CHAPTER 4: SAMPLE DESIGN

Introduction

The primary purpose of a sample design is to ensure the data collected are representative of the target population(s), and sufficient to draw defensible conclusions about the resources of interest. In this chapter, we discuss how our sample design ensures the scientific merit of our program. We assume that the reader is familiar with basic principles of sample design; appendix 4-1 contains a discussion of these principles and an elaboration of the concepts presented in bold face. Here we describe, in a broad context, how these principles will be employed in sampling terrestrial and aquatic habitats of our network. The specific designs detailed in individual protocols follow from these basic themes and incorporate variations as necessary. These details can be found in the monitoring protocols for individual vital signs (Supplemental Documents in Chapter 5). Important aspects of our sample design for all vital signs are summarized in Table 4-1.

Terrestrial Systems

Sample Selection

In general, the sample design for most terrestrial monitoring projects is based on a systematic grid in which all points, a systematic subset, or some random subset of the total may be sampled. This choice will ultimately depend upon park size, spacing between points, time required to sample each point, and available personnel. Location of sample points is determined by overlaying the area of interest with a two-dimensional grid. If **systematic sampling** is appropriate, then all or some systematic fraction of points are sampled. If not, then we randomly select some proportion of points to sample. If **stratification** is necessary, strata are defined before sites are determined. Regardless of the specific approach chosen (i.e., **systematic, random, stratified random**), the same underlying grid can be used at each park for different sampling protocols.

By sharing a common underlying grid, multiple protocols using different approaches to spatial allocation can maximize **co-location** of sample sites. Figure 4-1 illustrates a hypothetical example of superimposing several different survey designs on a single systematic grid. First, a relatively fine scale grid (e.g., 100 x 100m) is superimposed on the **sample frame**. Vertices of the grid form a pool of potential sample points, and those falling outside the reference frame are removed from consideration. For invasive plant species monitoring, for example, the HTLN is developing rapid data collection methods to maximize spatial coverage. All sample points in the reference frame (i.e., all filled circles) would be utilized in a systematic sample.

Protocols for monitoring breeding birds utilize a systematic survey design at a larger spatial scale (400 x 400m). The initial grid would be subsampled to the desired scale as indicated by blue circles. Initially establishing a relatively fine-scale grid allows flexibility in scaling up to meet different design requirements. At points represented by solid blue dots, both invasive plant species and breeding bird monitoring would be co-located.

Table 4-1. The overall sample design approach, methods for spatially allocating samples, and the revisit plan for vital signs monitoring.

Level 1	Level 2	Level 3	Network Vital Sign Name	Overall Sample Design Approach	Spatial Allocation	Revisit Plan
Ecosystem Patterns and Processes	Land Cover and Use	Land Cover and Use	Land Cover/Land Use			
Air and Climate	Air Quality	Ozone	Ozone	NA	NA	Continuous
		Wet and Dry Deposition	Wet and Dry Deposition	NA	NA	Continuous
		Visibility and Particulate Matter	Visibility and Particulate Matter	NA	NA	Continuous
		Air Contaminants	Air Contaminants	NA	NA	Continuous
	Weather and Climate	Weather and Climate	Weather	NA	NA	Continuous
Geology and Soils	Geomorphology	Stream/ River Channel Characteristics	Fluvial Geomorphology	Aquatic – one dimensional	GRTS	[1-0,1-4]
			Stream Habitat/ Riparian Assessment	Aquatic – one dimensional	GRTS	[2-5]
		Surface Water Dynamics	Stream Discharge	NA	NA	Continuous
	Water Quality	Water Chemistry	Core Water Quality Parameters	Aquatic – one dimensional	Various	Various
		Toxics	Pollutant Metals	Aquatic – one dimensional	GRTS	[1-0,1-4]
		Aquatic Invertebrates and Algae	Aquatic Invertebrates—Prairie Streams	Aquatic – one dimensional	Exhaustive Sample	Annual
			Aquatic Invertebrates—Rivers	Aquatic – one dimensional	GRTS	[1-0,1,4]
Biological Integrity	Invasive Species	Invasive/ Non-native Plants	Exotic Forest Plants	Terrestrial – two dimensional	Systematic	[1-5]
		Invasive/ Non-native Plants	Exotic Grassland Plants	Terrestrial – two dimensional	Systematic	[1-5]
	Focal Species or Communities	Wetland Communities	Wetland Plant Communities	Terrestrial – two dimensional	TBD	TBD
		Grassland Communities	Prairie Community Structure, Composition, and Diversity	Terrestrial – two dimensional	Stratified Random	[2-3]
		Forest Vegetation	Forest Community Structure, Composition, and Diversity	Terrestrial – two dimensional	Stratified Random	[2-3]
		Fishes	Fish Community—Prairie Streams	Aquatic – one dimensional	Exhaustive Sample	[1-0,1-4]
			Fish Community—Ozark Rivers	Aquatic – one dimensional	GRTS	[1-0,1-4]
		Birds	Land birds	Terrestrial – two dimensional	Systematic	Annual
		Mammals	Deer	Terrestrial – two dimensional	TBD	TBD
		Threatened and Endangered Species and Communities	Missouri Bladderpod	Terrestrial – two dimensional	Adaptive Cluster Sampling	Annual
			Ozark Hellbender	Aquatic – one dimensional	Dual Frame - GRTS	[1-0,1-2]
			Topeka Shiner	Aquatic – one dimensional	NA – Population Census	Annual
			Western Prairie Fringed Orchid	Terrestrial – two dimensional	NA – Population Census	Annual

