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Aridland Soil Structure and Stability Monitoring Protocol for the Greater Yellowstone Network

Natural Resource Technical Report NPS/IMR/GRYN/NRTR—2007/00X

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1. Introduction

Soils are the foundation of the terrestrial ecosystem. Maintenance of their physical and biological functions and processes is especially important in aridland systems, where aboveground biota are not abundant. Key physical properties of aridland soil systems are water storage, nutrient cycling, and provision of habitat for many plants, animals, fungi, and microbes. Arid systems can take decades or even millennia to recover from disturbances that are detrimental to soil processes and functions. Thus, it is important to protect aridland soils to ensure healthy ecosystem functioning.

Bighorn Canyon National Recreation Area (BICA) is located on the Wyoming–Montana border within an arid region east of the Pryor Mountains. A portion of BICA is included within the boundaries of the Pryor Mountain Wild Horse Range (PMWHR), which also encompasses parts of the Custer National Forest and the Bureau of Land Management's Billings Field Office management area, and will be an important focus of Greater Yellowstone Network soils monitoring.

The bedrock geology of BICA consists primarily of Permian, Jurassic, and Cretaceous sedimentary formations similar to those that typify the Colorado Plateau. The vascular vegetation is composed mainly of Utah juniper and curlleaf mountain mahogany; Utah juniper and bluebunch wheatgrass; sage-steppe; mixed desert shrub; and grassland communities (Knight et al. 1987). The dominant grasses in these communities (bluebunch wheatgrass [*Agropyron spicatum*[1]] being the most frequent and abundant) have C3 carbon fixation cycles and are dormant during the summer drought. Plants are spaced relatively widely, and plant interspaces are dominated by biological soil crust communities of mosses, lichens, cyanobacteria, blue-green algae, and microscopic fungi.

Mack and Thompson (1982) explained how areas in the western U.S. with high C3 grass-species dominance and high biological soil crust cover did not evolve with frequent, high-impact grazing by large-hooved ungulates. Heavy grazing of these C3-dominated grassland and shrub-steppe systems has resulted in permanent changes in vegetative composition, soil erosion, and loss of productivity. In the C4-dominated systems (of which grama [*Bouteloua*] species are the best indicators) typical of the shortgrass prairies in eastern Montana and Wyoming, heavy grazing does not cause permanent resource damage.

The first ancestral form of horse, which arose during the Eocene epoch and evolved over millions of years to the genus extant today, became extinct in North America about 10,000 years ago (MacFadden 2005). Because the fossil record shows that the flora of the Intermountain West arose during the Pliocene (Burkhardt 1995), aridland systems of the interior west must have evolved with horse use during the Pliocene and Pleistocene. Then as now, distribution and abundance of horse bands was largely determined by access to both water and food, and correlated with local and regional climate. Local and regional vegetative and biological crust community composition and structure are also correlated with climate.

Spanish explorers brought European horses to North America in the 1500s. By the early 1700s, the Native Americans of the northern Great Plains were using horses (Hansen 1994). Horses that were left to roam or escaped from human control formed feral bands in different areas of the

[1] The current taxonomic name for this species is *Pseudoregnaria spicata*. The taxonomy used in Knight and others (1987) is used in the text.

West. Eventually, these bands became known as "wild" horses. By the mid-1900s, wild horse herds on federal lands were controversial, with constituencies both in favor of and against maintaining them. Ultimately, national legislation was passed that established designated horse ranges and managed the herds so that "the natural ecological balance of all wildlife species" was protected (Public Law 92–195).

Although there might well have been some use of the BICA area by horses during the Pleistocene, the soils and vegetation that occur within the BICA portion of the PMWHR are not able to withstand the amount of horse grazing and loafing that now occur, especially in the territory of the resident Crooked Creek band. The results of a recent assessment of landscape health carried out in the PMWHR through the Natural Resources Conservation Service (NRCS) (Ricketts 2004) showed that the BICA unit of the PMWHR is in poor condition with regard to soils and site stability, water infiltration and runoff, and biological soil-crust and vascular-plant communities. Current plant communities bear only a 44% similarity to baseline data collected in 1981 (BLM and SCS 1981), and 67% are in a downward trend.

