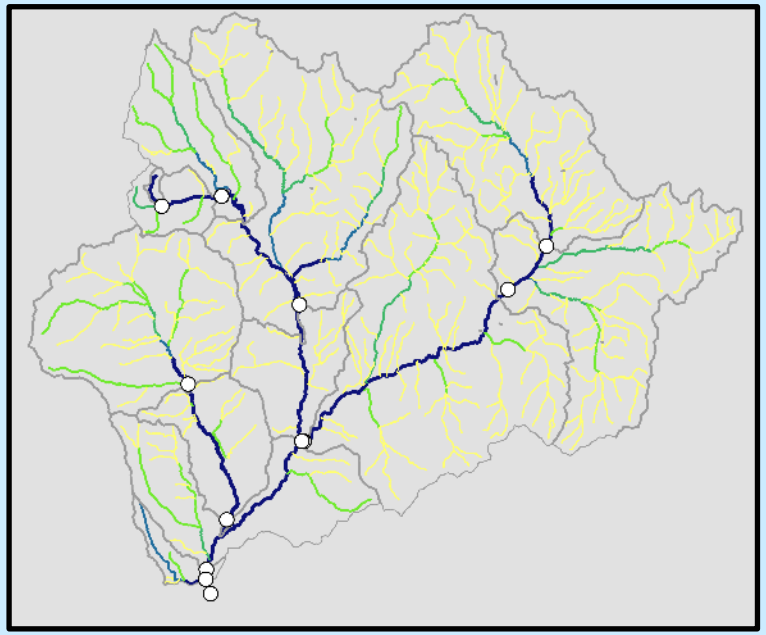

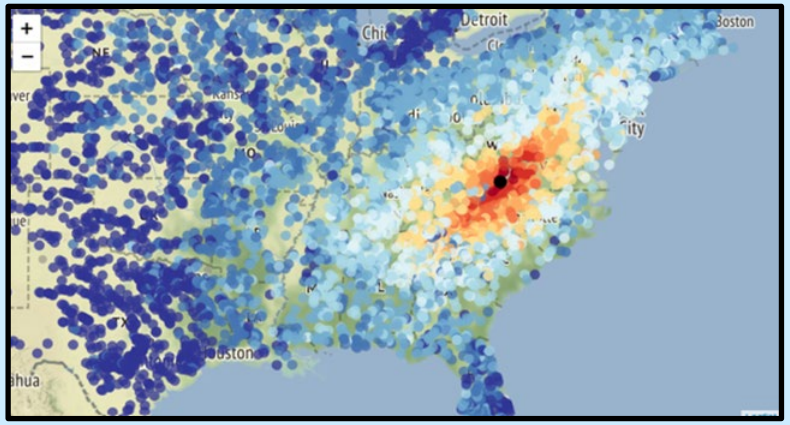

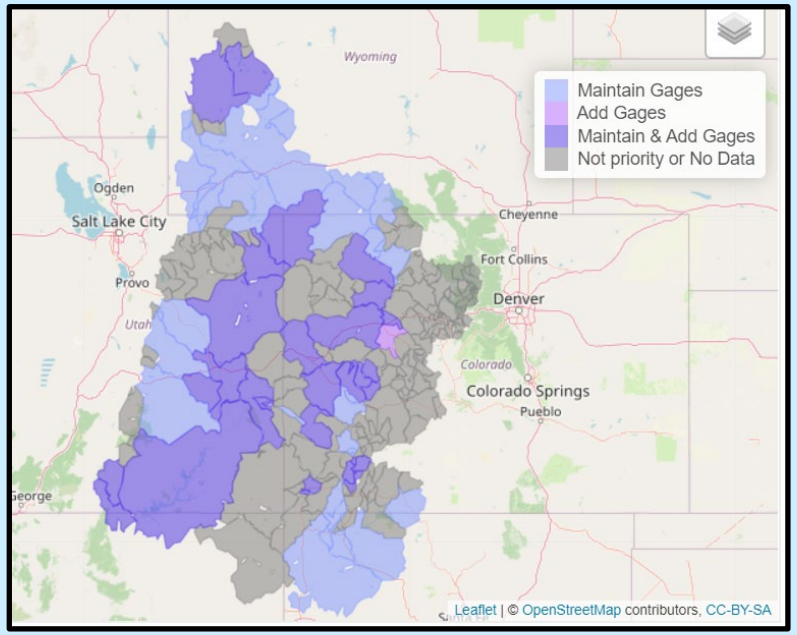

Coverage, Resolution and Representation of National Interests by the USGS Streamflow Monitoring Network

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Background

The USGS streamflow monitoring network provides information about water availability and hazards for many different users.

Sites are typically established and operated for local information needs, but the network must serve national interests.

USGS network analyses include Langbein,1954; Benson and Carter, 1973; Ficke and Hawkinson, 1975; Gilbert and Buchanan,1982; Thomas and Wahl,1993; USGS, 1998; Taylor and Alley, 2001; Landfear 2005; ACWII Subcommittee on Water, 2013, and Kiang and others 2013.

The current project expands the scope of USGS network analysis to the coverage, resolution, and representation of a broad set of national interests.

USGS Streamflow Gage on the Colorado River at Lee's Ferry, AZ

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Network Analysis Project Components

1. Gap Analysis

Objective: evaluate the network's coverage, resolution, and representation (CRR) of streamflow, material loads, (anthro-)physical controls, and administrative designations of land and water bodies.

Results: metrics of CCR for each of 41 variables and priority areas for maintaining or adding monitoring sites at national and river-basin (HUC4) scales for each variable (Konrad and others, 2021, https://doi.org/10.5066/P9TYCQGD).

2. Information-Transfer Analysis (Cross-Site Correlation)

Objective: identify the factors (precipitation, air temperature,....) that control the strength of cross-site correlation in streamflow and water temperature and develop models that can be used to estimate the strength of correlation between any pair of sites.

Results will inform three common questions: where is the best available gage(s) to estimate design flows for infrastructure planning at any ungaged site; 2) where is "best available" gage not very good and would benefit from additional gaging; 3) where are there alternative "best available" gages that could be used if a gage is discontinued.

How Current Project Advances USGS Network Analysis

- **Spatial framework extends across the US,** using the National Hydrography Dataset (NHD) for the 48 states of the contiguous United States (CONUS) and 12-digit hydrologic unit code (HUC12) watersheds for non-CONUS (AK, HI, Puerto Rico and other territories).
- **Coverage, resolution, and representation of the network are analyzed** for 41 variables of national interest including climate and land use per recommendation by the National Academy of Sciences (2018).
- **Variables are calculated for incremental gaged areas (IGAs),** which implements a recommendation by the National Research Council (2004).
- **Automated workflow implemented in the open-source, statistical programming language R that can be repeated** for any network of sites and expanded to include other datasets.

Workflow

Step 1. Define Spatial Framework >> 8000+ incremental gaged area (IGAs) for streamflow gages active in water year 2020 with their associated river segments based on the National Hydrography Dataset (NHD) for the contiguous United States (CONUS) and 12-digit hydrologic accounting units (HUC12) for non-CONUS areas.

Step 2. Assimilate Available Data >> 41 publicly available, georeferenced, national data sets with variables relevant to national interests in streamflow information including streamflow, loads of dissolved and suspended materials, their (anthro-)physical controls (climate, land cover), and administrative designations of rivers and streams. Values aggregated for each IGA and HUC12.

Step 3. Calculate Network Metrics >> 3 metrics of network coverage, resolution, and representation of each variable for US and each major river basin (4-digt hydrologic unit code or HUC4).