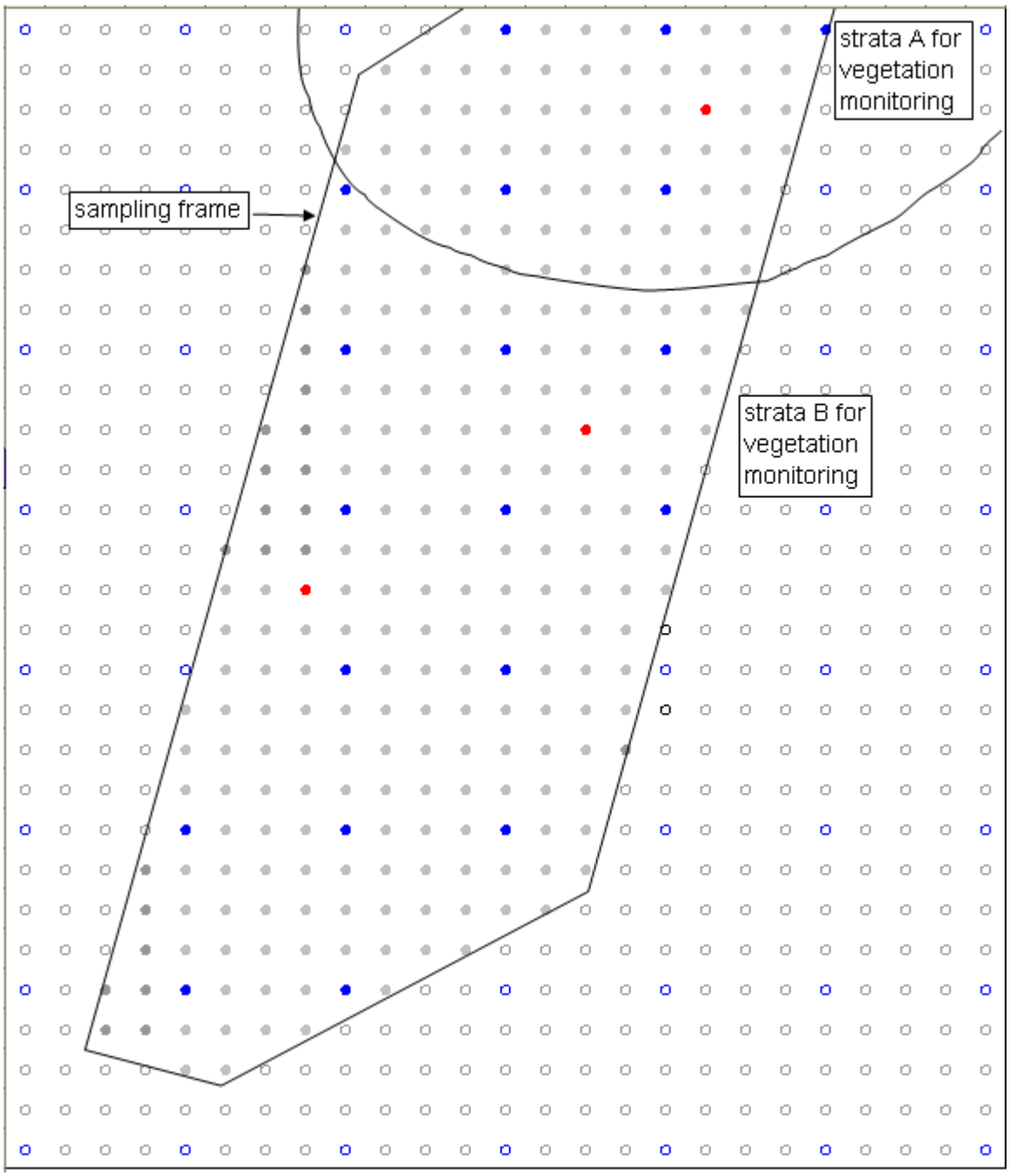


Figure 4-1. A hypothetical example of superimposing, on a single underlying grid, several monitoring projects each using a different technique for selecting sample locations. In this example, invasive plant monitoring would utilize a systematic sample from a fine scale grid (all solid dots). Breeding bird monitoring would utilize a systematic sample from a coarser scale grid (solid blue dots). Vegetation community monitoring would draw a relatively small stratified random sample from the pool of potential sites (solid red dots).

