Probability survey design alternatives for watershed-based stream and river monitoring programs

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Watershed Definition for Streams

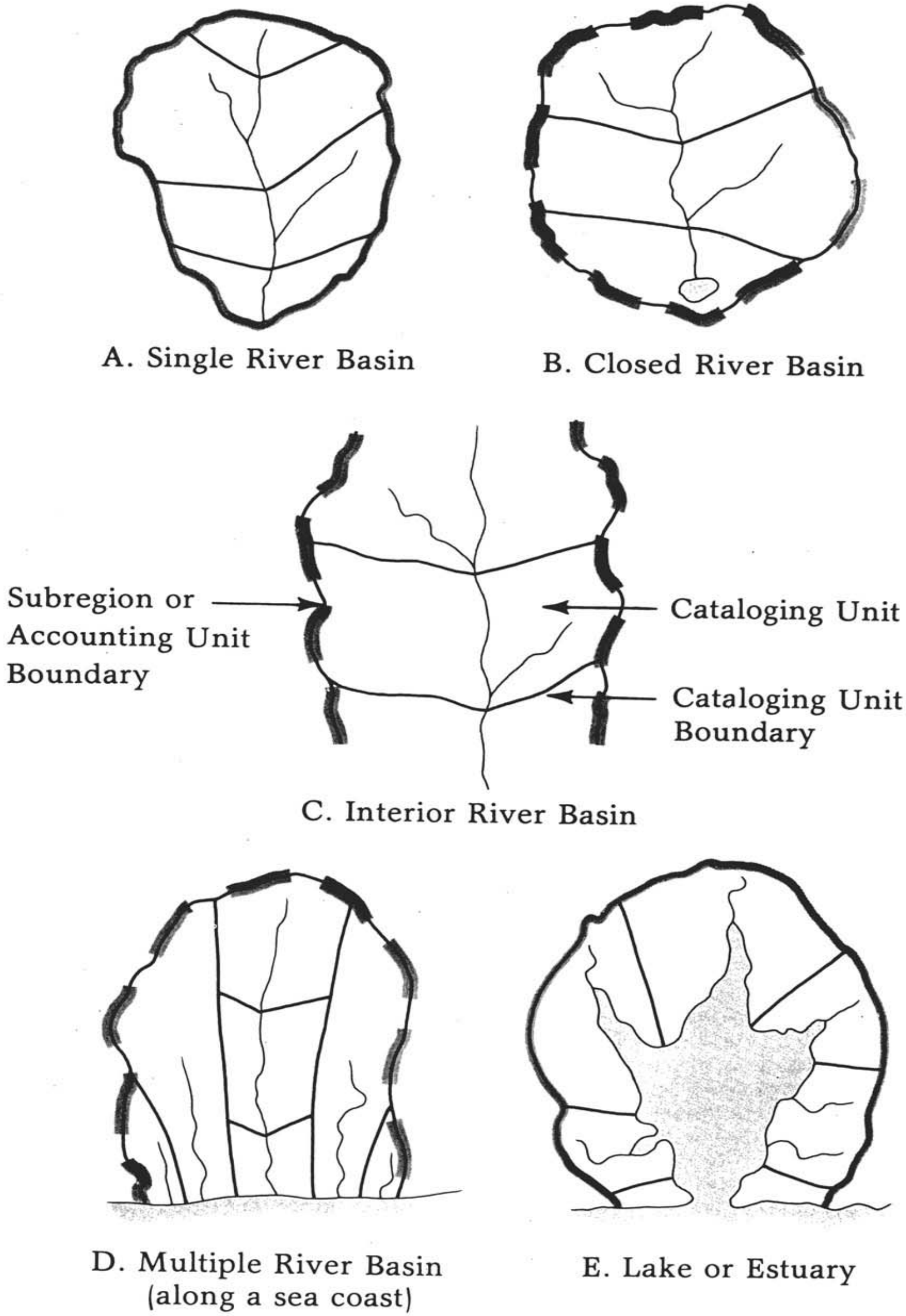
- "A region or area bounded peripherally by a water parting and draining ultimately to a particular watercourse or body of water" [Webster's]
- Common to apply definition at confluences
- Definition is hydrologic but typical to use terrain elevation to define watershed boundaries
- Definition applies to any point on a stream network