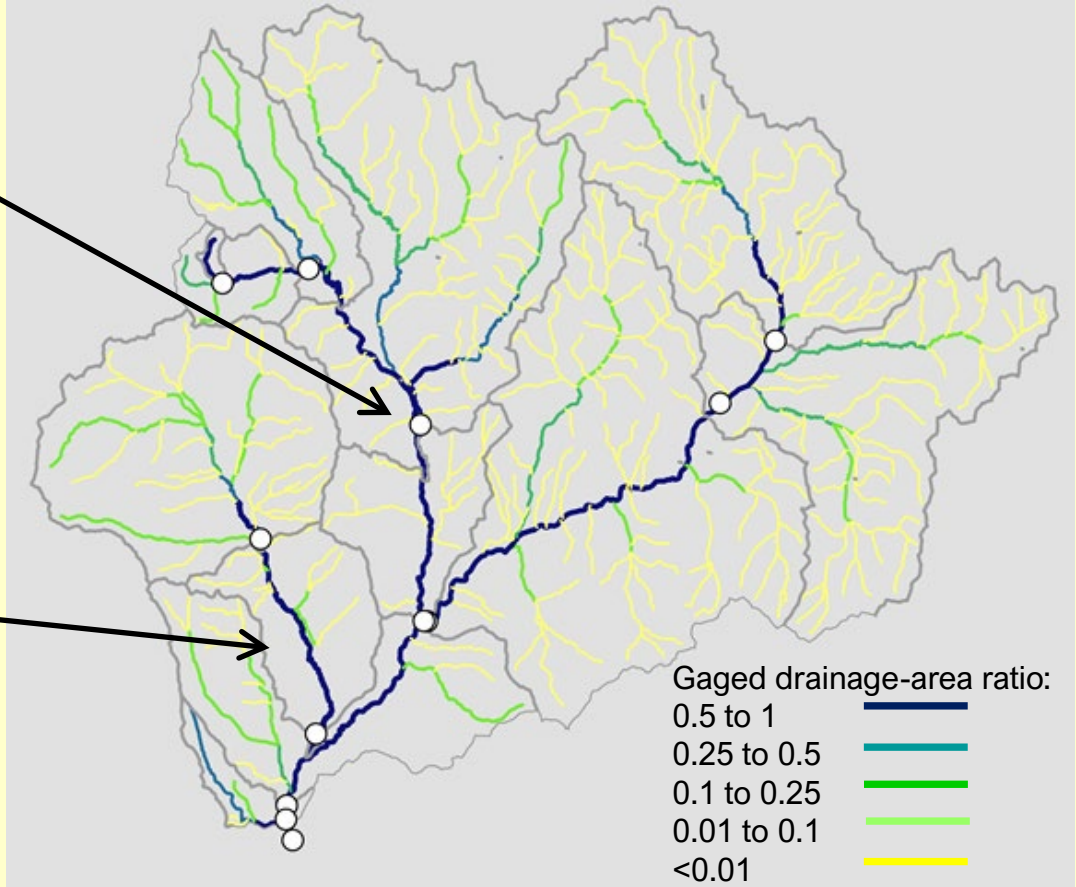
Step 4. Designate Priority Areas >> Standardized criteria are applied to the cumulative distribution of each variable to identify areas where maintaining or adding monitoring sites will support network coverage, resolution, and representation at national and HUC4 scales: *1.3 million priority designations in total (8000+ IGAs x 41 variables x 2 scales x 2 types of priorities)*

Spatial Framework

Network: 8000+ gages that were operated by USGS for at least 60 days during water year 2020 are assigned either to stream segments in the medium resolution (1:100,000) National Hydrography Dataset (NHD) for CONUS areas or 12-digit hydrologic unit code watersheds (HUC12) for non-CONUS areas.

Only one gage per NHD segment (CONUS) or per HUC12 (non-CONUS) is retained for the network in the analysis.

Incremental Gaged Areas: the drainage areas between gages or upstream of headwater gage are delineated using NHD catchments (CONUS) or HUC12s (non-CONUS). NHD catchments and HUC12s are assigned to IGAs or are classified as ungaged.



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Workflow Step 1: Spatial Framework

Variables in Network Analysis

Water Balance, Flood Hazard, Water Availability

- Mean annual precipitation volume
- Mean annual evapo- transpiration
- Median annual streamflow
- Median annual maximum streamflow
- Median annual minimum streamflow
- Volume of withdrawals
- Fraction of time with no flow

Hydrologic Responses to Climate

- Climate Divisions
- Coastal Rivers and Streams
- Minimum Temperature <0° C

Water Quality

- Length of stream segments listed as impaired for water quality under the Clean Water Act Section 303d
- Count of major NPDES discharges
- Total dissolved solid load
- Total suspended sediment load
- Total nitrogen load
- Total phosphorous load

Ecological Integrity

- Ecoregion Level III
- Undeveloped area
- Wilderness
- Wild and Scenic Rivers
- Reservoir Storage

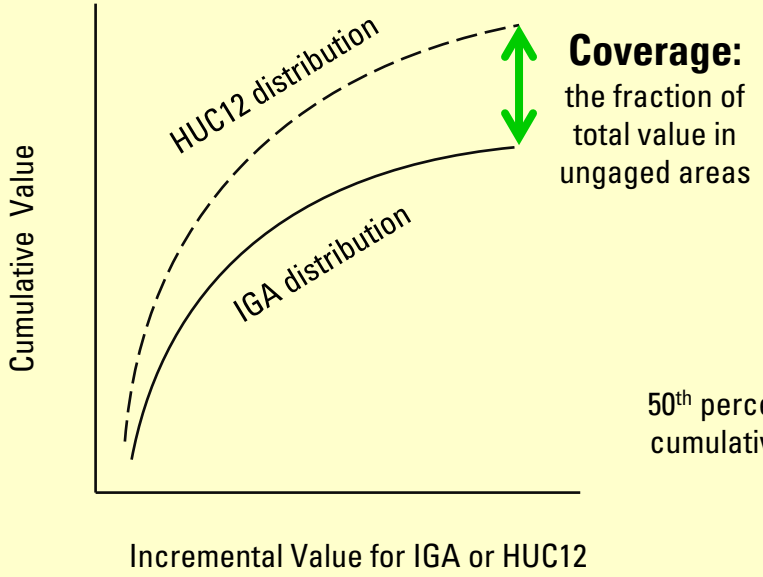
Federal and Tribal Land Management

- Bureau of Land Management
- Department of Defense
- Department of Energy
- Forest Service
- National Park Service
- Fish and Wildlife Service
- Native American

Land Cover

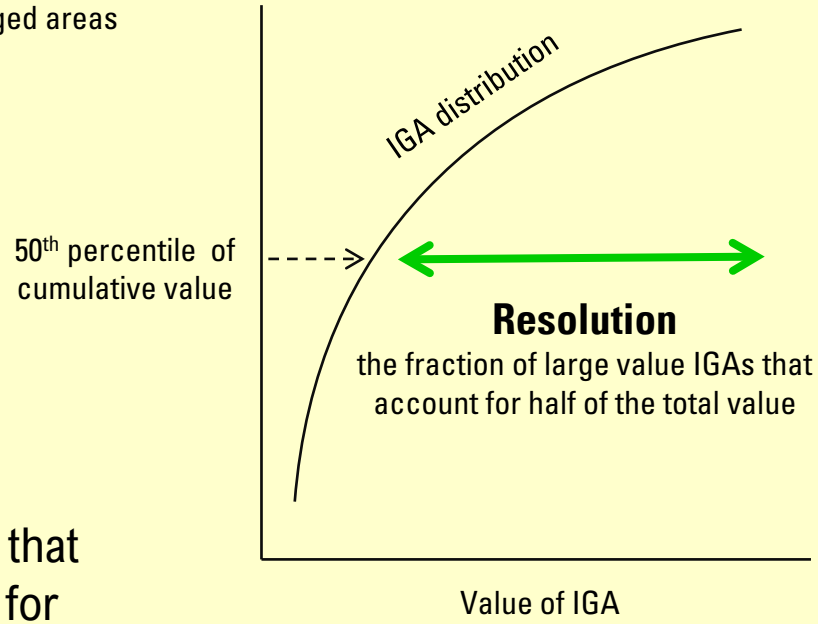
- Barren
- Cultivated
- Developed High
- Developed Low and Medium
- Developed Open
- Forest
- Grass
- Pasture
- Shrub
- Snow/Ice
- Water
- Wetland

Metrics of Coverage, Resolution, and Representation



Coverage

Fraction of total value of a variable that is in gaged areas; only calculated for spatially continuous data that are available outside of gaged areas (not streamflow or loads)