Finally, vegetation community monitoring methods are intensive and time consuming; therefore, total sample sizes must remain small. Given relatively small sample sizes and the desire to capture heterogeneity in vegetation communities that reflects underlying differences in soil type and aspect, a stratified random sample is drawn. In this example, the three sample sites are drawn at random from strata A and B with the number of sites per strata proportionate to the area of the strata, thus creating equal probability for selection. At points represented by solid red dots, both invasive plant species and vegetation community monitoring are co-located.

In addition to the general approach described above (e.g., systematic, stratified random), the HTLN is also utilizing adaptive **cluster sampling** and complete census techniques in monitoring rare plant populations (Table 4-1).

Panel Membership and Revisit Design

Panel membership and **revisit design** describe how sites at each park are sampled through time. As a demonstration of how the revisit design must accommodate a network-wide logistical plan, we continue the example from vegetation community monitoring. In general, vegetation community monitoring sites are sampled for two consecutive years followed by three years of no sampling (i.e., a [2 - 3] **rotating panel**; Table 4-2). This design is well suited for trampling-sensitive systems such as glades, tallgrass prairies, mixed grass prairies, and savannas; allows for a greater number of sites to be visited through time; and provides a three-year window in which to initiate management activities. Furthermore, sampling for two consecutive years statistically reduces the effect of annual variability on the detection of trends in plant communities that are temporally dynamic.

In two parks, more intensive monitoring is planned as part of ongoing research and design work. At Tallgrass Prairie National Preserve (TAPR), a **split panel** revisit plan is employed in which a subset of sites is sampled annually, while other sites are rotated on a four year cycle [1 – 0, 1 – 3] (Table 4-3). The **always revisit** panel is well suited to detect gross change and components of individual change. A primary drawback of the design is the burden placed on core sites through trampling pressure related to annual sampling. At TAPR, however, sampling-related trampling issues are minimal compared to the intensive cattle grazing currently implemented. This is the only park in the network able to sustain an annual sample because of the intensive grazing already occurring. The group of annually sampled sites is coupled with a second panel of sites from each pasture scheduled for monitoring on a four year rotation [1- 3]. The second panel provides a better estimate of status and improves our ability to compare plant communities among pastures under different management regimes.

At Effigy Mounds National Monument (EFMO), the plan for monitoring additional forest sites involves a rotating panel design [1 – 2]. All sample sites will be placed into three panels based on fire management units and tentatively sampled once every three years. Unlike TAPR, there is not an annually sampled panel at EFMO due to the sensitivity of the forest community to trampling.

Table 4-2. Network-wide logistical plan for rotating annual vegetation community monitoring effort among network parks. (Different vegetation communities are monitored at EFMO in the always revisit panel [forests] compared to the rotating panel [prairies]).

Tour	Region (Parks)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	Short-grass prairie tour (AGFO – SCBL)	X	X				X	X				X	X
2	Tallgrass prairie tour (HOME – PIPE)			X	X				X	X			
3	Deciduous forest tour (LIBO – HOCU - WICR)				X	X				X	X		
4	Ozarks tour (PERI – HOSP – ARPO)					X	X				X	X	
5	Prairie-savanna tour (EFMO – HEHO – GWCA)		X	X				X	X				X
6	Flint Hills tallgrass prairie tour (TAPR)	X	X	X	X	X	X	X	X	X	X	X	X
7	Eastern forest tour (EFMO)	X	X	X	X	X	X	X	X	X	X	X	X

In designing vital signs monitoring for multiple NPS units at the network scale, logistics may constrain the survey design at any particular park. For example, plant community monitoring is ongoing or scheduled for 14 parks dispersed widely across the Great Plains. We utilize sampling tours comprised of parks in geographic proximity to one another to achieve operational efficiency (Table 4-2, Figure 4-2). Every park in the tour is visited during a single trip (not to exceed 10 days). In most cases, all vegetation monitoring sites within a park are sampled during each visit. The tour concept ensures that parks in relatively close proximity of each other are sampled consecutively, thereby reducing time and travel-related expenses.

Table 4-3. Split panel revisit design for Tallgrass Prairie National Preserve [1 – 0, 1 – 3].

