A Robust Design for Great River Ecosystem Monitoring And Assessment

EMAP-GRE

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Natural Resource Management

What's Missing?

"Only a few studies of the Missouri River ecology view the river as a single system from headwater to mouth, or as a single system that considers biological and physical linkages… Without this fundamental information, cast within a system-wide perspective encompassing the entire Missouri River ecosystem, truly comprehensive assessments of the Missouri River are not possible."

– National Academy of Sciences, 2002

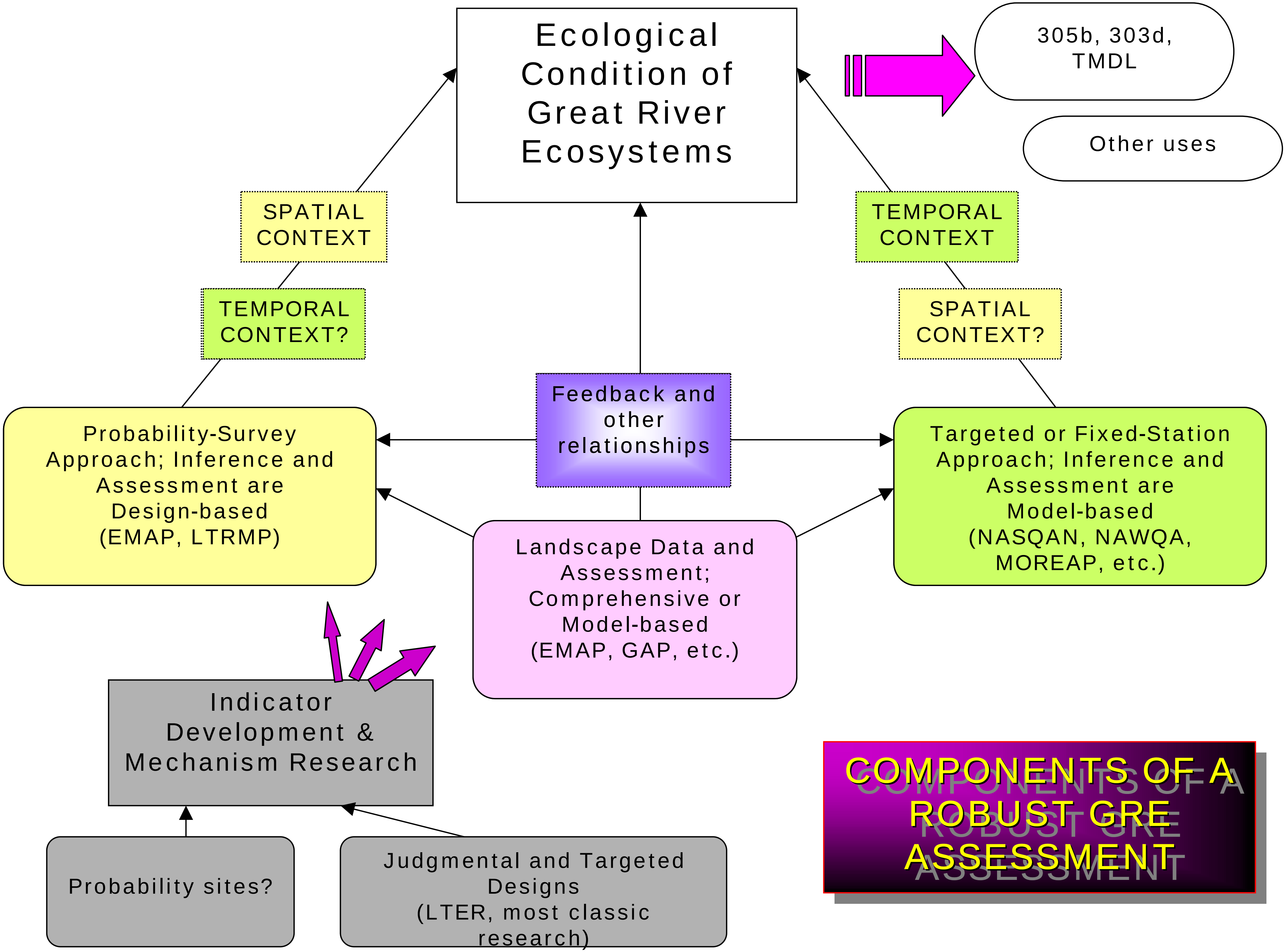
Comprehensive, large-scale, consistent monitoring of Great River Ecosystems is the vital and too often missing link

What EMAP brings to the GRE monitoring table

<u>KEY PRODUCTS:</u>

1. Research on GRE sample Designs, indicators and analytical techniques
2. Assist in development of a consistent ecological condition baseline across broad spatial scale
    1. Pilot monitoring and assessment results
    2. Initial description of trends in resource condition
    3. Identification and ranking of important stressors on GREs
    4. Integrated within a physical, chemical and landscape context

Office of Research and Development


Ecological Condition of Great River Ecosystems
305b, 303d, TMDL
Other uses
SPATIAL CONTEXT
TEMPORAL CONTEXT?
TEMPORAL CONTEXT
SPATIAL CONTEXT?
Feedback and other relationships
Probability-Survey Approach; Inference and Assessment are Design-based (EMAP, LTRMP)
Targeted or Fixed-Station Approach; Inference and Assessment are Model-based (NASQAN, NAWQA, MOREAP, etc.)
Landscape Data and Assessment; Comprehensive or Model-based (EMAP, GAP, etc.)
Indicator Development & Mechanism Research
Probability sites?
Judgmental and Targeted Designs (LTER, most classic research)
COMPONENTS OF A ROBUST GRE ASSESSMENT

The EMAP Design - Summary

Fundamental Attributes of EMAP Design

- Emphasis on ecological condition
- Broad spatial scale
- Sample survey
  - "Probability sample"
  - Representative
- Analyses via design-based inference
  - Unbiased…

EMAP Design Essentials

Inference; Design and Model-based

- **Design-based:**
  - **For each response measure (i.e., temperature) a FIXED value exists at each sampling location**
  - **NO uncertainty remains if a census of the population is done**
  - **The only variation that plays a role in estimating population statistics is the variability across probabilities of selecting sampling locations**
  - **Inference is independent from any assumptions about (statistical) population structure and distribution**