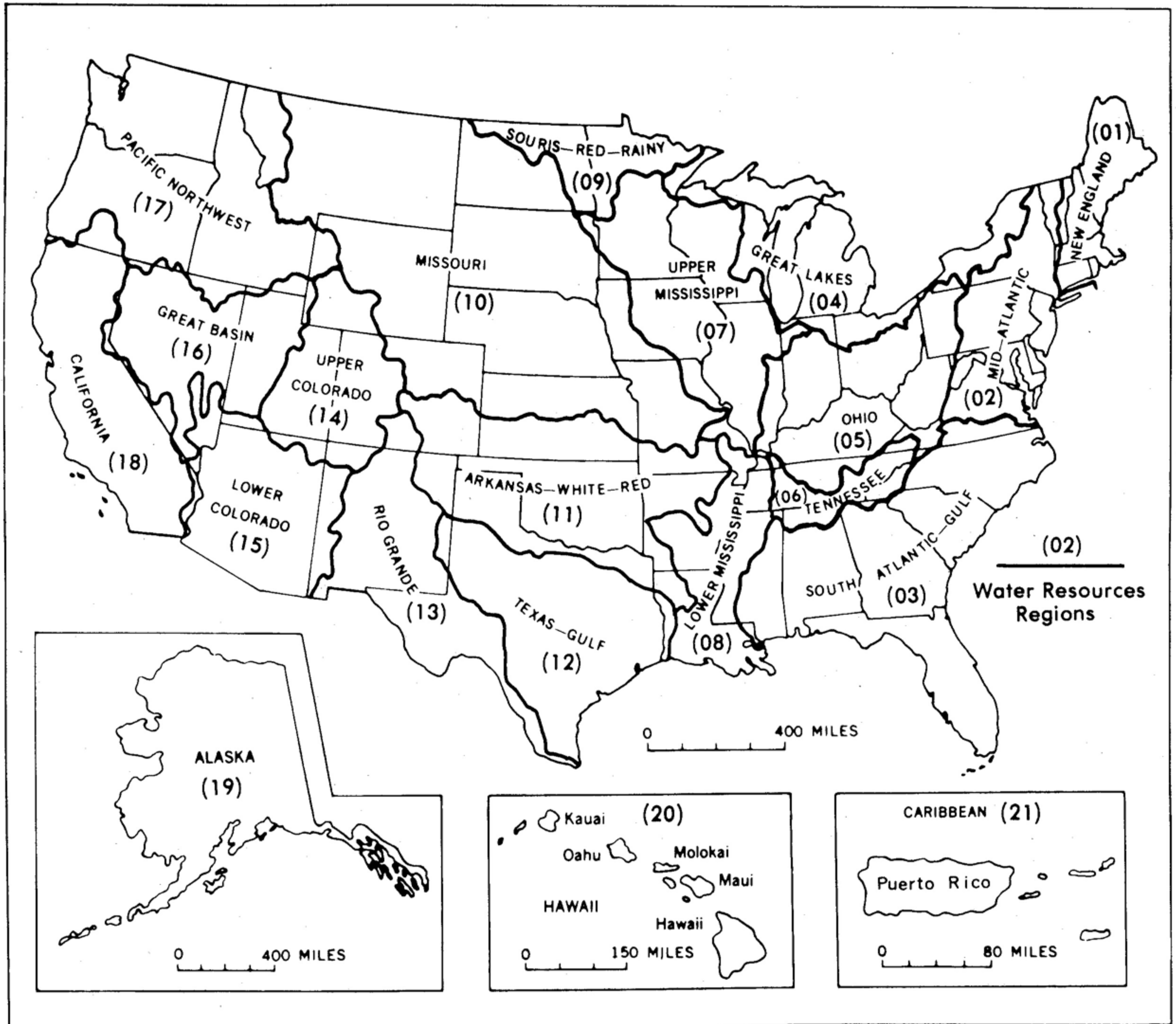
USGS Hydrologic Unit Maps

- Hierarchical subdivision of ***land area*** of United States based on hydrology
- National maps available for 1st, 2nd,3rd, and 4th fields: regions (21), subregions (222), accounting units (352), cataloging units (2150)
- Being extended to 5th and 6th field
- Approximately 50% of units at any level correspond to “true” watersheds

USGS Hydrologic Units

- "Provide a standardized base for use by water-resource organizations in locating, storing, retrieving, and exchanging hydrologic data, in indexing and inventorying hydrologic data and information, in cataloging water-data acquisition activities, and in a variety of other applications" (USGS Water-Supply Paper 2294, 1987)
- "A cataloging unit is a geographic area representing part or all of a surface drainage basin, a combination of drainage basins, or a distinct hydrologic feature"
- Almost all cataloging units are larger than 1800 sq km except in special circumstances.