Sample Panels	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Core sites (n=18)	X	X	X	X	X	X	X	X	X	X	X	X	X
Crusher pasture (n=5)	X				X				X				X
Redhouse pasture (n=6)		X				X				X			
Windmill pasture (n=8)			X				X				X		
Gashouse pasture (n=11)				X				X				X	

In determining the logistical plan, the timing of sampling within the growing season was considered, as well as the maximum number of plots that could be revisited within a year. With sampling limited to early May through mid-October, selecting the optimal sequence of tours is

crucial. Each community type has a unique sample time within the growing season that is optimal for capturing the diversity and complexity of the system. Plant communities are sampled at approximately the same time each year to remove seasonality from cover and frequency estimates. This minimizes difficulties in differentiating long-term trends from changes attributable to seasonal variability.

Unlike many large-scale environmental monitoring studies, region-wide inferences incorporating cross-tour analyses is not intended. In this case, the study units within the parks remain the framework for statistical interest. Results are not extrapolated to include all parks within a tour and trends will not be analyzed across tours.

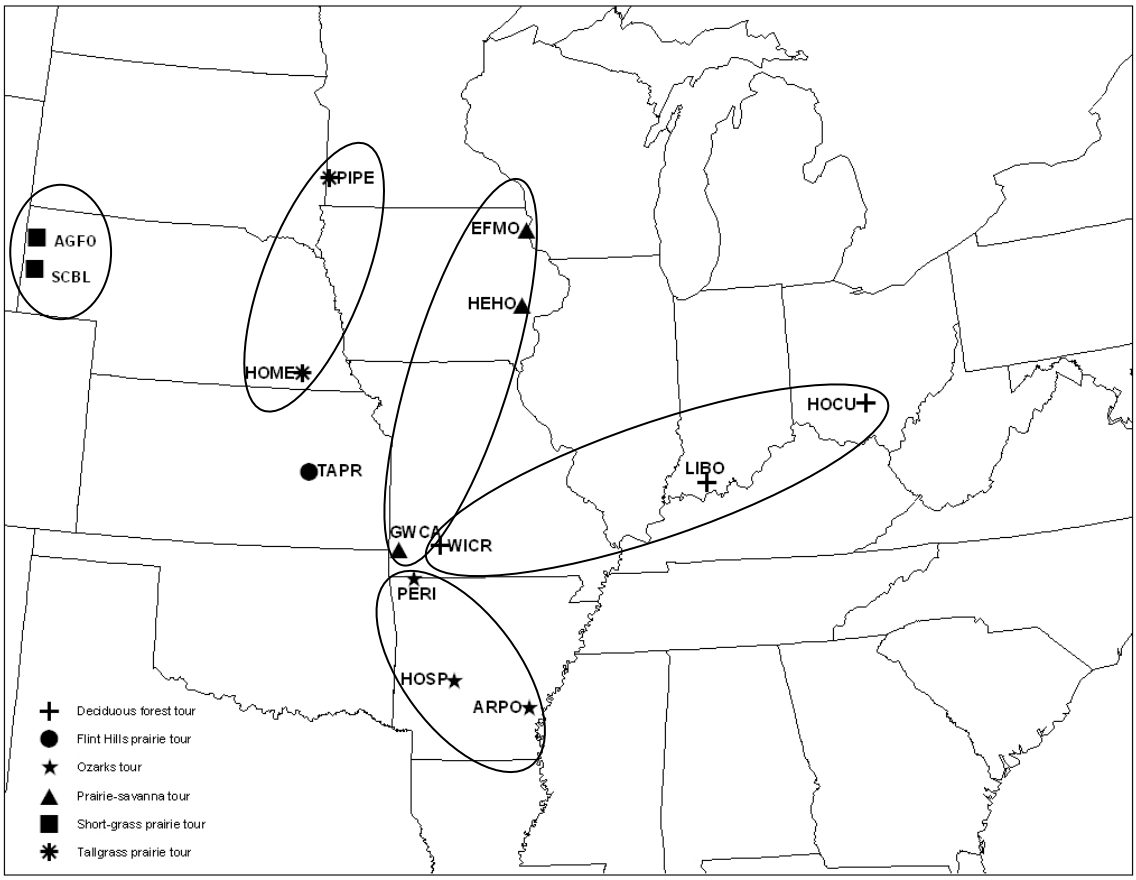


Figure 4-2. Groups of parks, or tours, scheduled in a single vegetation community monitoring field trip. (TAPR and forests at EFMO are sampled every year; prairies at EFMO are sampled on a rotating basis.)

