Monitoring Design: Component Details

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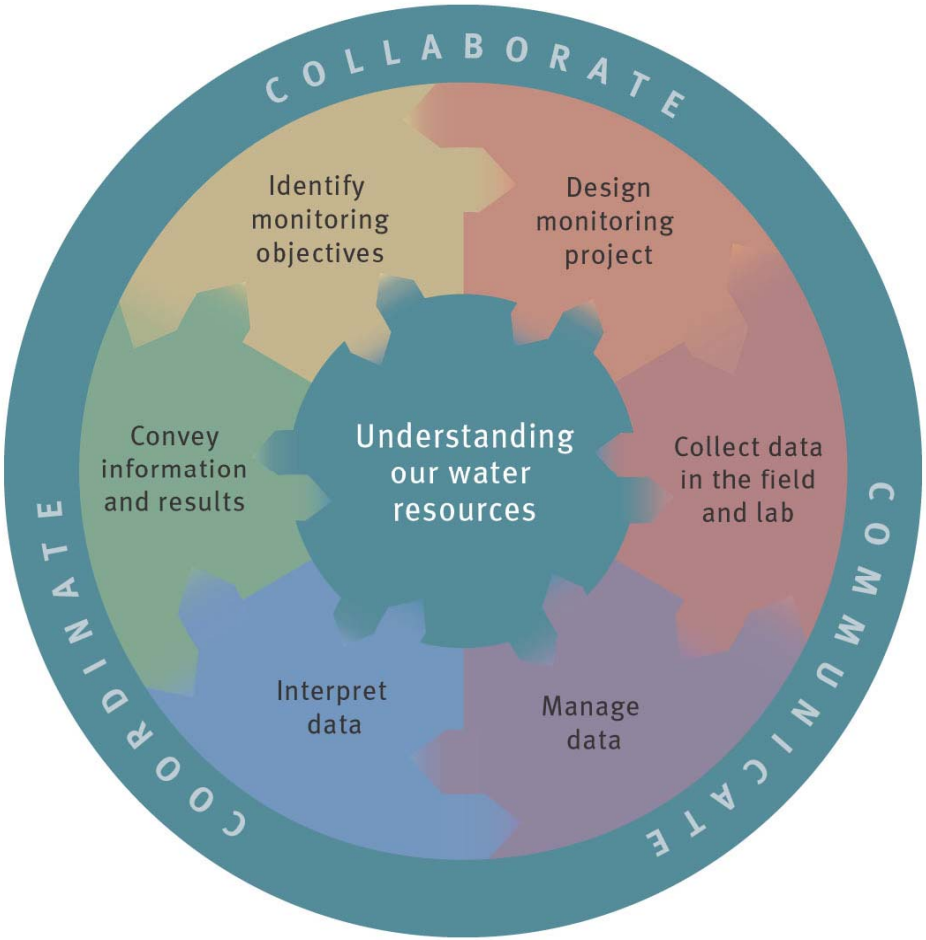
National Water Quality Monitoring Council: Monitoring Framework



- View as an information system
- Monitoring pieces must be designed and implemented to fit together
- Comprehensive monitoring strategy can become central organizing approach to managing all waters in a state

Monitoring Components
Objectives-Design-Analysis-Report

- **Monitoring objectives**
- **Institutional constraints**
- **Target population**
- **Sample frame**
- **Indicators and response design**
- **Design requirements**
- **Specification of survey design**
- **Site selection**
- **Site evaluation**
- **Conduct field and lab measurements**
- **Indicator results database**
- **Sample frame summary**
- **Adjust survey weights based on implementation**
- **Target population estimation**
- **Report results**

Identify Monitoring Objectives

- Monitoring program weakness: Objectives for monitoring are not clearly, precisely stated and understood
- Objectives must be linked to management decisions and reporting requirements
- Objectives determine the monitoring design
  - Usual to have multiple objectives
  - Precise statements are required
  - Objectives must be prioritized
  - Objectives compete for samples

From Questions to Objectives

- What is the overall quality of waters in the state?
- What is the overall quality of streams with flowing water during summer in the state?
- What is the biological quality of streams with flowing water during summer in the state?
- How many km of streams with flowing water during the summer are impaired, non-impaired, and marginally-impaired within the state?
  - How is impairment determined?
  - What is meant by summer?
  - Are constructed channels, canals, effluent-dominated streams included?

Objectives: Examples

- What is the nitrate concentration at the point of discharge into the receiving waters during normal operation of the facility?
- What is the average nitrate concentration within the mixing zone of the facility point discharge?
- How many km of streams within the Mohawk River watershed have nitrate concentrations greater than 40 μeq/L?
- What about time?

Monitoring Design

- What aquatic resource will be monitored (Target Population)?
- What will be measured (Indicators)?
- How will it be measured (Response Design)?
- Where will it be monitored (Site Selection)?
- How frequently will it be monitored (Time Selection)?
- How will measurements be summarized (Monitoring Analysis)

What is a Target Population?

- Target population denotes the ecological resource about which information is wanted.
- Requires a clear, precise definition
  - Must be understandable to users
  - Field crews must be able to determine if a particular site is included
- More difficult to define than most expect.
- Includes definition of what the elements are that make up the target population

Target Population: Lake Example

- All lakes (and reservoirs) within the conterminous U.S. excluding the Laurentian Great Lakes and the Great Salt Lake with permanent fish population
- A lake is defined as a permanent body of water of at least one hectare in surface area with a minimum of 1,000 sq m of open (unvegetated) water, and a maximum depth of one meter or more
- Elements are individual lakes
  - Lake is represented as a point
  - Single value for each indicator obtained for each lake

Target Population: Lake Example

- All lakes and reservoirs greater than 10 hectares in surface area within the state
  - Elements are all possible points on lake surface
  - Need to define what a lake is
- All lakes and reservoirs less than 10 hectares in surface area within the state
  - Elements are individual lakes treated as points
  - Need to define what a lake is

Target Population: Coastal Waters Example

- All estuarine areas within the state
  - Define what is estuarine
  - Is there a minimum depth?
  - Elements are all possible points within estuarine surface area
- All off-shore coastal waters within the state with depth between 30 and 100 meters

Target Population: Stream Examples

- All perennial wadeable streams (rivers) within the state
  - How is perennial determined?
  - How is wadeable determined?
  - Elements are all possible points on stream network (infinite number)
- All perennial wadeable stream reaches within the state
  - How are stream reaches defined?
  - Elements are all reaches (finite number)
- All stream channels within the state
  - How is stream channel defined?