Thirty-one percent of BICA's PMWHR unit is experiencing severe soil erosion, with pedestaling as high as two feet. Bare soil cover on the unit ranges from 22 to 74%; biological soil-crust cover ranges from 0 to 5%. By comparison, biological crust cover in the Horseshoe Bend area, which has been excluded from grazing since 1967, ranges from 11 to 30% (Ricketts 2004). Most of the soils in the PMWHR unit are calcium-rich (Ricketts 2004), and calcareous soils generally have high cover of species-rich biological crusts (Belnap et al. 2001). The NRCS's rangeland-health rating indicated that the PMWHR unit exhibits moderate-to-extreme departure from historic conditions. These impacts may be detrimental to long-term soil structure and stability.

There is also limited cattle grazing adjacent to the main road through BICA's south district (the designated driveway for a few cattle ranchers who have permits to move cattle to their lands north of the south district boundary). Two small pastures in the north end of the south district experience limited use. No data are available on impacts by cattle.

The BICA staff is concerned about the current and future condition of the unit's soil resources. Thus, they have chosen to monitor surface structure and stability as a high-priority vital sign. The information gathered through monitoring of soil surface structure and stability will be incorporated not only into decisions regarding the management and boundaries of the BICA unit of the PMWHR, but also may be used to assess impacts of future management and visitor activities on BICA lands.

1.1. Issues and threats

1.1.1. Grazing by cattle and horses

Despite the poor rangeland health conditions in the current BICA unit of the PMWHR, there is public pressure to expand the PMWHR into two more areas of BICA, the Sorenson Extension and East Trail Creek, both of which are north of the current BICA unit boundary and are currently in good condition. Ricketts (2004) states that unless the current size of the wild-horse herd was reduced, and their grazing behavior modified through changes in access to water, the same degradation would occur in these expansion areas.

In arid lands, overgrazing by ungulates can cause soil compaction, loss of vegetation, loss of biological soil-crust cover and diminishment of microbial activity, all of which can ultimately lead to soil erosion (Belnap et al. 2001; Evenari 1981; Lee 1981; Memmott et al. 1998; Metting 1991). Ecological responses of concern are described below.

1.1.2. Loss of infiltration and subsequent soil moisture

Soil compaction, which causes loss of plant roots (Whitford 2002), loss of macropores (Belnap 1995), bioturbators (when vegetative food sources diminish) (MacKay 1991), decreases water infiltration and reduces soil aggregates and pore space, which are important for soil stability and soil biota habitat (Belnap 1995; Lee 1981; Whitford 2002).

Losses of aboveground vegetative cover or changes in composition may result in reduction of underground phytomass. In aridland environments, which have sporadic temporal and spatial precipitation, underground phytomass reserves are important reservoirs that provide resilience in the face of erratic primary-production rates (Evenari 1981).

Loss of vegetative cover also reduces soil nitrogen retention (Hooper and Vitousek 1997; Tilman et al. 1997) and results in loss of food supply for soil bioturbators, such as ants and termites, which are essential for maintaining macropores and channels for water infiltration and for redistributing and decomposing organic matter (Lee 1981; MacKay 1991; Polis and Yamashita 1991; West 1981). Loss of biological soil crusts disrupts nitrogen and carbon cycles in interspaces between vascular plants (Belnap 1995; Harper and Pendleton 1993; Metting 1991). Nitrogen is a limiting nutrient in aridland systems (Whitford 2002).

Biological crusts improve water infiltration on fine-textured soils (Metting 1991) because the crust creates a well-aggregated, granular structure (Warren 2003). Thus, if the crust is destroyed by grazing, infiltration is decreased.

1.1.3. Loss of aggregate stability

Soil structure—that is, whether and how strongly soil particles are bonded together or aggregated—is important in terms of how water moves into the soil surface and through the soil profile, both vertically and horizontally (Birkeland 1984). Soil structure also influences the susceptibility of soil to erosion and soil porosity. Aggregated, as opposed to single-grain or massive, soil structure is often the best condition for the germination and growth of seedlings as well as the extension of rhizomes and the entire rooting structure of a plant (Hillel 1982). Factors affecting soil structure include texture (e.g., relative sand, silt, and clay content), organic-matter content, non-vascular plant and microbial exudates, moss rhizines, fungal hyphae, and vascular-plant rooting structures (Warren 2003).