River Systems

River systems are linear and require a different approach than terrestrial habitats. Buffalo National River (BUFF) and Ozark National Scenic Riverways (OZAR) are two 'river' parks within the HTLN network. Preserving the aquatic resources of these parks is of primary importance, and the park boundaries closely parallel the rivers and important tributaries. Five major vital signs are proposed for evaluation under a unified monitoring design: Ozark hellbenders, fish communities, invertebrates, geomorphology, and heavy metals (primarily lead, but also nickel and cadmium). In order to maximize sampling efficiency and the amount of information available for each site, we will **co-locate** and **co-visit** as many sample sites as possible. Although we monitor aquatic resources in other parks in the HTLN network, here we focus on BUFF and OZAR because they represent relatively large river systems requiring substantial sampling efforts. Also, other aquatic resources are being sampled as part of the PC-LTEM program, and their sample design has already undergone a thorough review.

Sample selection

We defined the sample unit to be the largest entity upon which one of the five study's field protocols could be applied. As a common sample unit definition, we will use a 'stretch' of contiguous river of some minimum and maximum length. Because the geomorphology of these waterways (and the resulting biological processes) are scale-dependent, different categories of stretch sizes will be employed. For example, as rivers become wider, the distance separating riffles increases. The protocol for sampling macroinvertebrates requires sampling three riffles, so this protocol will require longer sections in the main stems than in the tributaries. In the tributaries and upper main stems, stretch lengths of 1-3 km may be adequate. The middle and lower main stems may require stretch lengths of 3-5 km to accommodate all studies. A key characteristic of the overall design is that all studies are capable of producing unbiased estimates that are applicable to the entire stretch. While stretches must be long enough to accommodate unbiased estimates for all studies, they do not have to be the same size. Once defined, sample unit boundaries will remain fixed forever and be used by all studies under the unified monitoring design.

For both BUFF and OZAR, the sample frame will consist of all river stretches where it is theoretically possible to apply at least one study's field protocol. We will attribute each stretch in both frames with the following characteristics, which will be used as covariates (i.e., **domains**): (1) whether or not the stretch is significantly influenced by the presence of a major upstream spring or confluence, (2) the 'valley segment type' of the stretch (i.e., based on geographic information system [GIS] data; to allow for regional comparisons), and (3) whether or not the stretch is ephemeral (i.e., subject to intermittent flow). Other attributes are possible and will be considered. None of these attributes will be used to define sample strata; rather, they will be used during analysis to help explain variation in the measured variables.

For the five major studies at BUFF and OZAR, it is desirable for samples to be spatially balanced or 'well spread-out'. In river systems, space is 1-dimensional and equates with river mile. Spatial balance is important because all responses are known to be spatially autocorrelated

(i.e., units close to one another tend to yield correlated responses), and park-wide inferences are desired. When responses are correlated in space, spatial balance can greatly improve precision of the resulting estimates. Thus, we will employ the **Generalized Random Tessellation Stratified** (GRTS) design of sample selection. The GRTS technique generates a random sample that is spatially well balanced (see Appendix 4-1). It allows multiple studies to maximize overlap of selected streams by utilizing a common sample, and allows units to be added easily after an initial sample has been drawn. Additionally, because GRTS samples are not evenly spaced, it is not possible for sample locations to be in phase with a cyclic response.

The most desirable characteristic of GRTS sampling is that for any sample size, the first *n* stretches in the ordered GRTS sample constitute a spatially balanced sample of size *n*. Even if a small number of the first *n* units are not included in the sample, spatial balance of the GRTS sample will remain high. This characteristic is desirable because it allows multiple studies to maximize overlap and add stretches in a way that guarantees spatial balance. For example, assume 10 stretches are to be surveyed by the hellbender study, 2 stretches are to be surveyed by the geomorphology study, and 25 stretches are to be surveyed by the fish study. Under the GRTS design and assuming all three field protocols could be applied to all stretches, the hellbender project would visit the first 10 stretches in the ordered sample. The geomorphology study would visit the first 2 stretches, and the fish project would visit the first 25 stretches in the list. In this way, overlap is maximized because 10 of 25 fish stretches would also be sampled for hellbenders, and 2 of those 10 would also receive geomorphologic measurements. Furthermore, the 2 geomorphology, 10 hellbender, and 25 fish stretches would be spatially balanced.

Panel Membership and Revisit Design

The proposed membership design is specified in Table 4-4. To select sample units for most panels, an **interpenetrating** membership design will be used, in which the sites within each panel are spatially intermixed. The only exceptions will be the hellbender and heavy metal studies, in which a **dual frame** approach will be employed. Hellbenders are thought to be extremely rare and restricted to the main stem at OZAR. Panel 1 of the hellbender study will consist of only those stretches where hellbenders are known to exist. The remaining areas of the main stem rivers will be selected for the hellbender project using interpenetrating GRTS samples. For the heavy metal study, it is critical to sample the stretch containing Blair Creek, because heavy metal levels in this tributary are thought to be heavily influenced by an adjacent lead mine outside park boundaries. The Blair Creek stretch therefore will be placed in the heavy metal study's panel 1. All other stretches, including tributaries, will be sampled using an interpenetrating GRTS sample.