Subpopulations and Domains

- Subsets of the target population that are of particular interest
- Examples for aquatic ecosystems
  - Ecoregions, biogeographic regions
  - All lentic resources in region with area < 100 ha
  - All lotic resources with with Strahler order < 4
  - Tidal creeks versus open water estuarine areas
  - All lotic resources with < 20% riparian canopy cover
  - All 5-th field HUCs with >10 NWI wetland polygons
  - All 6-th field HUCs with >25% Federal land ownership

Subpopulations: Impact on Design

- Objectives identify critical subpopulations with expected sample sizes: Domains
- Survey design addresses domain sample size requirements
  - Explicitly using stratification, unequal weighting
  - Implicitly when other requirements provide sufficient sample sizes
- Other subpopulations can not be defined prior to sample selection

What is a Sample Frame?

- A representation of the target population that is used to select the sample sites
  - It consists of sample units that are potential members of the sample
  - Extent (size) of the frame is obtained by summation
- Almost always are not exact representations of the target population
  - may not include some Target Population elements: undercoverage
  - may contain non-target elements, e.g., mis-identified sample units: Overcoverage

Sampling Frame: Stream Target Populations

- GIS coverage that includes all streams in the target population
- River Reach File Version 3 (RF3); NHD
- Quality of RF3 as sampling frame
  - Undercoverage: excludes some channels that appear on 1:24,000 USGS maps and not on maps
  - Overcoverage: includes some channels/features that are not in stream target population
- Impacts survey design
  - Limited information available in RF3 to help define design for domains
  - Other GIS coverages can add some attributes required

Sampling Frame: Lake Target Populations

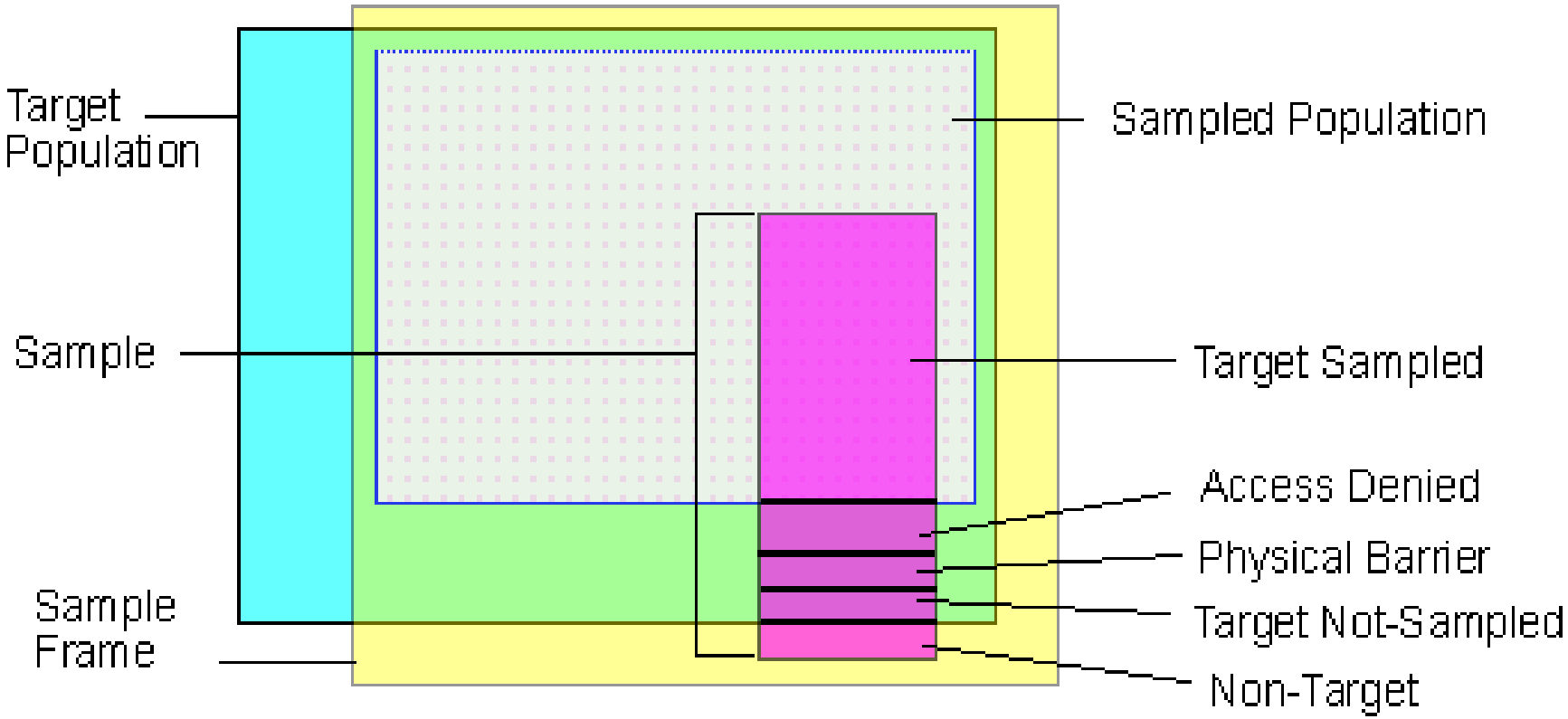
- GIS coverage of lakes and reservoirs
- RF3; NHD; state lists/coverages
- Lakes: two alternatives for elements
  - Each lake is element: lake viewed as a point
  - All points in all lakes are elements: area view
- Quality of RF3 as sampling frame
  - Undercoverage: Excludes some lakes and reservoirs
  - Overcoverage: Includes features that are not a lake or reservoir