A. Single River Basin
B. Closed River Basin
Subregion or
Accounting Unit
Boundary
Cataloging Unit
Cataloging Unit
Boundary
C. Interior River Basin
D. Multiple River Basin
(along a sea coast)
E. Lake or Estuary

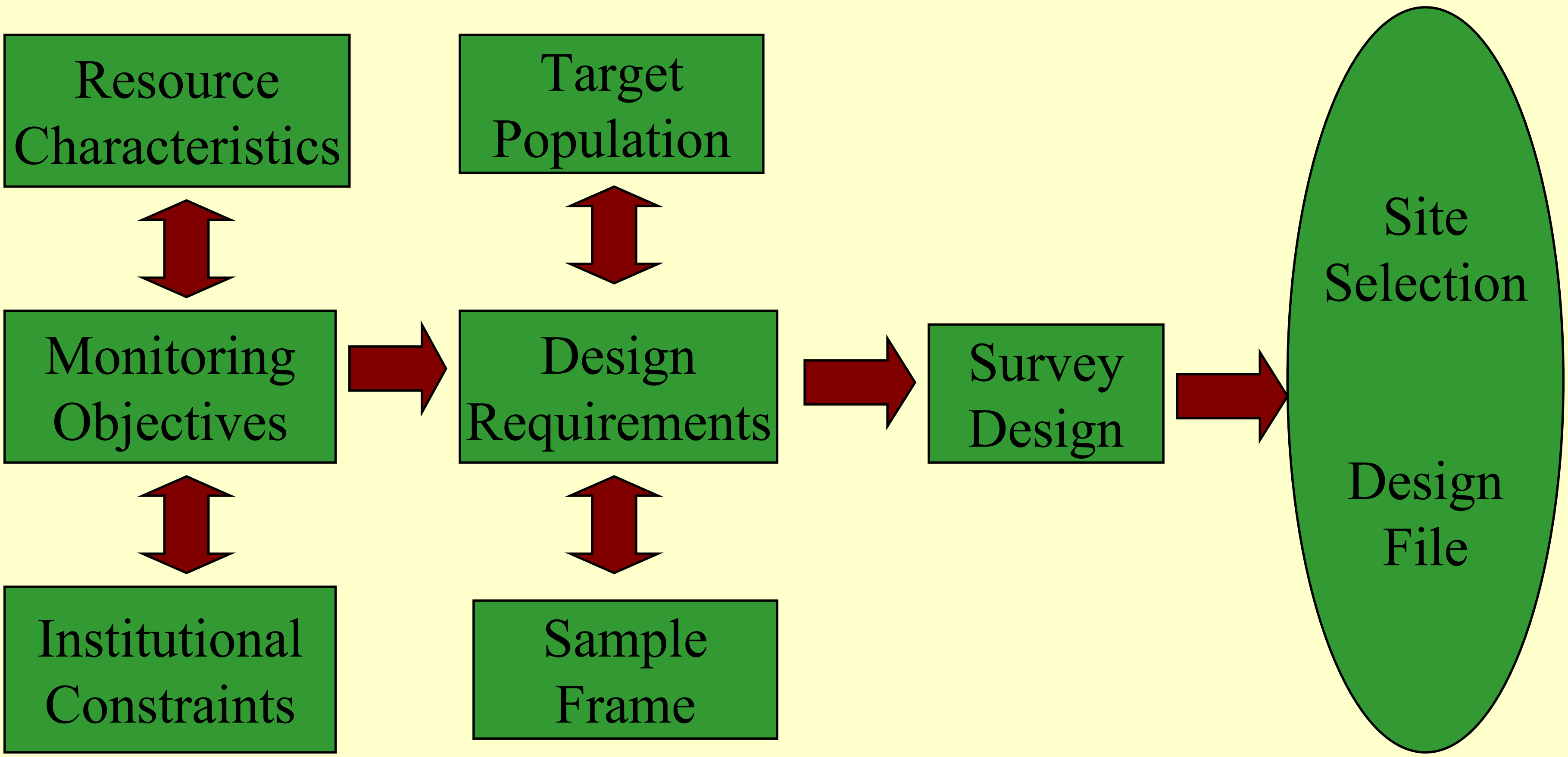


SOURIS—RED—RAINY
(09)
(01)
NEW ENGLAND
PACIFIC NORTHWEST
(17)
MISSOURI
(10)
UPPER
MISSISSIPPI
(07)
GREAT LAKES
(04)
MID-ATLANTIC
(02)
GREAT BASIN
(16)
UPPER
COLORADO
(14)
CALIFORNIA
(18)
OHIO
(05)
ARKANSAS—WHITE—RED
(11)
(06) TENNESSEE
LOWER
COLORADO
(15)
RIO GRANDE
(13)
LOWER MISSISSIPPI
(08)
SOUTH ATLANTIC—GULF
(03)
TEXAS—GULF
(12)
(02)
Water Resources
Regions
0
400 MILES
ALASKA
(19)
0
400 MILES
Kauai
(20)
Oahu
Molokai
Maui
HAWAII
Hawaii
0
150 MILES
CARIBBEAN (21)
Puerto Rico
0
80 MILES

Types of Statistical Designs

- Experimental designs
  - Random allocation of treatments to units
  - Not common in aquatic ecology
- Observational studies
  - Factor space designs
    - Gradient studies
  - Available sites
- Survey designs
  - Census
  - Probability survey

