Spatial Survey Designs for Aquatic Resource Monitoring

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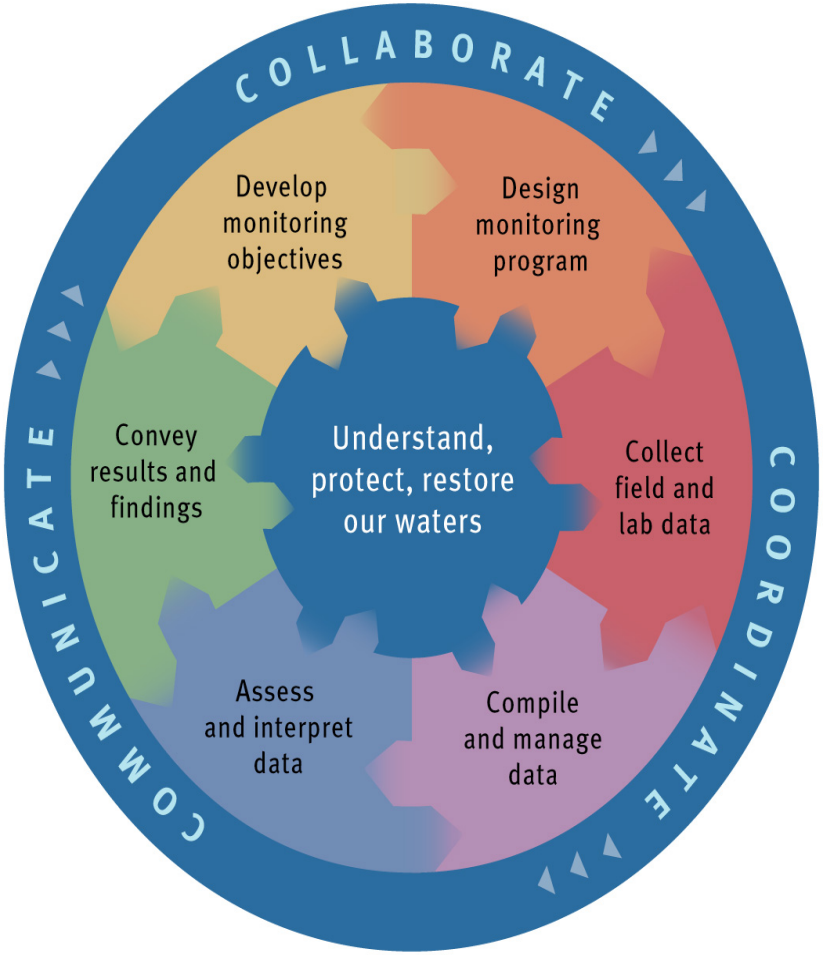
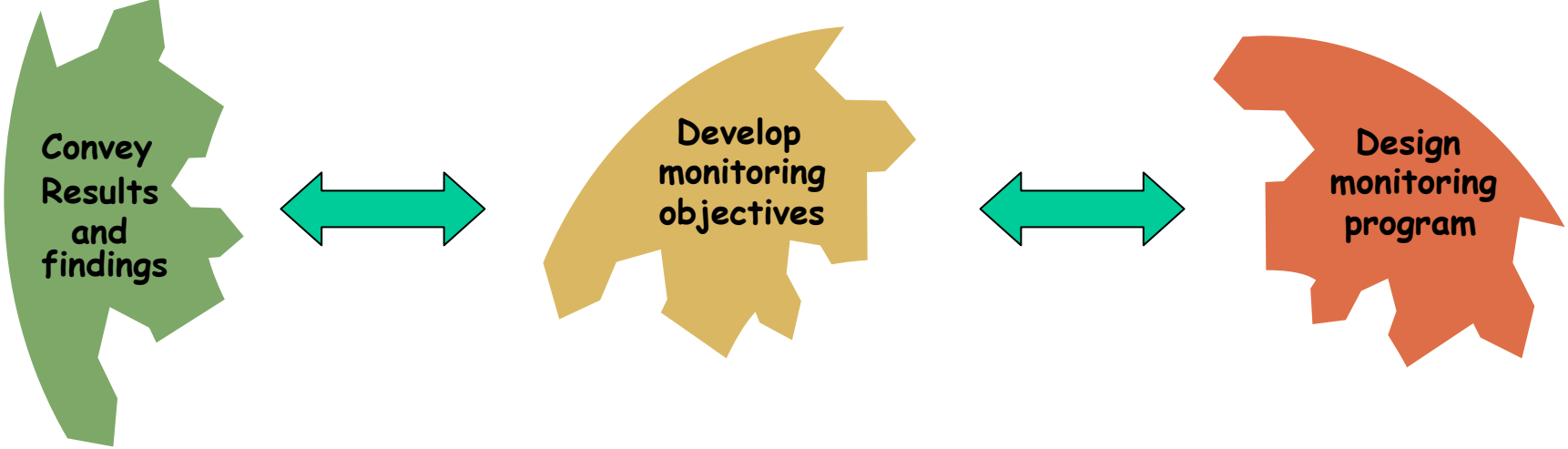
Short Course Objectives

- Gain understanding of role spatial survey design process plays in monitoring framework
- Gain an understanding of importance of developing survey design requirements for a monitoring program
- Learn to choose a spatial survey design that meets survey design requirements
- Illustrate selecting sites using R statistical software
- Show breadth of spatial survey design options available

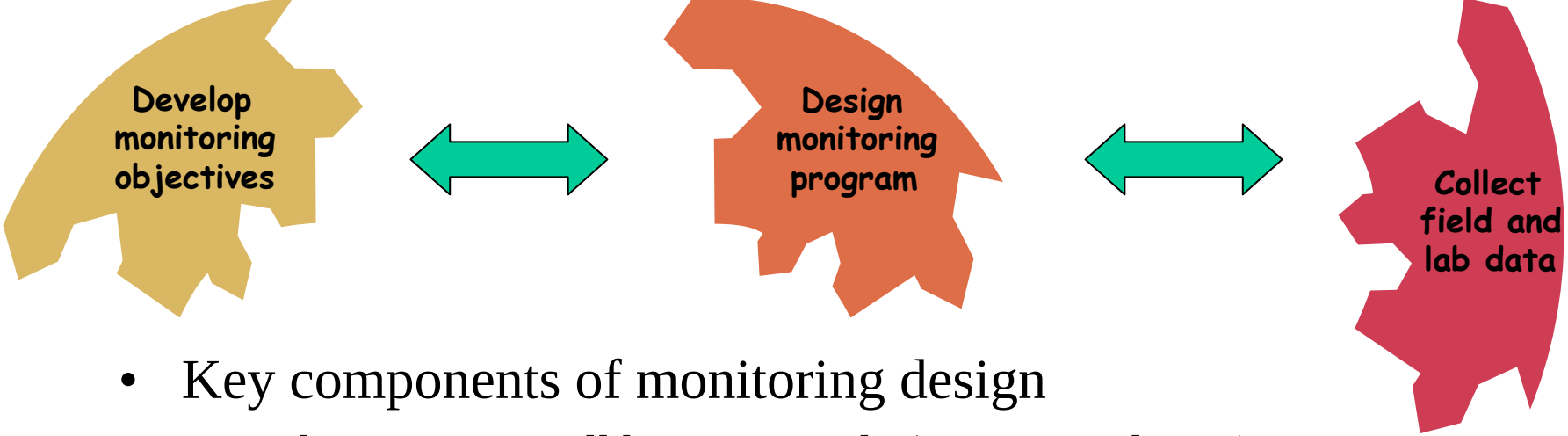
National Water Quality Monitoring Council: Monitoring Framework



- Applies to all natural resource monitoring
- Monitoring pieces must be designed and implemented to fit together
- View as information system
- National monitoring requires consistent framework
- Reference: Water Resources IMPACT, September 2003 issue

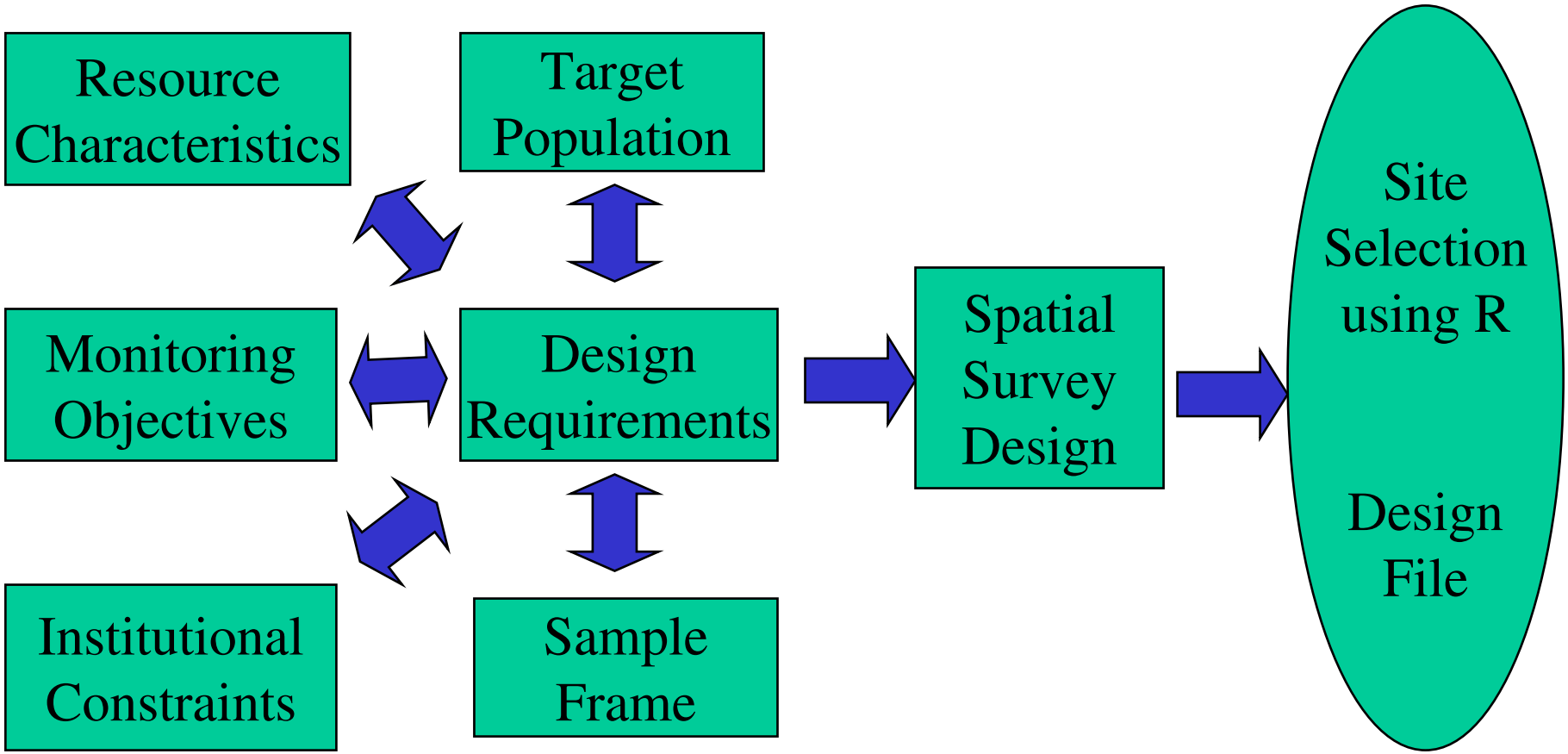


- Kish (1965): "The survey objectives should determine the sample design; but the determination is actually a two-way process…"
- Initially objectives are stated in common sense statements – challenge is to transform them into quantitative questions that can be used to specify the design.
- Statistical perspective
  - Know whether a monitoring design can answer the question
  - Know when the question is not precise enough – multiple interpretations



- Key components of monitoring design
  - What resource will be monitored? (target population)
  - What will be measured? (variables or indicators)
  - How will indicators be measured? (response design)
  - When and how frequently will the measurements be taken? (temporal design)
  - Where will the measurements be taken? (spatial survey design)
- Statistical perspective
  - Target population and its representation, the sample frame
  - Spatial survey design for site selection
  - Panel design for monitoring across years