Aggregate stability is more important in fine-textured soils than in coarse-textured soils, because fine-textured soils with poor stability have higher runoff rates. Coarse-textured (sandy) soils have higher infiltration rates, because the coarse soil particles act like very small soil aggregates. Soil texture changes extremely slowly and can be considered an intrinsic soil characteristic for the geologically short timespan of a monitoring program. Organic-matter content can change at a much faster rate and is influenced both by input of organic materials and rates of breakdown and oxidation. Non-vascular plant and microbial exudates, moss rhizines, fungal hyphae, and vascular-plant rooting structures can change relatively quickly. Mechanical disturbances (e.g., vehicles), grazing animals, and human foot traffic all directly affect soil structure, specifically aggregation. Soil compaction destroys aggregate stability by breaking down the structure of the soils (Belnap 1995; Lee 1981). Removal of vegetation or the death of plants and biological soil crust organisms indirectly affect soil structure, generally by decreasing aggregation of soil particles.

Soil aggregates are primarily formed in soils that have some clay content. The small, charged clay particles readily adhere both to each other and to larger particles. Aggregates are also formed by humic cements produced by microbial activity, which is promoted by the death of roots, particularly root hairs. These organic, binding substances, which are especially important in soils with low clay content, are transitory and need to be replenished by further microbial decomposition. Thus, in soils with lower clay contents, organic matter (the bulk of which is vascular plants and non-vascular crust organisms) must be replenished and supplied continuously if aggregate stability is to be maintained over time (Hillel 1982). Biological soil crusts increase soil-surface stability by trapping and binding soil particles together with polysaccharides emitted by cyanobacteria and green algae, and with lichen and moss rhizines (Belnap et al. 2001; Metting 1991; St. Clair and Johansen 1993). Accordingly, loss of biological crust cover decreases soil-surface stability (Whitford 2002). Recolonization of sites by crust cyanobacterial organisms takes 14–35 years. Recolonization by crust mosses and lichens takes 60–500 years (Belnap et al. 2001).

1.1.4. Soil erosion

Soil erosion disrupts the aridland ecological system because most soil biological processes occur within the upper 10–20 cm of soil (Evenari 1981; Myles and Hooten 2000). A positive feedback loop can be created in which loss of soil contributes to disruption of soil hydrological processes and loss of soil biota, which decimates nutrient cycling. Changes in soil hydrology and nutrient cycling can inhibit the establishment of vascular plants, leading to more erosion and a further breakdown in nutrient cycling and soil hydrological processes. In general, loss of soil, water, and nutrients leads to degradation of other ecosystem functions (Herrick and others 1995; NRC 1994). Erosion of the epipedon, or A, horizon results in a large decrease in organic matter and soil microbial populations. Subsequently, soil fertility and sites for germination of vascular plants decrease. It can take 5,000–10,000 years for the A horizon/epipedon to re-form (Dregne 1983).

1.1.5. Magnitude of threat

Ricketts's (2004) report indicates that the magnitude of the grazing threat is large in the BICA unit of the PMWHR, especially with regard to the loss of biological soil crusts and erosion. Much damage has already occurred, and could be extended into the proposed expansion areas. There were some weaknesses in the sampling design with regard to estimation of changes in vascular plant species composition, so it is difficult to know the exact threat of vegetation loss. There are no data on the cattle grazing areas that could be used to report or estimate the magnitude of the threat. Studies were conducted of horse grazing of vegetation inside and outside exclosures in the PMWHR during the 1990s (Singer and Schoenecker 2000). Although grazing effects on vascular vegetation cover were inconclusive, long-term study of these sites may provide better information about the magnitude of grazing effects on vegetation.

1.1.6. Spatial extent of threat

The threat posed by wild-horse grazing is confined to the current boundaries of the PMWHR within BICA, but would expand concomitantly with expansion of the horse range in the Sorensen Extension and/or East Trail Creek, which is adjacent to the northern boundary of the current BICA unit of the PMWHR. The threat posed by cattle grazing occurs in the cattle-trailing areas along the main road through the south district; the Common Corrals, where cattle are held overnight while trailing; and areas where stray cattle loaf.