Sampling Frame: Coastal Waters Target Populations

- GIS coverage of coastal waters in study
  - Estuary open water
  - Tidal streams
  - Near-shore waters
- Elements are all point locations within target population

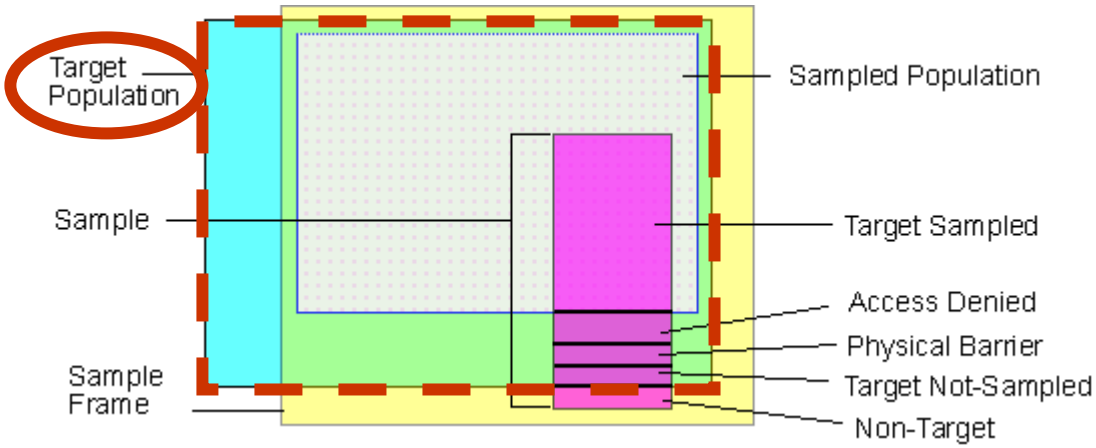
Target Population, Sample Frame, Sampled Population

We Live in an Imperfect World…



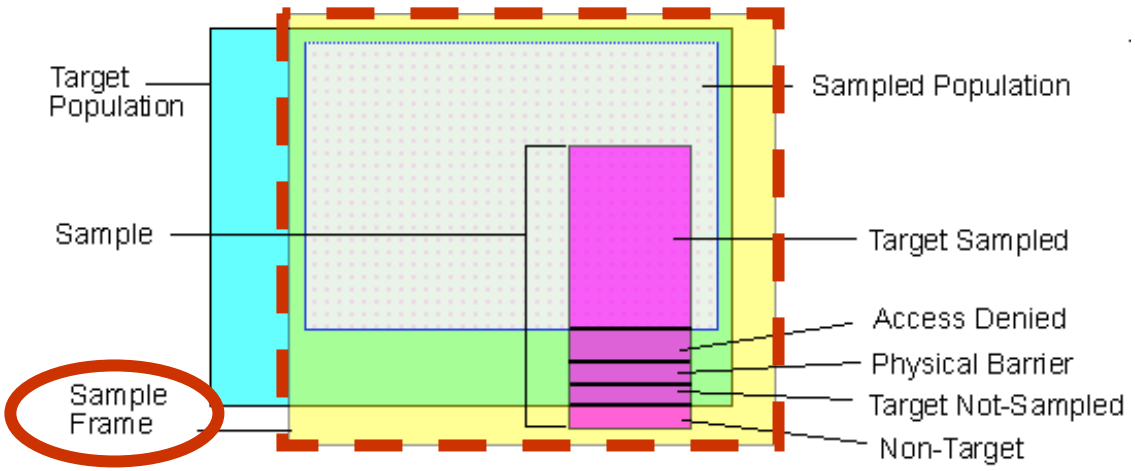
Ideally, cyan, yellow, gray squares would overlap completely

Target Population



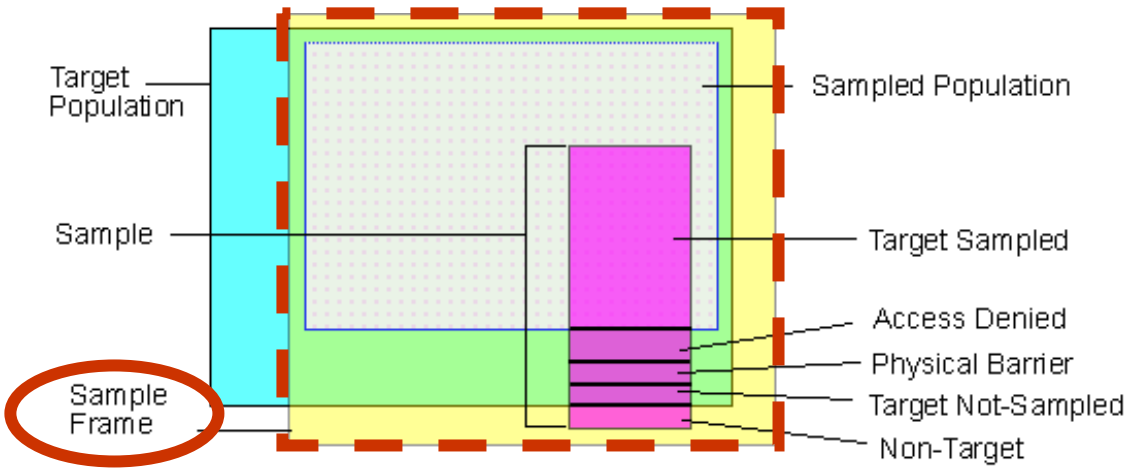
- All streams and rivers with flowing water during index period
- Collection of all streams and rivers for which we want to make inferences
- Rarely does an implemented monitoring program actually match the target population
  - Sample frame may have left some streams and rivers out
  - Some sites on streams and rivers can not be sampled