Spatial Survey Design Process



Spatial Survey Design Options and Illustration of Site Selection using R

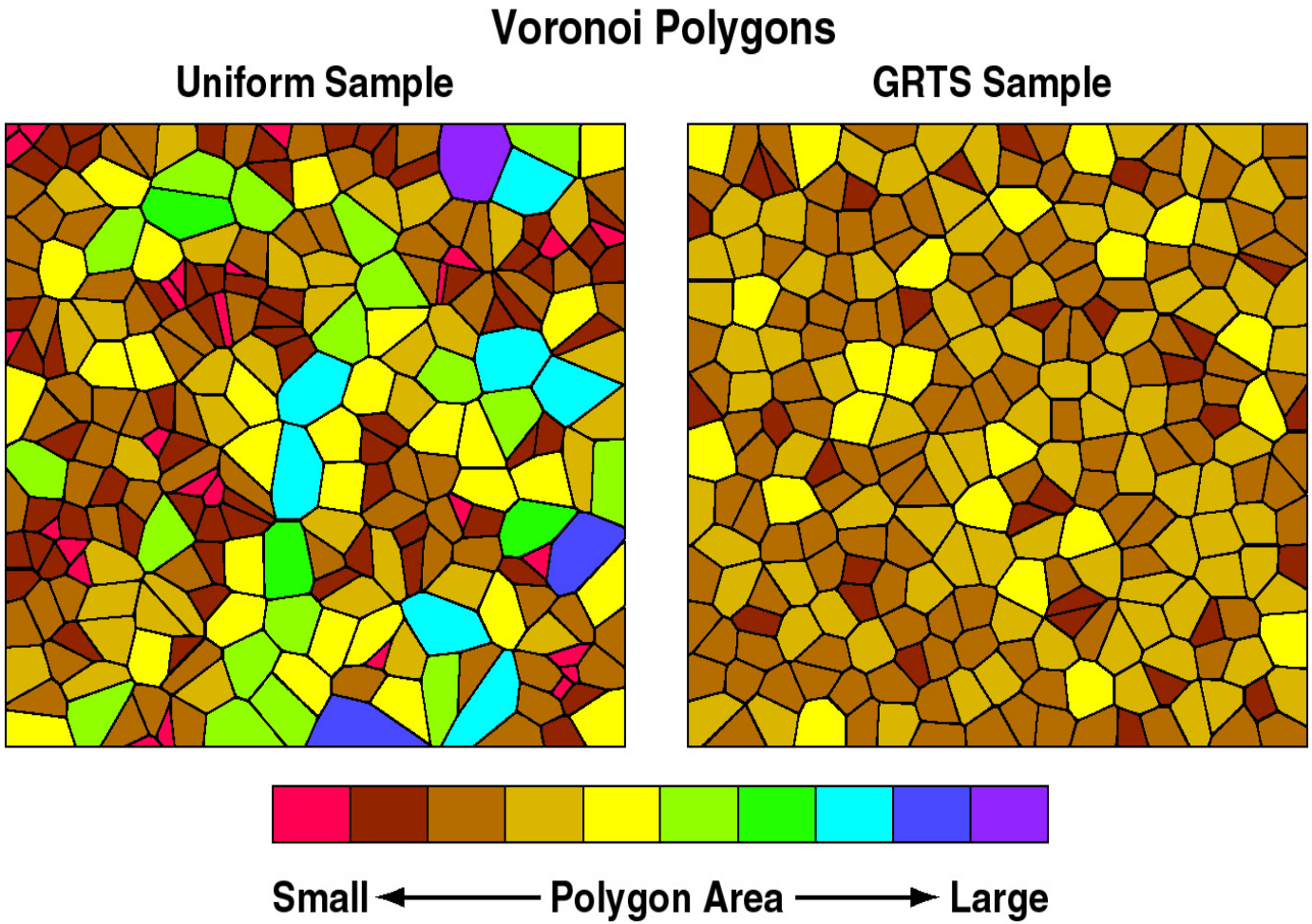
Basic Spatial Survey Designs

- Simple Random Sample
- Systematic Sample
  - Regular grid over a geographic region
  - Regular spacing on linear resource
- Spatially Balanced Sample
  - Characteristics from both simple random and systematic options
  - Guarantees all possible samples are distributed across the sample frame
  - Generalized Random Tessellation Stratified (GRTS) design

Generalized Random Tessellation Stratified (GRTS) Survey Designs

- Probability sample producing design-based estimators and variance estimators
- Another option to simple random sample and systematic sample designs
  - Simple random samples tend to “clump”
  - Systematic samples difficult to implement for aquatic resources and do not have design-based variance estimator
- Emphasize spatial-balance
  - Every replication of the sample exhibits a spatial density pattern that closely mimics the spatial density pattern of the resource

Spatial Balance: 256 points



Why aren't Basic Designs Sufficient?

- Monitoring objectives may include requirements that basic designs can't address efficiently
  - Estimates for particular subpopulations requires greater sampling effort
  - Administrative restrictions and operational costs
- Natural resource in study region makes basic designs inefficient
  - Resource may be known to be restricted to particular subregions
- Complex designs may be more cost-effective

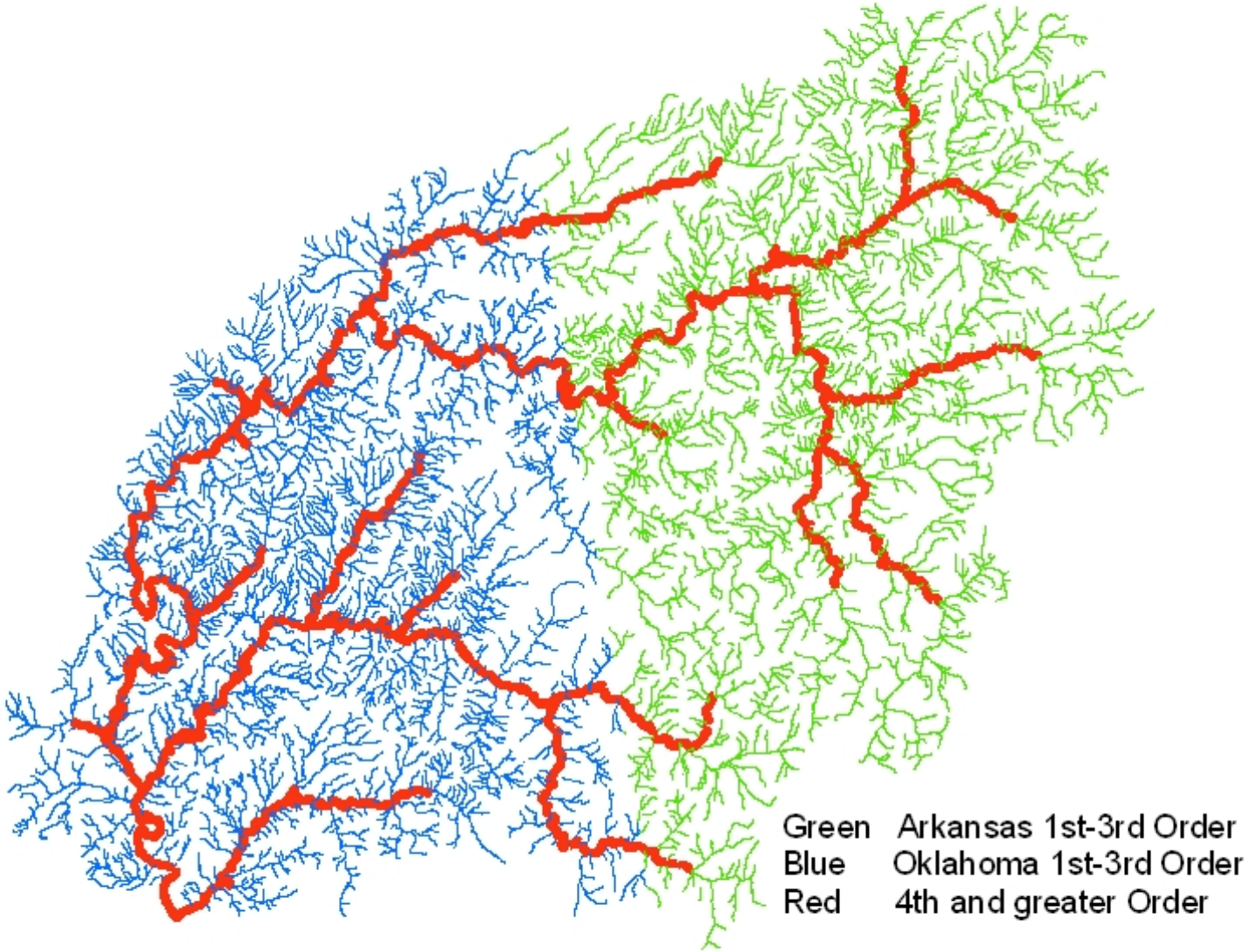
Options to use with GRTS

- Three sample frame types (shapefile types)
  - Point or finite
  - Linear network
  - Area or polygon
- Survey Design features
  - Stratification
  - Equal, unequal, or continuous probability of selection
  - Over sample for use when some sites can not be used
  - Panels for surveys over time
  - Two stage survey designs

Specifying Designs in R

```
design1 = list(None=list(panel=c(Panel_1=50),
                         seltype= “Equal”) )

design2 = list(None=list(panel=c(Panel_1=50, Panel_2=50),
                         seltype= “Equal”,
                         over=100) )

design3 = list(Stratum1=list(panel=c(Panel_1=50),
                  seltype= “Equal”
                  over=50)
               Stratum2=list(panel=c(Panel_1=50),
                             seltype= “Unequal”
                             caty.n=c(category1=25, category2=25) ) )
```

Illinois River Basin Streams and Rivers



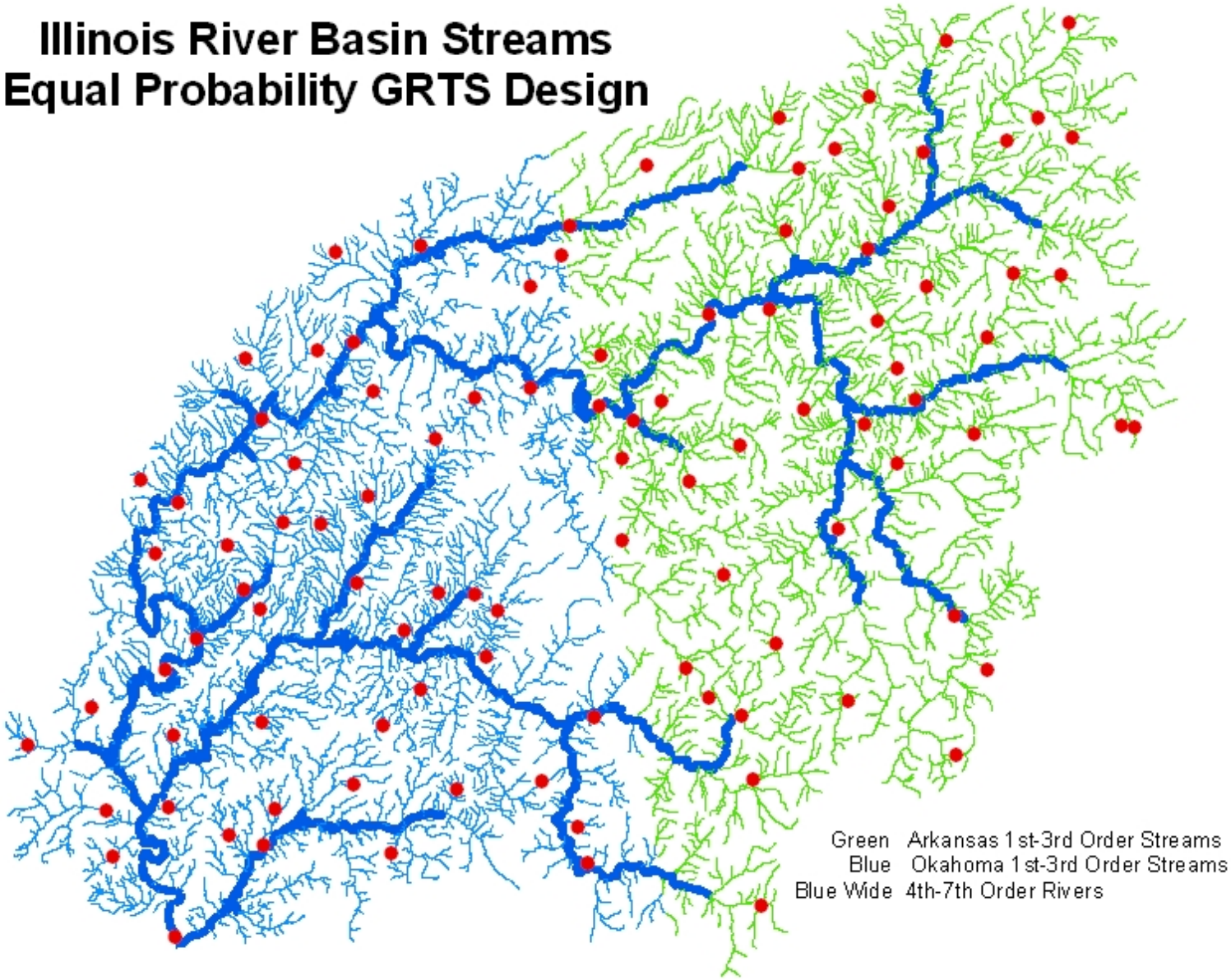
Illinois River Basin GRTS designs for Streams

```
dsgn <- list(None=list(panel=c(Panel_1=100),
                       seltype="Equal" ))

dsgn <- list(Oklahoma=list(panel=c(Panel_1=50),
                     seltype='Unequal',
                     caty.n=c("1st-3rd"=25, "4th-7th"=25),
                     over=50),
             Arkansas=list(panel=c(Panel_1=50),
                     seltype='Unequal',
                     caty.n=c ("1st-3rd"=25, "4th-7th"=25),
                     over=50)
             )
```

