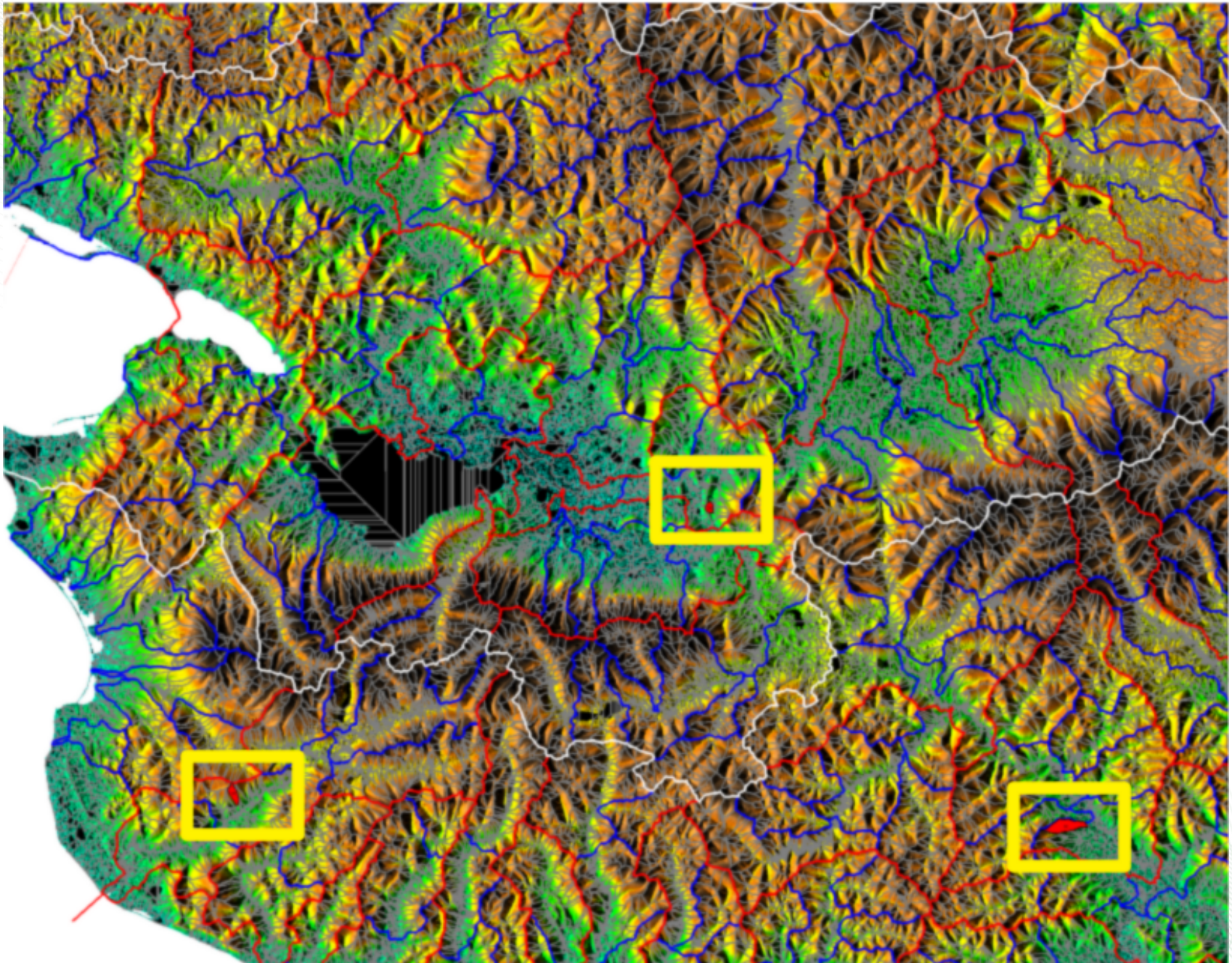
Southern Seward Peninsula: HUC8+HUC10+HUC12



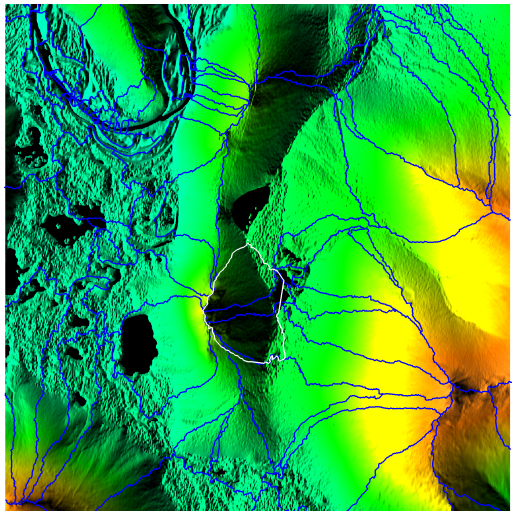
Southern Seward Peninsula: HUC8+HUC10+HUC12 + High res. watersheds



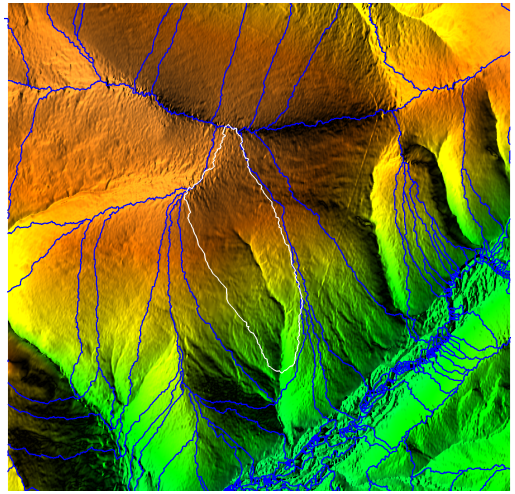
Southern Seward Peninsula: NGEE Arctic Sites



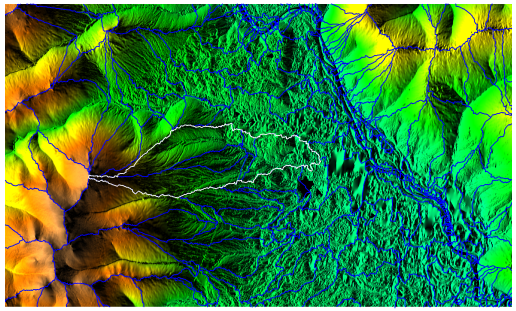
Southern Seward Peninsula: NGEE Arctic Sites



Kougarok

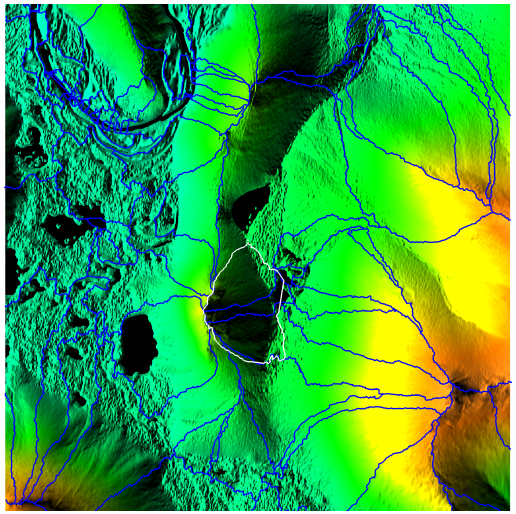


Teller

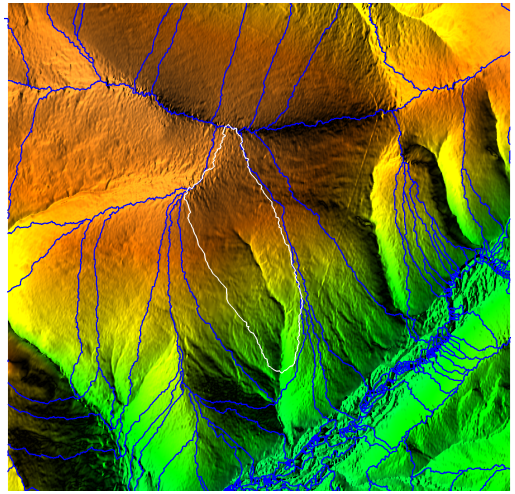


Council

Southern Seward Peninsula: NGEE Arctic Sites



Kougarok



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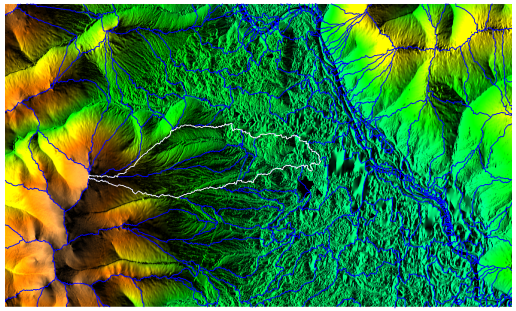

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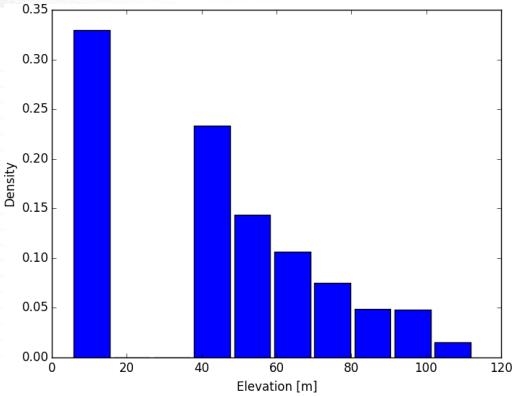
How can we extrapolate/scale up the observations and understanding we gain from our intensive field, laboratory, and modeling studies at these three watersheds to the larger landscape.

Landscape structure and heterogeneity

- In complex topographic landscape hill slope hydrologic processes have dominant controls on nutrient flows and vegetation distributiom.
- Landscape structure: Elevation, Slope, Aspect, Watershed shape
- Landscape heterogeneity: Vegetation, soil properties, nutrients availability
- Structure and heterogeneity controls hydrologic response of the watershed/landscape, which in turn is key to modulate ecological processes (like vegetation distribution).