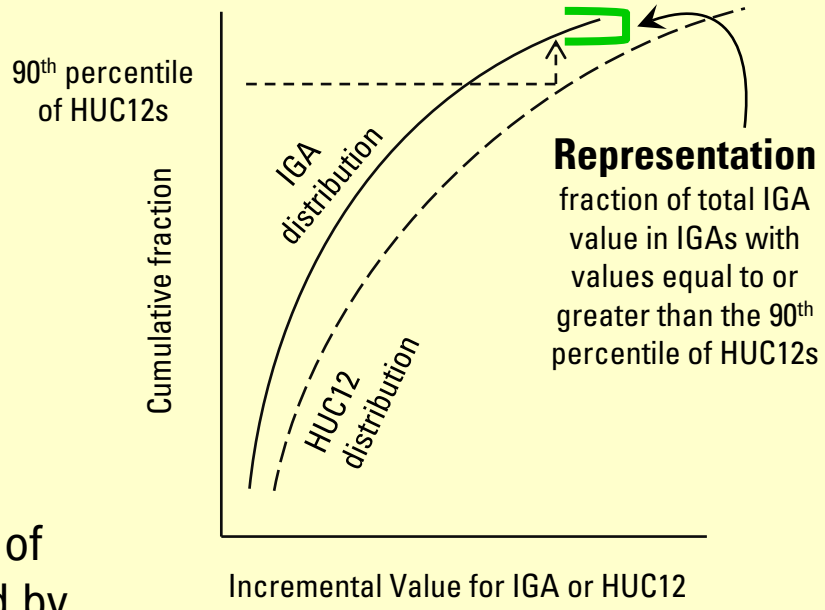


Resolution

Fraction of IGAs comprising the upper half of the cumulative IGA distribution; standardized by the number of IGAs (increasing the number of IGAs does not necessarily increase resolution)

Representation

Fraction of total gaged value of variable that is in IGAs in the upper 90th percentile of HUC12s; indicates the relative contribution of "high-value" IGAs in the network; it can only be calculated for spatially continuous variables (not streamflow or loads)



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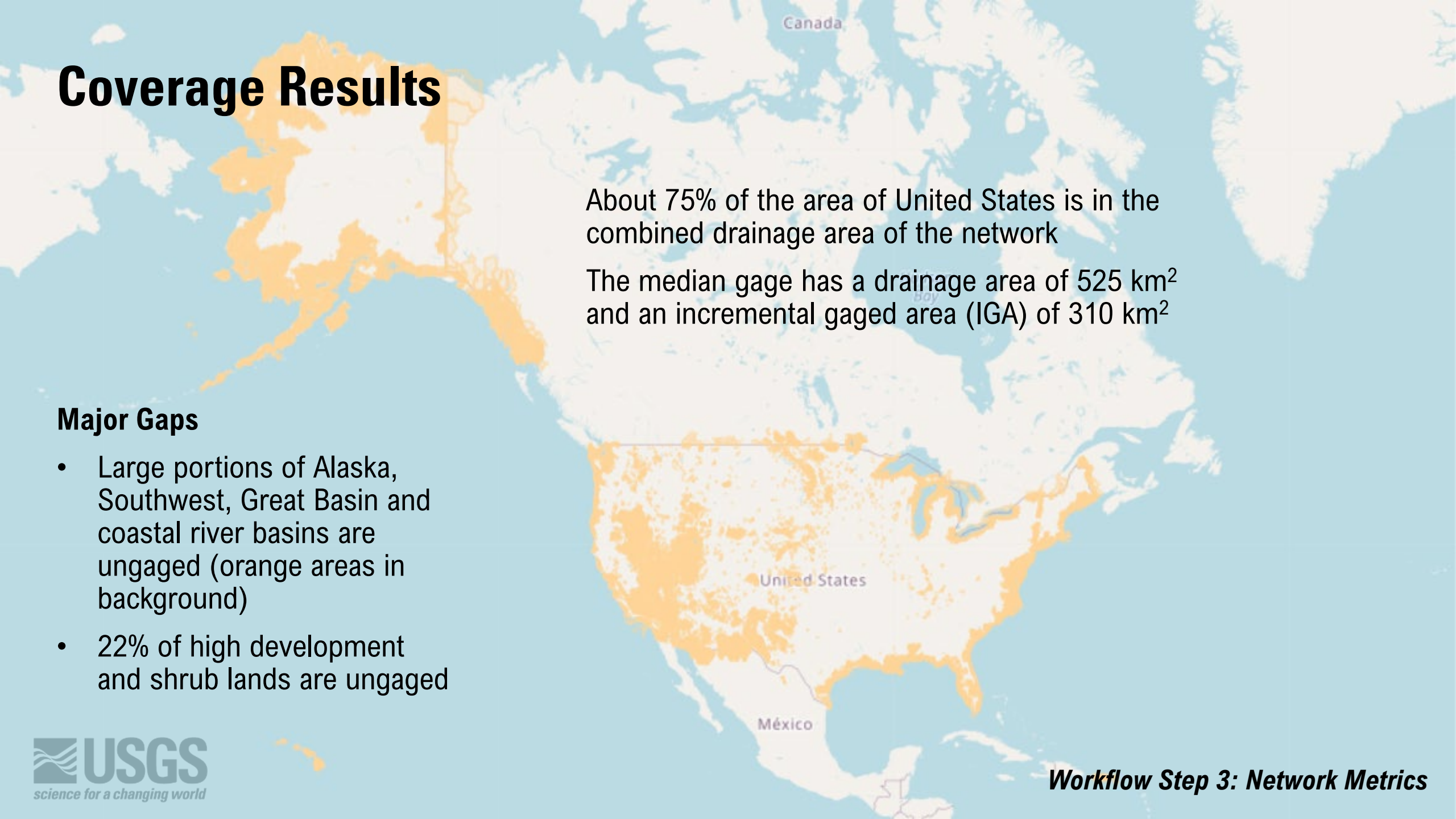
Workflow Step 3: Network Metrics

Coverage Results



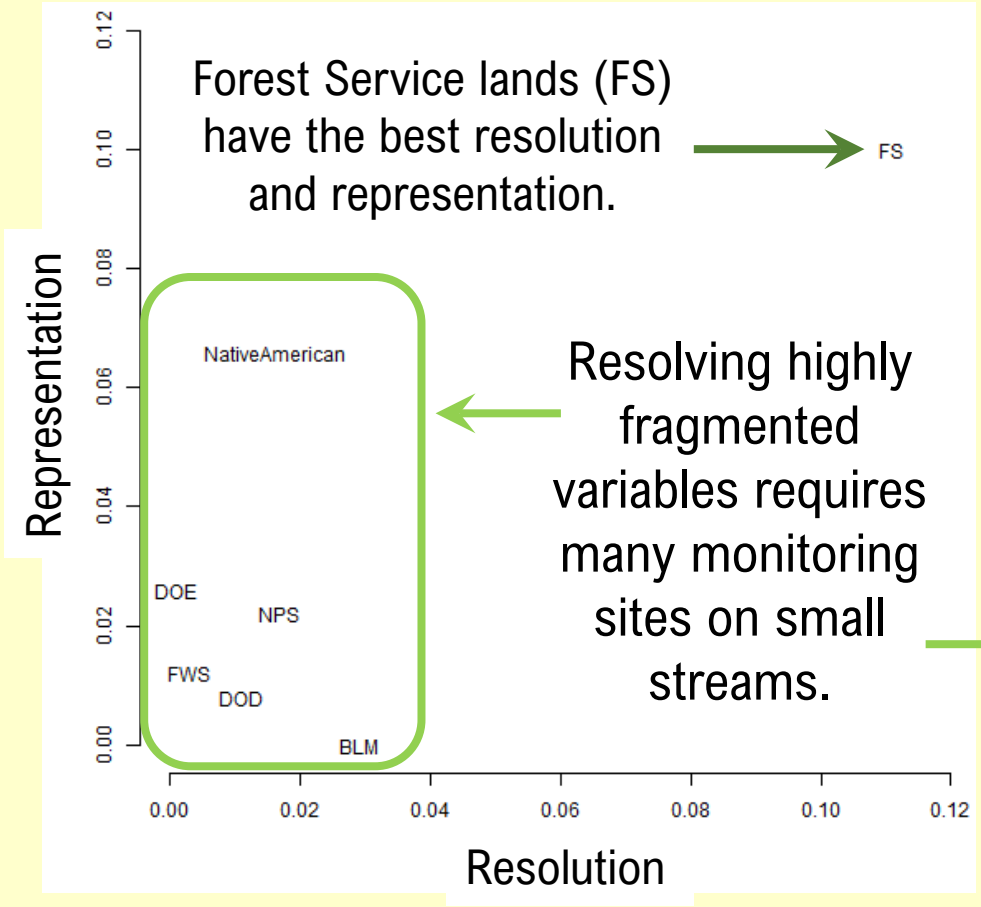
About 75% of the area of United States is in the combined drainage area of the network