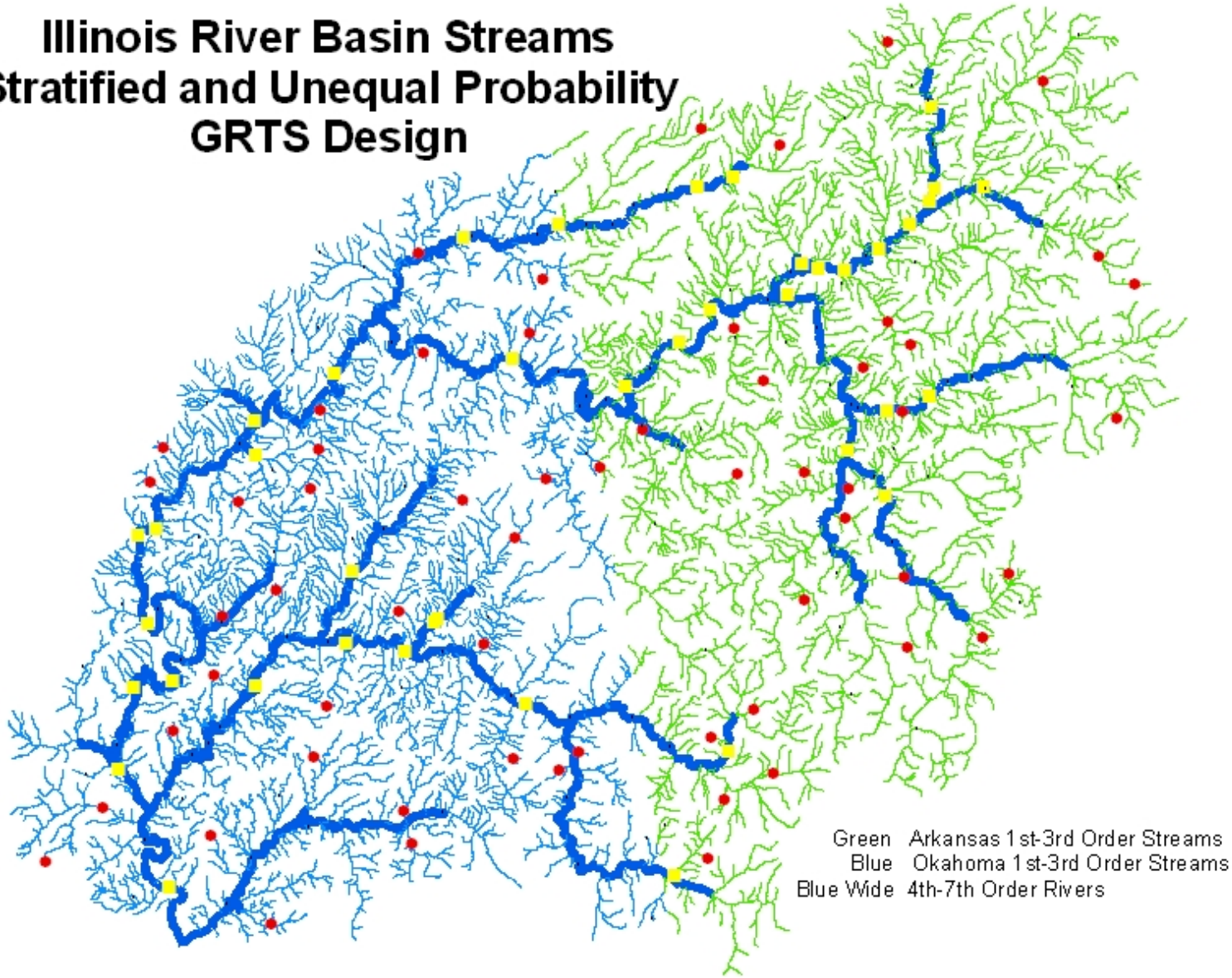
Illinois River Basin Site Selection using R

```
library(spsurvey)

att <- read.dbf('Illinois_ri_ok_ar')

sites <- grts(design=dsgn,
              DesignID="OKI06594",
              type.frame="linear",
              in.shape="Illinois_ri_ok_ar",
              att.frame=att,
              stratum="STATE_NAME",
              mdcaty="SO_CAT",
              prjfilename='Illinois_ri_ok_ar',
              out.shape="Illinois River Basin Sites")
```

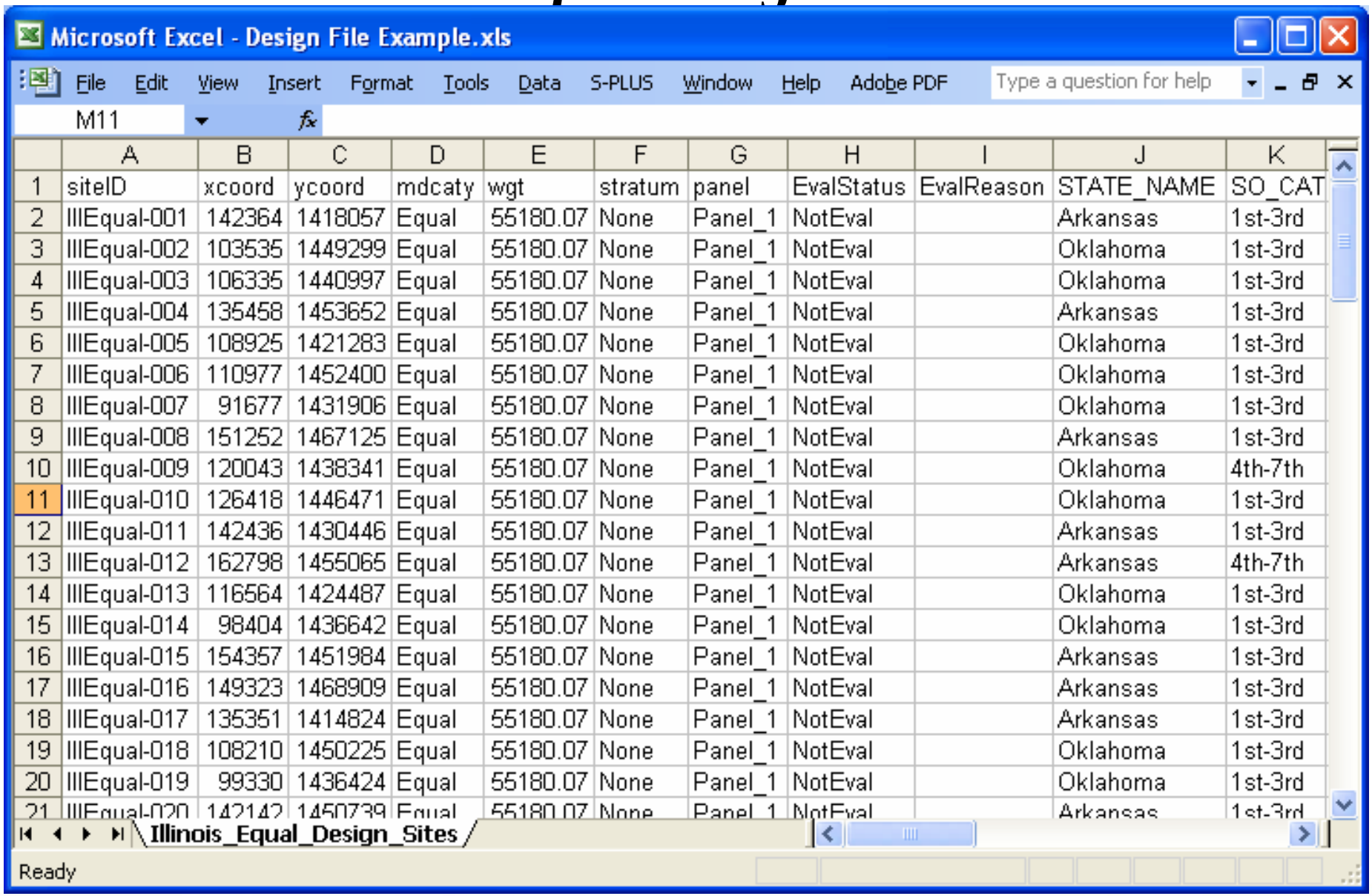
Illinois River Basin Streams
Equal Probability GRTS Design



Illinois River Basin Streams Stratified and Unequal Probability GRTS Design



Example Design File



Microsoft Excel - Design File Example.xls

File Edit View Insert Format Tools Data S-PLUS Window Help Adobe PDF Type a question for help

M11

	A	B	C	D	E	F	G	H	I	J	K
1	siteID	xcoord	ycoord	mdcaty	wgt	stratum	panel	EvalStatus	EvalReason	STATE_NAME	SO_CAT
2	IllEqual-001	142364	1418057	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd
3	IllEqual-002	103535	1449299	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
4	IllEqual-003	106335	1440997	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
5	IllEqual-004	135458	1453652	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd
6	IllEqual-005	108925	1421283	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
7	IllEqual-006	110977	1452400	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
8	IllEqual-007	91677	1431906	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
9	IllEqual-008	151252	1467125	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd
10	IllEqual-009	120043	1438341	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	4th-7th
11	IllEqual-010	126418	1446471	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
12	IllEqual-011	142436	1430446	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd
13	IllEqual-012	162798	1455065	Equal	55180.07	None	Panel_1	NotEval		Arkansas	4th-7th
14	IllEqual-013	116564	1424487	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
15	IllEqual-014	98404	1436642	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
16	IllEqual-015	154357	1451984	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd
17	IllEqual-016	149323	1468909	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd
18	IllEqual-017	135351	1414824	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd
19	IllEqual-018	108210	1450225	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
20	IllEqual-019	99330	1436424	Equal	55180.07	None	Panel_1	NotEval		Oklahoma	1st-3rd
21	IllEqual-020	142142	1450739	Equal	55180.07	None	Panel_1	NotEval		Arkansas	1st-3rd

Illinois_Equal_Design_Sites

Ready

R and spsurvey library

- R statistics program and spsurvey library are free
- Information on where to get them and how to install available at http://www.epa.gov/nheerl/arm under "Download Software" on left hand menu
- All commands necessary to create Illinois designs were given on previous slides
- Example "R scripts" and shapefiles are available on ARM web site
- Challenges
  - Creating appropriate shapefile for the sample frame
  - Learning basics of R
  - Selecting appropriate spatial survey design

Specifying Design Requirements

- Design requirements impacted by
  - Monitoring objectives
  - Aquatic resource characteristics
  - Target population and subpopulations
  - Sample frame
  - Institutional constraints
- Iterative process involving professionals with different backgrounds and perspectives
  - Managers (decision makers)
  - Aquatic resource experts (ecologists, biologists, chemists, etc) with monitoring expertise
  - Statistical experts (experience in spatial survey design)
  - GIS specialists