Southern Seward Peninsula: NGEE Arctic Sites



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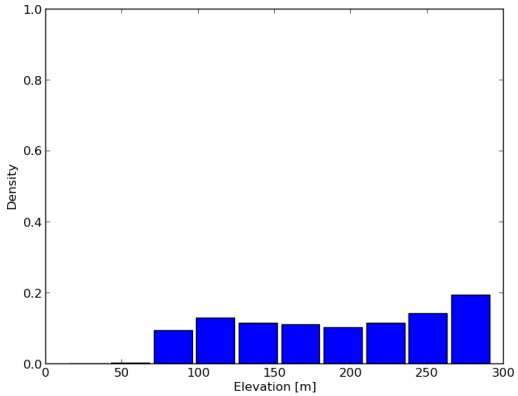

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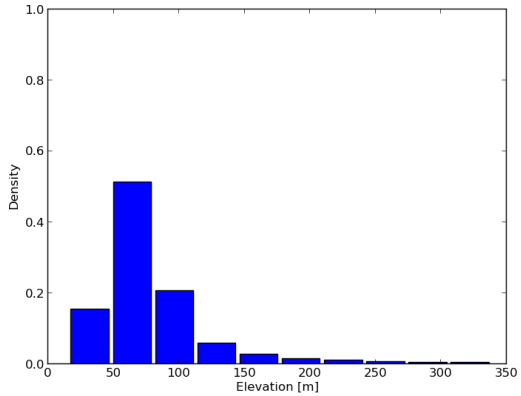

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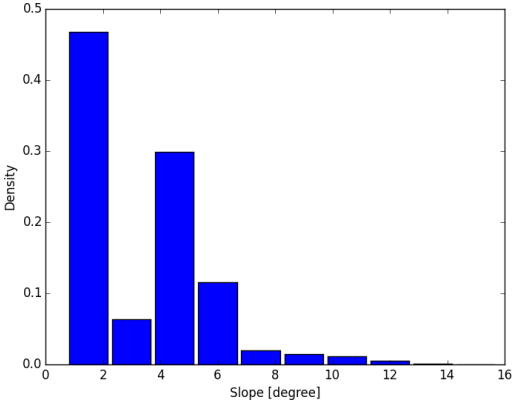
Distribution of elevation across NGEE-Arctic watersheds.



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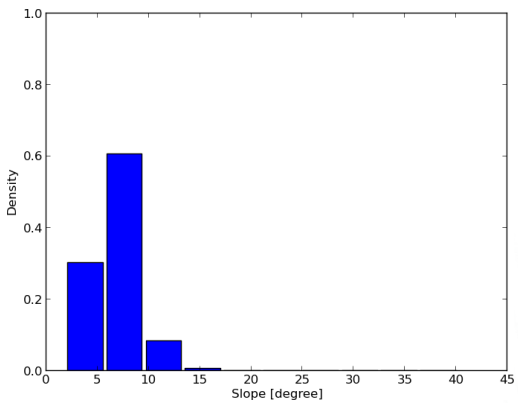

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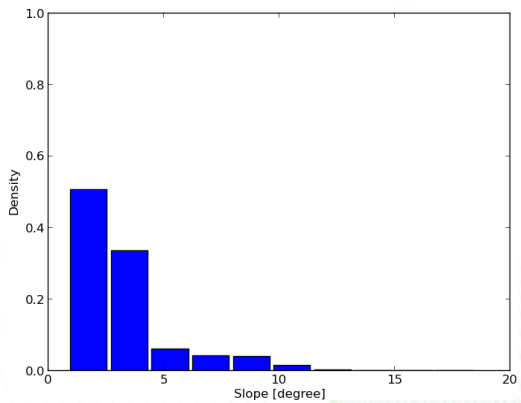
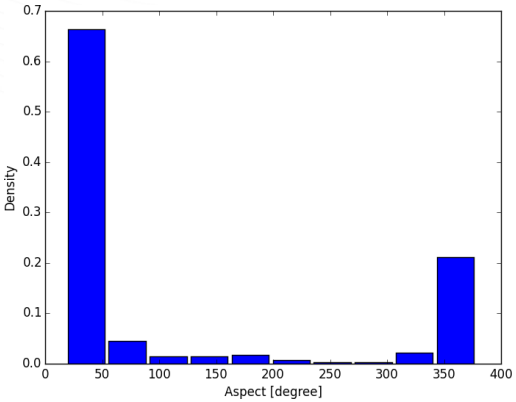


Council

Distribution of slopes across NGEE-Arctic watersheds.

Southern Seward Peninsula: NGEE Arctic Sites



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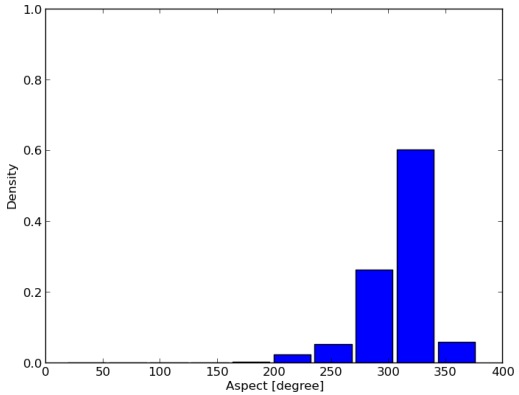

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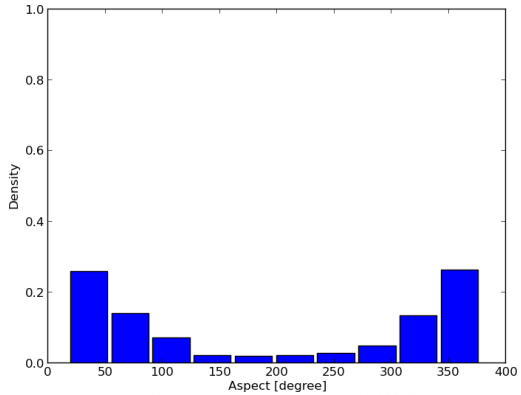
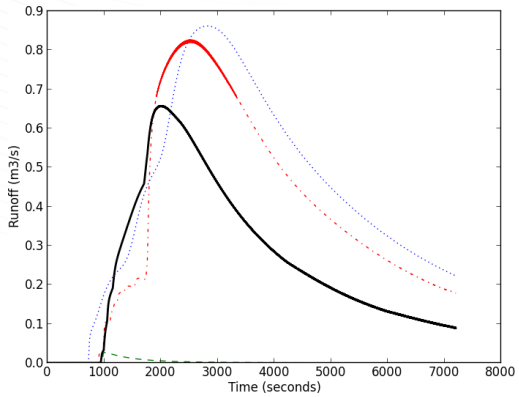


Council

Distribution of aspect across NGEE-Arctic watersheds.

Southern Seward Peninsula: NGEE Arctic Sites



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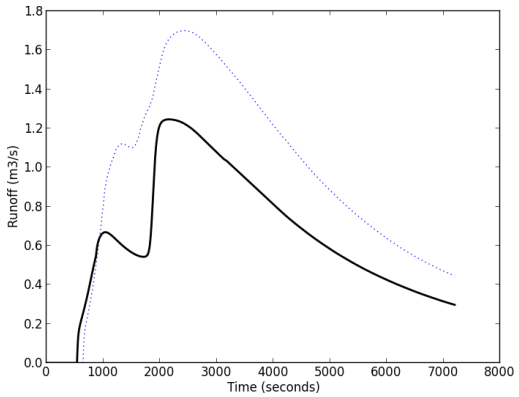

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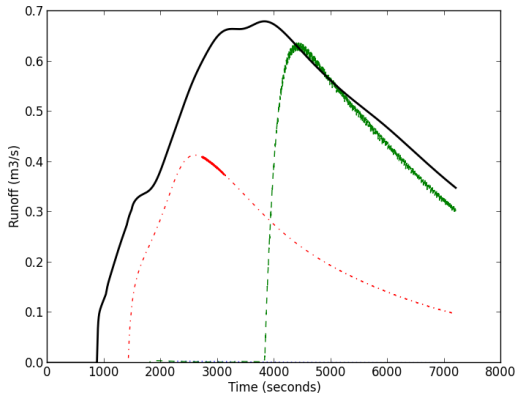


Council

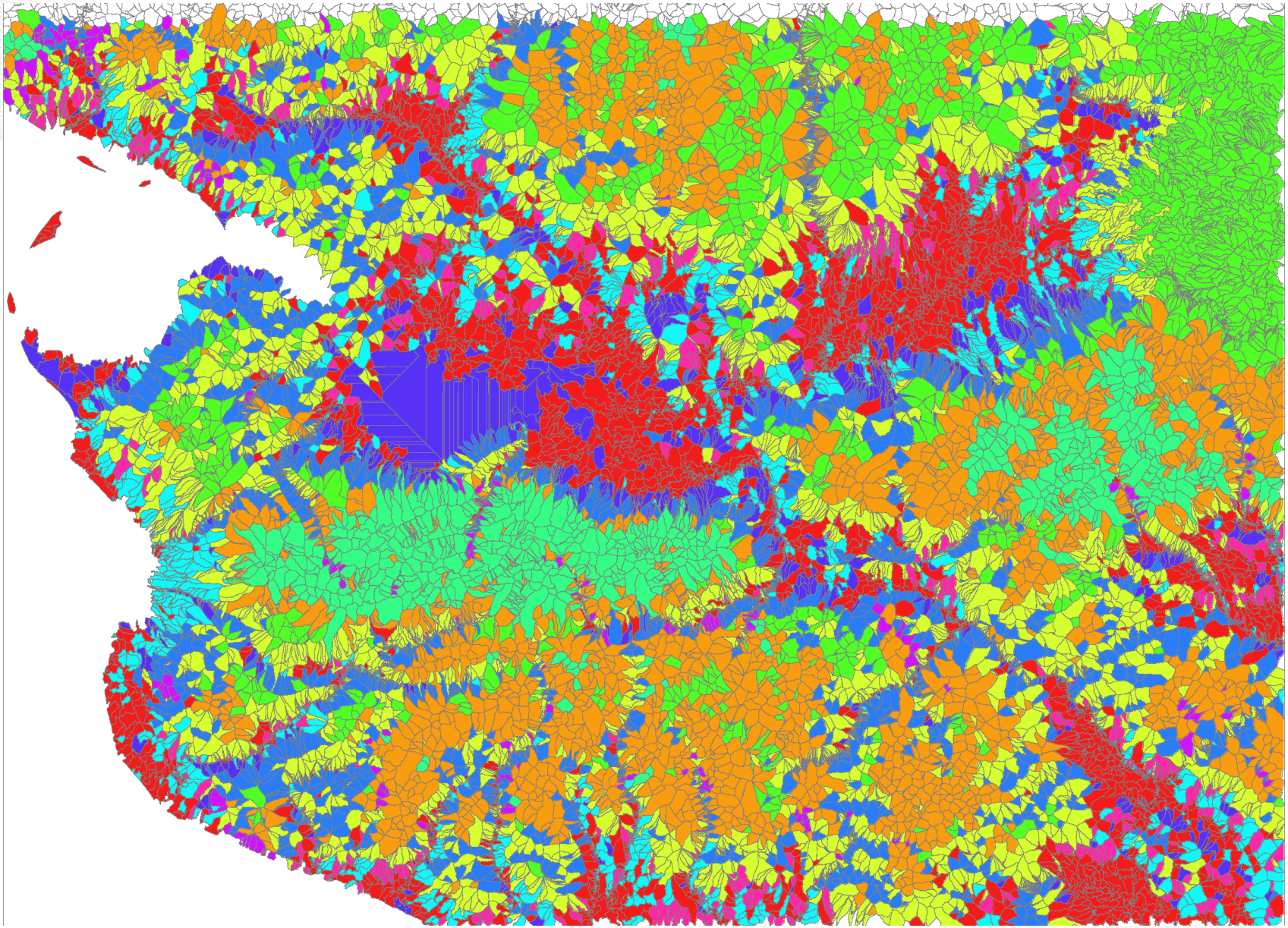
Unique landscape structure in the watershed lead to unique hydrologic response.