1.1.7. Temporal scale of threat

This threat operates over two timescales: the yearly duration of grazing within the affected areas and the cumulative number of years of grazing. It is difficult to say, even with some initial monitoring, how quickly aggregate stability and biological crust cover are lost following new or increased grazing disturbance.

1.2. Measurable objectives

Several facets of the ecosystem could be monitored to assess status and trend relative to grazing impacts: vascular vegetation cover, composition, density, frequency and/or productivity; soil organic-matter content; soil aggregate stability; biological soil crust cover and/or composition; soil nutrient content and cycling; microbial community composition and abundance; and actual soil erosion rates. To monitor all of these ecosystem attributes would be cost-prohibitive, and some of the methods could prove difficult and destructive. Thus, this protocol will focus on ground-cover attributes and soil aggregate stability, which are direct measures of soil erosion potential.

1.2.1. Objective 1. Detect changes in biological soil crust cover

The goal of monitoring under Objective 1 will be to estimate changes in the status and rate of increase or decrease of ground-cover classes (e.g., moss-lichen biological crust, cyanobacterial biological crust, rock, litter, downed wood, basal vegetation, bare soil) over time, both for individual ecological types and for the entire BICA portion of the PMWHR. Information about all of these ground-cover categories is important to successful interpretation of potential soil surface stability. However, only basal vegetative cover and biological soil crust cover are directly affected by grazing. Although the amount of exposed rock, bare soil, and litter will fluctuate with increased erosion and deposition (i.e., movement of soil across the landscape), these measures are secondary effects of detrimental grazing. However, collecting data on these categories will make it possible to analyze their correlation to crust and basal vegetative cover, if desired.

1.2.2. Objective 2. Detect changes in soil aggregate stability

The goal of monitoring under Objective 2 will be to estimate changes in the status and rate of increase or decrease in soil aggregate stability over time, both for individual ecological types and for the entire BICA portion of the PMWHR. Aggregate stability is a measure of the ability of aggregates in the soil to resist being broken down by destructive forces (Hillel 1982). The higher the aggregate stability of a soil, the less prone it will be to wind and water erosion. Aggregate stability is measured by testing how much aggregates slake in water, and is assigned a ranking from 1 to 6, lowest to highest in stability.

2. Sampling design

2.1. Targeted scope of inference

The targeted scope of inference for this protocol consists of soil surfaces on slopes of less than or equal to 50% in the nine delineated ecological-type units that occur in BICA, both inside and outside the PMWHR (see Figure 1). Units of interest outside of the horse range occur primarily in the central portion of the south district. Aquatic, riparian, and other wetland sites are excluded from the scope of inference.

For this protocol, ecological types are defined as having a unique combination of soil properties (derived either directly from geologic parent materials or from pedogenesis), climatic characteristics (rainfall and temperature), and vascular-vegetation structure and composition within which a biological soil crust community with characteristic abundance and composition occurs. This definition of ecological types is not the same as, and is not meant to correlate to, descriptions used in other publications or by land management agencies such as the U.S. Forest Service, the Natural Resources Conservation Service, or the Bureau of Land Management.

2.2. Overall sampling design

The sampling design uses two spatially balanced, random samples: one within the BICA unit of the PMWHR, where the horse-grazing disturbance is occurring (hereafter referred to as INSIDE), and one within BICA but outside of the PMWHR, where no horse-grazing disturbance is occurring (hereafter referred to as OUTSIDE). The samples are stratified by eight delineated ecological-type map units (described below). Within each stratum, unequal selection probabilities are assigned to three slope classes: 0–20%, 20–30%, and 30–50%. The randomness of the design prevents bias and allows for statistical analysis. The spatial balance of the design allows for better representation of the landscape; that is, it overcomes the common problem of spatial interaction in natural landscapes, and thus allows for more efficient sampling with fewer overall samples (Stevens and Olsen 2004). The sample was selected using the Generalized Random-Tesselation Stratified Design (GRTS) procedure in the psurvey.design package (Olsen and Kinkaid 2005), which is used in the freeware statistical computer program R (R Development Core Team 2005).