Sample Frame



- Best representation of target population
  - Some of target population may not be included in frame
  - Frame may include sites not in target population
- Only make inferences to portion of the target population that is included in the sample frame

Sampled Population



- Portion of the target population and sample frame
  - that can actually be sampled
  - to which inferences can be made
- Portion of the target population that is within the sample frame may not be sampleable due to
  - Landowner denies access
  - Physical barrier (safety) to reaching
  - Other reasons

Site Selection

- Goal is to obtain a “representative” site
  - At least 7 definitions for representative
  - Useful concept and yet difficult to obtain
- Basic Alternatives
  - Authoritative selection
    - Biased to achieve specific objective
    - Judgment based on knowledge
  - Statistical designs
- Objective is to generalize from the selected sites to the target population
- Critical link: Objectives-design-analysis

Types of Statistical Designs

- Experimental designs
  - Random allocation of treatments
- Observational studies
  - Factor space designs
    - Gradient studies
  - Available sites
- Survey designs
  - Census
  - Probability survey

Survey Design
Response Design

- Survey design is process of selecting sites at which a response will be determined
  - Probability model for inference is based on the randomized selection process
  - Has a spatial component and may have a time component
- Response design is process of obtaining a response at a site:
  - A single index period during a year
  - Multiple periods during year: monthly, quarterly

The Response Design: Index Period

- Time period within year selected for measurement (ecologically based)
- Measurements may be taken more than once during index period with response design giving protocol for obtaining single value for indicator
- Indicator variability within index period contributes to non-survey sampling error

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?

- 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
- Ecological resource occurrence in study region makes basic designs inefficient
  - Resource is known to be restricted to particular habitats

Stratification: Reasons to Use

- Administrative or operational convenience
  - Regions or states need to be operationally independent
- Particular portions of the target population require different survey designs
  - Design for extensive wetlands (Everglades) may be different from praire pothole wetlands
- Increase precision by constructing strata that are homogeneous

More complex Survey Designs

- Spatial strata random sample
  - Don’t have a list frame
  - Alternative way to spatially balance sample
- Unequal probability sample
  - Alternative to stratification
  - Requires auxiliary information
- Cluster sample
  - Can decrease field operation
- Multiple stage sample
  - Way to decrease cost of sample frame construction
- Adaptive Sampling

Stratification and Unequal Probability Selection

- Stratification: reasons
  - Improve precision of results
  - Operational/administrative efficiency
  - Different subpopulations require different survey designs
- Unequal weighting
  - Allocate sample to subpopulations
  - Improve precision of results
  - Based on auxiliary information

State-wide Monitoring: When Multiple Years Required

- Rotating basins
  - Each year monitor subset of state
    - Census
    - Probability Survey
  - Complete all subsets in 5-years
- State-wide
  - Each year sample over entire state
  - Complete all sites to be sampled in 5-years
    - Census: partition all sites into 5 subsets
    - Probability survey over time

Status, Change, Trend

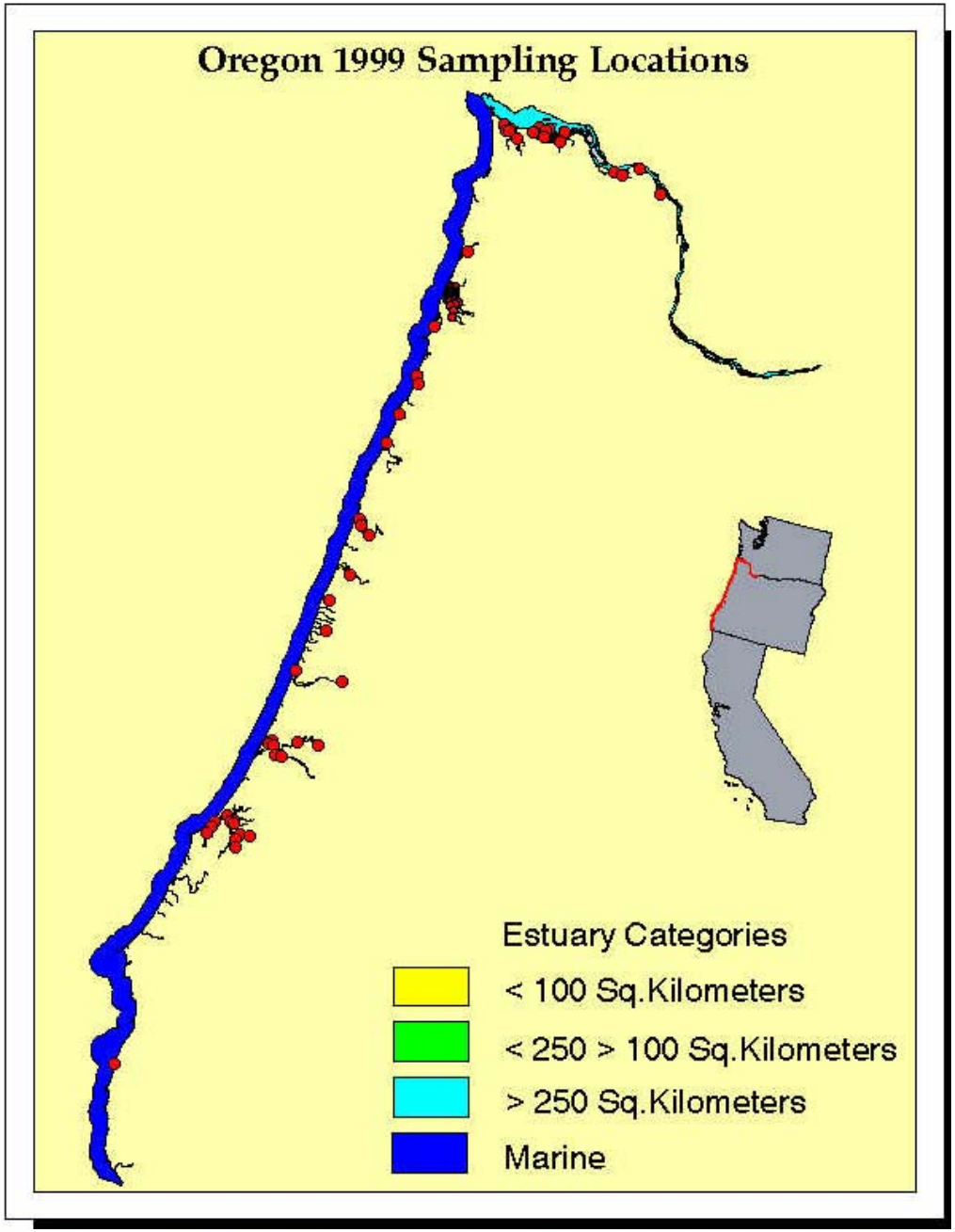
- Status
  - How many stream km in Region III meet their designated use?
  - How many stream km have degraded riparian zones?
- Change/Trends
  - Has the status of the streams in Region III changed between two time periods?
  - What is the trend over the last 10 years in the percent of stream km in Region III that meet their designated use?
  - What is the trend in nitrate concentration on the Santiam River at its confluence with the Willamette River.