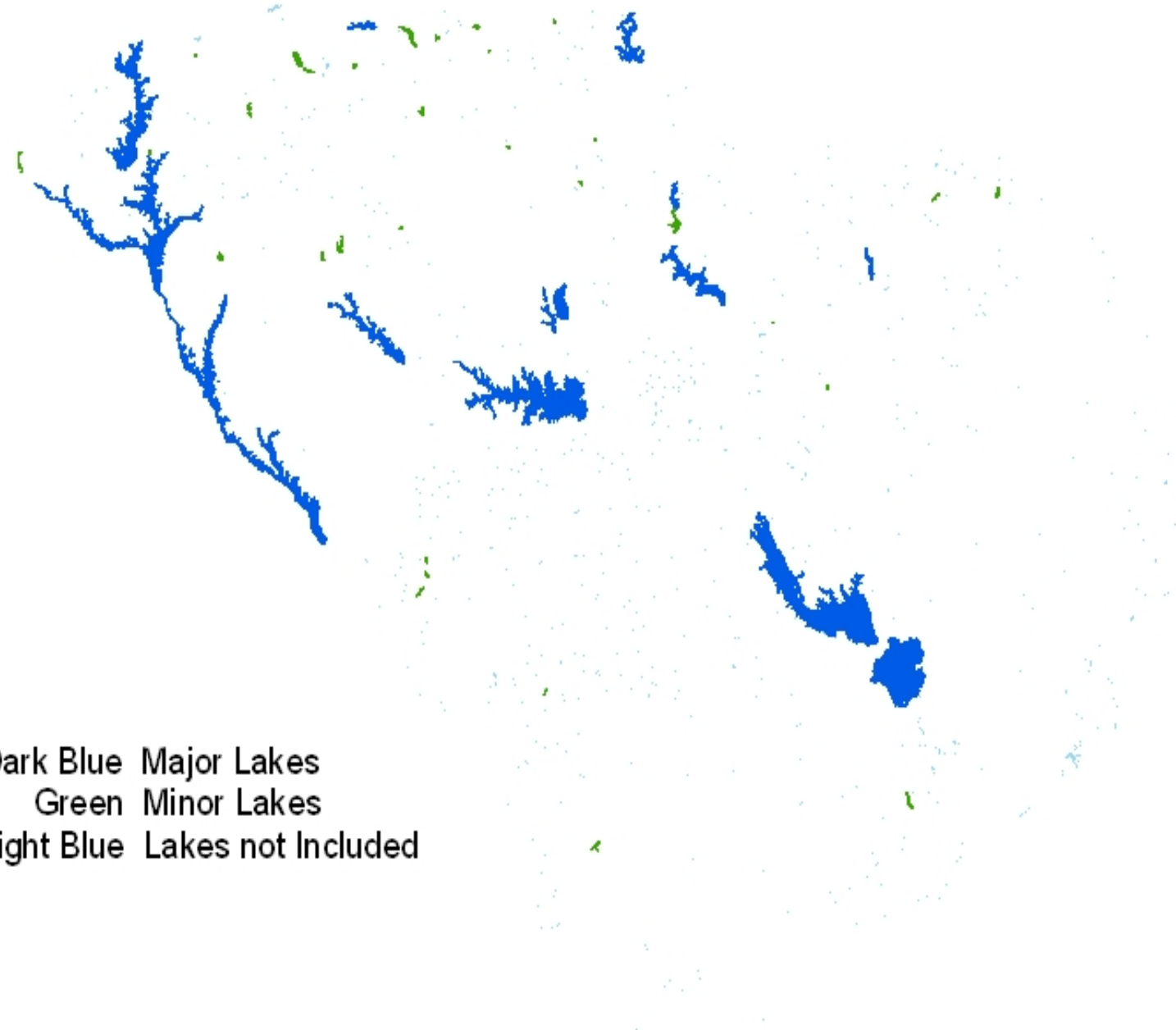
Survey Design & Response Design

- Survey design is process of selecting sites at which a response will be determined
  - Which sites will be visited (spatial component)
  - Which year will sites be visited (temporal component, panel design)
- Response design is process of obtaining a response at a site:
  - When site is to be visited within a monitoring season
    - A single index period visit during a monitoring season
    - Multiple visits during monitoring season: e.g. monthly, quarterly
  - Field plot design
  - Process of going from basic field measurements to indicators

Use examples to illustrate generation of different spatial survey design requirements and selection of spatial survey designs

- Lakes
  - South Carolina Lakes as area resource
  - National Lake Assessment lakes as point lake resource
- Streams
  - Illinois River Basin streams as linear stream resource
  - Pennsylvania attaining stream segments as point stream resource
- Estuaries
  - Puget Sound?
  - Southern California Bight
- Wetlands
  - Iowa points
  - Ohio area
  - Minnesota wetlands as two-stage design

South Carolina Lake Design

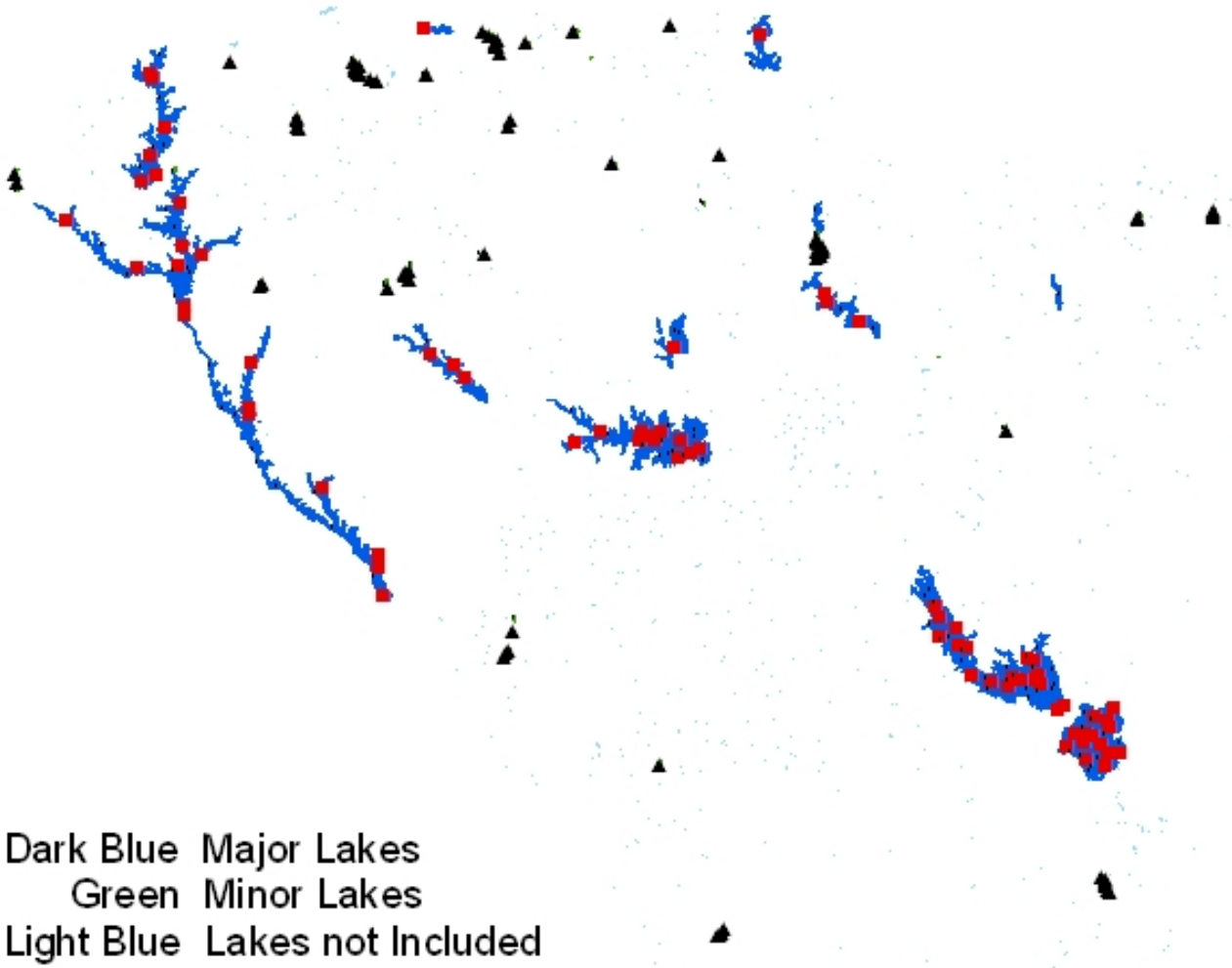


Dark Blue Major Lakes
Green Minor Lakes
Light Blue Lakes not Included

Lake Design: South Carolina

- Monitoring Objectives
  - Estimate the number of hectares of major and minor lakes in South Carolina that meet water quality criteria (also other indicators)
- Target Population and Resource Characteristics
  - State identifies 17 major lakes and 35 minor lakes
  - Require estimates for major, minor, and combined lake subpopulations
  - Elements are all possible locations within surface area of identified lakes
- Sample Frame
  - Shapefile from NHD
  - Attribute that identifies minor, major, and other lakes within state
- Institutional Constraints
  - Sample size 30 sites per year across target population
  - Complete survey over 5 year period