EMAP Design Essentials

Inference; Design and Model-based

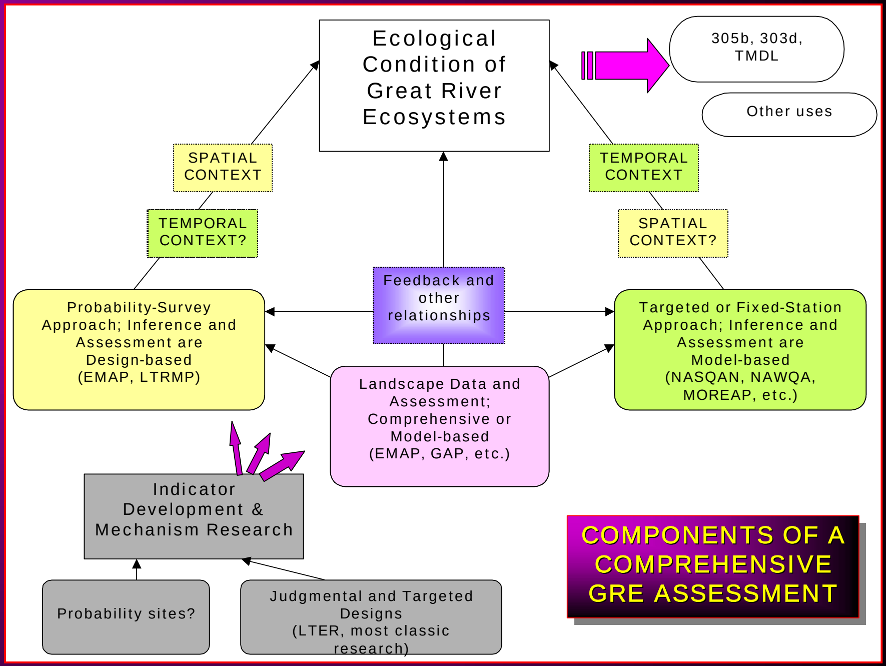
- **Model-based:**
  - **Values at a point are just one possible realization of an underlying RANDOM process**
  - **Assumptions are formalized in a model relating samples to parametric population (i.e., geostatistical or other familiar classic statistical methods)**
  - **If a census of the population is done, *one* realization of the random underlying process would be known, <u>but uncertainty in the parameters of the model remain</u>**
  - **The key variation that plays a role in estimating population statistics is the stochasticity in the assumed underlying process that controls the values at each point**
  - **Inference is NOT independent from any assumptions about (statistical) population structure and distribution**

	Design	Model
Benefits	•spatial autocorrelation may be ignored •if correctly applied with reasonable N, robustness of estimates is guaranteed •design-based inferences are more elementary from a statistical perspective •models or auxiliary data may be used to structure design details (i.e. stratification), improving efficiency •allows and strengthens use of model based inference	•mechanistic models can be formulated for long-term prediction •can be used with non-probability sample •may be advantageous for small N •may be useful when portions of population are known to be unreachable for sampling •may allow easier integration of existing data (but bias still an issue) •more familiar to most biologists
Costs	•less familiar to most biologists and resource managers •must be based on probability sample •can not directly be used for prediction	•quality of estimations depend on quality of model •models may need to be very complex with multiple parameters to fit ecological systems •with selection bias there is less confidence that model will hold for all non-sampled units •no basis for bias correction •estimates of precision may be misleading

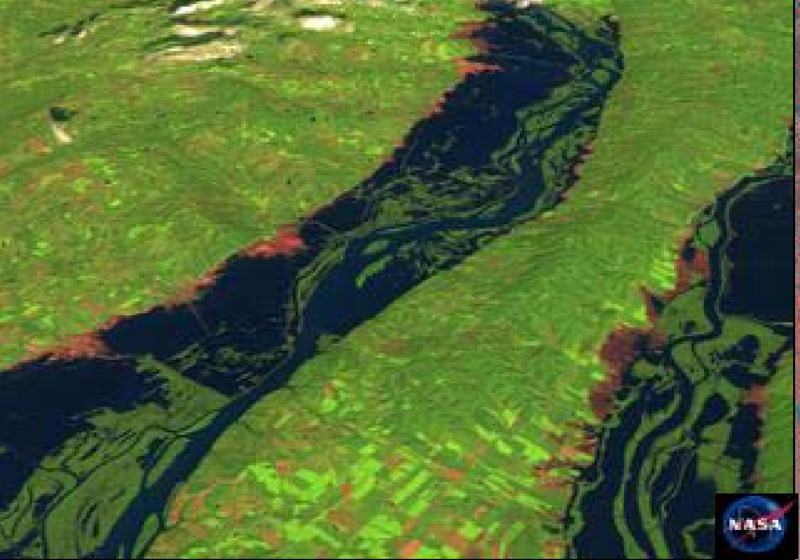
EMAP Design Essentials

Inference Methods - Comparison

- **Depends on question and goals**
- **Not Design-based *versus* Model-based**
- **Optimal monitoring approach includes both methods**