Survey Design Structure



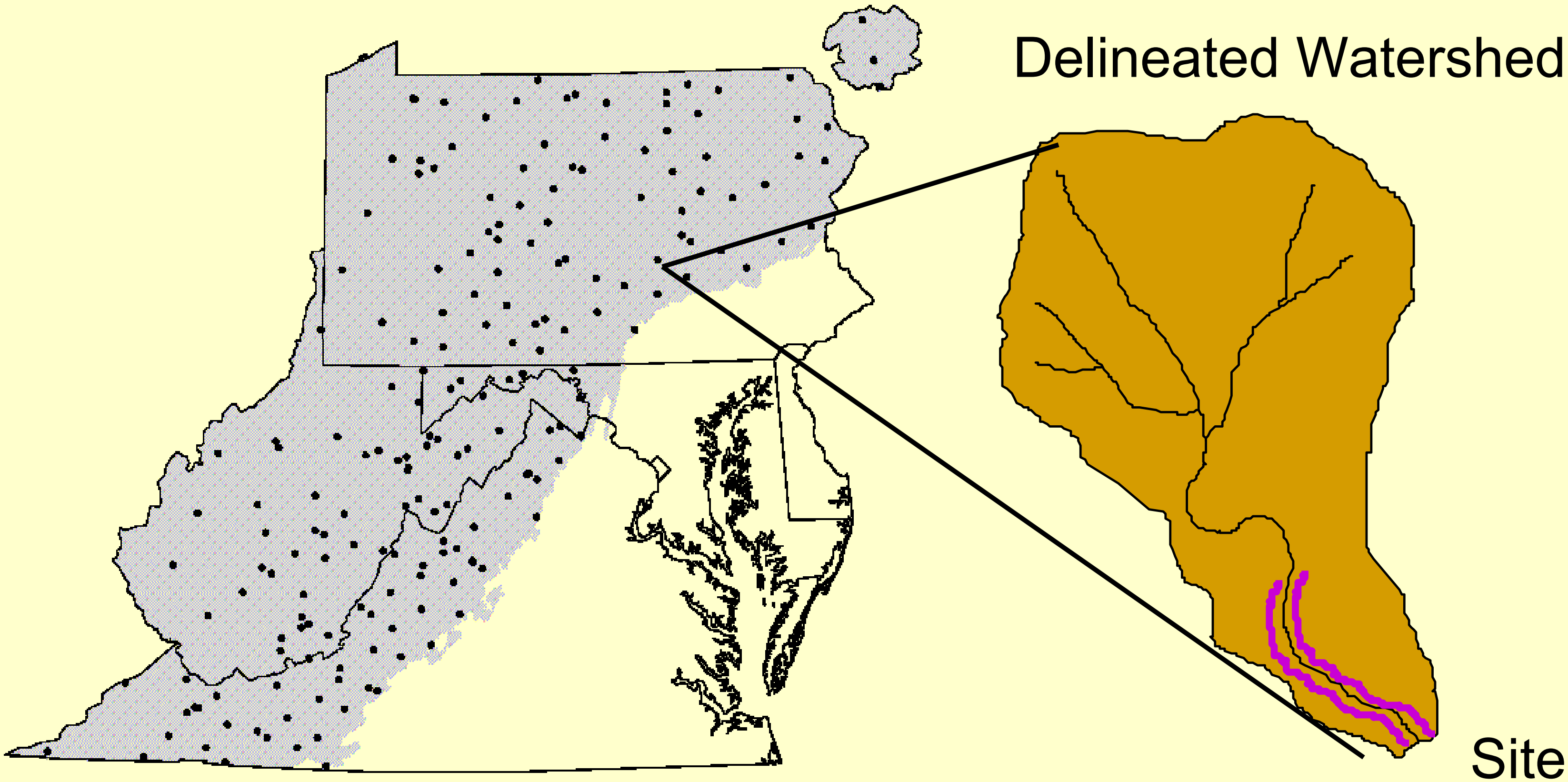
Target Population and Watersheds

- Target population denotes the ecological resource about which information is wanted.
  - Requires a clear, precise definition
  - Includes definition of the ***elements*** that make up the target population
  - More difficult to define than most expect
- "Watershed" based alternatives for ***elements***