The median gage has a drainage area of 525 km^2 and an incremental gaged area (IGA) of 310 km^2

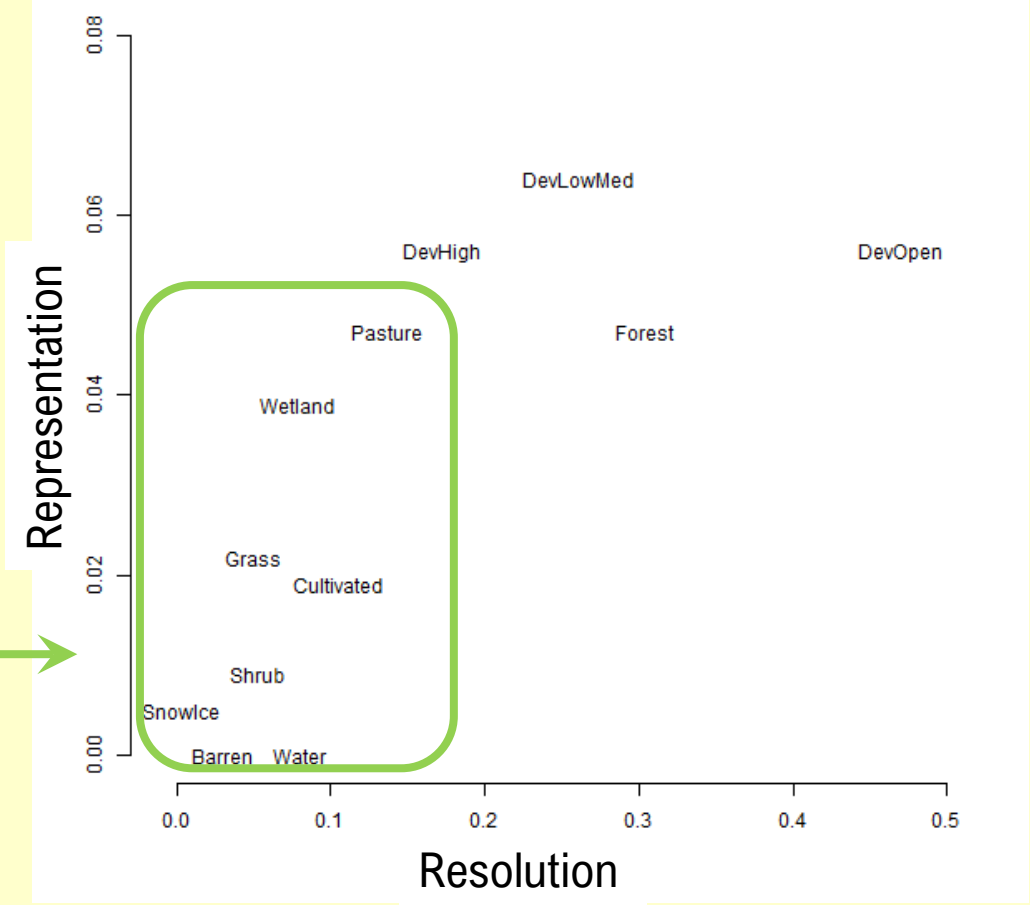
Major Gaps

- Large portions of Alaska, Southwest, Great Basin and coastal river basins are ungaged (orange areas in background)
- 22% of high development and shrub lands are ungaged

Network Metrics for Resolution and Representation of Land Management and Land Cover



Resolving highly fragmented variables requires many monitoring sites on small streams.



Federal and Tribal Land Management

Land Cover

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Workflow Step 3: Network Metrics

Resolution of Streamflow

Lowest resolution for minimum streamflow: 0.2% of IGAs account for 50% of total low flows (resolution metric)

Medium resolution for mean streamflow: 2% of IGAs

Highest resolution for maximum streamflow: 7% of IGA

Low-flow resolution of the network could be improved through synoptic, low-flow measurements without new gages.

(*Median annual incremental daily values*)

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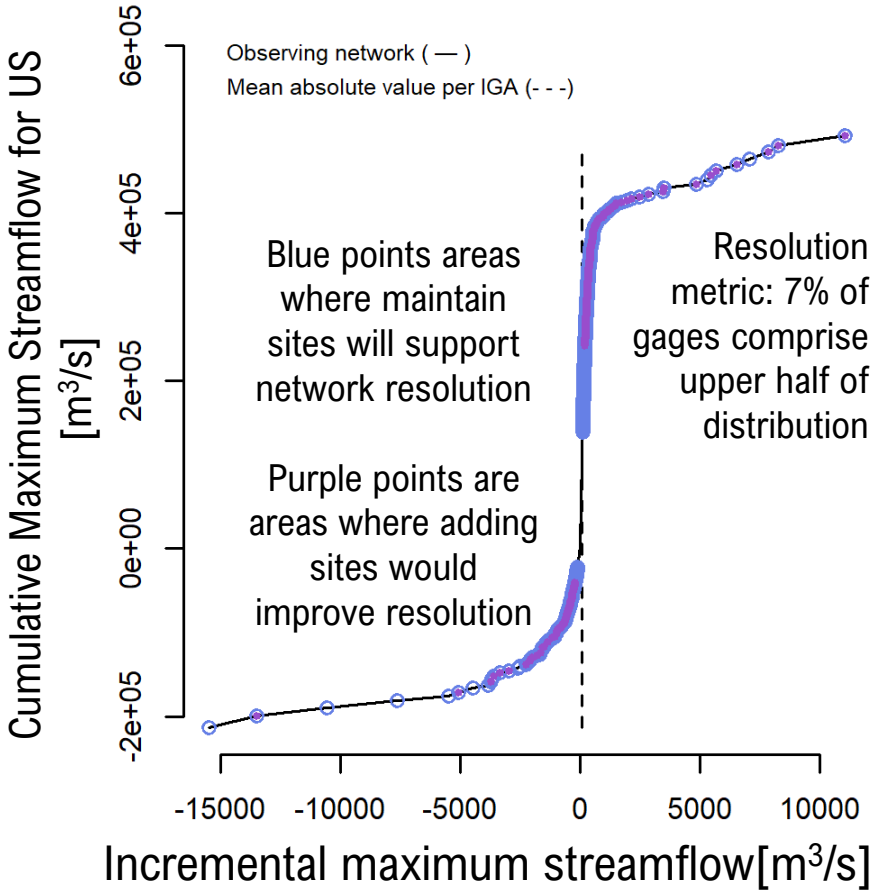
Comparison of Network Resolution of Maximum and Minimum Streamflow for the United States