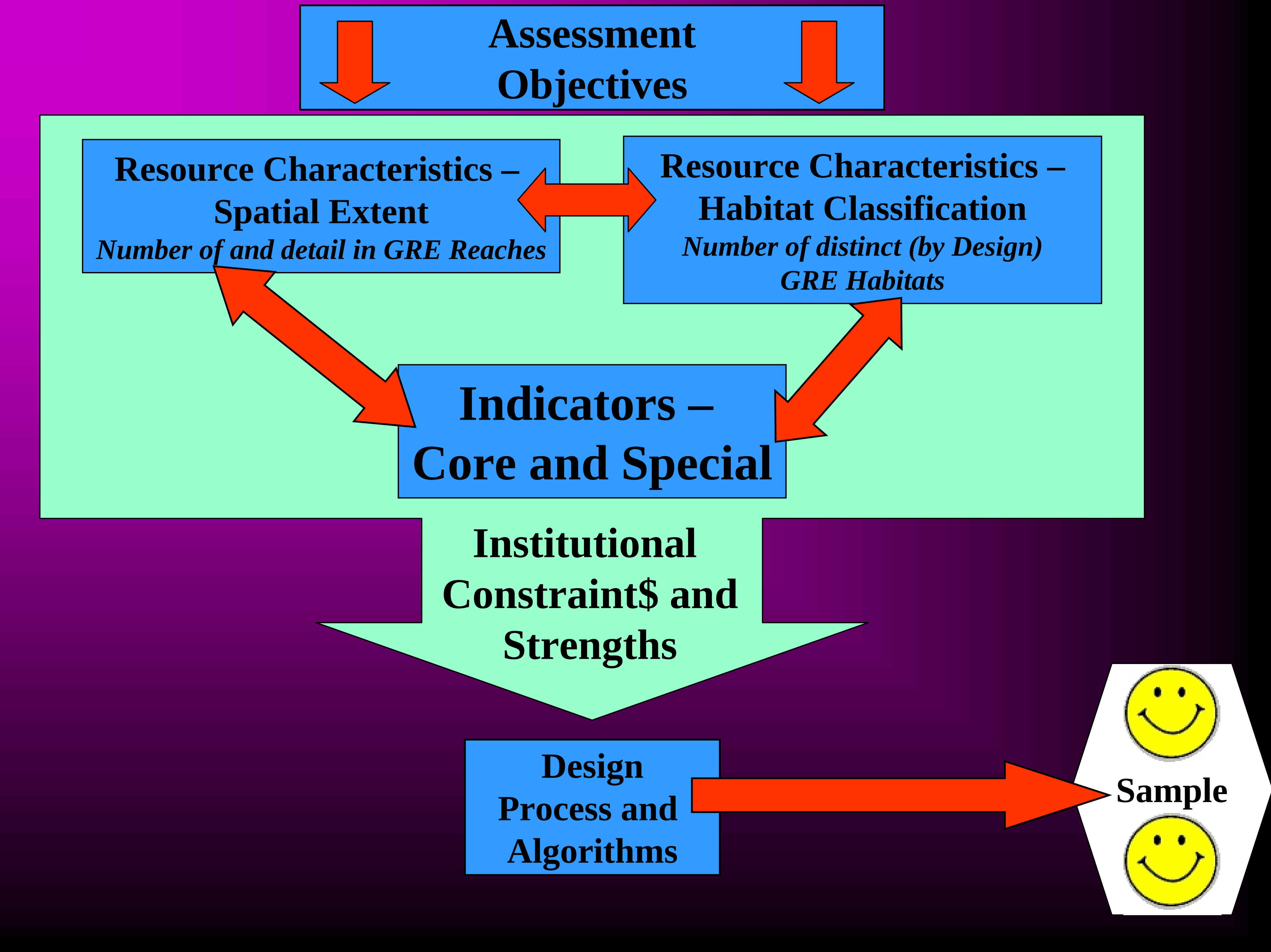
"If results are to be used in resource management or statutory regulation, objective estimation procedure is paramount, independent of subjective decisions"



EMAP-GRE
Straw Man Design

EMAP-UMR

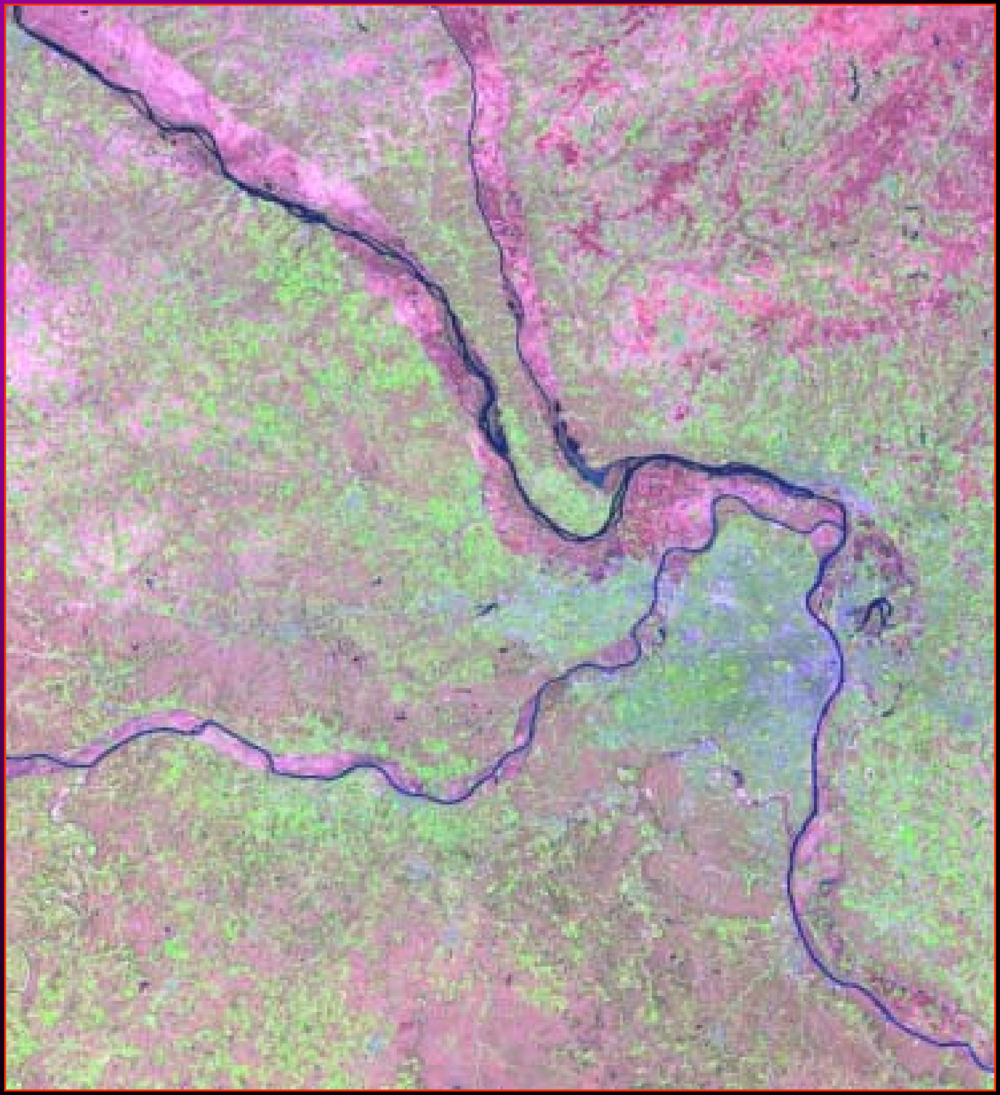
- Ongoing work on the Upper Missouri River serves as test-bed for many of these ideas
- Direct involvement of stakeholders in planning
- Probability survey
- Biological focus
- Multi-resource
  - riverine, riparian, reservoir & landscapes…
- Novel GRE indicators and protocols


Assessment Objectives
Resource Characteristics – Spatial Extent
Number of and detail in GRE Reaches
Resource Characteristics – Habitat Classification
Number of distinct (by Design) GRE Habitats
Indicators – Core and Special
Institutional Constraint$ and Strengths
Design Process and Algorithms
Sample

EMAP-GRE Straw Man Design

Target Population; What and Where

- *That to which final statements of condition shall apply*
  - Must be defined explicitly and (eventually) operationally
- "GRE of the Mississippi Basin"
  - Will require extensive clarification
  - Solution may be through consensual edict?