Table 4-4. Membership designs for monitoring studies proposed at BUFF and OZAR. Each study's annual sample size is assumed to be *n*.

Study	Total Sample Size	Area of Inference	Panel #	# Stretches	Membership Design
Hellbender (OZAR only)	3*n*-2*k*	Known main stem hellbender stretches	1	*k*	Main stem stretches in which > 0 hellbender were found during reconnaissance surveys. Number unknown, assumed = *k*
		Unknown main stem hellbender stretches	2	*n-k*	First *n-k* main stem stretches in GRTS sample that are not known hellbender stretches.
			3	*n-k*	Second *n-k* main stem stretches in GRTS sample that are not known hellbender stretches.
			4	*n-k*	Third *n-k* main stem stretches in GRTS sample that are not known hellbender stretches.
Fish	4*n*	Stretches fishable by similar gear	1	0.25*n*	First 0.25*n*stretches in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
		Stretches fishable by similar gear	2	0.75*n*	First 0.75*n*stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			3	0.75*n*	Second 0.75*n*stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			4	0.75*n*	Third 0.75*n*stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			5	0.75*n*	Fourth 0.75*n*stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			6	0.75*n*	Fifth 0.75*n*stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.

Table 4-4. (Continued)

Geomorphology	5*n*	All stretches	1 *n*	First *n* stretches in park-wide GRTS sample.
			2 *n*	Second *n* stretches in park-wide GRTS sample.
			3 *n*	Third *n* stretches in park-wide GRTS sample.
			4 *n*	Fourth *n* stretches in park-wide GRTS sample.
			5 *n*	Fifth *n* stretches in park-wide GRTS sample.
Macroinvertebrates	3*n*	All stretches	1 0.5*n*	First 0.25*n* stretches in park-wide GRTS sample.
		All stretches	2 0.5*n*	First 0.75*n* stretches after panel 1 in park-wide GRTS sample.
			3 0.5*n*	Second 0.75*n* stretches after panel 1 in park-wide GRTS sample.
			4 0.5*n*	Third 0.75*n* stretches after panel 1 in park-wide GRTS sample.
			5 0.5*n*	Fourth 0.75*n* stretches after panel 1 in park-wide GRTS sample.
			6 0.5*n*	Fifth 0.75*n* stretches after panel 1 in park-wide GRTS sample.
Heavy metals	*n*	The Blair stretch	1 1	The Blair Creek stretch. This stretch is 1.4 km long and is potentially influenced by an adjacent mine.
		All stretches minus Blair	2 *n*-1	First *n*-1 stretches in park-wide GRTS sample that are not Blair.

The revisit design is presented in Table 4-5. With the exception of geomorphology and heavy metals, all vital signs have an always revisit panel and a set of rotating panels. Because the geomorphology and heavy metal contamination of these rivers would not be expected to change rapidly (in the absence of major flood events or new mining activity), revisiting sites on an annual basis is not likely to be informative for these vital signs. For the others, the revisit plan is a compromise between power to detect trend and precision of mean level estimates. The compromise involves allocating some fraction of annual field effort toward re-sampling stretches on a frequent basis. The remainder of annual field effort will be allocated toward re-sampling stretches on a less frequent basis. For example, in the invertebrate study, 50% of annual sample size will be dedicated to re-visiting stretches in a single panel every year. The remaining 50% of annual sample size will be dedicated to visiting one of five additional panels on a 5-year rotating basis.

Table 4-5. Revisit plans for monitoring studies proposed at BUFF and OZAR. An 'x' in the right-most columns indicates all sample units in that panel are to be visited that year.

Study	Revisit Notation	Panel #	% of Annual Effort	Year 1	2	3	4	5	6	7	8	9	10	11	12
Hellbender	[1-0,1-2]	1	Unknown	x	x	x	x	x	x	x	x	x	x	x	x
		2	Unknown	x			x			x			x		
		3			x			x			x			x	
		4				x			x			x			x
Fish	[1-0,1-4]	1	25%	x	x	x	x	x	x	x	x	x	x	x	x
		2	75%	x					x					x	
		3			x					x					x
		4				x					x				
		5					x					x			
		6						x					x		
Geo-morphology	[1-4]	1	100%	x					x					x	
		2			x					x					x
		3				x					x				
		4					x					x			
		5						x					x		
Macroinvertebrates	[1-0,1-4]	1	50%	x	x	x	x	x	x	x	x	x	x	x	x
		2	50%	x					x					x	
		3			x					x					x
		4				x					x				
		5					x					x			
		6						x					x		
Heavy Metals	[1-9,1-9]	1	1 stretch	x										x	
		2	100% - 1 stretch	x										x	

We plan to coordinate the membership and revisit designs of the different monitoring protocols as much as possible. In general, co-location and co-visitation are desirable because logistics may be simplified, allowing multiple vital signs to be measured at the same location and same time by the same field crew, decreasing travel costs and time spent in the field. There is a [1-4] revisit component in 3 of the 5 proposed studies (Table 4-5).