1701 IGAs are priorities for maintaining sites

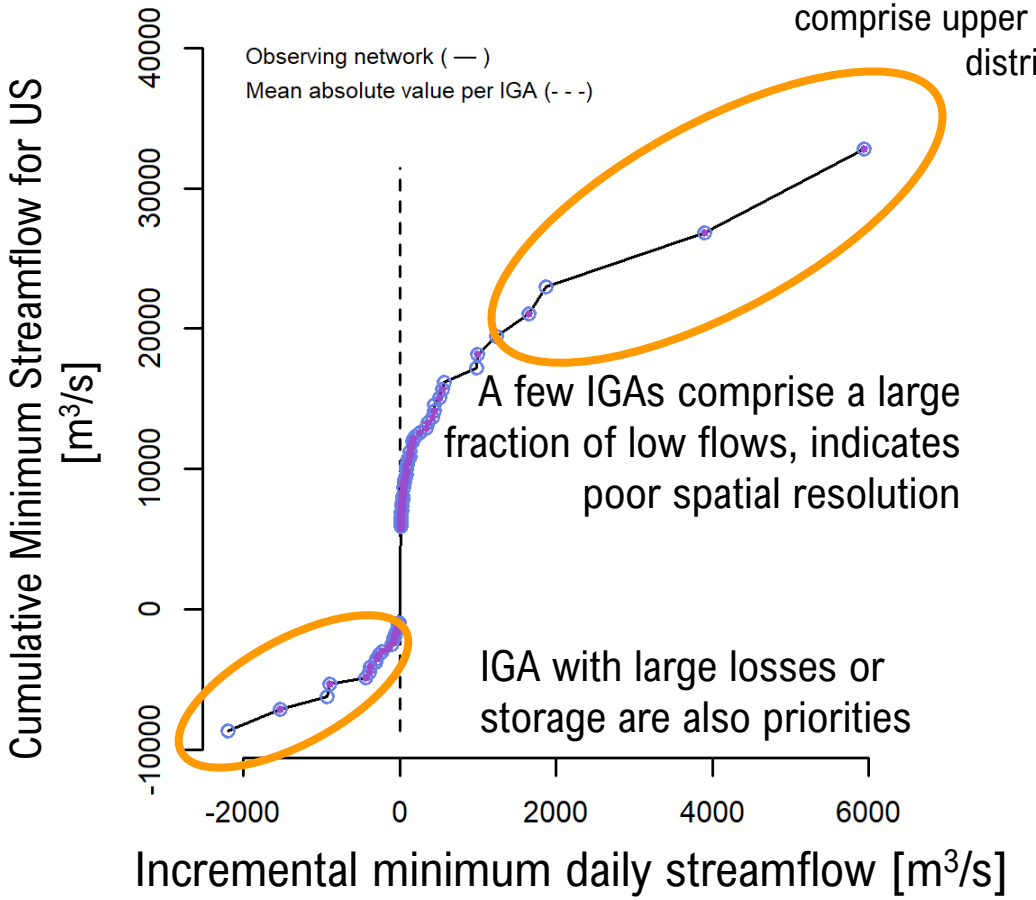
IGA value is greater or equal to than 50th percentile of cumulative distribution (106 M3.S)

or has less than 5 years of record and is upstream of an IGA meeting the criteria

562 IGAs are priorites for adding sites

where IGA absolute value is greater than 2 x mean absolute IGA value (204 M3.S)

Resolution metric: 0.2% of gages comprise upper half of distribution



170 IGAs are priorities for maintaining sites

IGA value is greater or equal to than 50th percentile of cumulative distribution (168 M3.S)

or has less than 5 years of record and is upstream of an IGA meeting the criteria

199 IGAs are priorites for adding sites

where IGA absolute value is greater than 2 x mean absolute IGA value (12.3 M3.S)

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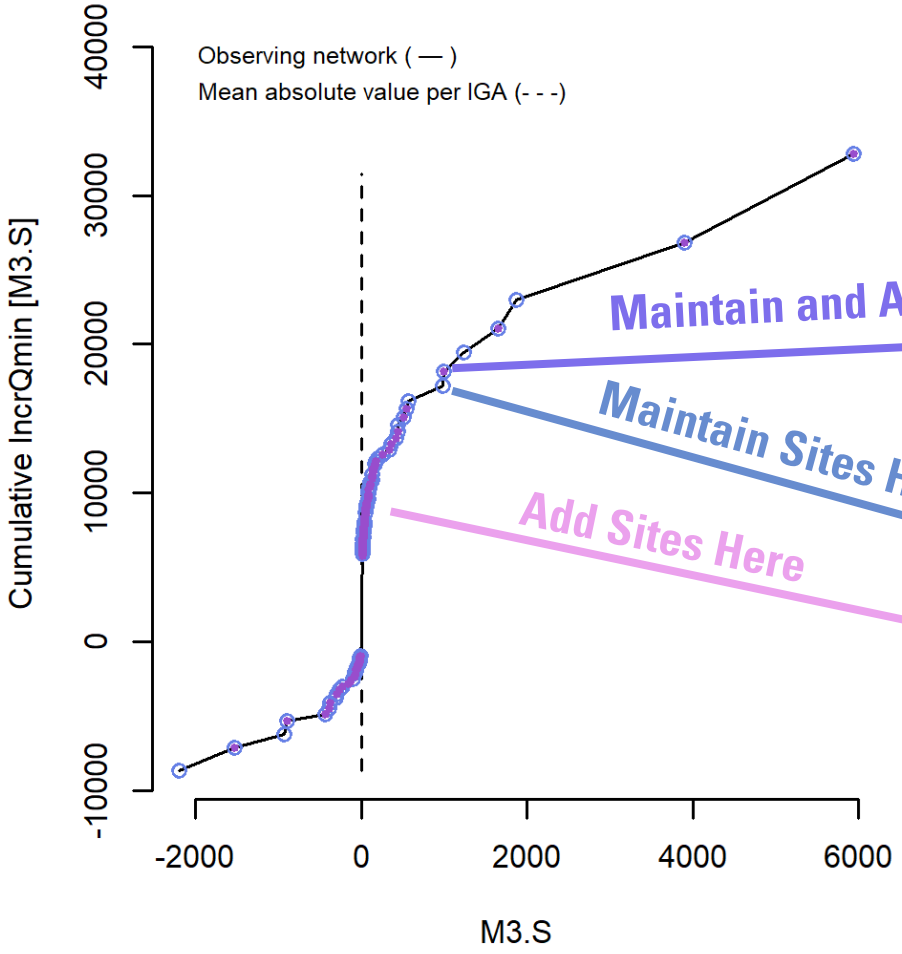
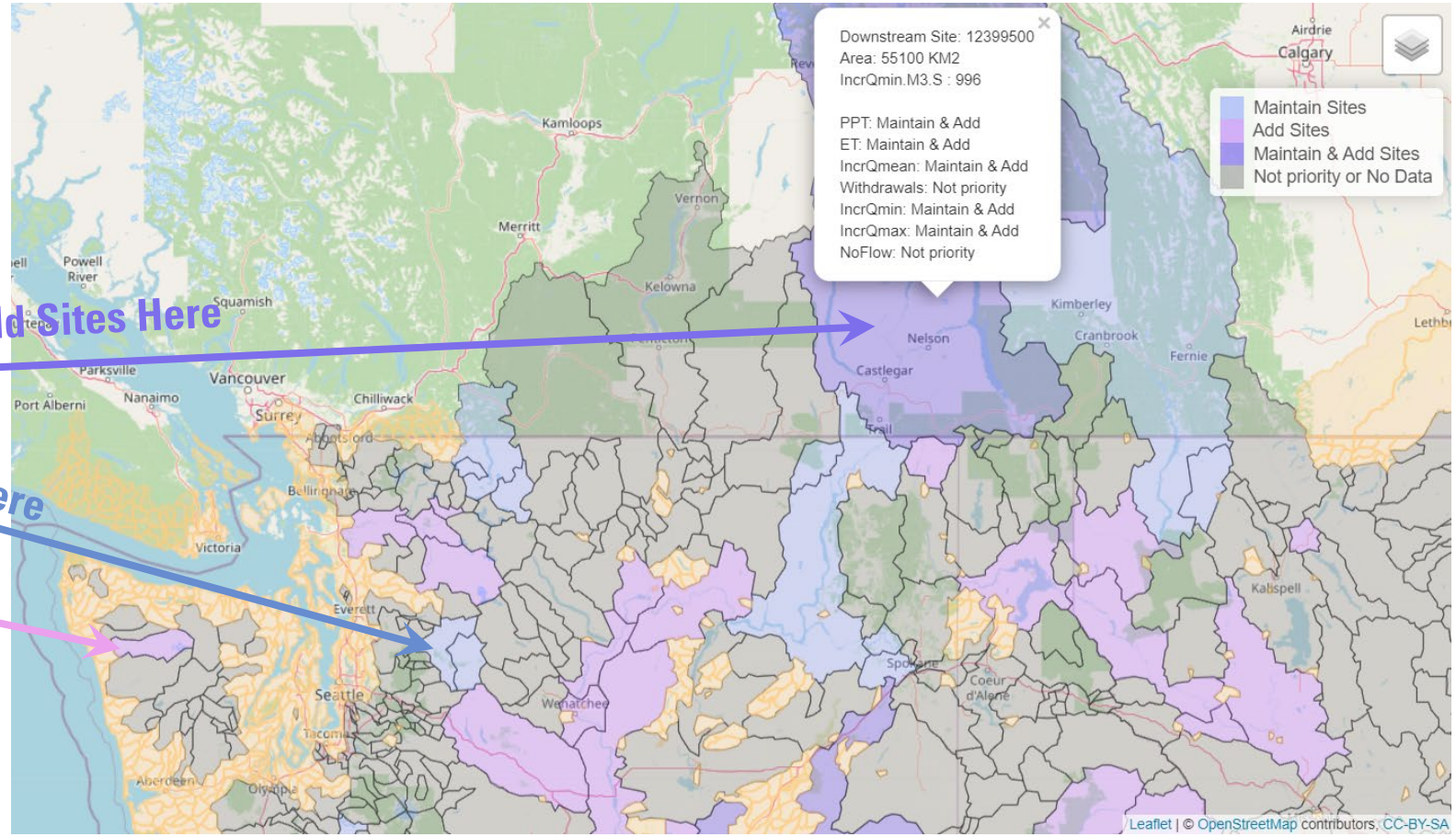
Mapping Priority Areas for Monitoring Low Flows