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Target Population; Domains

- Hierarchical sub-division of resource - creation of "Domains" at the regional, within-region, and macrohabitat scales
  - Reduces, or aids in the understanding, of sources of variation in response measures
  - Allow statements about meaningful management units

- Strategy must compromise between ecologic and socioeconomic constraints

- Variety of design mechanisms to accomplish the subdivision

EMAP-GRE Straw Man Design

Target Population Extent and Domains

Design Version	Regional sub-divisions II	Regional sub-divisions I	Regional Extent
Full Geomorphic	**Mississippi Reaches (4?):** *R1(P1-13);R2(P14-26);R3(OR); Lower Navigation[?]* **Missouri Reaches (10?):** *Wild and Scenic; Ft.Peck; Garrison; Recreational; Upper Navigation?; Lower Navigation?; Main Stem Reservoirs(3+1)?* **Ohio Reaches (3):** *Upper-Greenup, Middle-Falls, Lower-Mouth* **Total: 17**	**Upper Mississippi / Lower Mississippi;** **Upper Missouri / Lower Missouri;** **Ohio** **Total: 5**	**'Complete' Rivers in Greater Mississippi Basin** **Total: 3**
Full Political	**Mississippi States (7):** *MN+IA+MO(=WI&IL),KT,TN,AR+MS(=LA)* **Missouri States(6):** *MT,ND,SD,NE(=IA),KS,MO* **Ohio States(4):** *PA,IL+IN+OH(=KY&WV)* **Total: 17** (some reaches are shared)	**States with Significant River** *MN,IA,MO,MT,ND,SD,NE,MO, IL,IN,OH,KY,WV* **Total: 12** (some reaches are shared)	**'Complete' River in EPA Regions: R8, R7, R5, R4, R6, R3** **Total: 6** (some reaches are shared)

SCALE

EMAP-GRE Straw Man Design

Target Population Extent and Domains

SCALE →

Design Version	Regional sub-divisions II	Regional sub-divisions I	Regional Extent
Reduced Geomorphic	**Mississippi Reaches (4?):** ***R1(P1-13);R2(P14-26);R3(OR); Lower Navigation[?]*** **Missouri Reaches (10?):** ***Wild and Scenic; Ft.Peck; Garrison; Recreational; Upper Navigation?; Lower Navigation?; Main Stem Reservoirs(3+1)?*** **Total: 14**	**Upper Mississippi / Upper Missouri / Lower Missouri** **Total: 3**	**'Complete' Rivers in Upper Miss. and Missouri Basins** **Total: 2**
Reduced Political	**Mississippi States (5):** ***MN+IA+MO(=WI&IL),KY,TN*** **Missouri States(6):** ***MT,ND,SD,NE(=IA),KS,MO*** **Total: 11**	**States with Significant River** ***MN,IA,MO,MT,ND,SD,NE,MO*** **Total: 8** **(some reaches are shared)**	**'Complete' River in EPA Regions: R8, R7, R5** **Total: 4** **(some reaches are shared)**

EMAP-GRE Straw Man Design

Target Population – Macrohabitat Classes as Domains

- Smallest scale of sub-division discussed here is the macrohabitat
- A Design that excludes a macrohabitat does not allow separate inferences to this habitat
  - No independent statement about such habitats is possible, must be subsumed within another macrohabitat (e.g., "backwaters of the Missouri" vs. "the Missouri River")
  - If habitats have distinct ecology (as many components of GRE may), then the ability to describe this is lost in a Design that does not include said macrohabitat
- Level of macrohabitat detail may have a direct impact on the response or plot design
  - A more fine sub-division may reduce complexity of response design

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Target Population – Discrete or Continuous

- Discrete vs. continuous
  - Impact on nature of final statements
    - "% of habitat type X area" vs. "% of individual instances of habitat type X"??
  - Different, but related, statistical theory and mechanisms for sample site selection and data analysis
- Working hypothesis: GRE and most constituent macrohabitats are best sampled as continuums
  - Typically simplifies the response design (measures representative of a point vs. whole unit)
  - Intuitive for most habitat types within GREs
  - Stratification in Design allows for both types

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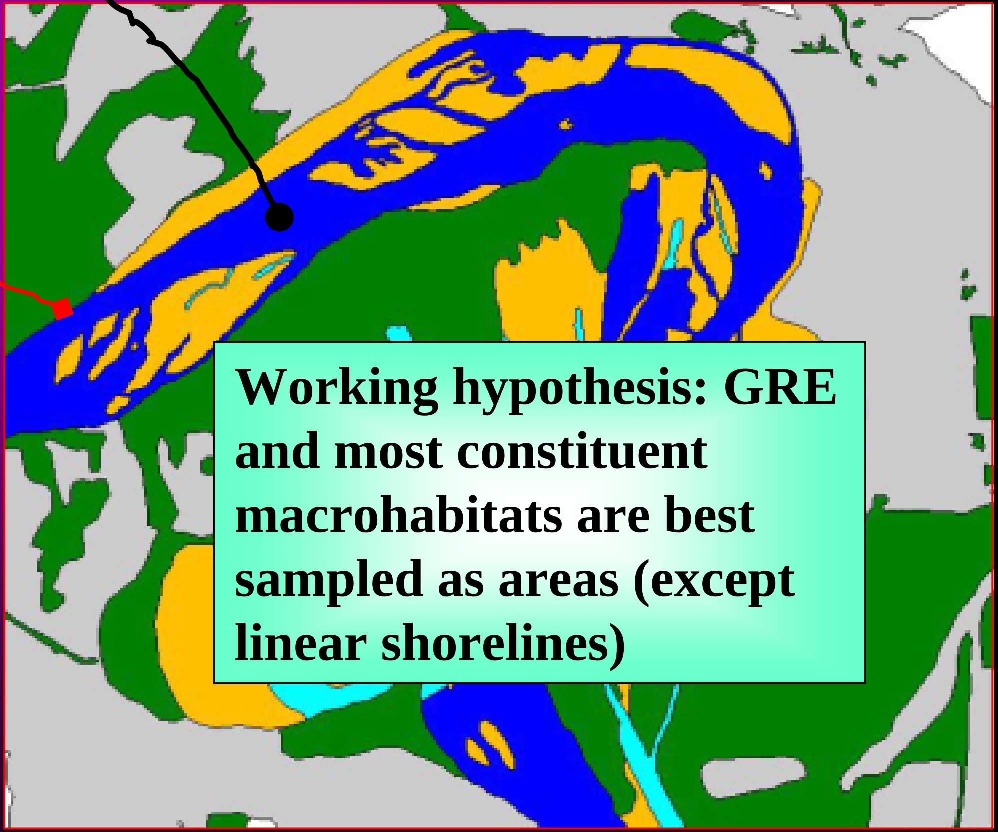
Target Population - Dimensionality