Idealized storm runoff simulations were conducted in surface-subsurface flow and reactive transport model PFLOTRAN. Heterogenous surface condition, snow melt processes etc. were ignored.

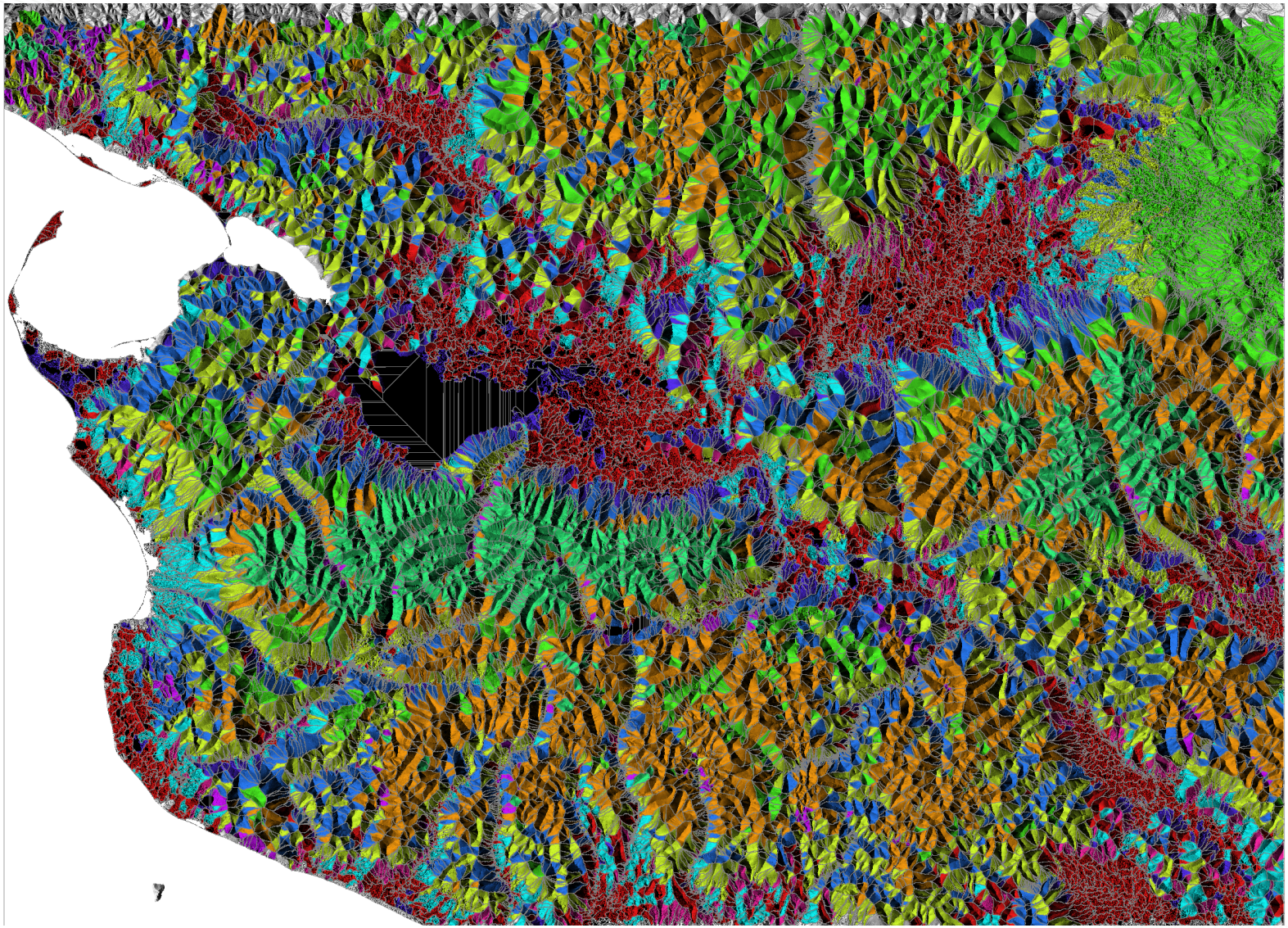
Classification of watershed

- Capture the distribution of topographic properties of the watershed using high resolution DEM.
- Beyond mean
  - **Elevation**: mean, std. dev., median. first/third quartile
  - **Slope**: mean, std. dev., median. first/third quartile
  - **Aspect**: mean, std. dev., median. first/third quartile
  - **Watershed shape index**
- Unsupervised classification approach, since we don't know the classes or number of classed apriori.

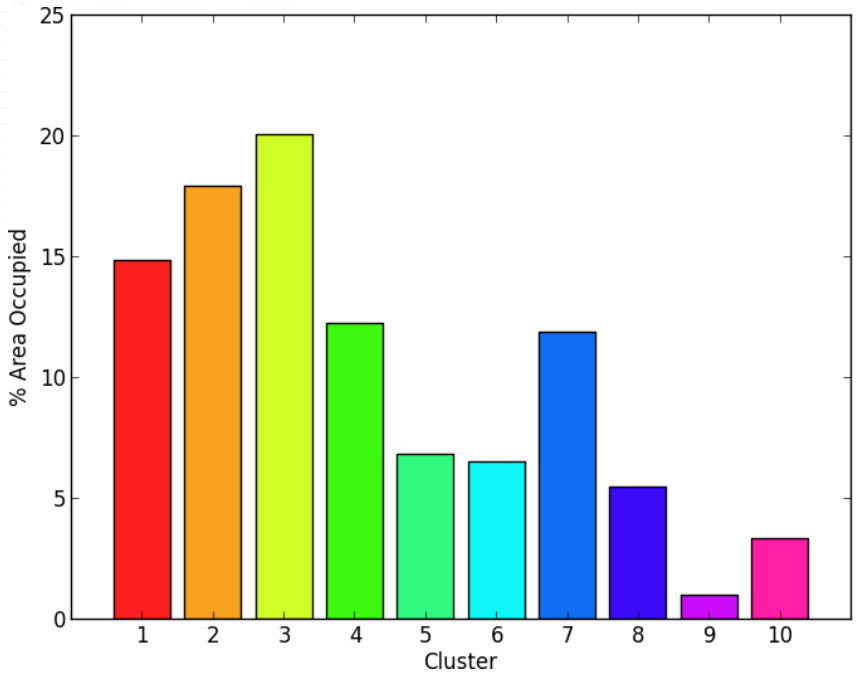
In addition to topography, heterogeneous distribution of vegetation, surficial geology and permafrost conditions, soil physical and chemical properties, and nutrient availability are key for these characterizing the landscape, however, they were not included in the current analysis.



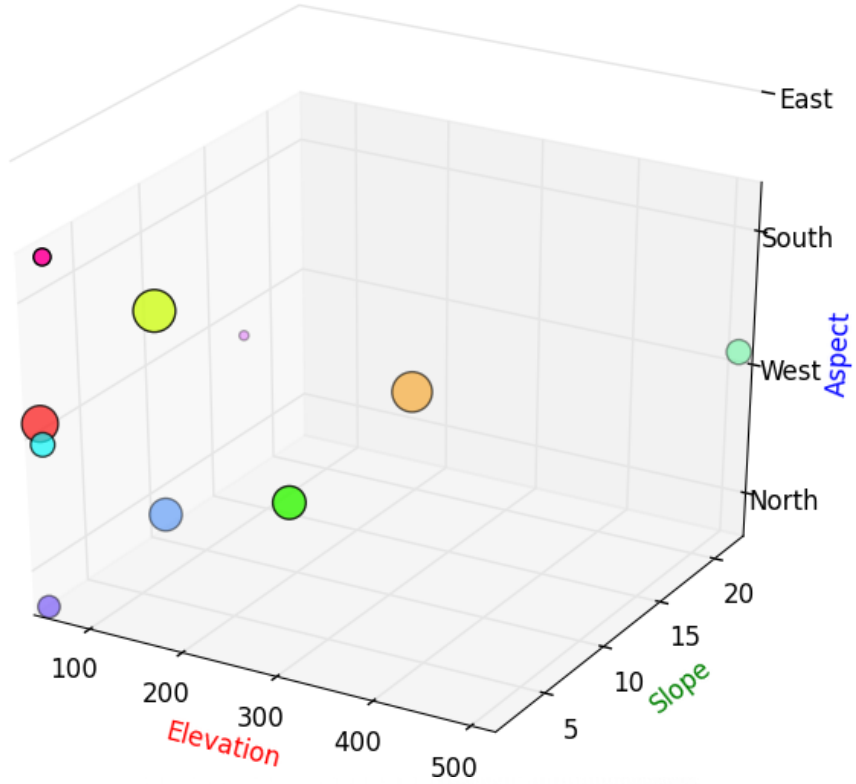
Ten unique watershed classes for Southern Seward Peninsula.