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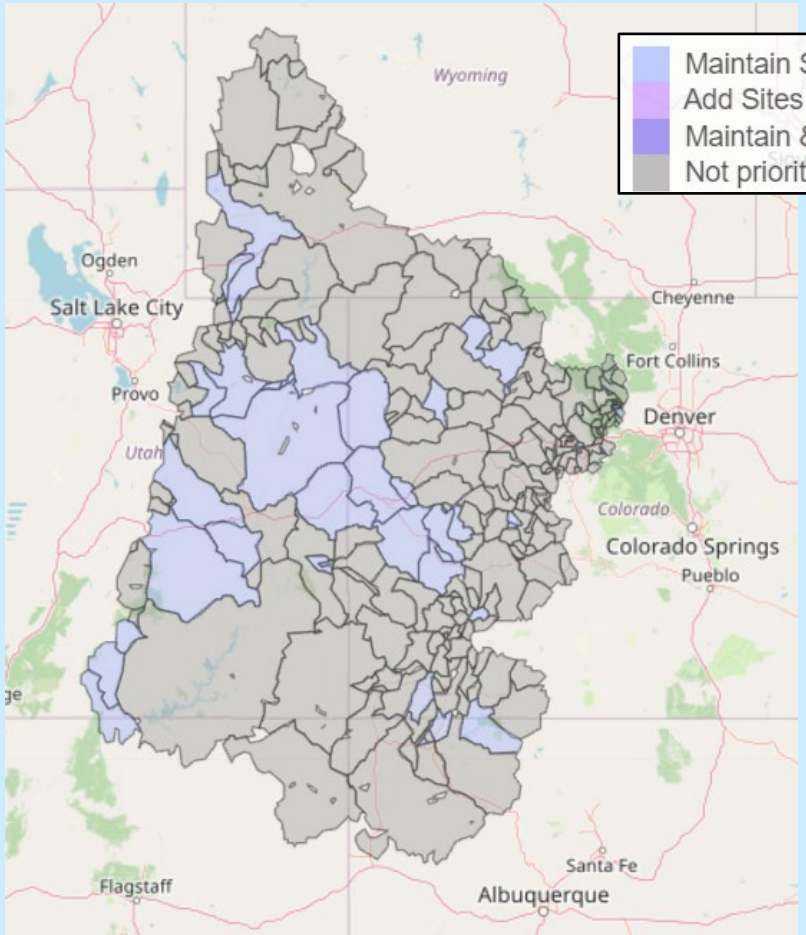
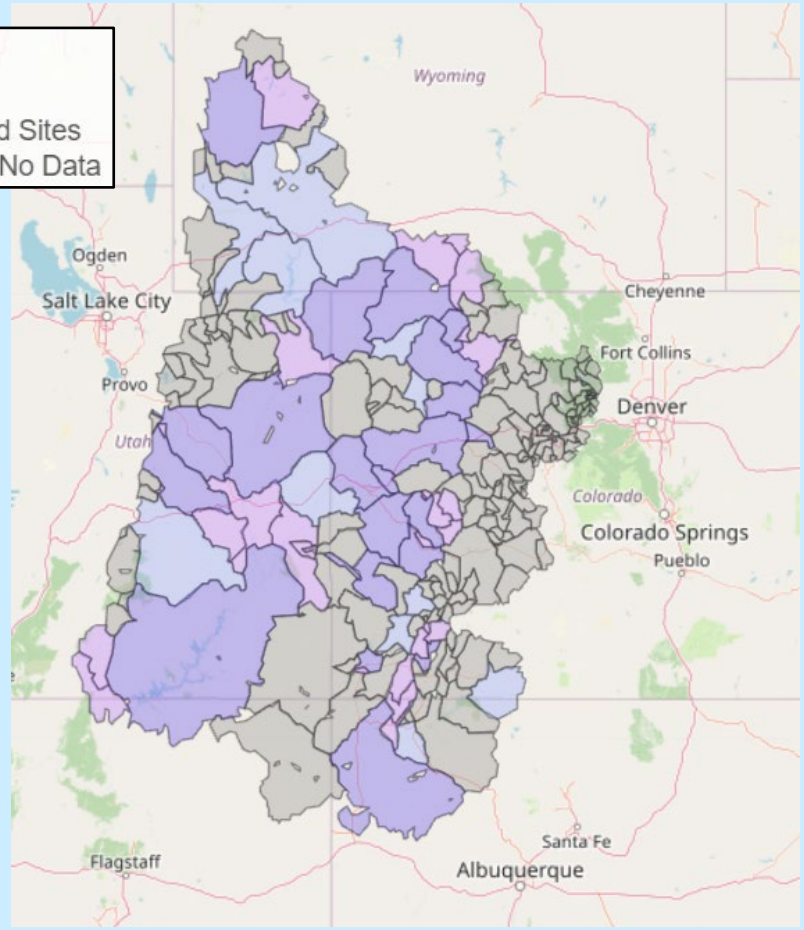
Workflow Step 4: Priority Areas

Comparing Priorities for Multiple Water Quality Interests in the Upper Colorado River Basin



Priority Areas for Monitoring Rivers with Impaired Water Quality



Priority Areas for Monitoring Total Dissolved Solid Loads

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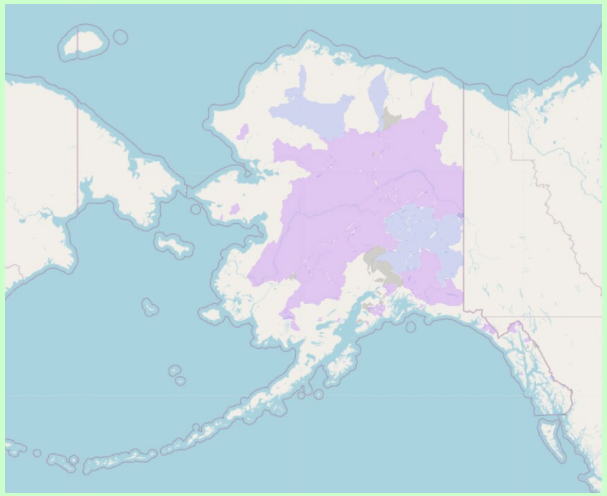
Workflow Step 4: Priority Areas

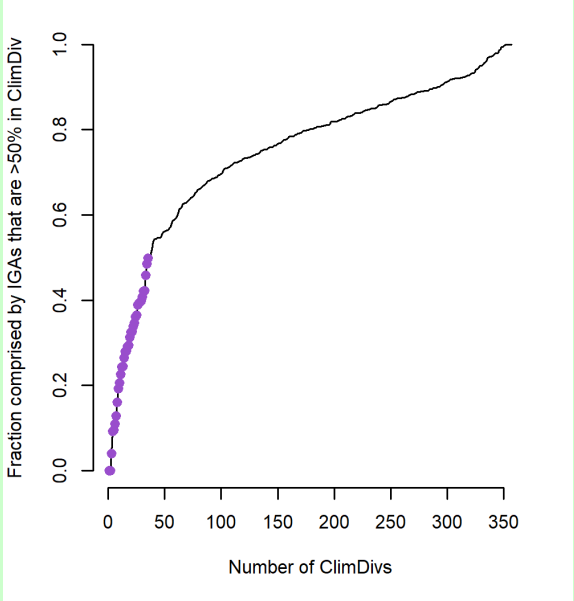
Network Resolution of Streamflow Responses to Climate Change