- **Areal vs. linear**
  - **Impact on final statements:**
  - **"% of area" vs. "% of miles"??**
  - **What makes the most ecological sense?**
- **May vary with macrohabitat (i.e., shoreline vs. riparian)**
  - **Stratification in Design allows assessment to include resources of different dimension, however, there is no clear way to integrate across resources with different dimensions**
  - **i.e., a statement that *statistically* combines "% of linear shoreline in condition X" with "% of river area in condition X" - ?**



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Dimensionality and Habitat Classes

Design Version	Dimension	Habitat Class
Full – All Habitats	Most are areal	Aquatic Riverine (3-15+) *EXAMPLES*: LTRMP classes (7+); L.Miss River (18+); UMR Classes (3:Open Water, Backwaters, Shoreline) Riparian/Wetland/Floodplain (2-12+) *EXAMPLES*: LTRMP classes (12+); L.Miss River (9+); UMR Classes (2:In channel, Terrace Forest) Lentic LTRMP classes (4+); L. Miss. River classes (9+); UMR-Reservoirs (2:Open Water, Bays) Avg. = 12
Reduced – Some Habitats	Most are areal	Aquatic Riverine *EXAMPLES*: Open Water, Backwaters, Shoreline **other Macrohabitats subsumed in Response Design** Avg. = 3
Simplest – One Habitat	Areal (linear perspective more tenable)	"The River" **all Macrohabitats subsumed in Response Design, EMAP-SW approach** 1

EMAP-GRE Straw Man Design

Sample Size for Example Designs

Design Version	# of Geographic Sub-divisions (largest scale / smallest scale)	Number of Habitat Sub-Divisions	Domains to be reported on (largest scale / smallest scale)	Sample Size@ 35 per (largest scale / smallest scale)	QA and repeat visits (largest scale / smallest scale)
Full Geo. + All Habitats	3 Rivers 17 reaches	12 Avg. number across major reaches	36 204	1260 7140	126 714
Full Geo. + Reduced Habitats	3 Rivers 17 reaches	3 Avg. number across major reaches	9 51	315 1785	32 179
Full Pol. + All Habitats	6 Region-States 17 States	12 Avg. number across major reaches	72 204	2520 7140	252 714
Full Pol. + Reduced Habitats	6 Region-States 17 States	3 Avg. number across major reaches	18 51	630 1785	63 179

EMAP-GRE Straw Man Design

Sample Size for Example Designs

Design Version	# of Geographic Sub-divisions (largest scale / smallest scale)	Number of Habitat Sub-Divisions	Domains to be reported on (largest scale / smallest scale)	Sample Size@ 35 per (largest scale / smallest scale)	QA and repeat visits (largest scale / smallest scale)
Reduced Geo. + All Habitats	2 Rivers 14 Reaches	12 Avg. number across major reaches	24 168	840 5880	84 588
Reduced. Geo. + Reduced Habitats	2 Rivers 14 Reaches	3 Avg. number across major reaches	6 42	210 1470	21 147
Reduced Pol. + All Habitats	4 Region-States 11 States	12 Avg. number across major reaches	48 132	1680 4620	168 546
Reduced Pol. + Reduced Habitats	4 Region-States 11 States	3 Avg. number across major reaches	12 33	420 1155	42 116

EMAP Design To-Dos

- Major decisions about target population
  - Which are the ‘Great River Ecosystems of the Central Basin’
    - Why?
  - Domains: Geo-reach? State? Level of detail?
  - Macrohabitats: Which? Where? Why?
    - Ted’s talk
  - Spatial nature of target resource: Discrete? Continuous? Linear? Areal?
- What level of precision do we need? (sample size)
  - Is around +/- 10% appropriate?

EMAP To-Dos: For Another Day

- What suite of indicators work best with the EMAP Design?
  - Biological; hydrologic; food web; nutrients…
  - What is the appropriate local (response) scale of variation?
- How should we integrate with existing monitoring?
  - NASQAN, LTRMP, EMAP-SW
    - Important issue of EMAP-SW approach that uses a linear criteria (% of river miles) vs. proposed EMAP-GRE areal criteria (% of river habitat X area)

EMAP To-Dos: For Another Day

- How can we efficiently deal with temporal variation?
  - Nothing of a statistical nature about EMAP Design disallows temporal perspective
  - Panels
  - Continuous data-loggers
  - Nested subset of sites used to track long-term trends
    - Random selection of these long-term sites assures that they are representative (at large scale)
  - Judicious use of and integration with existing targeted long-term data in an EMAP assessment (via joint modeling efforts?)


8/31/2000

Extra Slides Follow:

- **Statistics don't lie, but statisticians do.**
- **Statistician -- someone who insists on being certain about uncertainty.**
- **Forty-two percent of all statistics are made up on the spot.**
- **The 50-50-90 rule: Anytime you have a 50-50 chance of getting something right, there's a 90% probability you'll get it wrong.**

- **Q: Why do people decide to become statisticians?**
A: They find accounting too exciting.
- **A statistician is a person whose lifetime ambition is to be wrong 5% of the time.**
- **Following a flaming snowmobile crash, one statistician asked the other if he was OK. The second said "well, my hair's on fire and my toes are frostbitten, but overall I feel pretty good."**

Natural Resource Management Meetings

What's Missing?