Survey Design Key Components

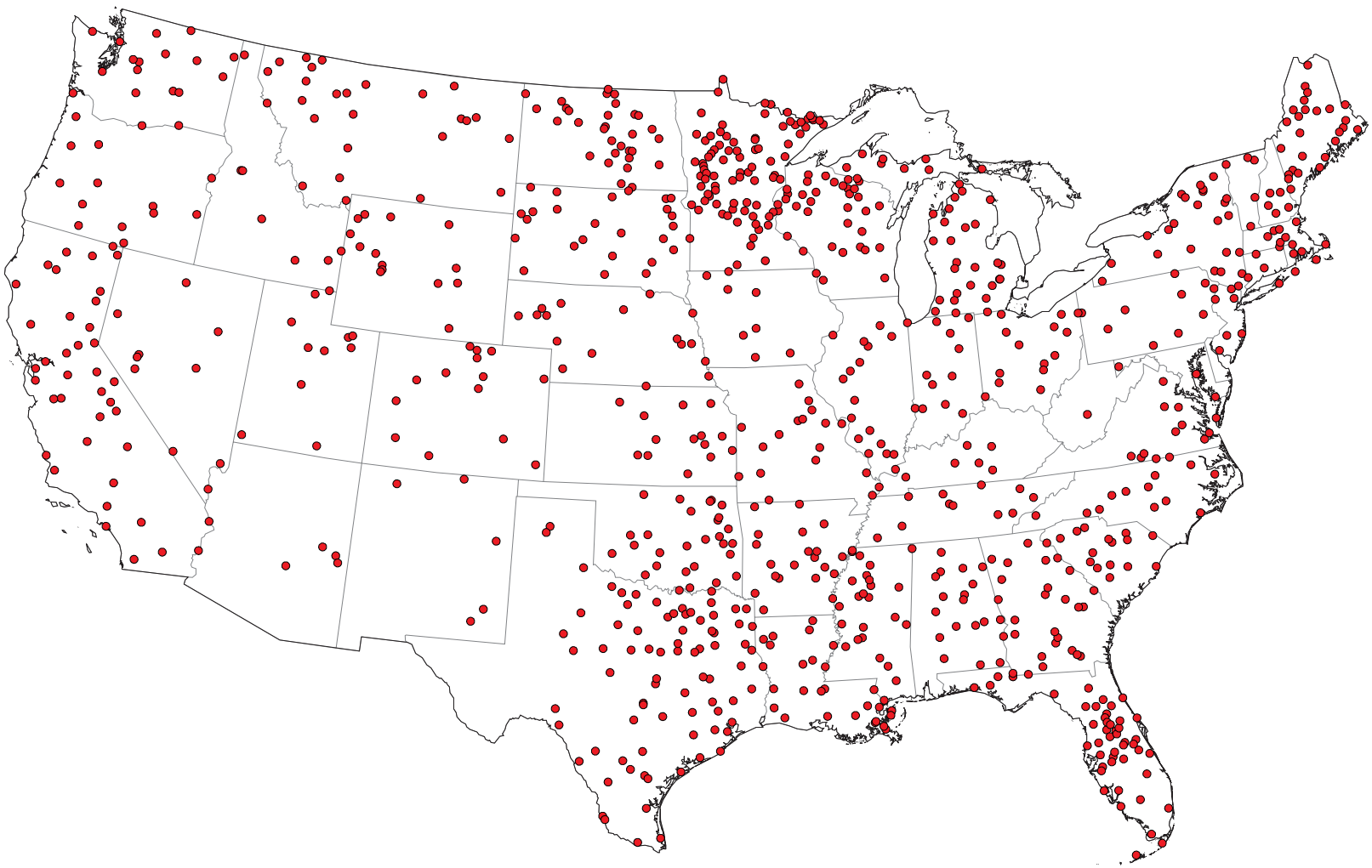
- Objectives stated precisely and quantitatively
- Target population explicitly, precisely defined
- Sampling frame constructed that represents the target population
- Decision on which survey design meets needs
- Selection of sites using survey design
- Statistical analysis match survey design