When draped over hill shade map, we can observe how these various watershed classes vary regionally across Seward peninsula.



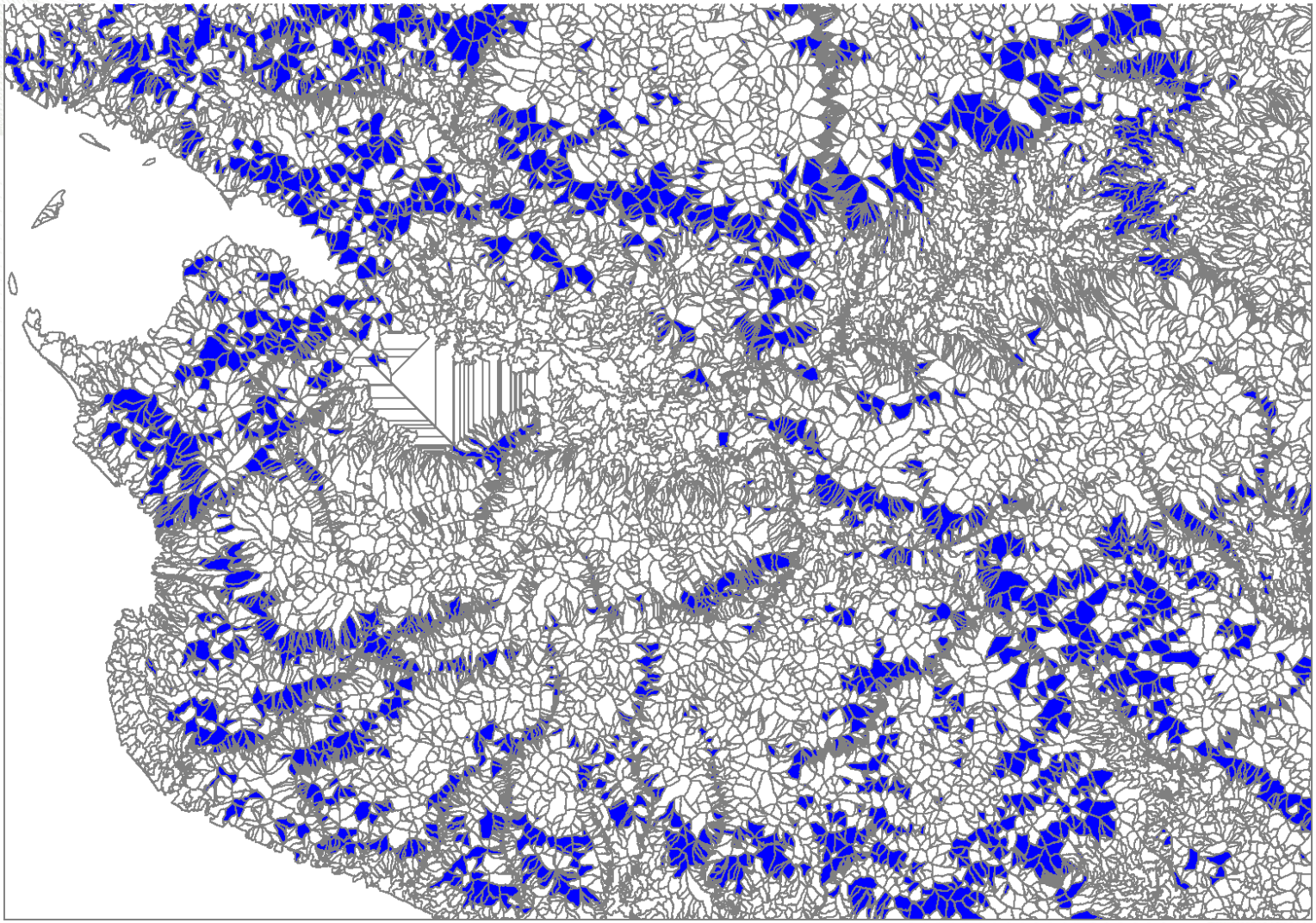
Area occupied by watershed classes



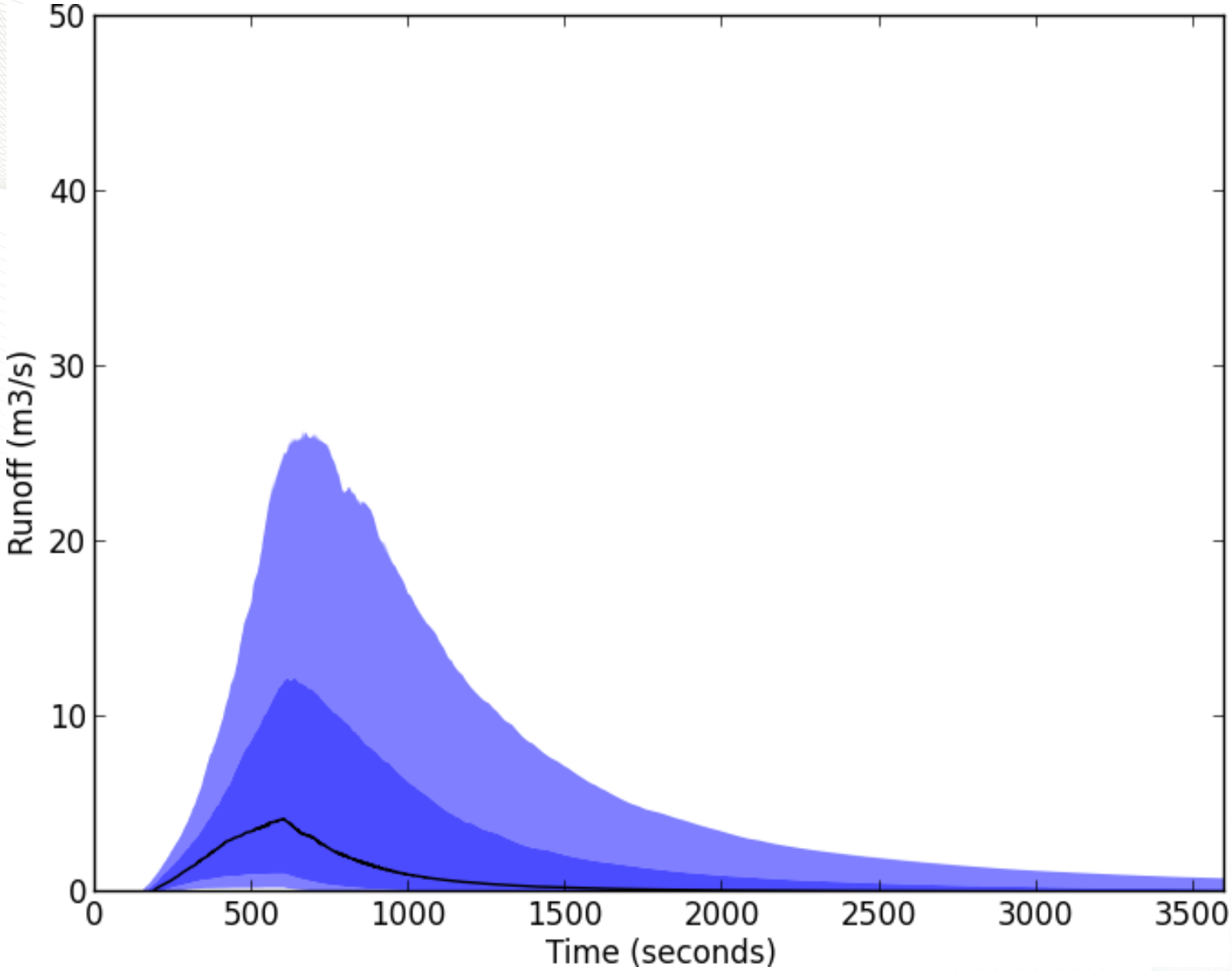
Topographic characteristics of watershed classes

Watershed classes vary in their abundance and occupy different regions of multi-variate state space.

Does these watershed classes help us understand ecohydrological processess on the landscape?



Distribution of watershed class k=3 on the landscape.