- **How do we know conclusions apply to systems other than that from which they were measured?**
- **Can results functionally contribute to *Adaptive Management*?**
- **Are the data/conclusions the right 'kind' for pressing management issues:**
  - **"What is the extent and condition of our renewable natural resources?"**
  - **"Where and what parts of the environment are changing?"**

Missouri River Natural Resources Conference, 2002

GRE Monitoring Programs

Design Challenges

- Objectives for monitoring are not clearly, precisely stated and understood
- Monitoring measurement protocols, survey design, and statistical analysis become scientifically out-of-date
- Monitoring results are not directly tied to management decision making
- Results are not timely nor communicated to key audiences
- Results are not comparable across programs
  - Or within programs across political boundaries

Great River Ecosystems

Sample of Existing GRE Monitoring – Central Basin of the US

Program	Agency	Relevant Resource	Focus	Sampling Frequency	Site selection	Inference
NASQAN	USGS	Mo., Miss. & Ohio Riv.	WQ – Flux & Loadings	~monthly	Site-criteria	Model
NAWQA	USGS	Upper Miss. Basin	WQ, Biological Condition	<1yr	Site-criteria	Model
LTRMP	USGS	Upper Miss. Riv.	WQ, Bio. Cond., Habitat Needs	vary	Site-criteria and P-sample (limited target pop.)	Model and Design(?)
BEST (fish)	USGS	Mo., Miss. & Ohio Riv.	Fish Tissue Toxicity	2 yrs	Site-criteria	Model
305(b)/303(d) and other State Monitoring	States	Mo., Miss. & Ohio Riv.	WQ, Bio. Cond., Phy-hab. Fish Tissue Toxicity, etc.	vary	Vary; Site-criteria	Vary; Model
Benthic Fish Study	State & USGS	Mo. Riv.	Fish Species & Habitat	once	Site-criteria	Model
ORSANCO	ORSANCO	Ohio Riv.	Bio Cond., Fish Tissue Toxicity, WQ	vary	?	?
ACOE monitoring	US ACOE	Mo., Miss. & Ohio Riv (?)	WQ, T&E Species	<daily to once	Site-criteria	Model
National Sediment Inv.	EPA?	Mo., Miss. & Ohio Riv (?)	Sediment Contamination	?	Site-criteria	Model

Incomplete and simplified!

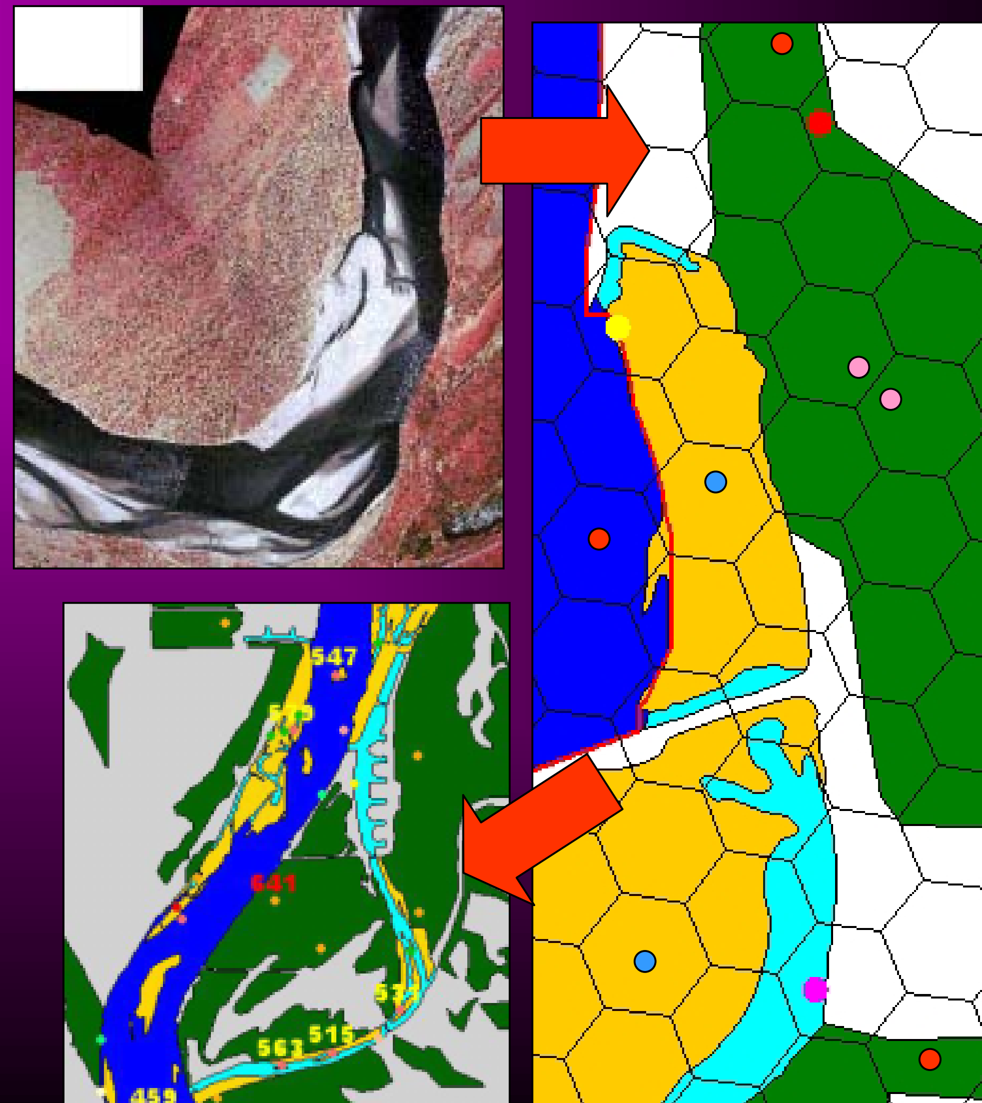

South Dakota
Wisconsin
Nebraska
Iowa
Missouri
Illinois
Kansas
LTRMP, STORET, NSI, NASQAN

The EMAP Design - Summary

Fundamental Attributes of EMAP Design

<u>**Probability sample**</u>

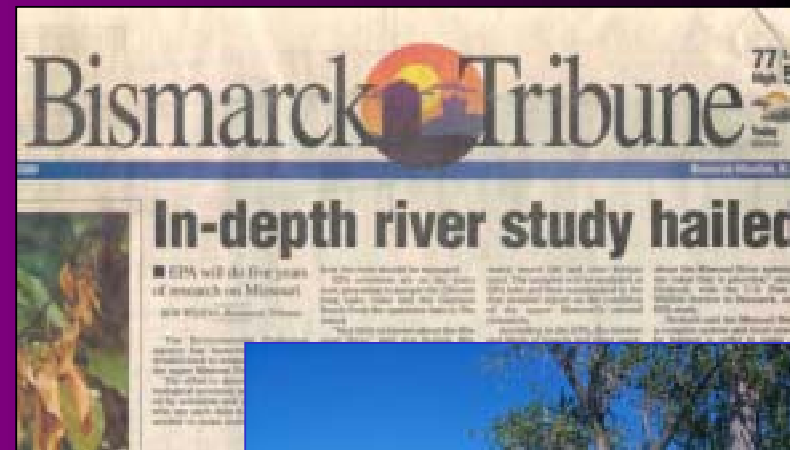
- **Site selection by process that includes explicit random element**
- **Every element in the population has the opportunity to be sampled**
- **Precision of results is known**
- **Explicit spatial balance in Design**



EMAP-GRE Straw Man Design

Monitoring and Assessment Objectives

- **Assessment Questions may range from quantitative and specific to general**
- **Develop in consultation with stakeholders**
- **Optimal design for *all* stakeholders involved does not exist**


Bismarck Tribune

In-depth river study hailed

EMAP-GRE Straw Man Design

Sample size

- Why an N of 35-50 per hopeful reporting unit?