Example Designs

- Everglades marshes and canals
- Streams and rivers in 12 western states
- Headwater watersheds in coastal plains of Mid-Atlantic
- Prairie pothole wetlands in North Dakota and South Dakota
- 6-th field hydrologic units in Pacific Northwest
- Riverine wetlands associated with the Great Lakes
- All Lakes >1 ha for fish tissue contaminants

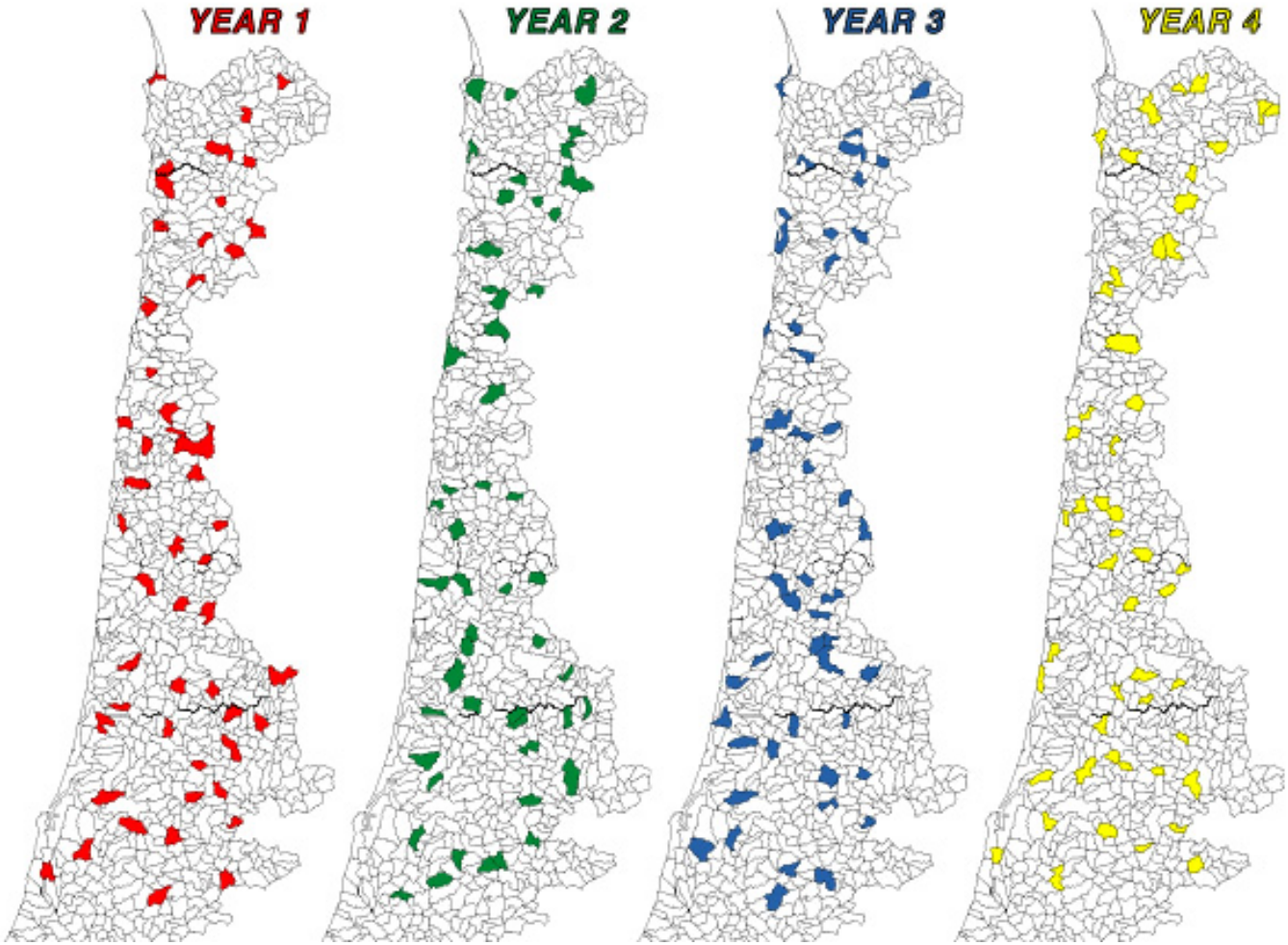

Oregon 1999 Sampling Locations
Estuary Categories
< 100 Sq.Kilometers
< 250 > 100 Sq.Kilometers
> 250 Sq.Kilometers
Marine