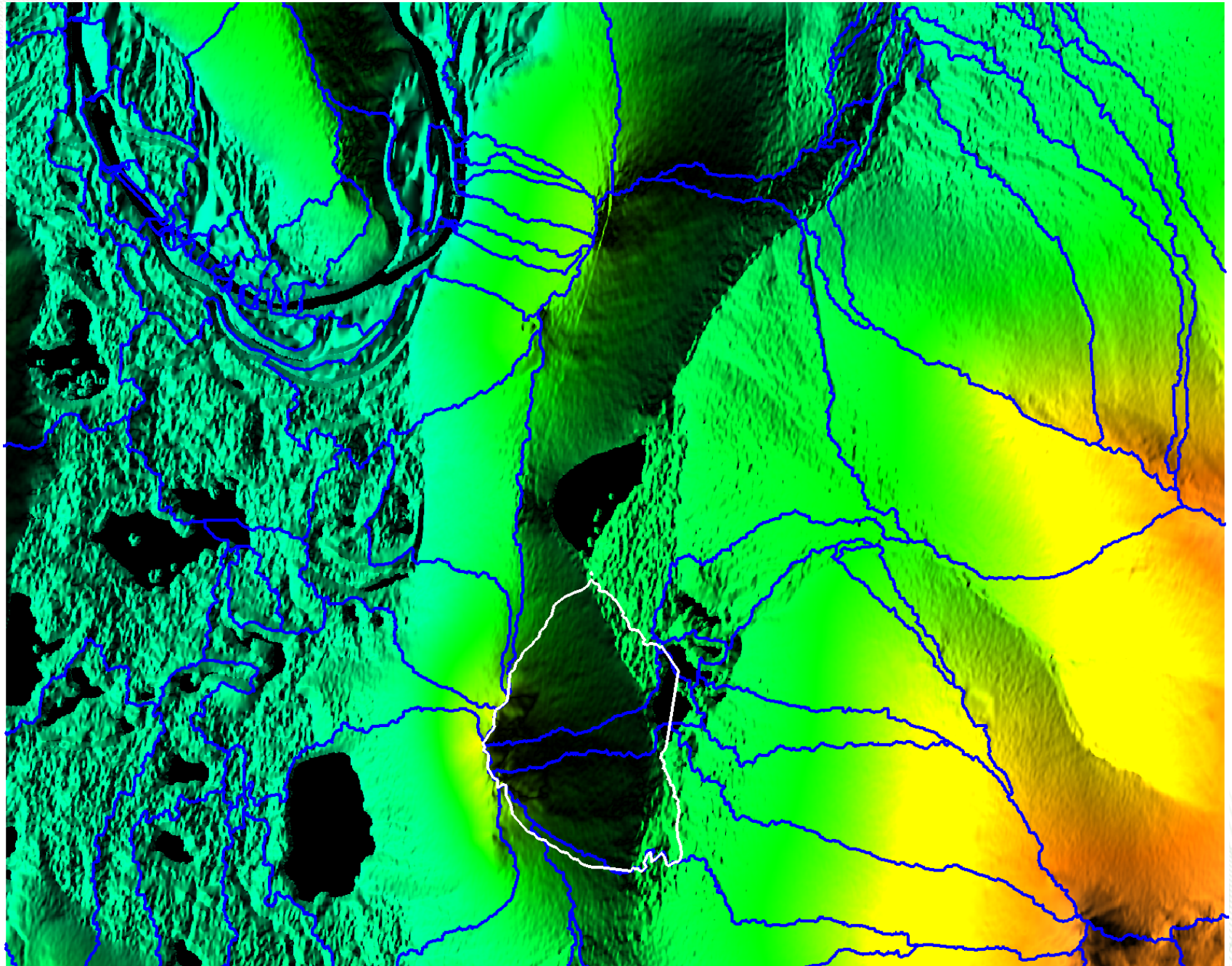


Hydrologic response of these watershed show similarities, and range of variability.

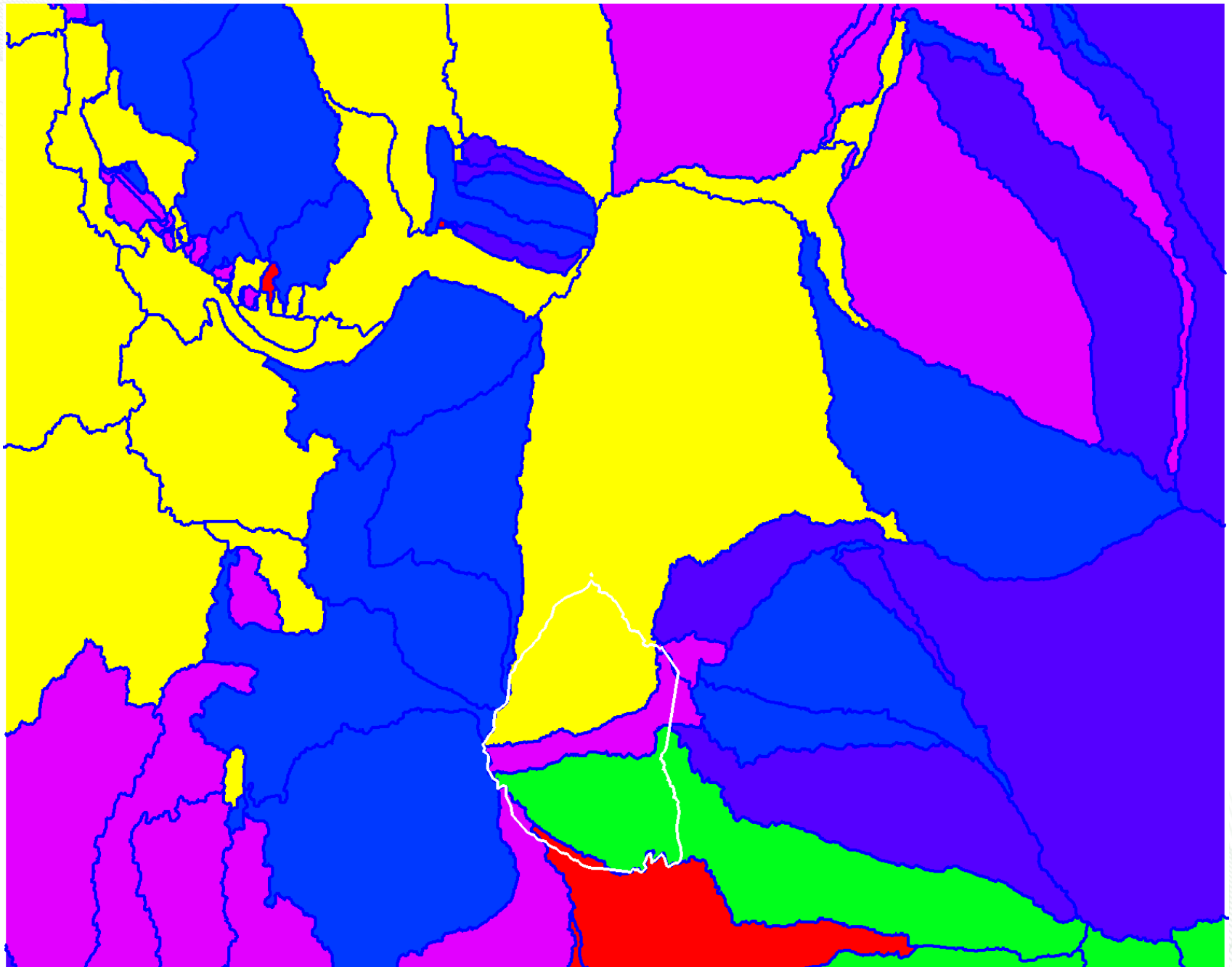
Scales matter!

Watersheds exhibit fractal behavior, and thus resolution and scales matter.