Assumed Proportion (percent)	Precision with 90% Confidence for alternative sample sizes					Precision with 95% Confidence for alternative sample sizes				
	25	50	100	400	1000	25	50	100	400	1000
20%	±13	±9	±7	±3	±2	±16	±11	±8	±4	±3
50%	±17	±12	±8	±4	±3	±20	±13	±10	±5	±3

- Precision important in ability to detect changes
- Administrative and QA constraints define sample size limits
  - Size of sample, vs. size of target population, affects precision

EMAP-GRE Straw Man Design

Target Population; Domains

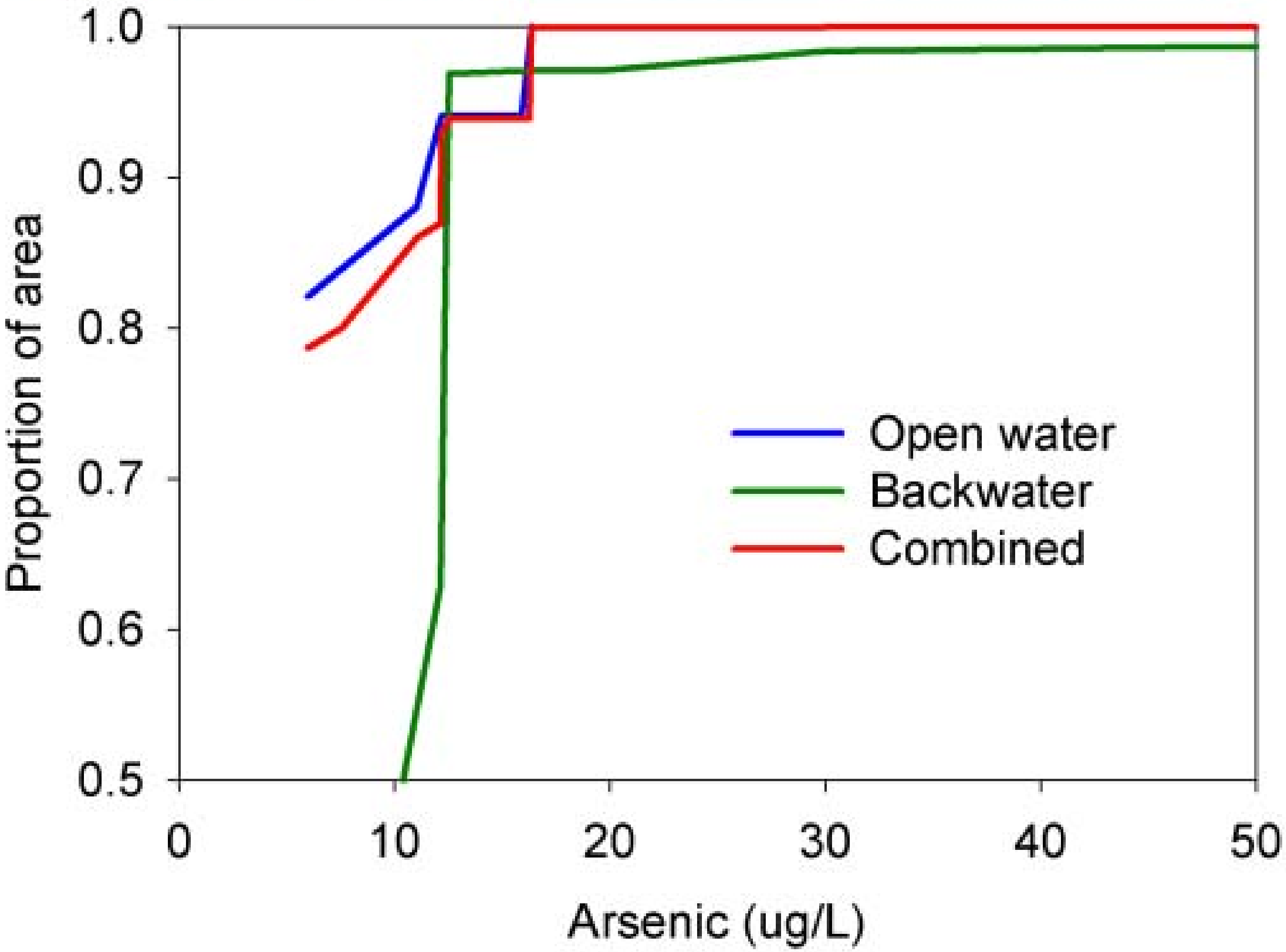
- Stratification
  - Results in operationally distinct Designs
    - Operational/administrative efficiency (e.g., giving States independent samples)
  - Improve precision of results, BUT a >20% misclassification rate results in worse precision than no strata

- Unequal selection probabilities (across subpopulations of interest)
  - Samples are all part of the same Design
  - Improve precision of results
  - N is approximate, not *a priori*
    - Size classes of backwaters
    - Secondary channel habitat in delta zone
  - Integrity of Design still maintained

EMAP-GRE Straw Man Design

Affect of Habitat classes, Response Designs and Dimensionality

In combined assessment, virtually no area has high arsenic values



ontana
Minnesota
Wisconsin
South Dakota
Wyoming
Iowa
Nebraska
Missouri
Illinois
Colorado
Kansas

EMAP-GRE Straw Man Design

Response Design - Timing

- Index period
  - Period of sample collection keyed to important biological events such as maximum stress of biota or key points within the hydrocycle
  - 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
- Can this deal with the important temporal variability in some GRE indicators?