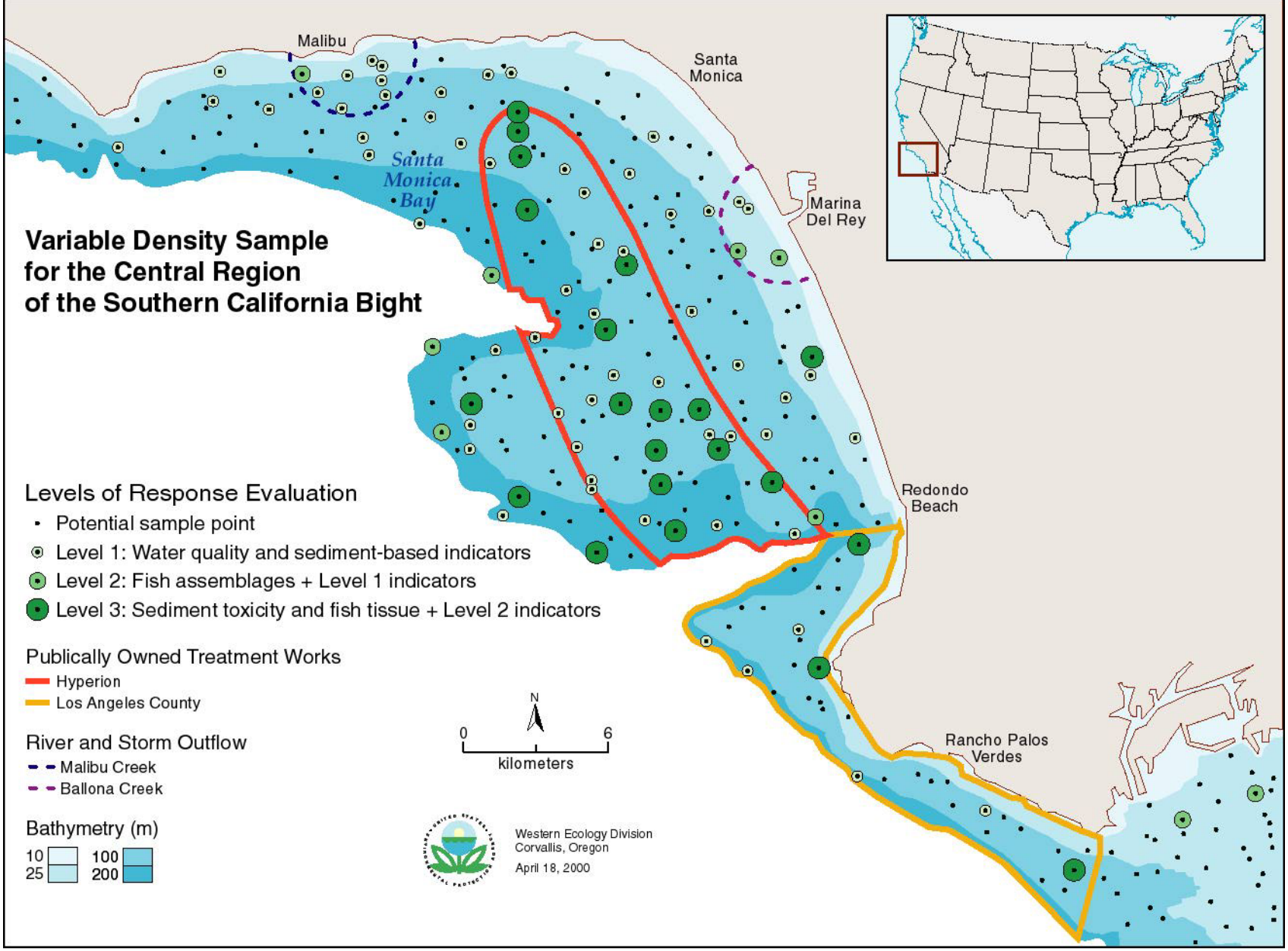
National Fish Tissue Contaminant Lake Survey