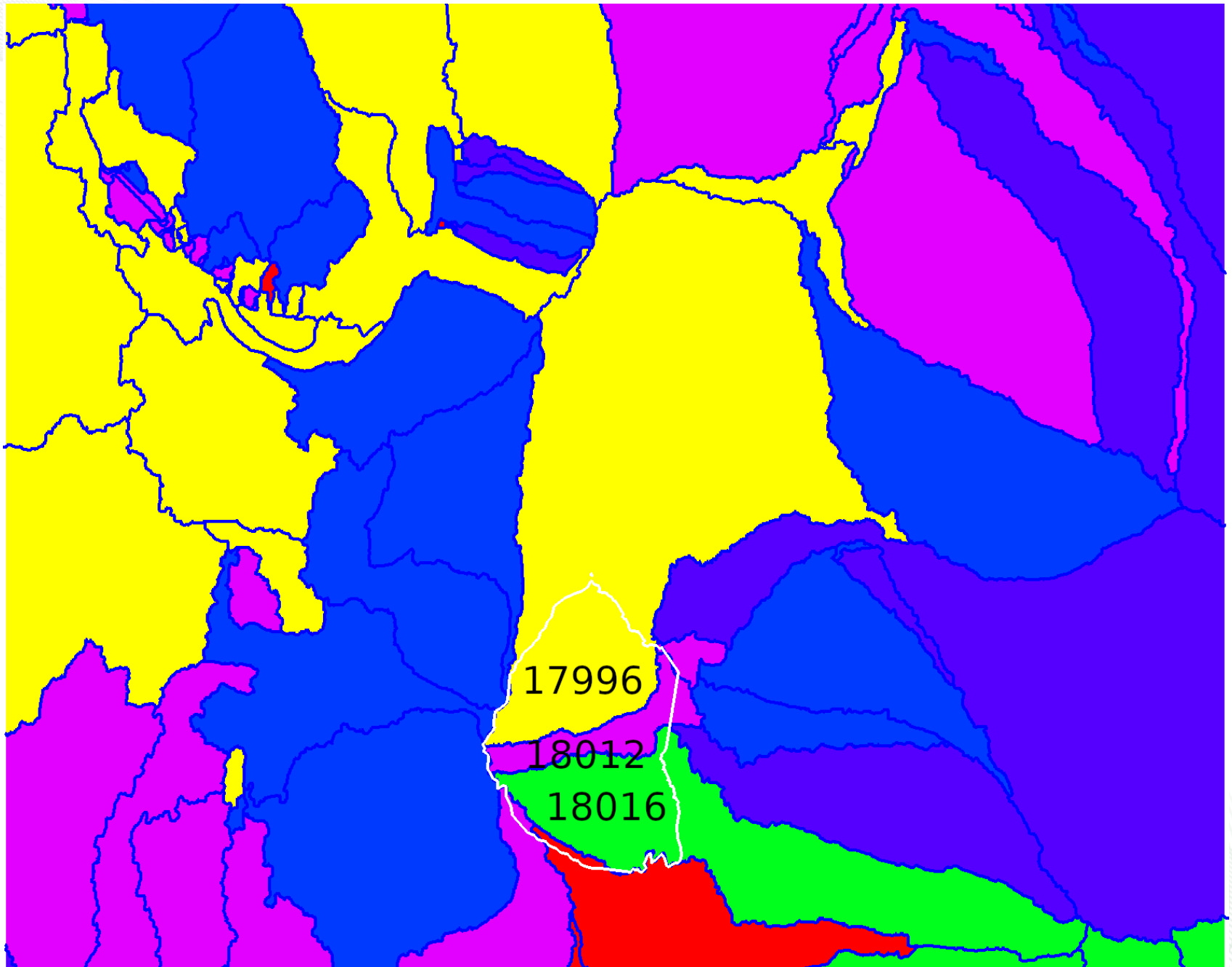
Kougarok Watershed: Hill shade map



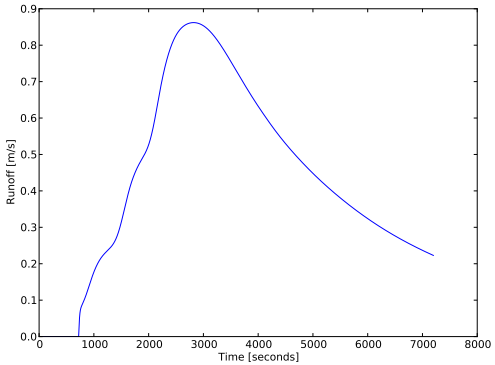
Kougarok Watershed: watershed classes



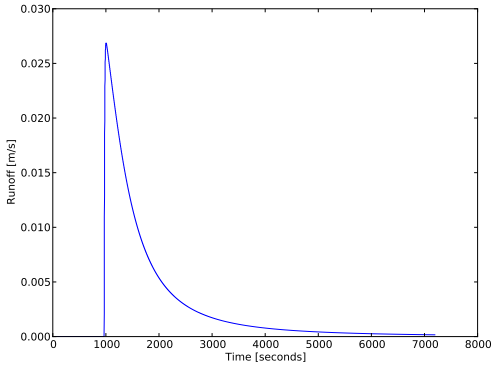
Kougarok Watershed: watershed classes



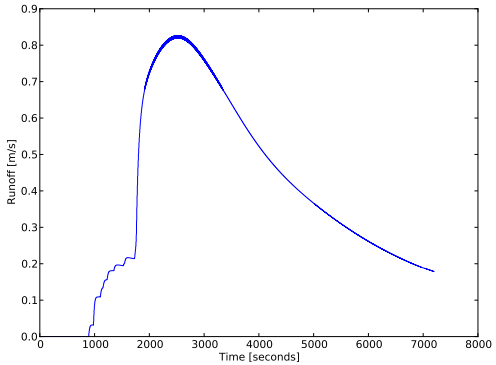
Hydrologic response of fine scale watersheds



17996: Hydrograph

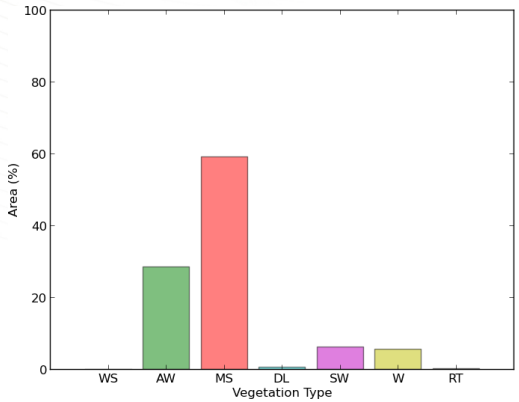


18012: Hydrograph

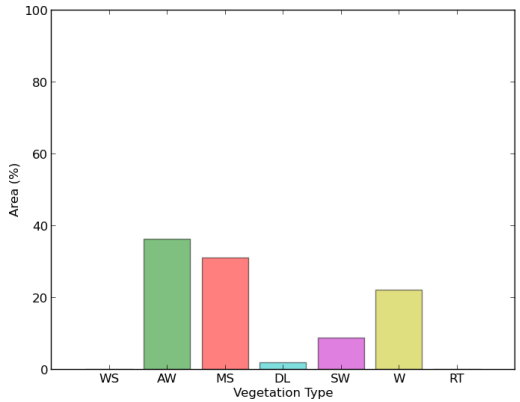


18016: Hydrograph

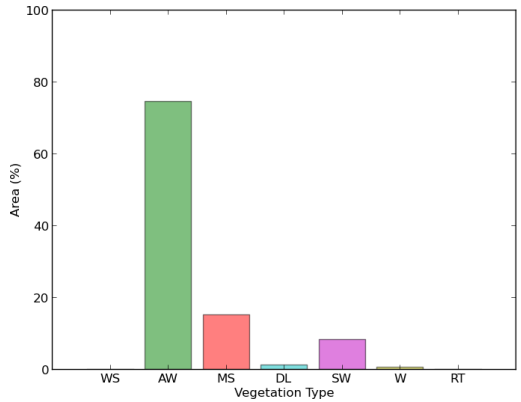
What vegetation distributions do they support?



17996: Vegetation distribution



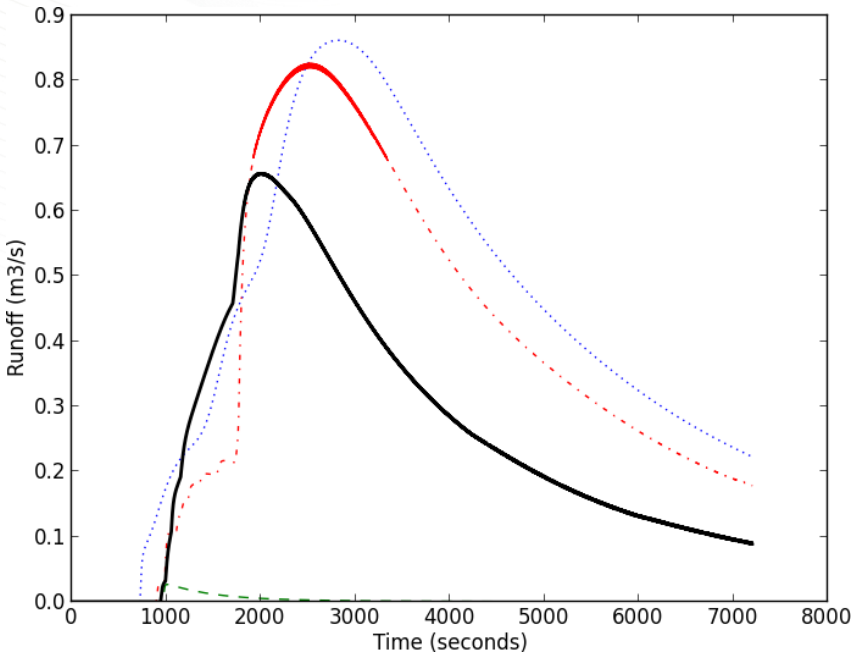
18012: Vegetation distribution



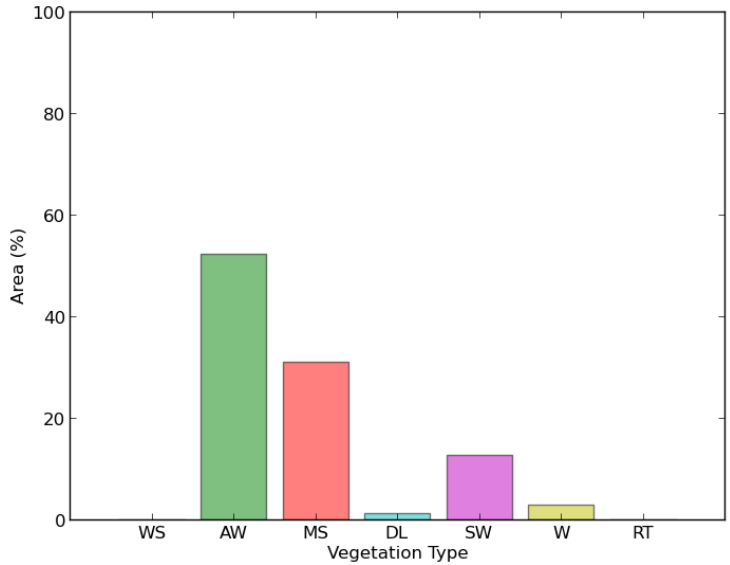
18016: Vegetation distribution

Remote sensing (SPOT5 + SAR) based vegetation map for Seward peninsula was used for this analysis. Extent of vegetation map was smaller than our study region of Southern Seward Peninsula, thus the vegetation statistics are based on common overlapping region only.

Moving up in scale to entire Kougarok watershed



Hydrologic response

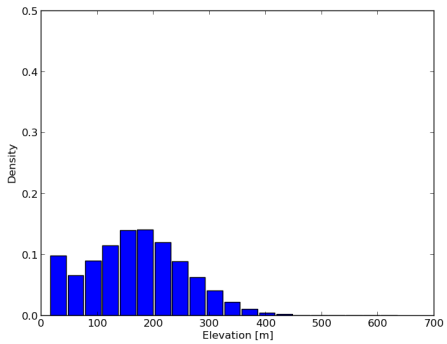


Vegetation distribution

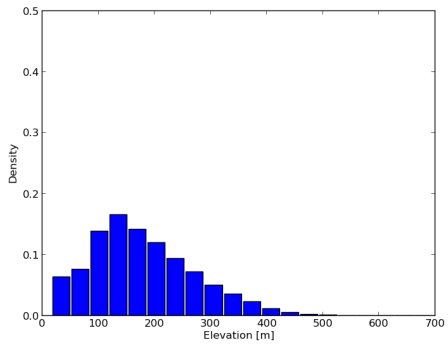
Watersheds are complex mosaics of multi-scale heterogenous properties and processes. Understanding these units at and across and scales can help us project/predict the ecohydrology of regions where direct observations are difficult (or impossible).

How does vegetation distribution vary across the landscape? Does the landscape characteristics help estimate vegetation distribution?