One of two basic types of membership plans may be employed, depending upon the relative advantages of co-visiting sites. In both types of membership plans, different studies will use the same sites, resulting in a high degree of co-location. The advantage of co-locating sites, other than sampling efficiency, is that it allows the acquisition of information for multiple variables at each site. The specific membership plan will depend upon how important it is to sample the same sites for different vital signs at the same time (i.e., co-visitation).

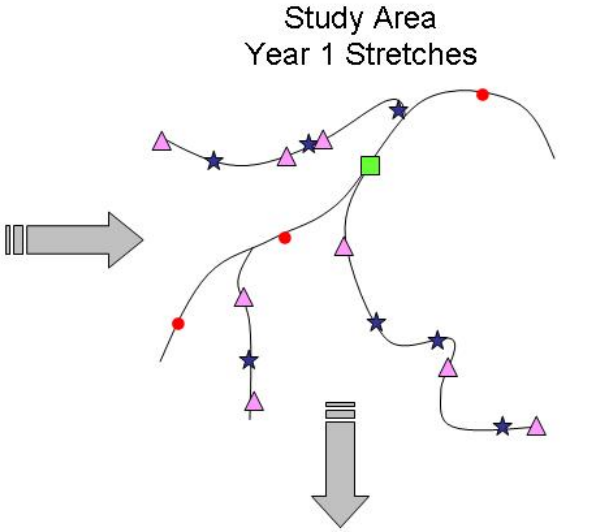
In the first type of plan (Figure 4-3), assuming that n_1 sample units are required in panel 1, n_2 sample units are required in panel 2, and so on, the first n_1 sample units in the GRTS sample would be assigned to panel 1, the next n_2 units would be assigned to panel 2, etc. This assignment causes the sample units in each panel to interpenetrate in space due to the spatial balance inherent in the GRTS. The primary advantage of this membership design is that each panel is itself a spatially balanced sample of river stretches drawn from the entire population, and inferences can therefore be made to the entire population using data from every panel. A disadvantage of this membership design is that travel costs between sample units are higher than in some alternate plans. Thus this membership plan assures a large degree of co-location across studies, but not necessarily co-visitation.

A second type of membership plan could be employed for two or more studies where co-visitation of sample units is logistically efficient (Figure 4-4). This membership design assures a large degree of co-visitation and co-location, but does not guarantee spatial balance of the total sample from studies with less than the maximum sample size. In this membership design, the study with the maximum sample size requirement would be allocated sample units as described above. Panels of other studies with the same revisit schedule, but lower sample size requirements, would be allocated a subset of the sample units.

If, for example, because of specialized expertise or seasonality issues, different sampling crews will need to visit sites independently or at different times of the year, there may be no practical benefit of co-visitation. Thus the first type of membership design described above (Figure 4-3) will be used, since it results in the highest degree of spatial balance. Alternatively, if the same sampling crews are able to obtain data for multiple vital signs from the same site at the same time, the logistical benefit may outweigh the potential sacrifice in spatial balance, and the second type of membership design (Figure 4-4) may be more appropriate.

It will be possible to utilize both membership designs, allocating some projects to one and the remainder of the other. This could, in theory, maximize spatial balance and optimize sampling logistics when considered across all projects within the limits of resources available for field work.

GRTS Sample			Membership Plan		
Sample #	Unit ID	Location	Macro-inver-tebrate Study	Geo-morph Study	Hell-bender Study
1	1700	Trib	Panel 1	Panel 1	
2	2003	Main	Panel 1	Panel 1	Panel 2
3	5729	Trib	Panel 1	Panel 1	
4	5533	Trib	Panel 1	Panel 1	
5	8641	Main	Panel 1	Panel 1	Panel 2
6	489	Main	Panel 1	Panel 2	Panel 2
7	230	Trib	Panel 1	Panel 2	-
8	1460	Trib	Panel 1	Panel 2	-
9	4199	Trib	Panel 1	Panel 2	-
10	5783	Trib	Panel 1	Panel 2	-
11	19	Trib	Panel 1	Panel 3	-
12	5034	Trib	Panel 1	Panel 3	-
13	5536	Trib	Panel 2	Panel 3	-
14	9364	Trib	Panel 2	Panel 3	-
15	8830	Trib	Panel 2	Panel 3	-
16	1758	Trib	Panel 2	Panel 4	-
17	4225	Trib	Panel 2	Panel 4	-
18	9434	Trib	Panel 2	Panel 4	-
19	9179	Main	Panel 3	Panel 4	Panel 2
20	8975	Main	Panel 3	Panel 4	Panel 3
21	8002	Main	Panel 3	Panel 5	Panel 3
22	1832	Trib	Panel 3	Panel 5	-
23	958	Trib	Panel 3	Panel 5	-
24	4719	Trib	Panel 3	Panel 5	-
25	1657	Trib	Panel 4	Panel 5	-
26	9283	Trib	Panel 4	Panel 6	-
27	9181	Trib	Panel 4	Panel 6	-
28	8833	Trib	Panel 4	Panel 6	-
29	9555	Trib	Panel 4	Panel 6	-
30	5112	Trib	Panel 4	Panel 6	-