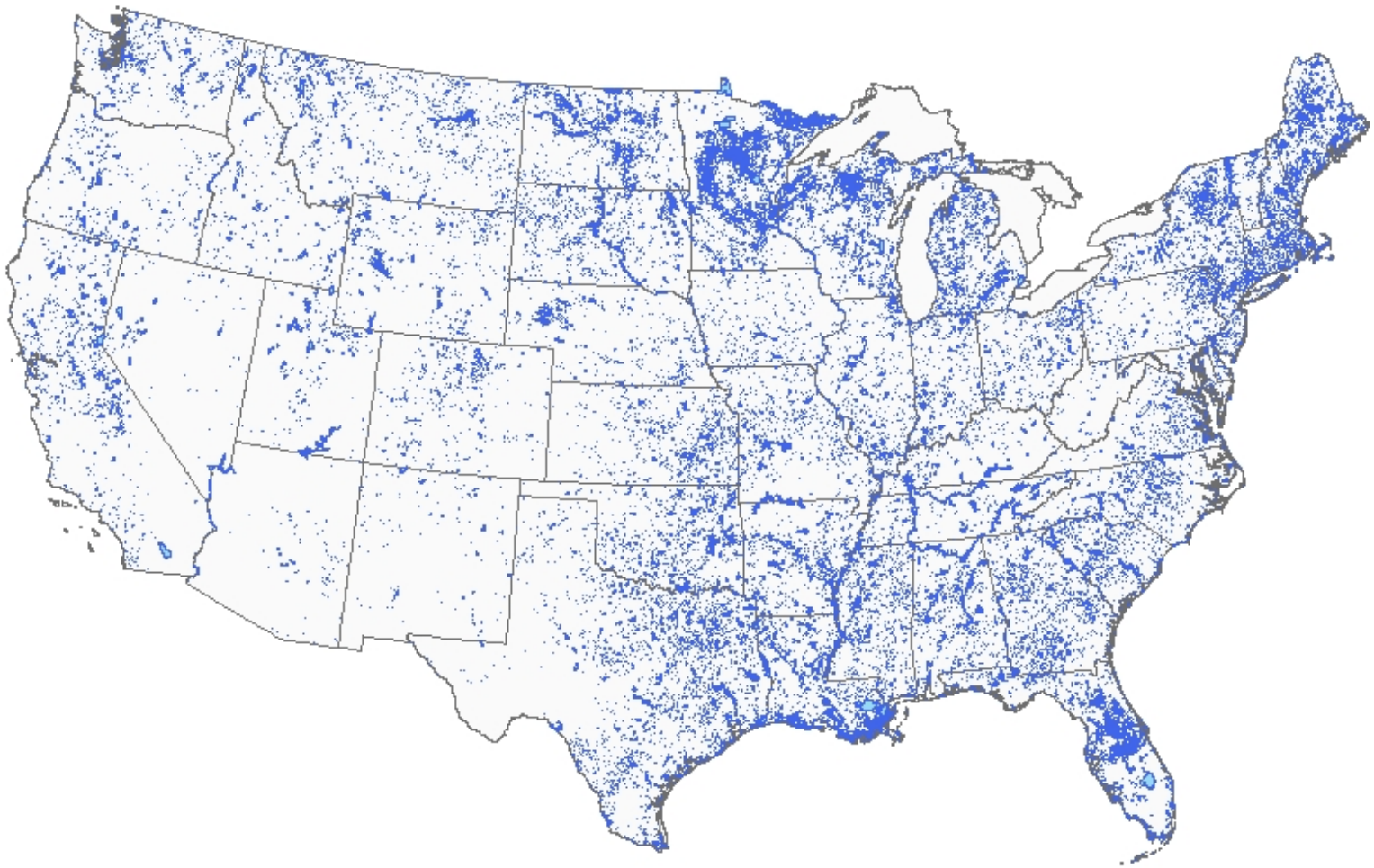
South Carolina Lake Design



Dark Blue Major Lakes
Green Minor Lakes
Light Blue Lakes not Included

Unequal Probability with Over Sample Design

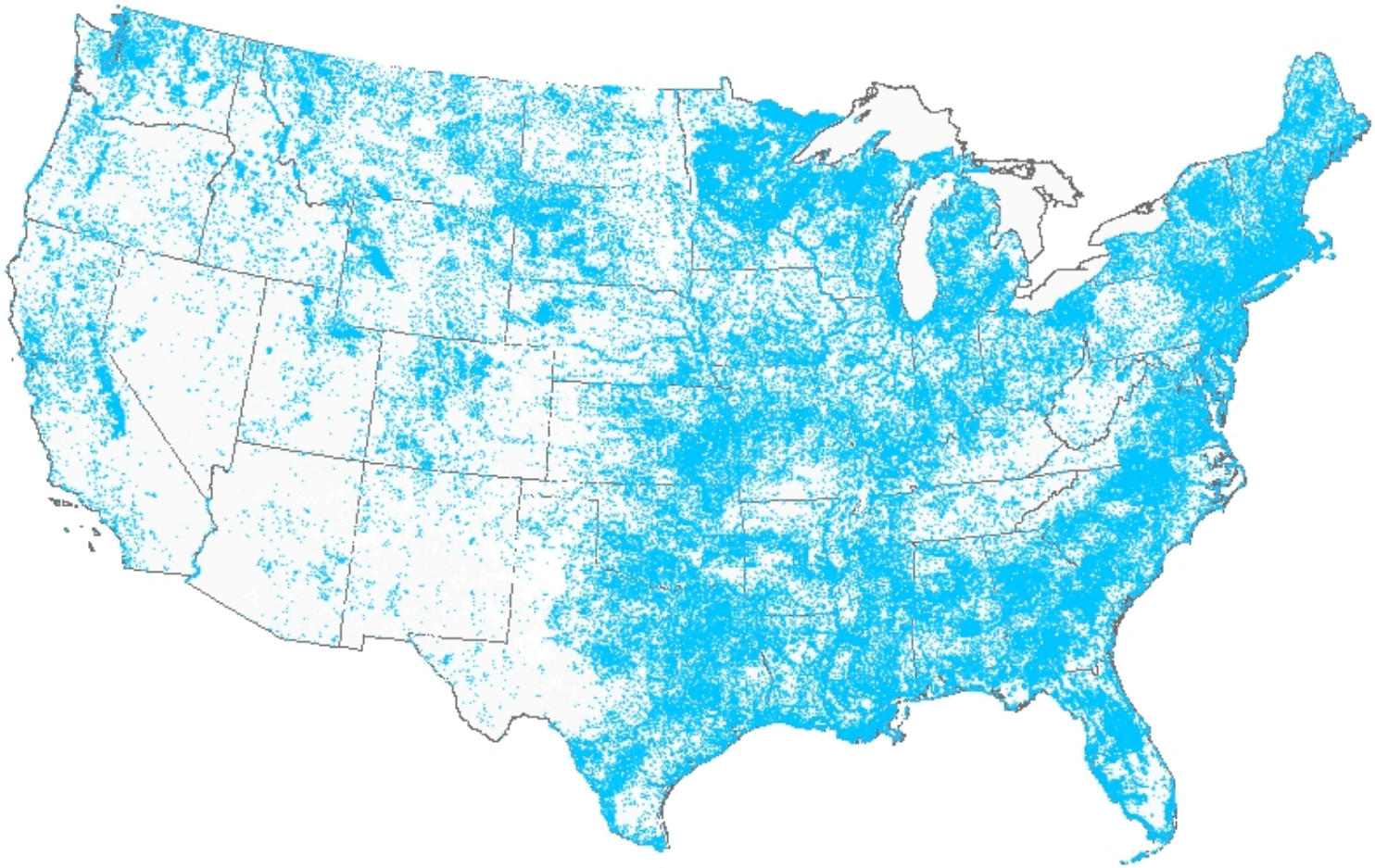
NHD Lakes

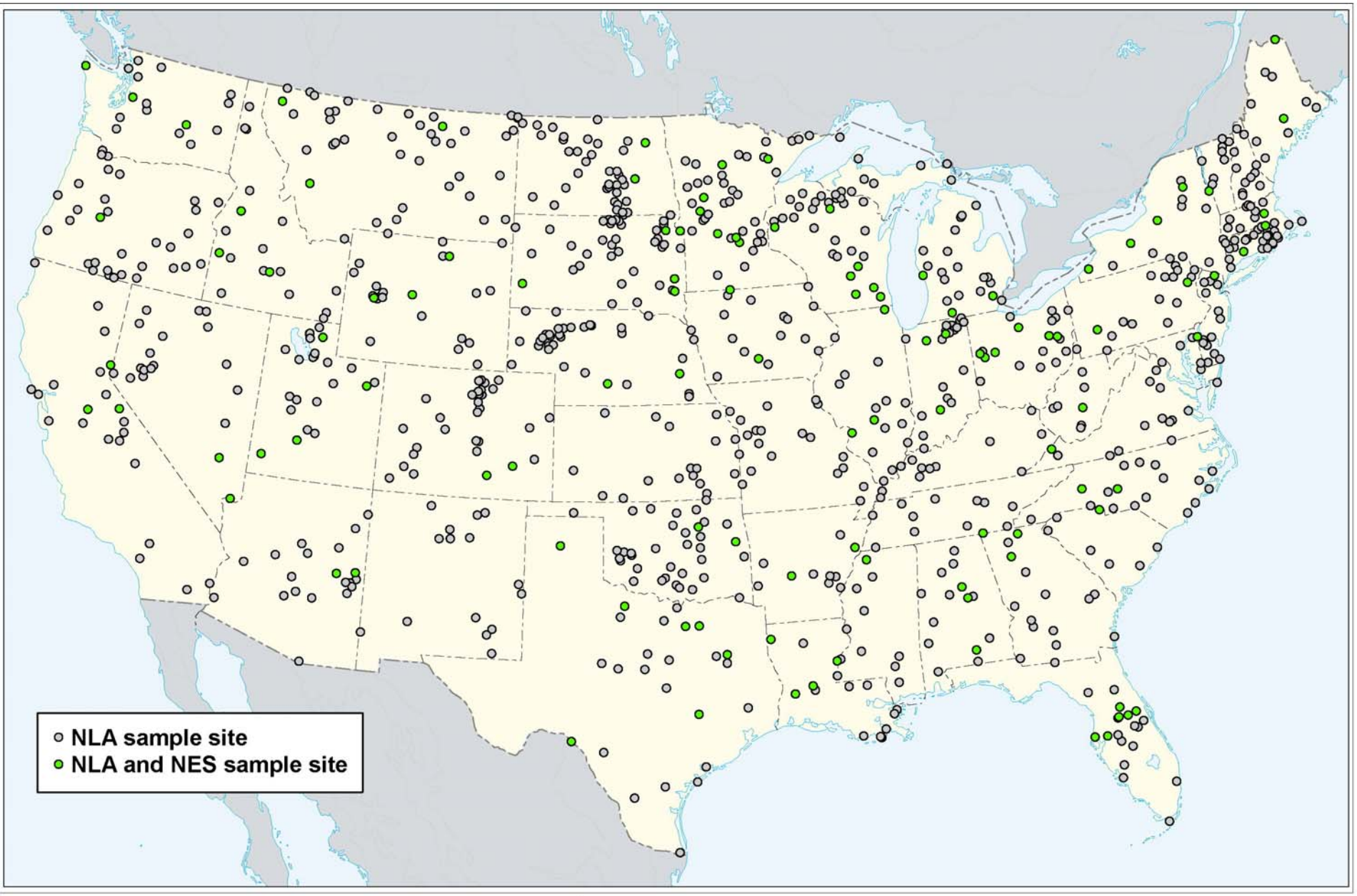


Lake Design: National Lake Assessment

- Monitoring Objectives
  - Estimate number of lakes in 48 states that are in “good” condition nationally and by 9 aggregated ecoregions
  - Estimate change in eutrophication status for 1972-76 National Eutrophication Study lakes
- Target Population and Resource Characteristics
  - All lakes/reservoirs/ponds greater than 4 hectares
  - Elements are individual lakes
  - Very skewed lake area size distribution
- Sample Frame
  - Shapefile based on NHD
  - Attributes for state, lake area category, ecoregion, and NES lake
- Institutional Constraints
  - Total number of lakes that can be sampled: 1000
  - States operate independently
  - Survey occur in one year

NHD Lake Sample Frame: Points




NLA sample site
NLA and NES sample site

National Lake Survey: Overview

Distribution of Lakes in Survey

Lake Size Category	# of Lakes Selected	Total # of Lakes in the US
10-25 acres (4-10 hectares)	104	68,559
25-50 acres (10-20 hectares)	185	24,902
50-125 acres (20-50 hectares)	184	16,488
125-250 acres (50-100 hectares)	172	6,134
> 250 acres (>100 hectares)	264	7,356
Total	909	123,439