  - All watersheds associated with every location on stream/river linear network ("watersheds", infinite #)
  - All hydrologic units at a specified field level for HUCS ("HUCs", finite #)
  - All watersheds associated with streams defined at confluence ("confluence watersheds", finite #)

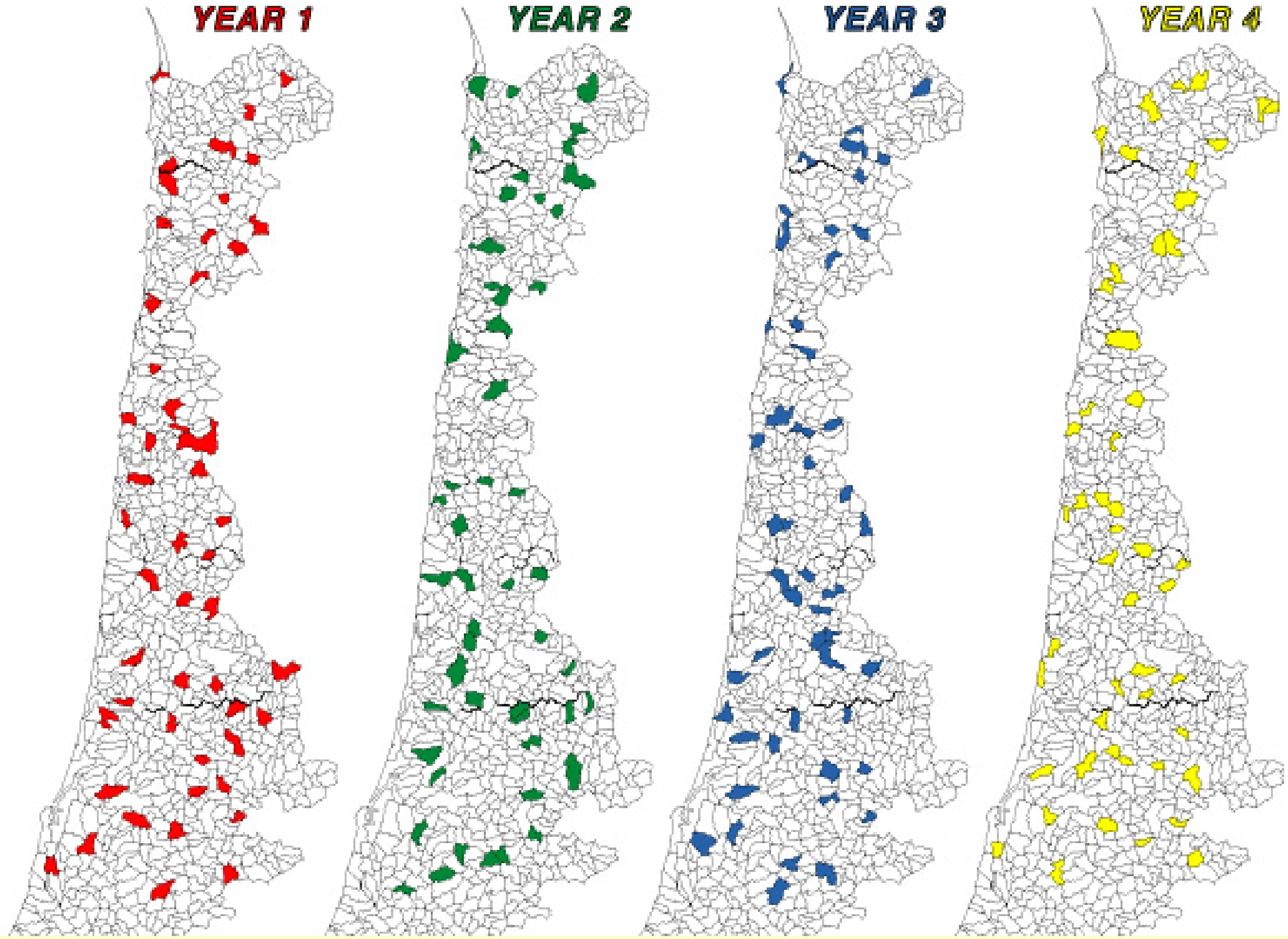
Monitoring Objectives Determine Element Definition Choice