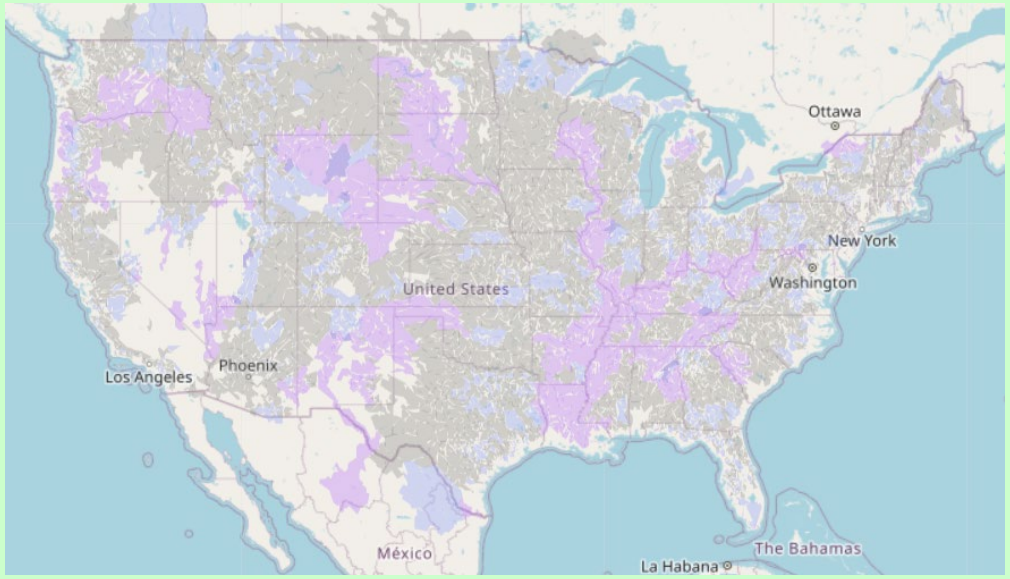


NOAA Climate Divisions provide a spatial framework for assessing streamflow response to climate change.

- ~90% of NOAA Climate Divisions are well gaged.
- Adding sites in 35 Climate Divisions (purple and orange areas) would improve spatial resolution of streamflow responses to climate change.

Gaps are defined as climate divisions with less than 50% area in IGAs that are predominantly in that division





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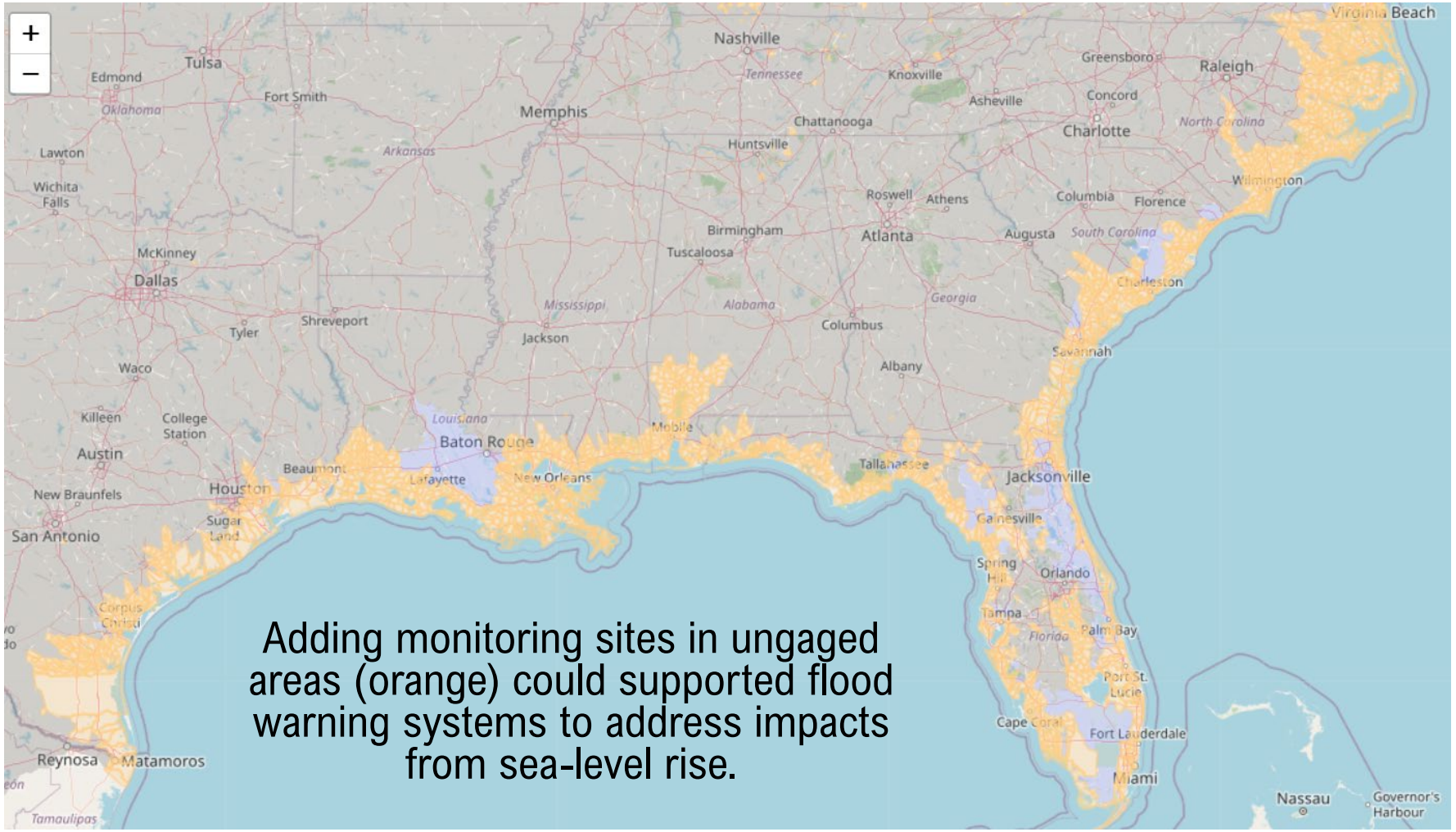
Workflow Step 4: Priority Areas

Increased Flood Hazard from Sea-Level Rise

Flood risk in populated, coastal areas is increasing because of sea-level rise.

Network has poor coverage of coastal areas because of many, small independent rivers and streams.

Information on the exposure of people to flooding could be used to target ungaged areas for network expansion.



Adding monitoring sites in ungaged areas (orange) could supported flood warning systems to address impacts from sea-level rise.

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Key Results of the Gap Analysis

The USGS streamflow monitoring network covers 75% of the United States. The network has a high degree of nesting: 90% of gages are in the watershed of another gage, so network analysis should be based on incremental gaged areas (IGAs) rather than assume the independence of sites.

Ungaged coastal areas where flood hazard is likely increasing in response to sea-level rise are a key gap in the network coverage. Information about the exposure of people to flooding could be used to prioritize monitoring in these areas.

Spatial resolution of streamflow and material loads can be improved by additional monitoring. The network has the poorest spatial resolution of low flows and total dissolved solids, though nutrients and total dissolved solids are not well resolved. Synoptic low-flow measurements and adding water quality sampling/analysis to gages would be an efficient way to increase the network's spatial resolution.

Many gages are required to resolve or represent spatially fragmented variables (e.g., urban development, coastal streams). Hydrologic models that account fine-grained spatial heterogeneity in forcing may be a practical alternative to extensive monitoring of smaller streams.

Prioritization in Network Planning/Design

Network prioritization requires well-defined network objectives and a more complete understanding of needs for information (e.g., exposure to hazards), trade-offs between different interests, and site-specific cost/funding information.

A ranked list of priority areas or sites for monitoring is only possible when network objectives are well specified including explicitly or implicitly defined trade-offs among different interests.