Total number of lake visits: 1,000
909 unique lakes
91 lakes for repeat sampling

Number of Lakes from 1972-76 National Lake Eutrophication Study (NES):
113

Number of Lakes per state:
Range: 4-41

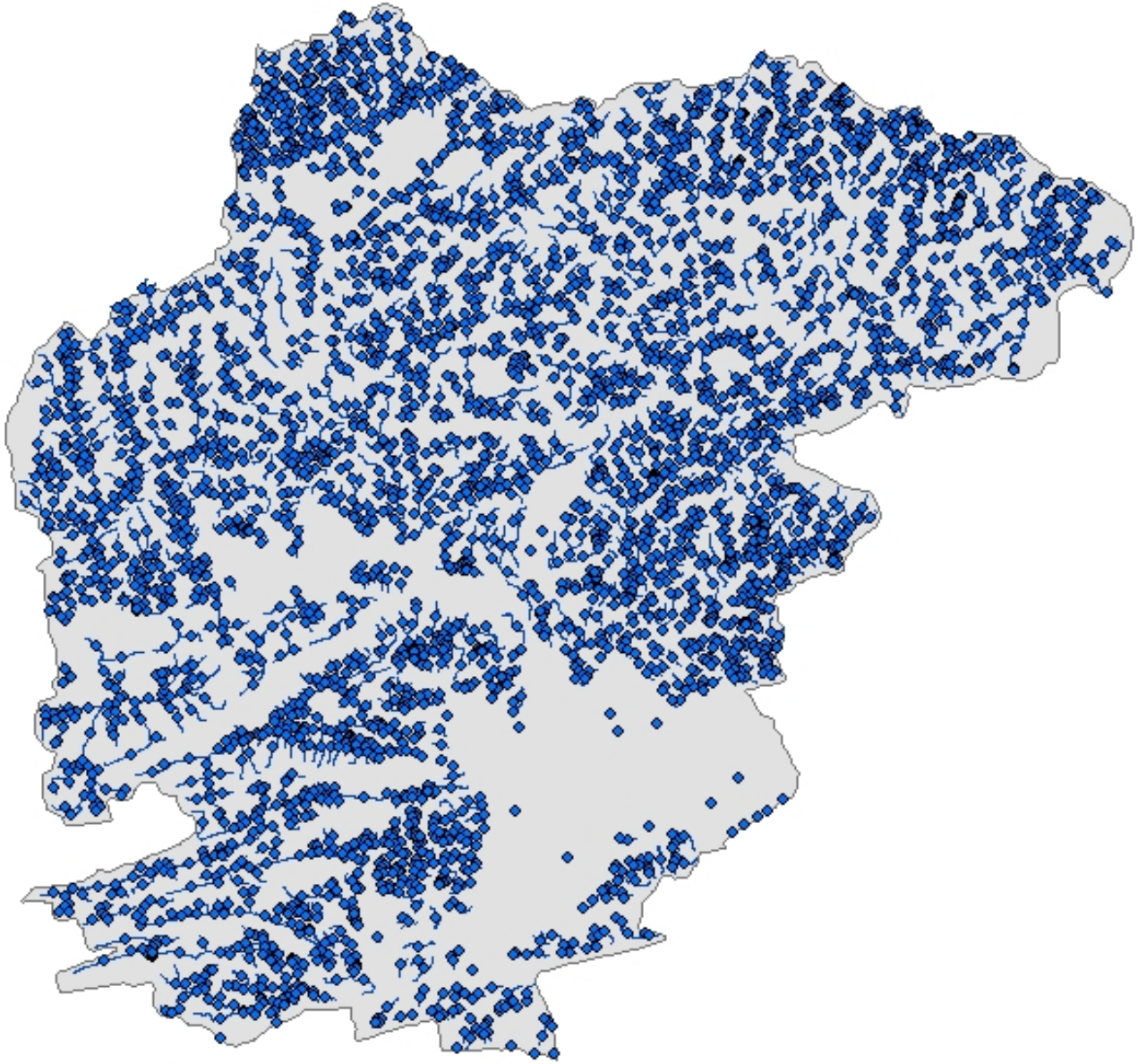
Median: 18

Number of lakes per ecoregion:
Range: 84-119

Median: 101

Stream Network for North Central Basin

Stream Network for North Central Basin

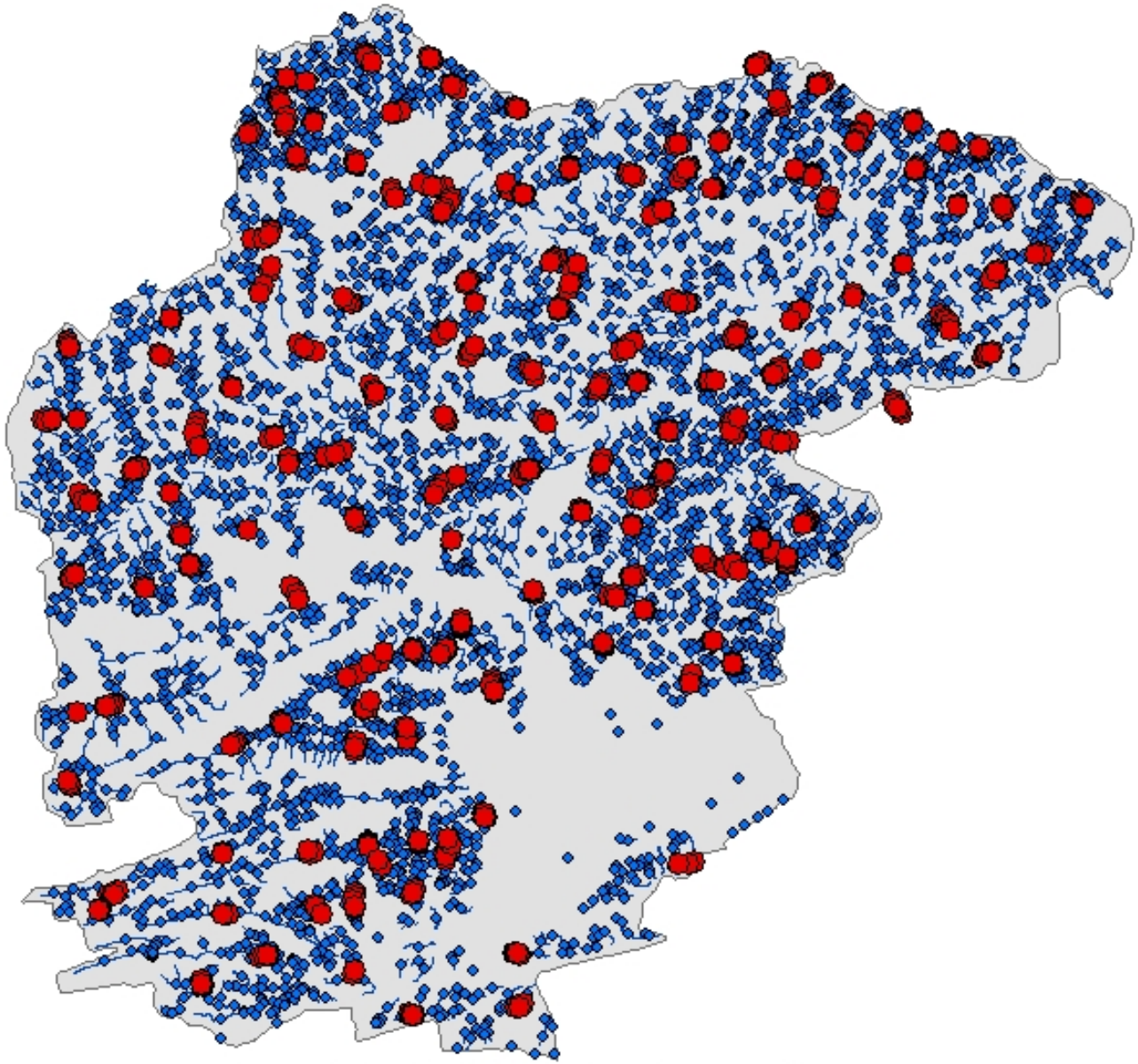


Points are centroid of attaining segments

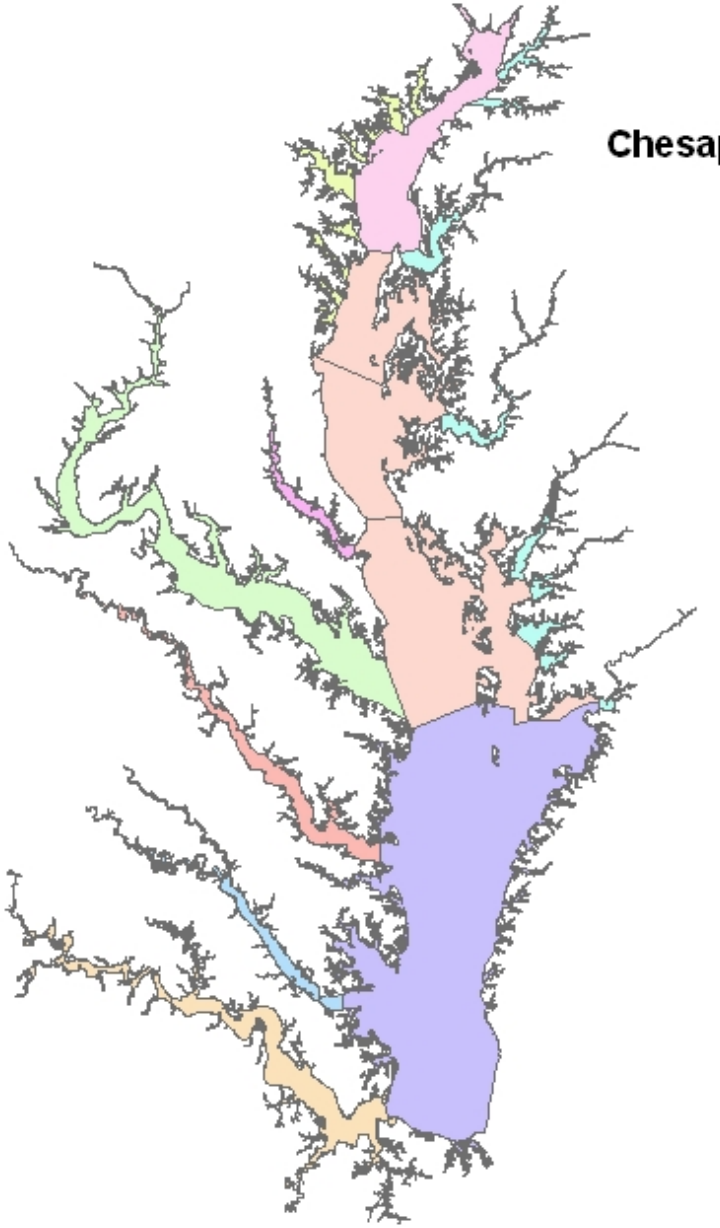
Stream Design: Pennsylvania Attaining Segments

- Monitoring Objectives
  - Estimate number of currently attaining stream segments within each basin that remain attaining
- Target Population and Resource Characteristics
  - All attaining stream segments within each basin in Pennsylvania
  - Elements are stream segments not point on stream linear network
- Sample Frame
  - Polyline shapefile of stream network and point shapefile of segment centroids
- Institutional Constraints
  - 30 segments sampled per basin
  - 5 random locations on each of the 30 segments; one of which will be sampled
- Two-stage spatial survey design
  - Stage 1: select equal probability sample of segments within basin using GRTS for finite/point resource
  - Stage 2: select sites within each segment using GRTS for linear resource