- How many stream/river km in the United States meet their designated use?
- What is the condition of all 6th field hydrologic units in the Northwest Forest Plan region?
- What proportion of headwater watersheds in the Mid-Atlantic coastal region exceed total nitrogen criteria at outflow of watershed?

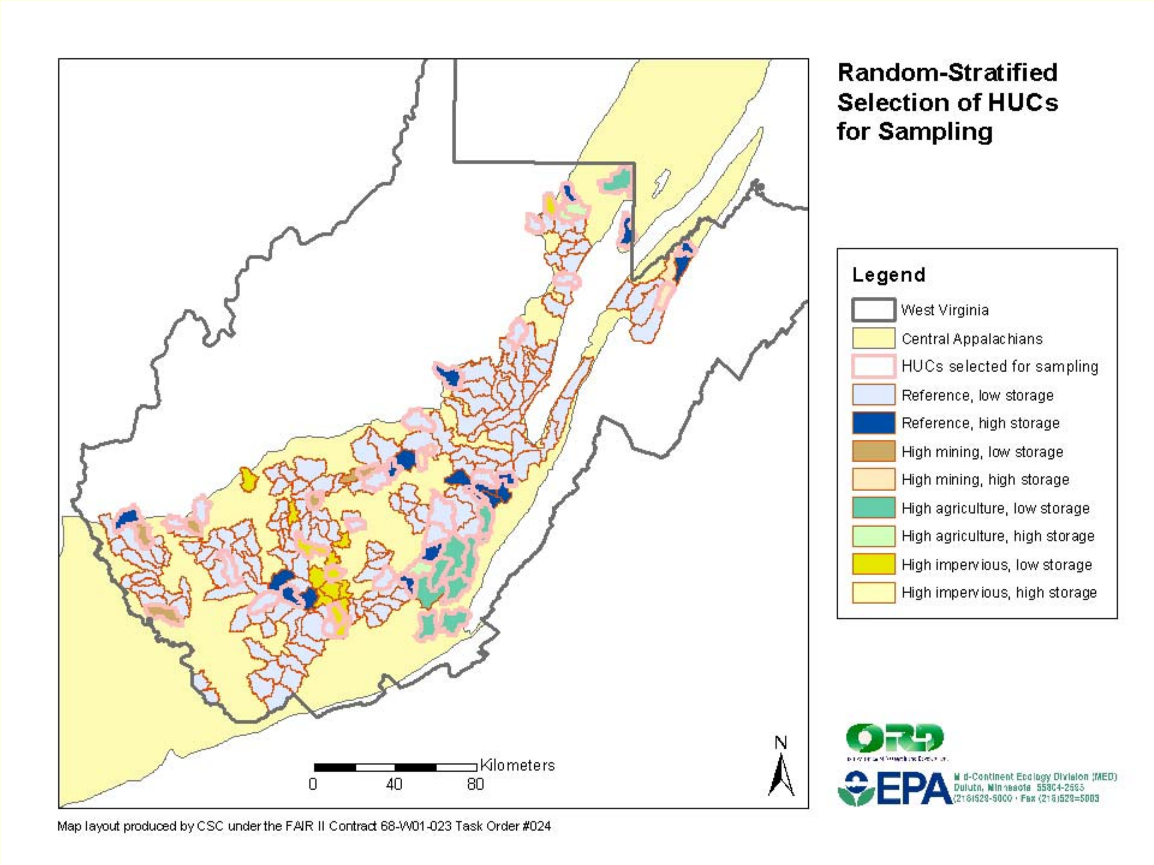
EMAP Mid-Atlantic Highland Streams



Spatially-Balanced Sample of 6-th Field Hydrologic Units
Coastal Region of Oregon



West Virginia Diagnostic Study
Detenbach: NHEERL MED



Basic Spatial Survey Designs

- Simple Random Sample
- Systematic Sample
  - Regular grid
  - Regular spacing on linear resource
- Spatially Balanced Sample
  - Combination of simple random and systematic
  - Guarantees all possible samples are distributed across the resource (target population)
  - Generalized Random Tessellation Stratified (GRTS) design

Why aren't basic designs sufficient for watershed studies?

- **Estimates for particular subpopulations requires unequal allocation of sampling effort**
  - **Stratification**
  - **Unequal probability**
- **Diagnostic modeling requires survey design that ensures complete factor space coverage, i.e. sample includes range of each predictor variable**
- **Not possible to delineate all watershed units before selecting sample (frame not available)**
  - **Two-stage survey design**

GRTS Survey Design Options

- Multiple density categories to allocate samples: unequal probability
- Nested subsamples for measuring additional indicators or duplicate samples
- Panels for monitoring over time
- Oversample selection to address non-target and inaccessible sites
- Special study areas with study-wide base
- Explicit stratification
- Incorporate multiple stage sampling

Example Watershed Designs

- **LIPS-MACS: headwater watersheds in Mid-Atlantic Coastal Plain**
  - Stratified by Hydrogeologic framework
  - GRTS unequal probability within strata by Percent Developed Land
- **West Virginia Diagnostic Study of 4th field HUCs with 2nd order stream outflow**
  - Stratified random sample