Priority areas for maintaining or adding monitoring sites can be aligned for multiple interests if priorities for each interest are defined broadly.

Many areas may have equivalent value for maintaining or adding monitoring sites especially in sparse networks. In these cases, prioritization needs to be based on other considerations such as:

- local needs for hydrologic information,
- discontinued sites with historical information,
- field-based assessment of potential sites including evaluation of access and safety, and
- resources available for establishing and operating sites.

Potential for Information Transfer

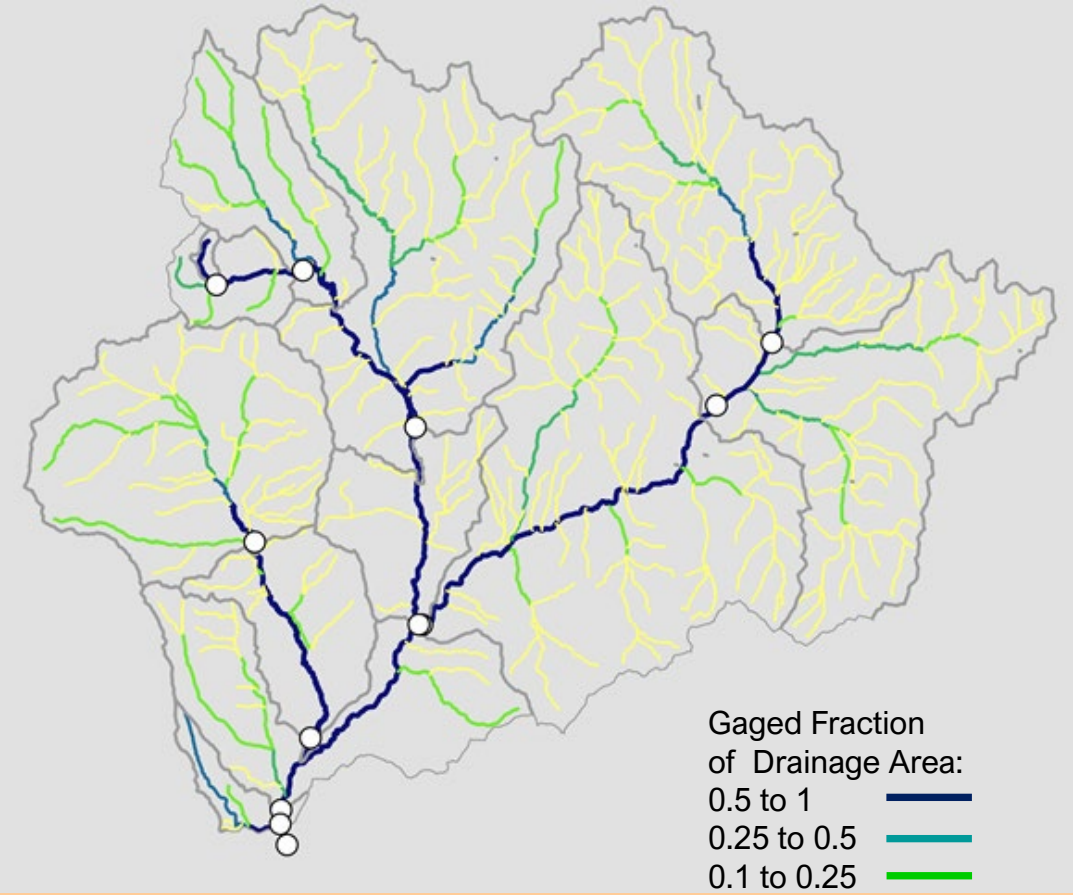
The extensive coverage of the USGS streamflow monitoring network and its nested structure presents many opportunities for transferring information from gaged to ungaged sites.

Analysis of spatial auto-correlation (cross-site correlation of streamflow supports three key questions:

1. Where is the best gage to transfer information to an ungaged site, for example, to estimate design flows for infrastructure planning?

2. Where would additional gages add value for transferring information to ungaged sites?

3. Are there alternative equivalent gages that could be used for information transfer information if a gage is discontinued?



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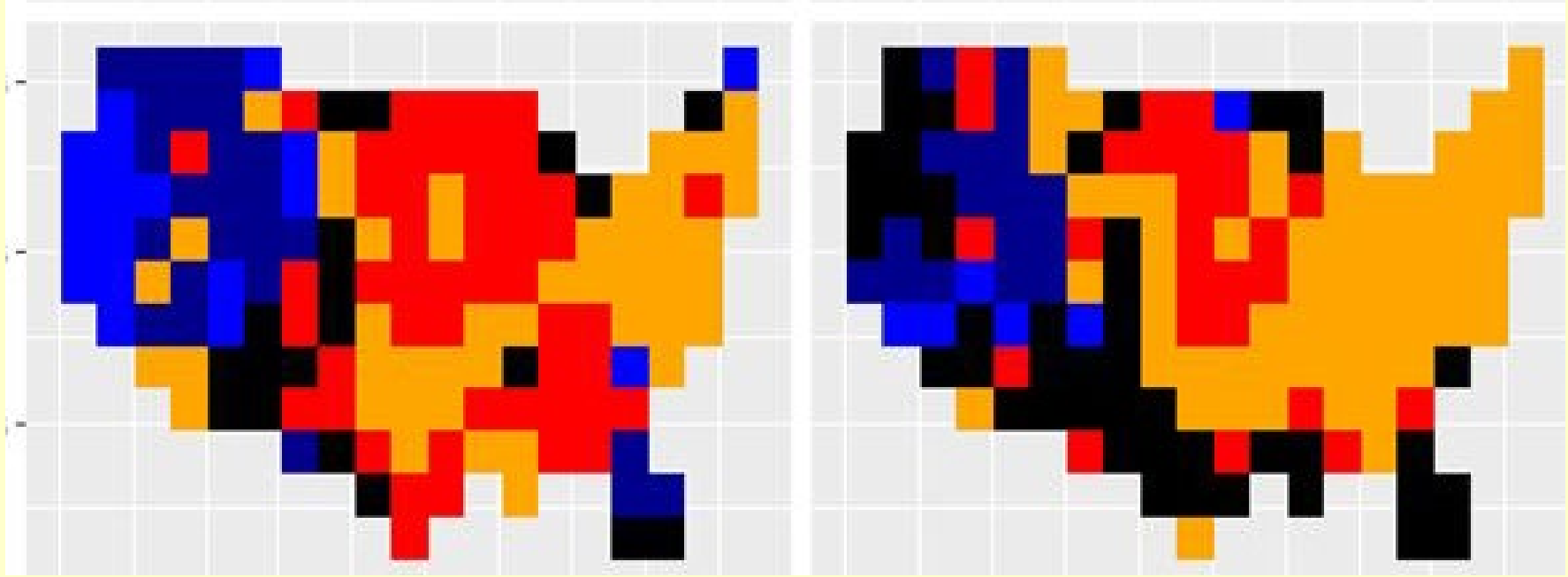
Predicting Cross-Site Correlation of Streamflow

The primary physical control on streamflow varies across the US and varies for monthly and peak streamflow: *the best gage for predicting monthly streamflow at an ungaged site may be different than the best gage for predicting peak streamflow*.



Correlation of PRISM precip

Correlation of PRISM temp

Difference in mean temperature

Difference in fraction of 'cold' precipitation (snow vs. rain)

Centroid distance

Most important variable for predicting cross-site correlation in streamflow

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Summary

A gap analysis of the USGS streamflow gaging network provides information on how well the network serves national public interests in water availability and hazards, effects of climate and land use changes, the ecological integrity of rivers and streams, and water resources on federal and tribal lands.

The analysis evaluates the network's coverage, resolution, and representation of 41 variables using incremental gaged areas. Initial results available on USGS Science Base, https://doi.org/10.5066/P9TYCQGD

Priority areas for maintaining or adding sites for monitoring each variable were determined using standardized criteria applied to the US and ~220 large river basins. The number of priorities does not reflect the comparative of value of the variables nor the resources available for monitoring.

Network prioritization is a larger effort requiring well-defined network objectives, additional information including the exposure of populations to hazards and a more complete understanding of stakeholder needs for information, trade-offs between different interests, and site-specific cost/funding information.

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