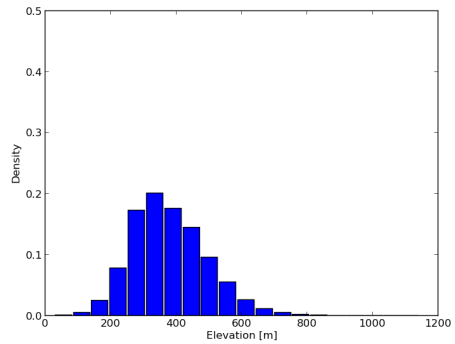
Vegetation distribution across topography



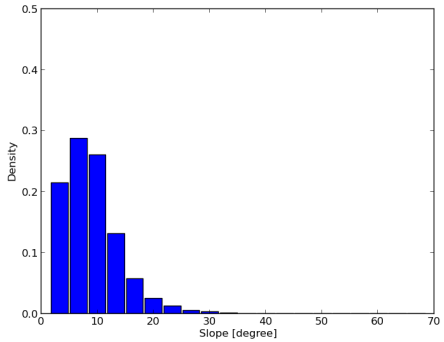
Alders & Willow



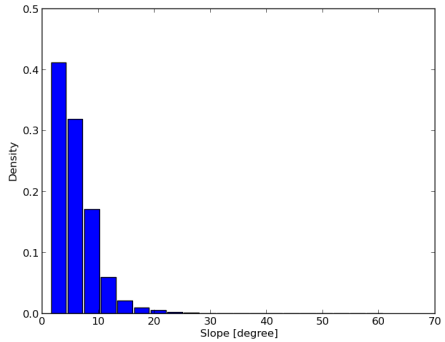
Mixed Shrub Sedge Tussock Tundra



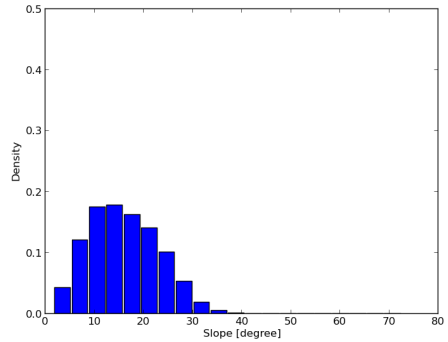
Dryas Lichen/Dwarf Shrub



Alders & Willow



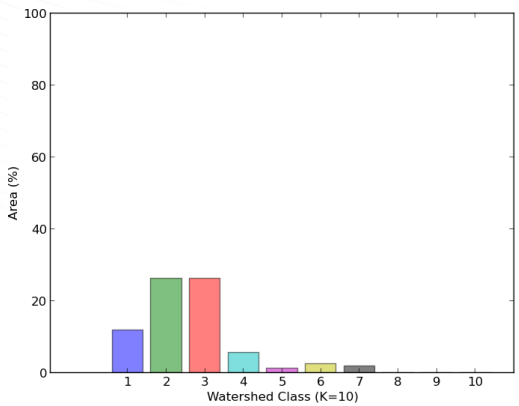
Mixed Shrub Sedge Tussock Tundra



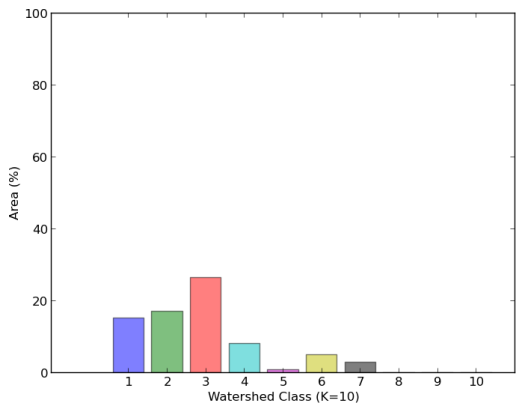
Dryas Lichen/Dwarf Shrub

Figure: How different vegetation types are distributed across topographic gradients

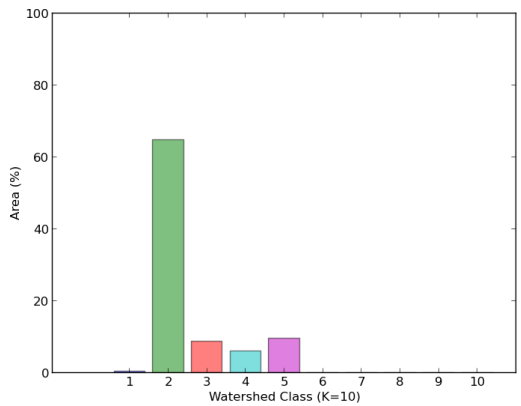
Vegetation distribution across watershed classes



Alders & Willow



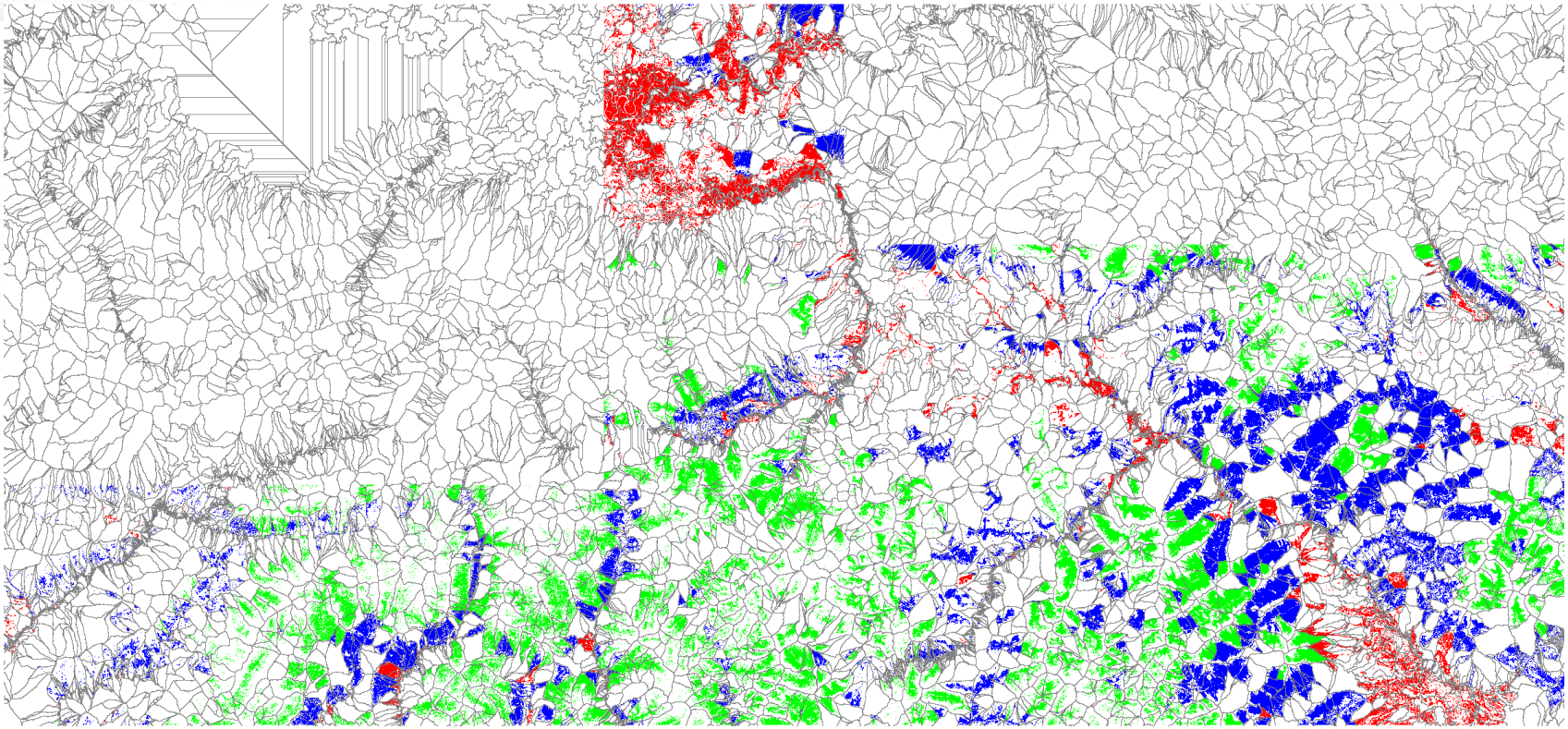
Mixed Shrub Sedge Tussock Tundra



Dryas Lichen/Dwarf Shrub

Figure: Distribution of vegetation types across watershed classes

Where do we find Alder-Willow?



Watershed Class	Elevation: Median	Slope: Median	Aspect: Median	Shape Index
1	49.090	1.444	189.435	1.865
2	304.777	11.491	191.648	2.025
3	124.982	4.906	255.978	2.348
4	282.225	3.434	159.942	2.058
5	515.046	22.263	189.543	2.037
6	50.407	1.475	175.392	1.597
7	114.044	5.995	110.654	2.172
8	49.695	1.375	64.014	1.791
9	91.416	14.026	186.153	1.860
10	54.452	1.842	297.256	1.617