- **Northwest Forest Plan 6th field HUC study**
  - First stage: GRTS sample of 5th field HUCs
  - Second stage: IRS of 6th field after delineation
  - Third stage: GRTS sample of stream sites

Example Watershed Designs (continued)

- West Virginia rotating basin biological monitoring
  - Stratified by groups of 4th field HUCs (basins)
  - GRTS unequal probability sample of points on stream network within strata
    - by Strahler order
    - by HUC groups within strata
- Sierra Nevada Mountain Yellow-legged Frog
  - First stage: GRTS unequal probability subsample of an FIA systematic point sample
  - Delineate 7th field HUCs in regions of first stage sample
  - Second stage: GRTS unequal probability sample of 7th fields

Watersheds, HUCs and Confluence Watersheds?

- **Survey designs possible regardless of choice; hence survey design is not deciding factor**
- **Watersheds include all possible true watersheds, at cost of variable size**
- **Confluence Watersheds are a subset of watersheds**
- **HUCs tile the landscape into elements at the same scale approximately, at cost of introducing "incomplete" watersheds**

Watersheds

Advantages

- Complete watersheds
- Include all possible watersheds
- Consistent with 305(b) reporting
- Consistent with watershed management view
- Can restrict estimates to watershed area classes

Limitations

- Watersheds overlap
- Wide range in watershed areas
- Infinite number of watersheds
- 303(d) listing requires definition of unit to list

HUCs

Advantages

- Tile landscape at selected scales: 1st-6th field
- Easy to display results of HUC condition

Limitations

- Incomplete watersheds 50% of time
- Only available at selected scales
- No agreement on which scale to do analysis
- How to generalize to all possible watersheds

Conclusions

- Survey designs can, and have, been applied to all three alternative definitions for watersheds
- Monitoring objectives drive the choice of watershed definition
- Defensible scientific inference from the sample to the target population is critical