Stream Network for North Central Basin



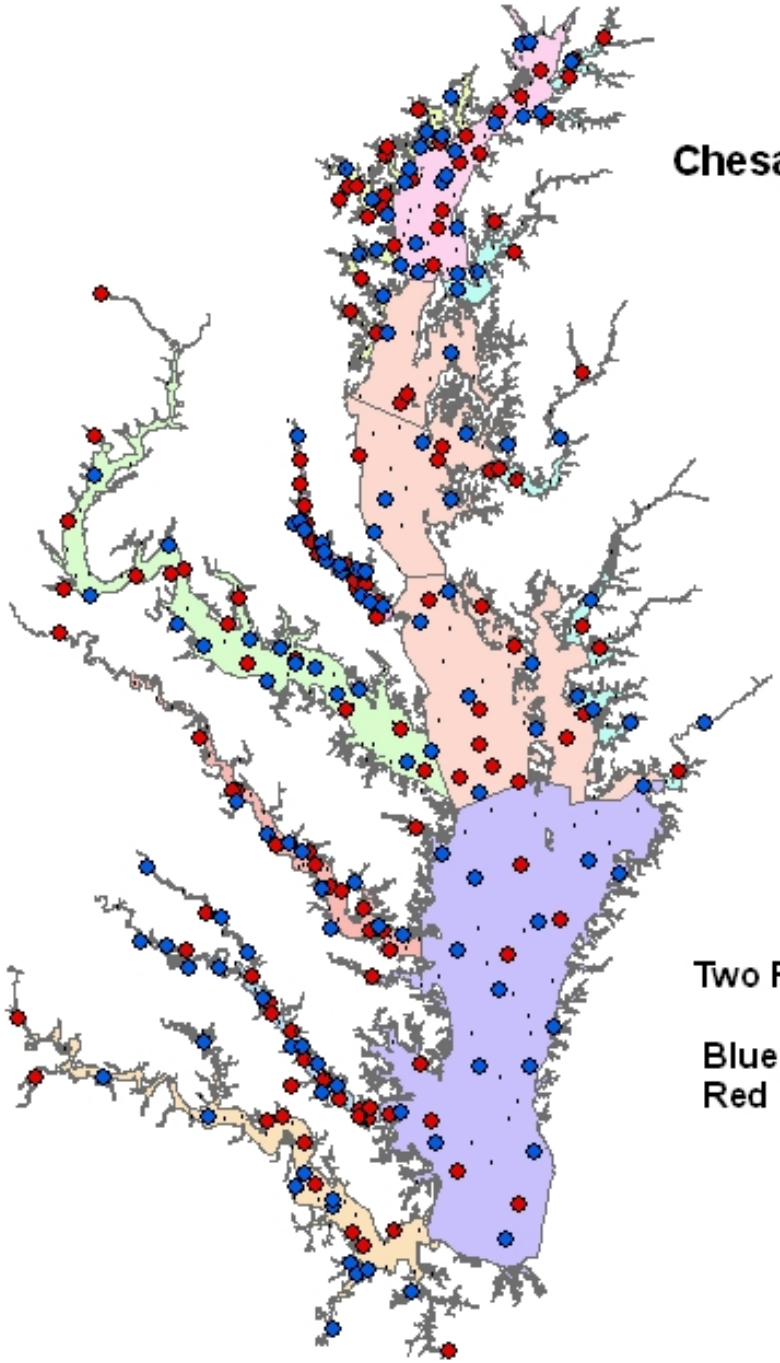
Red Selected Attaining Segments



Chesapeake Bay Sample Frame with subregions

Estuary Design: Chesapeake Bay NCA

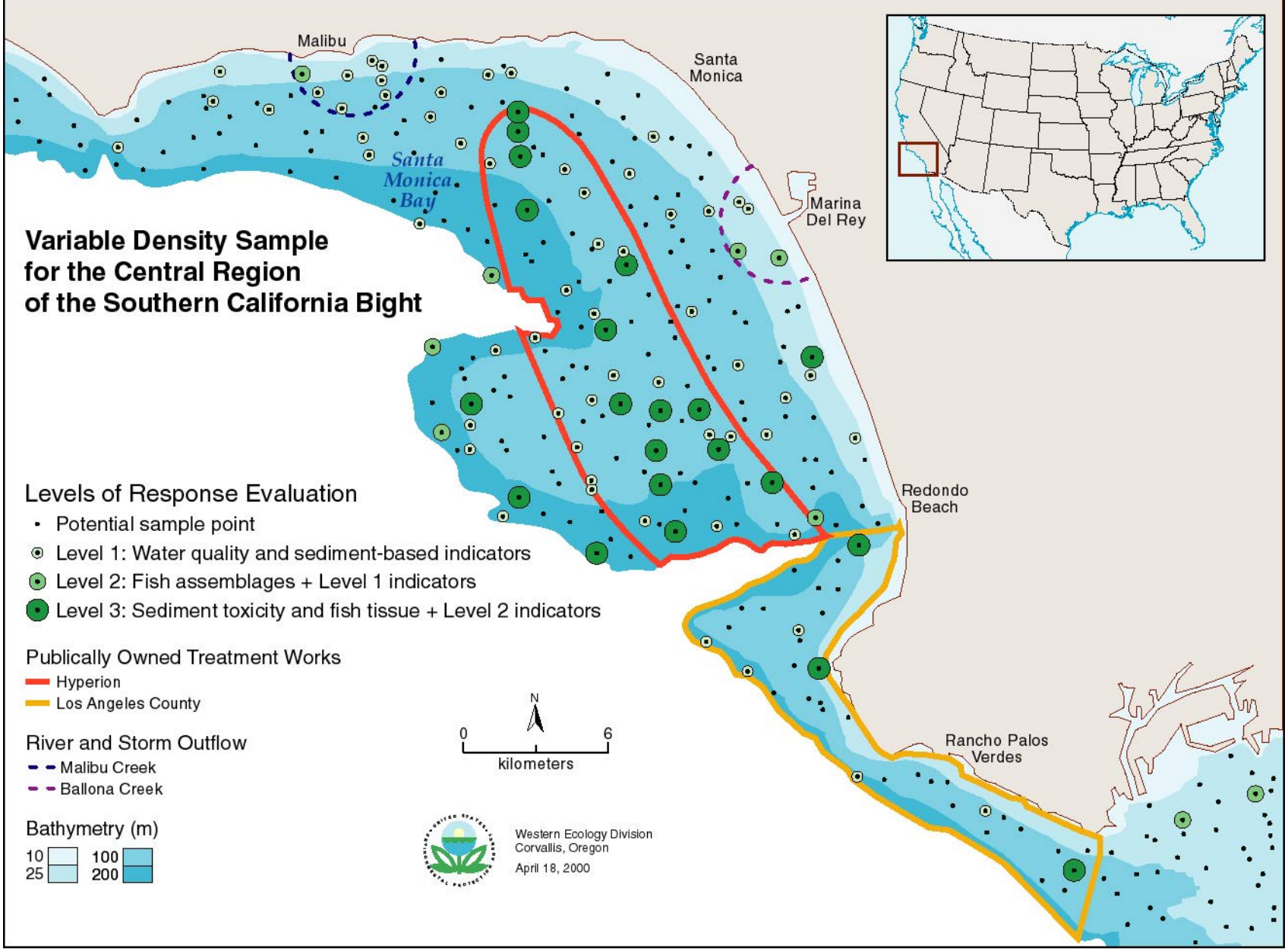
- Monitoring Objectives
  - Estimate the square kilometers of Chesapeake Bay and 10 subregions that are in “good” condition
- Target Population and Resource Characteristics
  - Surface area of Chesapeake Bay estuary
  - Elements are all locations
  - Subpopulations are 10 subregions
- Sample Frame
  - NCA generated polygon shapefile
  - Attribute for subregions
- Institutional Constraints
  - 125 sites sampled in 2005 and 2006
- Spatial survey design for an areal resource with unequal probability for 10 subregions



Chesapeake Bay Sample Frame with subregions

Two Panel Unequal Probability Design

Blue 2005 sites
Red 2006 sites



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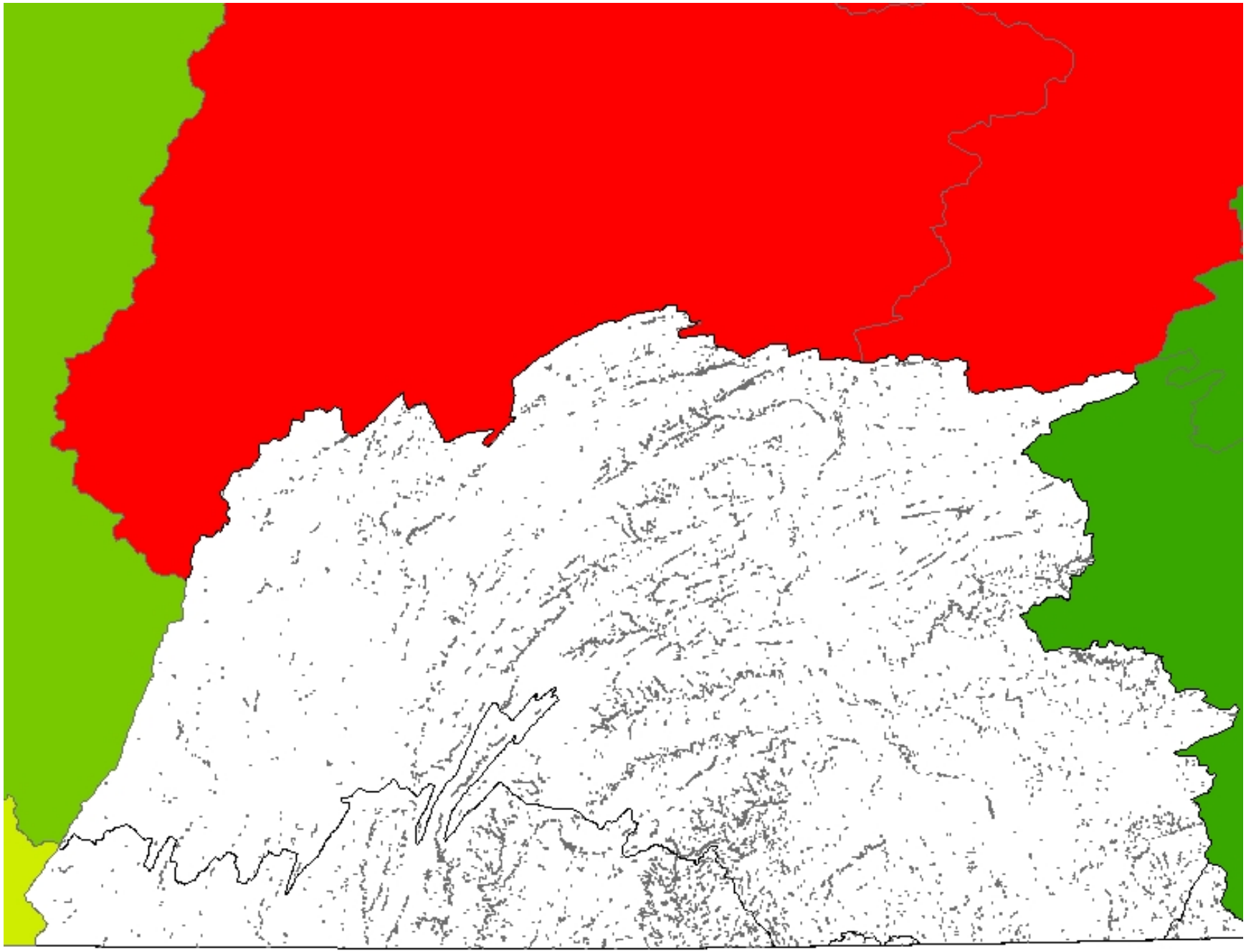
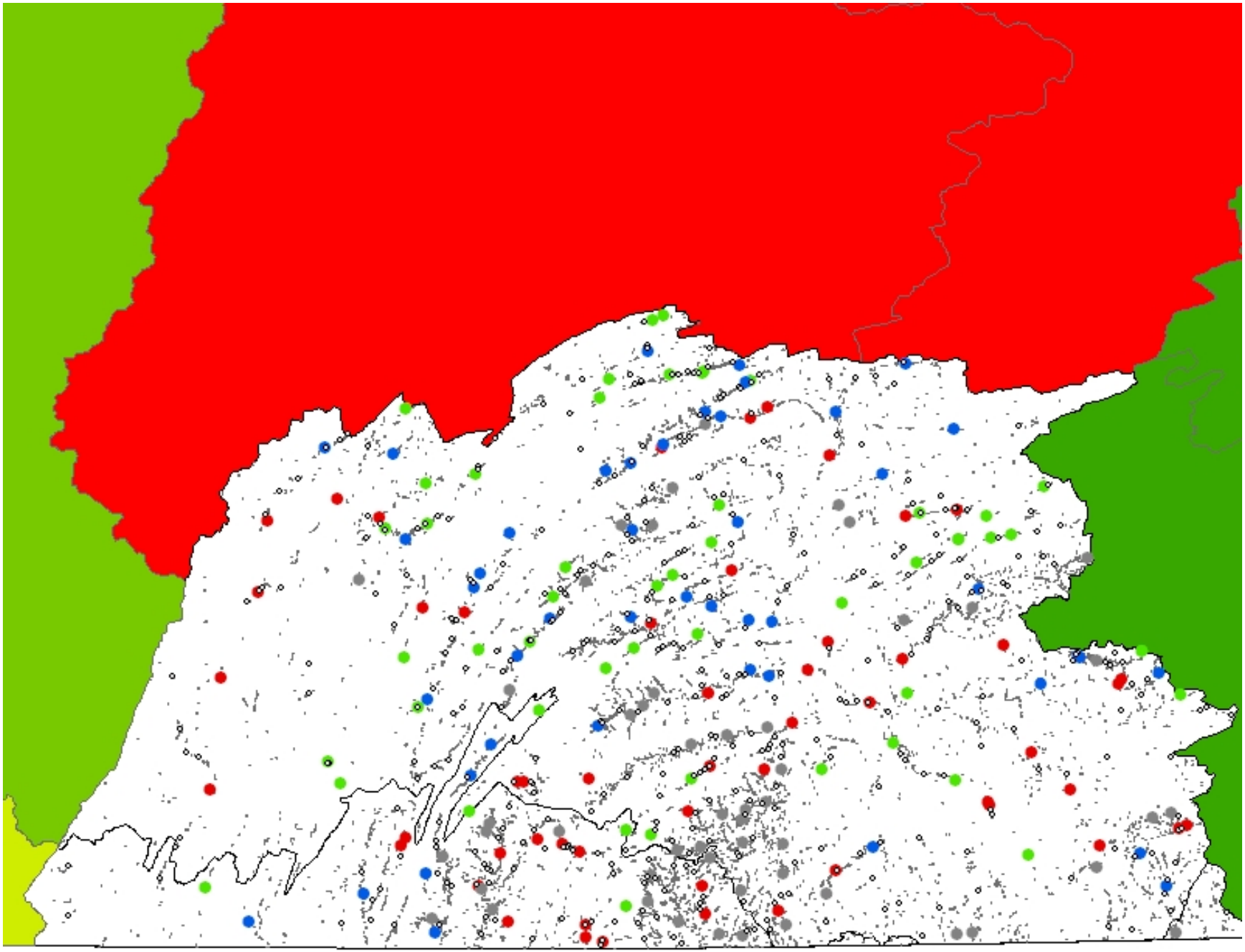
4/18/00 smp