EMAP-GRE Straw Man Design

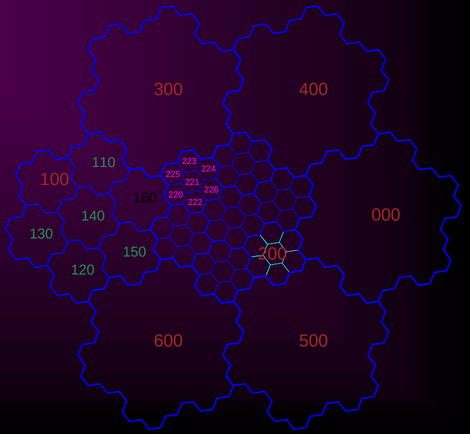
Panels - Timing

- Design may be structured such that only a portion (a Panel) is done in a single sampling period
  - Panels are representative samples in and of themselves
- Trends can be quantified via a Panel Design where it is possible to balance priority of status estimation versus trend estimation
  - Basic design is single panel
  - 5-year rotating panel: panel 1 visited in year 1, 6, 11,etc; panel 2 visited in year 2, 7, 12, etc; …

EMAP-Design

Implementing the Generalized Random Tessellation Stratified Design

- **Steps in EMAP Design Algorithms:**
  - **Randomly locate a grid over extent of resource population**
  - **Calculate the expected number of samples in each grid**
  - **Randomly order cells using a hierarchical randomization of recursive-partition addresses, cell weight equal to its expected number of samples**
  - **Select systematic sample of grid cells**
  - **Select a sample point at random from the population elements contained within each chosen grid cell**



EMAP-GRE Straw Man Design

Sample Frame

- Explicit unambiguous representation of population
  - Provides basis for sample selection
  - Typically as a GIS Map with the spatial locations and extent of elements of population
- Status for GRE of the Central Basin
  - Good. Should be feasible to create adequate frame. Not a simple or trivial GIS task, but doable.

EMAP-GRE Straw Man Design

Dot-$-Math

Design Version	Sample Size@ 35 per + QA (largest scale / smallest scale)	Total Cost $$$$$ @ 5k per site	Design Version	Sample Size@ 35 per + QA (largest scale / smallest scale)	Total Cost $$$$$ @ 5k per site
Full Geo. + All Habitats	1386 7854	6,930,000 39,270,000	Reduced Geo. + All Habitats	924 6468	4,620,000 32,340,000
Full Geo. + Reduced Habitats	347 1964	1,735,000 9,820,000	Reduced Geo. + Reduced Habitats	231 1617	1,155,000 8,085,000
Full Pol. + All Habitats	2772 7854	13,860,000 39,270,000	Reduced Pol. + All Habitats	1848 6006	9,240,000 30,030,000
Full Pol. + Reduced Habitats	693 1964	3,465,000 9,820,000	Reduced Pol. + Reduced Habitats	462 1502	2,310,000 7,510,000

Frame

- Frame: explicit unambiguous representation of population
  - Typically as a GIS Map with the spatial locations and extent of elements of population
  - Provides basis for sample selection
  - Status for GRE of the Central Basin is good. Should be feasible to create adequate frame. Not a simple or trivial GIS task, but doable.
  - IDEAL – more real-time Frame, such that lags less of an issue?
  - Integrate hydrogeo

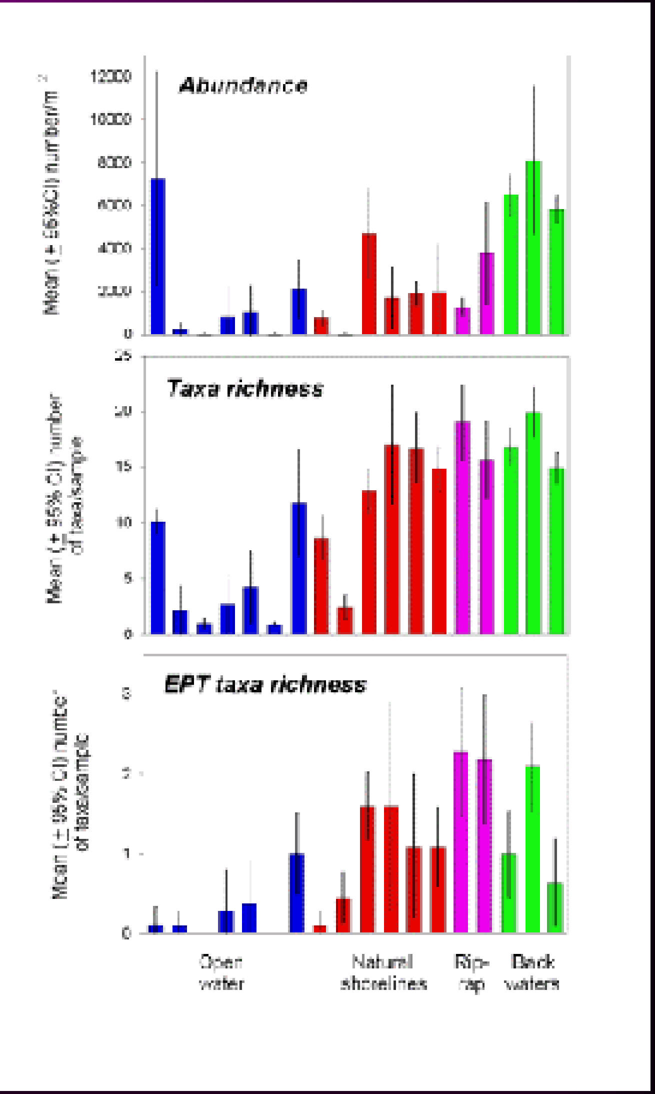
Indicators & EMAP-GRE

- TALK ABOUT IN THE DISCUSSION SESSION

EMAP-Analysis Overview

Example from UMR

- **Populations typically described through use of cumulative distribution functions (CDFs) with associated confidence intervals**
  - Conveys more information than simple means, etc.
  - May be expressed as 'executive summary pie charts', means, dispersion, etc.
- **Algorithms include integration of probability Design elements (weights) in every analysis**
  - May summarize data with out these steps (as in a Model-based approach) but power of Design is lost and (in the simplest case) results only apply to sampled sites



Lake Oahe 2001 Example WQ Results

Discussion and Conclusions

- Beyond EMAP – how does an EMAP-GRE interface with existing monitoring or other designs
  - Integration with EMAP-SW
- Gulf hypoxia
- 305b/303d
- Dealing with temporal variation
- Long-term fixed station monitoring
- The landscape component