US EPA NHEERL-WED EMAP Stat&Design j199.ow.lakes/plots/owsampall.ai 5/5/1999

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





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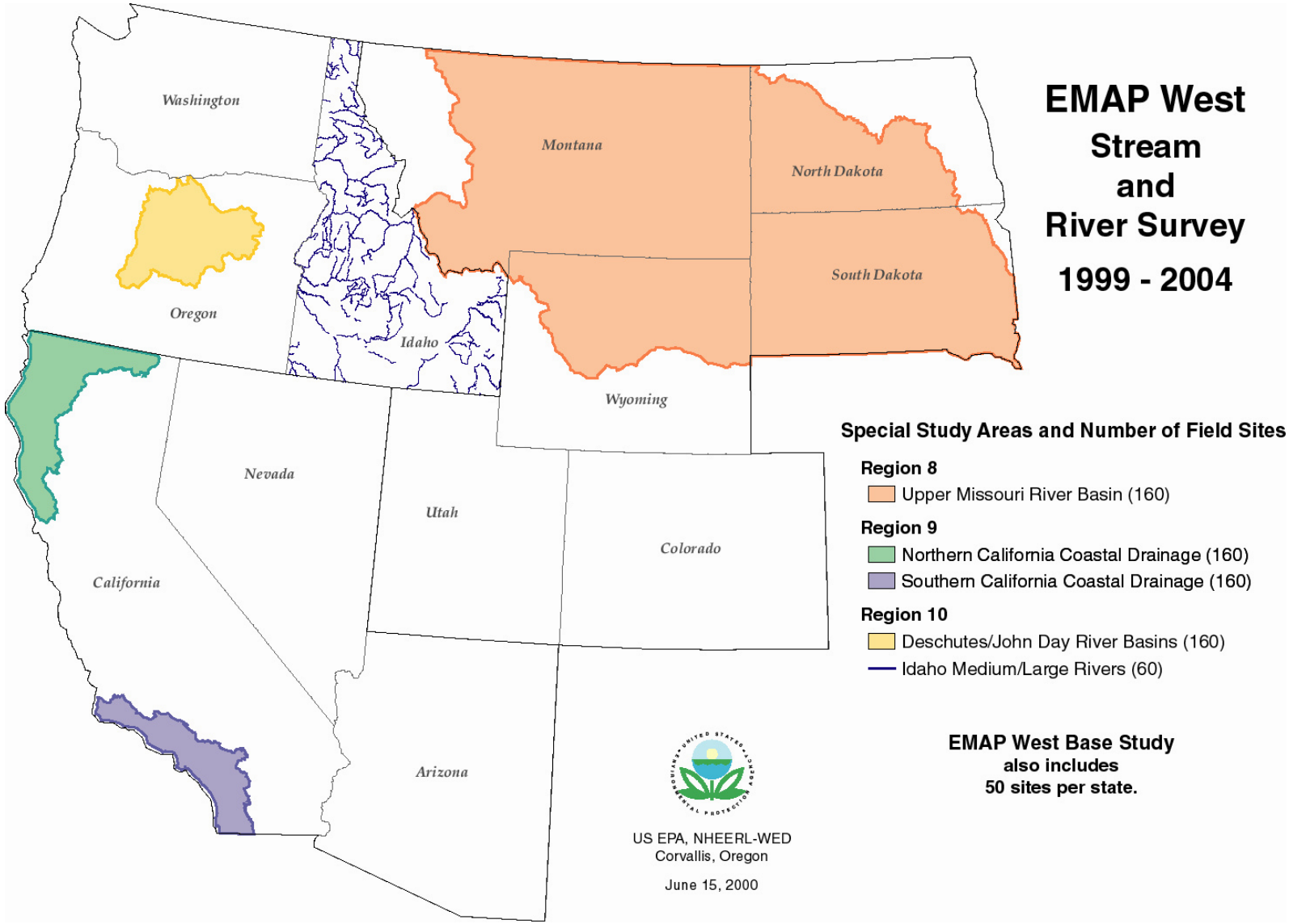
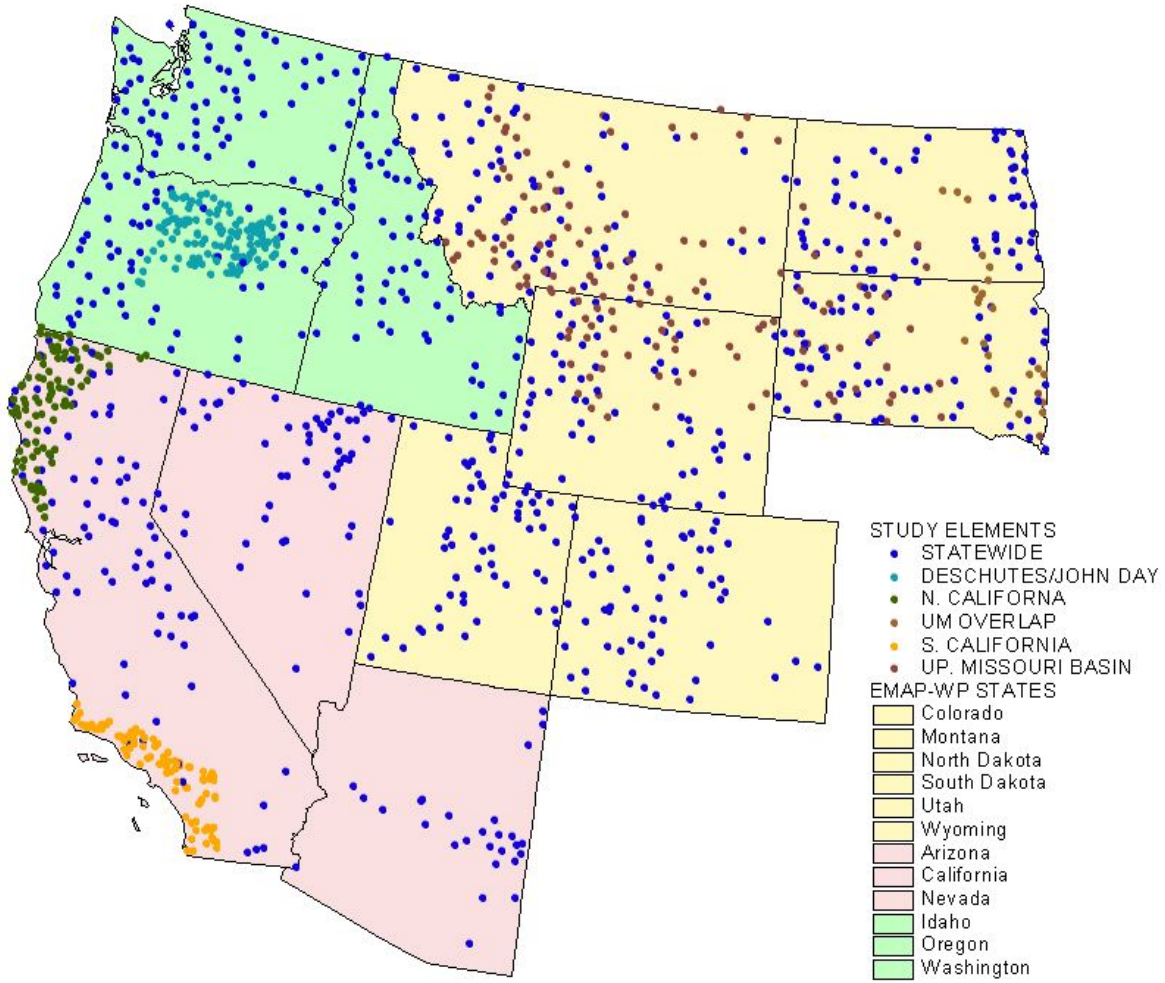

Washington
Montana
North Dakota
South Dakota
Oregon
Idaho
Wyoming
Nevada
Utah
Colorado
California
Arizona
EMAP West
Stream
and
River Survey
1999 - 2004
Special Study Areas and Number of Field Sites
Region 8
Upper Missouri River Basin (160)
Region 9
Northern California Coastal Drainage (160)
Southern California Coastal Drainage (160)
Region 10
Deschutes/John Day River Basins (160)
Idaho Medium/Large Rivers (60)
EMAP West Base Study
also includes
50 sites per state.
US EPA, NHEERL-WED
Corvallis, Oregon
June 15, 2000

PRIMARY CANDIDATE SAMPLING SITES: 2000-2003



Monitoring Design Information

- Aquatic Resource Monitoring Web Page: http://www.epa.gov/nheerl/arm
  - Overview of survey design
  - Bibliography
  - Design and analysis information
- EMAP Design Team
  - Works with States, Tribal Nations, EPA Regions, Other Federal Agencies
  - Members from ORD ecology divisions, NERL, Office of Water
  - Contact: Web page above