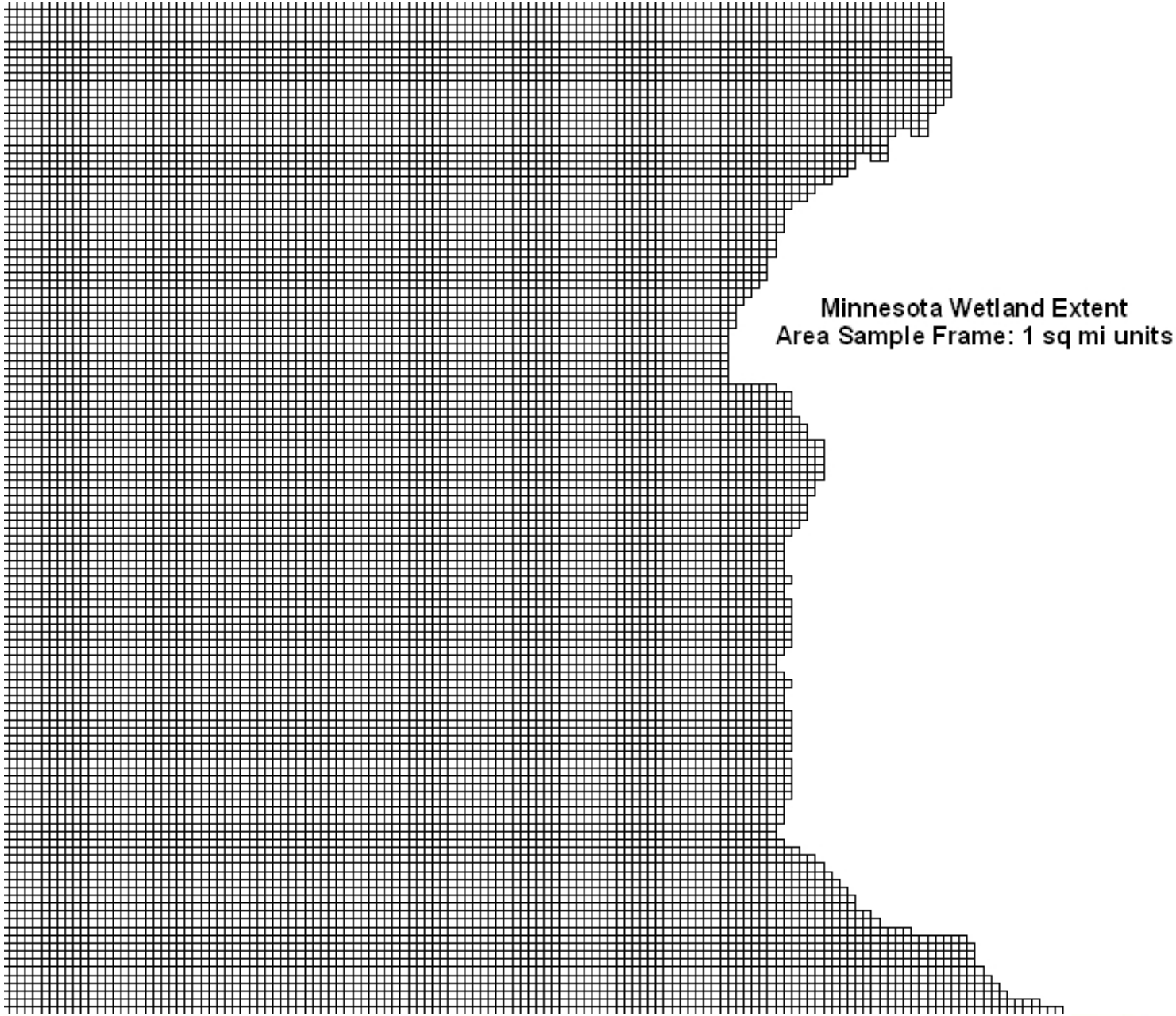
Palustrine Wetland Polygons

Wetland Design: Pennsylvania

- Monitoring Objectives
  - Estimate number of hectares of palustrine wetlands that are in “good” condition based on a level 2 assessment for each basin in Pennsylvania and for four landcover classes within each basin
- Target Population and Resource Characteristics
  - All mapped NWI vegetated wetlands within the Palustrine Emergent, Palustrine Scrub Shrub and Palustrine Forested classifications that have a predominance (>50%) of emergent, herbaceous or woody vegetation
  - Elements are all possible locations within the mapped polygons
- Sample Frame
  - NWI polygon shapefile restricted to palustrine classes defined
  - Attributes added identify 4 landcover classes and reporting basins
- Institutional Constraints
  - Monitoring to be completed over 5 years; each year a basin in each of the six reporting regions of state will be sampled
  - Expected sample size of 50 in each landcover class in each basin
  - Over sample of 200% due to sample frame deficiencies
- Spatially balanced survey design for an areal resource with unequal probability

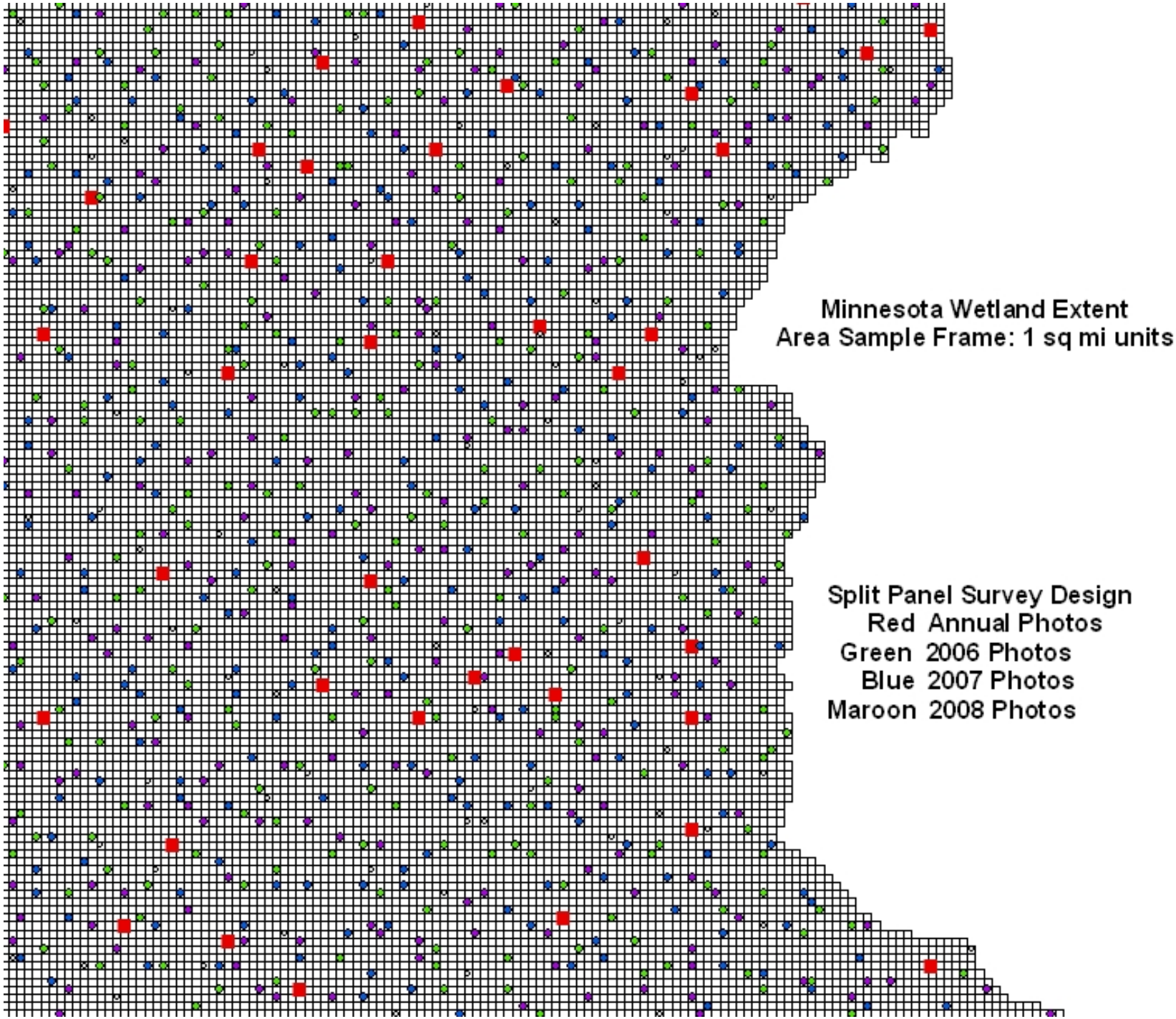


Palustrine Wetland Polygons


Minnesota Wetland Extent
Area Sample Frame: 1 sq mi units

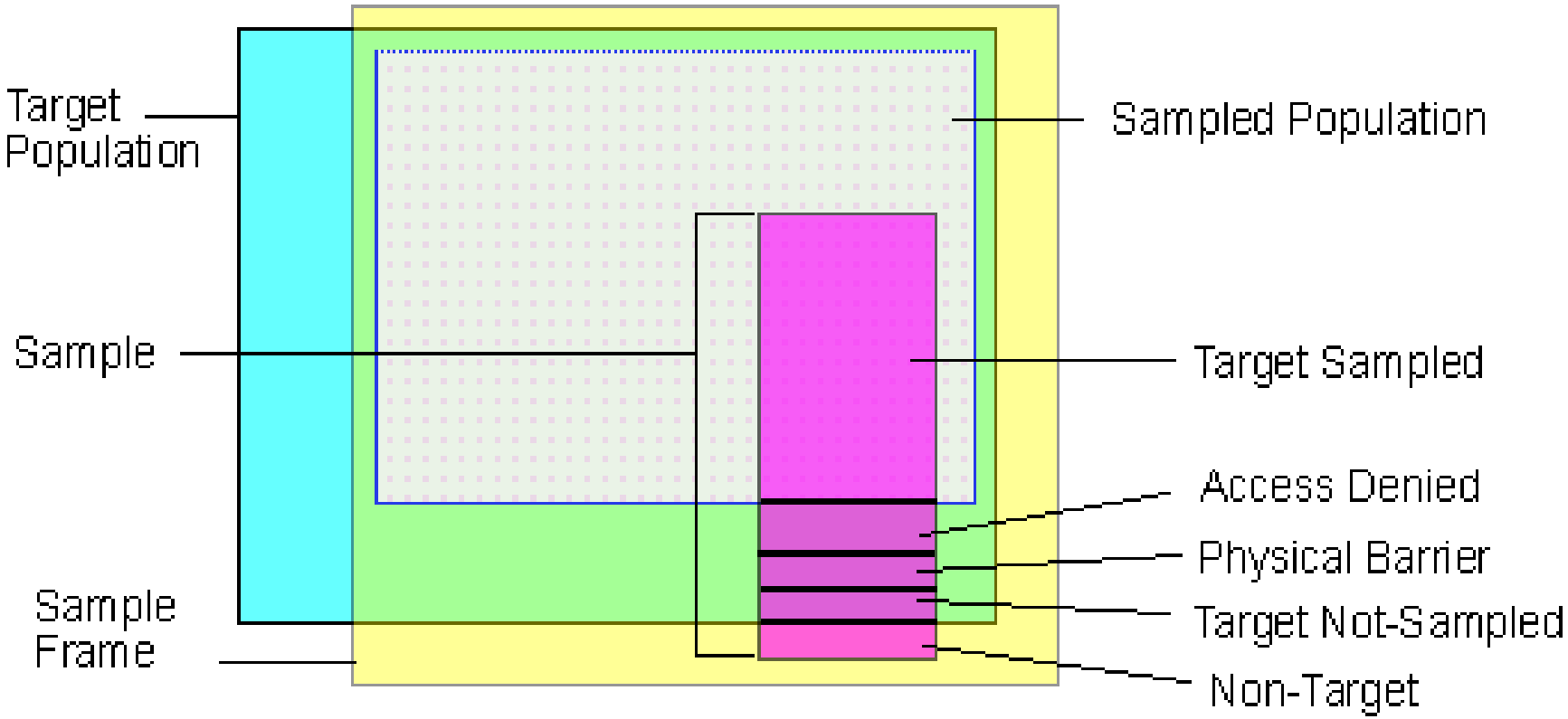
Wetland Design: Minnesota

- Monitoring Objectives
  - Estimate total hectares of wetlands by wetland class and major basin in Minnesota
  - Estimate number of hectares of depressional wetlands that are in good condition by major basin and state-wide
- Target Population and Resource Characteristics
  - All wetlands that can be identified from aerial photointerpretation using USFWS NWI status and trends mapping procedures
  - For extent the elements are 1 sq mile pixels that cover Minnesota
  - For condition the elements are all locations within wetland polygons delineated on aerial photos
- Sample Frame
  - For extent, a point shapefile of centroids of 1 sq mile pixels: an “area frame”
  - For condition, all wetland polygons within sampled extent pixels
- Institutional Constraints
  - 1800 1 sq mile pixels can be photo interpreted each year
  - Must cover entire state each year
- Two stage survey design
  - Stage 1: Split panel design (annual repeat panel, 3 year panels) equal probability
  - Stage 2: GRTS design for area resource: remainder to be determined


Minnesota Wetland Extent
Area Sample Frame: 1 sq mi units
Split Panel Survey Design
Red Annual Photos
Green 2006 Photos
Blue 2007 Photos
Maroon 2008 Photos

Target Population, Sample Frame, Sampled Population

We Live in an Imperfect World…



Ideally, cyan, yellow, gray squares would overlap completely

http://www.epa.gov/nheerl/arm

Aquatic Resource Monitoring - Microsoft Internet Explorer

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Aquatic Resources Monitoring

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- Aquatic Resource Monitoring
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- Introduction
- Design & Analysis
  - Process Overview
  - Design: How to
    - GRTS Designs
  - Analysis: How to
  - Download Software
- Aquatic Resources
  - Estuaries
  - Lakes
  - Streams
  - Wetlands
  - Great Rivers
- Indicators
- Monitoring Programs
  - Office Water

Aquatic Resources Monitoring Web Site

Environmental Monitoring and Assessment Program

Hosted by the
Monitoring Design and Analysis Team
USEPA ORD
National Health and Environmental Effects Research Laboratory,
Western Ecology Division,
Corvallis, OR

This Web site provides information on monitoring of aquatic resources in the US, primarily focused on design and analysis of probability based surveys. Links are provided to other aquatic resources monitoring information available on the internet.

ARM is designed to provide users needing information in several areas:

1. Introductory, conceptual and overview information on the overall approach, concepts and benefits.
2. Program level information on details of the approach, requirements, alternatives and examples.
3. Technical level information on the design and analysis details, including access to example data sets, results and statistical algorithms.
4. Implementation Issues, Indicators, and Field Manuals
5. Presentation and training materials
6. Reference information, internet links, brief descriptions of Federal, State, Tribal monitoring and research programs on aquatic resource monitoring.
7. Related publications and documents and program links.

Check out Current Events and Related Information. For Navigational Hints visit the Site Map

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