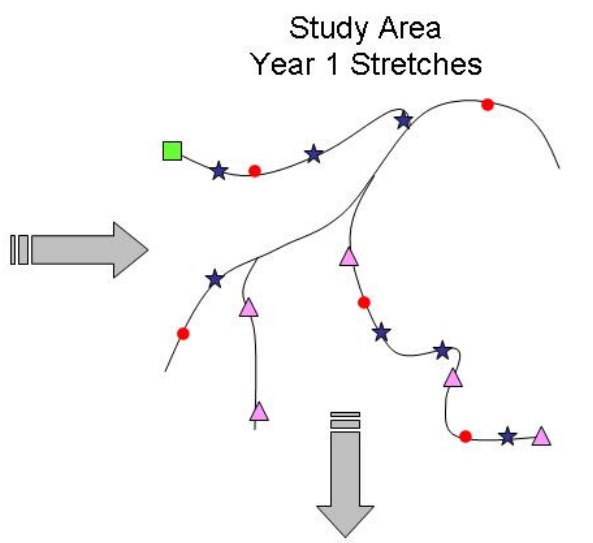


Co-Located Stretches

Symbol	Macroin.	Geomorph.	Hellbender
●	X	X	X
★	X	X	–
△	X	–	–
□	–	–	X

Figure 4-3. Potential membership plan for BUFF and OZAR yielding high co-location of points across studies, but not necessarily high co-visitation. In the table at left, a GRTS sample is allocated to panels of the macroinvertebrate, geomorphology ("geomorph"), and hellbender studies. Co-located stretches are indicated on the right. Even though stretches are co-located, some are in different panels and receive different visitation schedules. Revisit plans for panels in this example appear in Table 4-5.

GRTS Sample			Membership Plan	
Sample #	Unit ID	Location	Macro-inver-tebrate Study	Geo-morph Study
1	1700	Trib	Panel 1	Panel 1
2	2003	Main	Panel 1	Panel 1
3	5729	Trib	Panel 1	Panel 1
4	5533	Trib	Panel 1	Panel 1
5	8641	Main	Panel 1	Panel 1
6	489	Main	Panel 1	-
7	230	Trib	Panel 1	-
8	1460	Trib	Panel 1	-
9	4199	Trib	Panel 1	-
10	5783	Trib	Panel 1	-
11	19	Trib	Panel 1	-
12	5034	Trib	Panel 1	-
13	5536	Trib	Panel 2	Panel 2
14	9364	Trib	Panel 2	Panel 2
15	8830	Trib	Panel 2	Panel 2
16	1758	Trib	Panel 2	Panel 2
17	4225	Trib	Panel 2	Panel 2
18	9434	Trib	Panel 2	-
19	9179	Main	Panel 3	Panel 3
20	8975	Main	Panel 3	Panel 3
21	8002	Main	Panel 3	Panel 3
22	1832	Trib	Panel 3	Panel 3
23	958	Trib	Panel 3	Panel 3
24	4719	Trib	Panel 3	-
25	1657	Trib	Panel 4	Panel 4
26	9283	Trib	Panel 4	Panel 4
27	9181	Trib	Panel 4	Panel 4
28	8833	Trib	Panel 4	Panel 4
29	9555	Trib	Panel 4	Panel 4
30	5112	Trib	Panel 4	-



Symbol	Co-Located Macroin.	Co-Located Geomorph.	Co-Visit Schedule
●	x	x	[1-0]
★	x	–	–
▲	x	x	[1-4]
■	x	–	–

Figure 4-4. Alternative potential membership plan for studies with common revisit schedules. In the table at left, stretches in the GRTS sample are first allocated to panels of the macroinvertebrate study, which has the maximum panel sizes (annual sample). Stretches are then allocated to the geomorphology ("geomorph") panels from similar numbered panels in the invertebrate study. For example, stretches in panel 1 of the geomorphology study are a subset of the stretches in panel 1 of the invertebrate study.