1: RED; 2: GREEN; 3: BLUE

Effect of local scale hydrology on vegetation

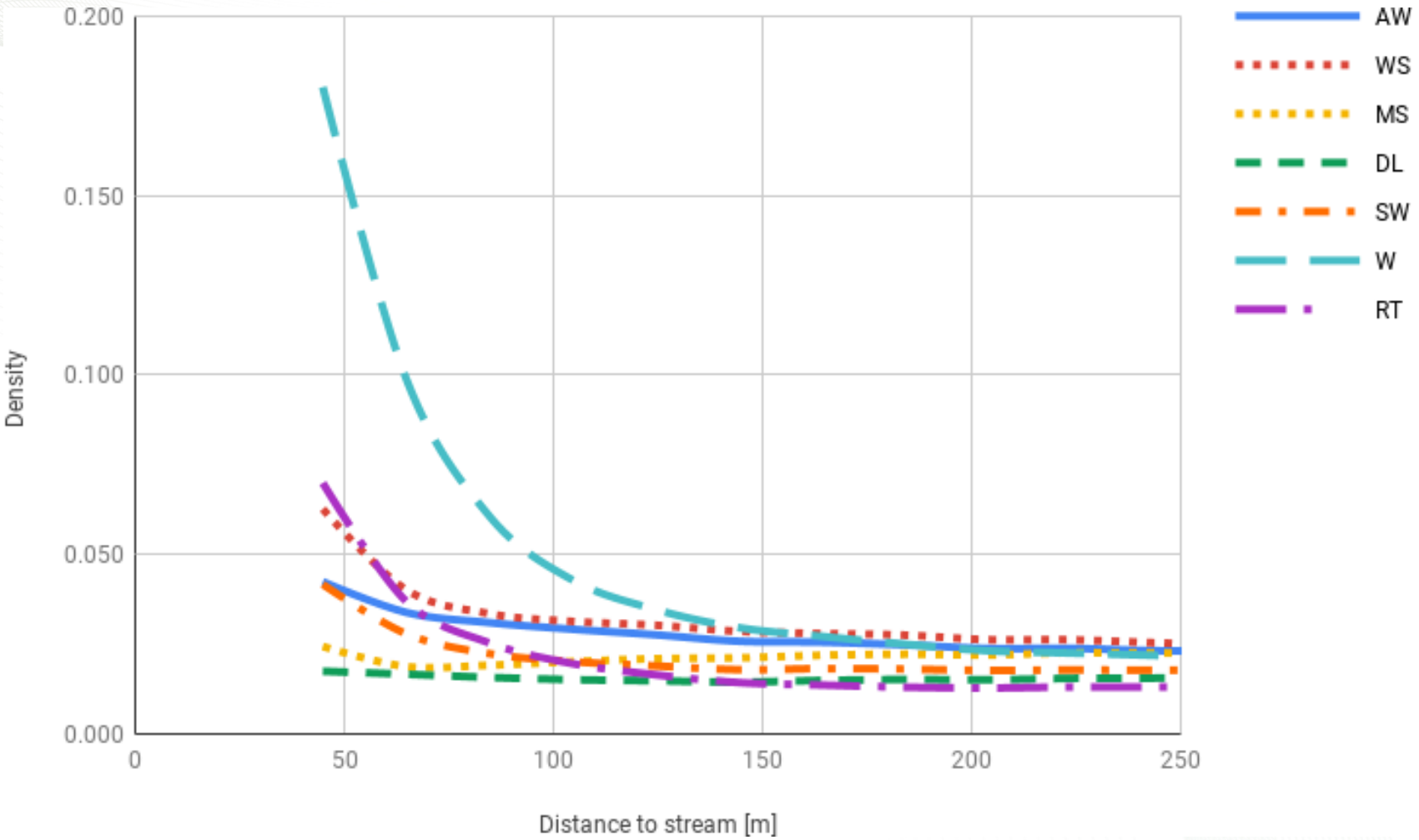


Figure: Influence of local hydrology, and wetness on vegetation abundance. Distance from streams is an indicator of vegetation abundance.

Effect of local scale hydrology on vegetation

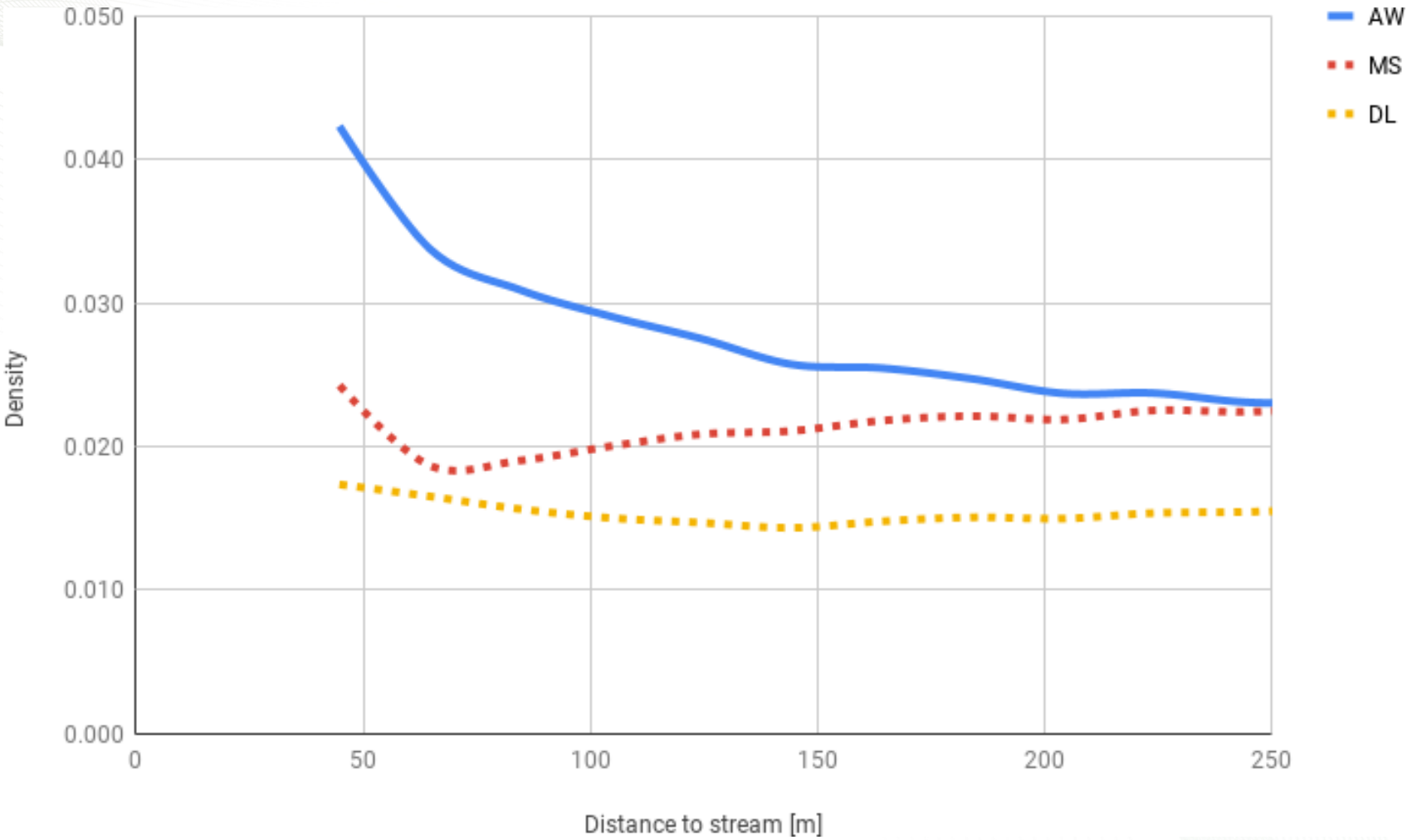
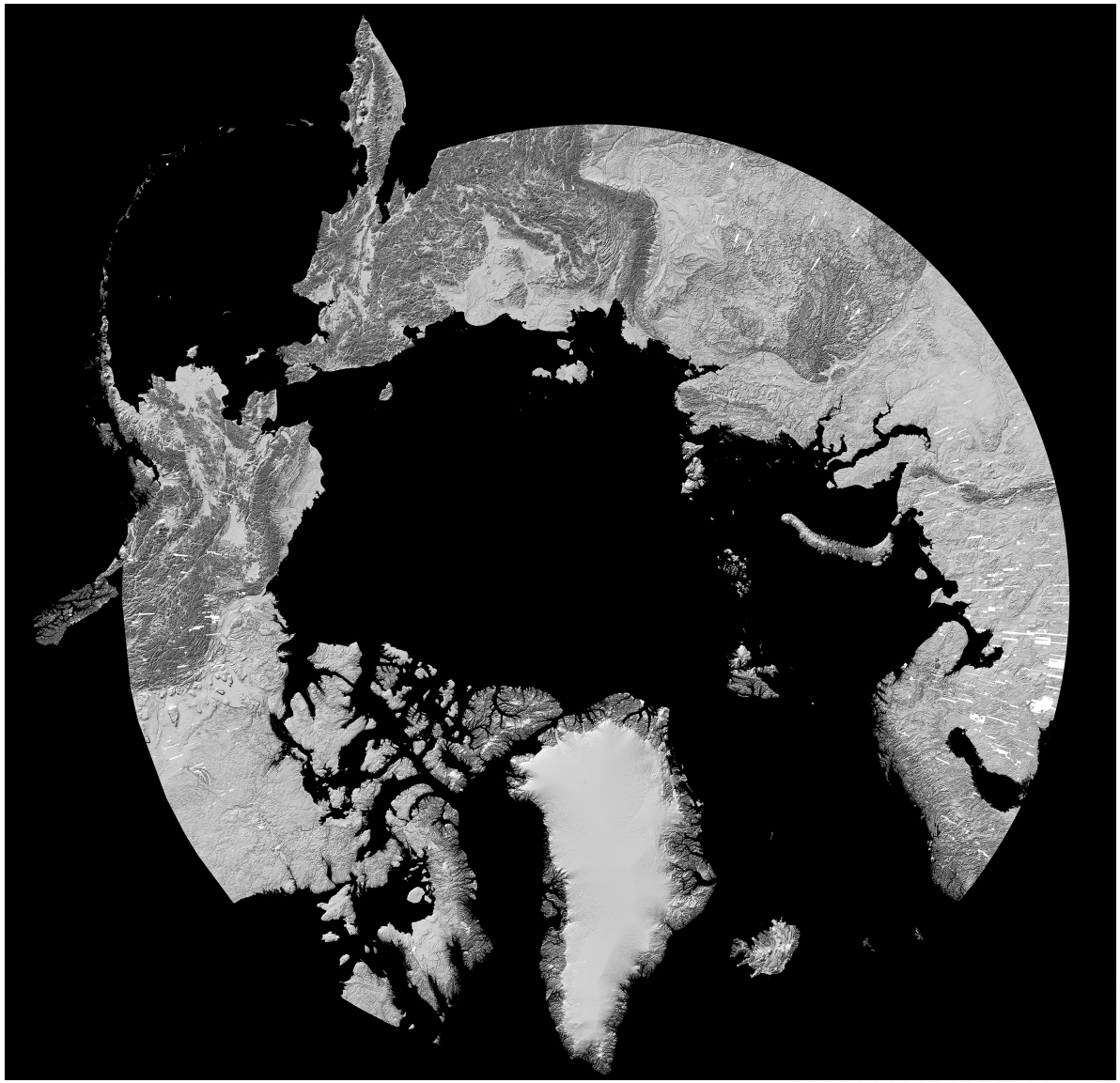


Figure: Influence of local hydrology, and wetness on vegetation abundance. Distance from streams is an indicator of vegetation abundance.

Summary

- Availability of high resolution digital elevation has enabled analysis of large scale landscape patterns.
- Landscape is moasic of heterogeneous properties and characterizing the building blocks across scale would allow us to expand understanding of ecohydroligical processes to remote regions of Arctic.
- Landscape characteristics show good predictablity to infer hydrological and ecological processes in complex terrain.
- In our continued work, we are adding range of soil and permafrost properties to improve our understanding of landscape controls.
- Analysis would provide key input for new class of global land surface models (like DOE E3SM) that use watershed as grid units characterized by topography.



New datasets like "Arctic DEM" allows opportunity for Pan-Arctic analysis.

Thanks for your attention!

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