2.2.1. Assignment of selection probabilities for slope classes

The selection probabilities assigned to the three slope classes in the targeted scope of inference were based on analysis of horse use of slope ranges as determined in the PMWHR survey and assessment (Ricketts 2004). The Bureau of Land Management Billings Field Office (which manages the herd) collected horse-use data for several years and was able to determine the amount of time spent on different slope classes during the summer and winter months. Table 1 shows the use of slope classes by season.

Table 1. Wild horse use of slope classes by season, and selection probability.

Slope class	December–April	May–November	Selection probability
0–20%	–	85%	.70
20–30%	80%	10%	.20
30–50%	15%	5%	.10
>50%	5%		—

All slopes greater than 50% were eliminated from the sampling frame. They are little used by horses and steep enough to make sampling somewhat hazardous for crews. The greatest damage to biological soil crusts probably occurs with summer horse use, when soils are drier and crust organisms more fragile. Thus, the greatest selection probability was assigned to the 0–20% slope class: 0.70, or seven sampling sites of a total of 10 per ecological unit. A selection probability of 0.20 was assigned to the 20–30% slope class: two plots out of a total of 10 per ecological unit. A selection probability of 0.10 was assigned to the 30–50% slope class: one plot out of a total of 10 per ecological unit.

The relative proportions of slopes classes in each ecological type were calculated to see how closely they matched horse use by slope class. There was enough discrepancy that selection probabilities had to be specified when running the GRTS code to select sample sites.

2.2.2. Major components of variance

There are four major components of variance that may affect ability to detect trend in biological crust cover and aggregate stability: population variance, temporal variance, site-temporal variance, and residual variance (Urquhart et al. 1998). Population variance will be minimized as much as possible through the spatially balanced, random design and by sampling as many sites as is economically feasible. Temporal variance will be identifiable in the OUTSIDE sample and can be used to distinguish temporal variance from other sources of variance in the INSIDE sample. Site-temporal variance, that is, the variance of sites in an individualistic manner over time, can be examined for individual site data. If a few sites vary quite differently than other sites in their ecological type, they can be further examined in the field for anomalous features or disturbances. There would be no reason to exclude these sites unless it was determined that they did not belong to the ecological type to which they were originally assigned. Residual variance, that is, variance caused mainly by measurement error and inter-observer error, will be minimized as much as possible through use of easily repeatable measurement methods, good crew training, and as much crew consistency as possible.

2.3. Development of sampling frame

Five digital base maps were combined and edited to delineate ecological types throughout the south district of BICA:

- 1:24,000-scale BICA-wide vegetation-type map (Knight et al. 1987);
- 1:100,000-scale Bridger-quadrangle bedrock-geology map, clipped to cover the Montana portion of BICA (Lopez 2000);
- 1:500,000-scale Powell-quadrangle bedrock-geology map, clipped to cover the Wyoming portion of BICA (Love and Christiansen 1985);
- 1:24,000-scale Carbon County-area soil-survey map, clipped to cover the Montana portion of BICA (Parker et al. 1975); and
- 1:100,000-scale Bighorn County, Wyoming, soils map, clipped to cover the Wyoming portion of BICA (Munn and Arneson 1999).

Two additional hard-copy bedrock-geology maps that covered portions of BICA within the extent of the Bridger Quadrangle were used to digitize smaller features that were too small to be mapped at the 1:100,000 scale and were important to include because they had different surface soil texture and/or chemistry that would affect the natural abundance and composition of biological soil crust communities:

- 1:62,000-scale Bighorn Canyon–Hardin, Montana-area bedrock-geology map (Richards 1955); and
- Geology of the Dryhead–Garvin Basin (Stewart 1974).

The digital geology and soils maps were corrected for obvious mapping errors, for instance, terrestrial polygon boundaries that extended into Bighorn Reservoir and vice versa. However, there are likely still many flaws in the sampling frame. Comparison of the hard-copy geology maps and the digital geology maps often showed contradictory map units. For example, two overlapping geologic polygons may have been mapped as Madison limestone and Amsden shale.

These same polygons may have then overlapped a soils polygon mapped as primarily having calcareous-sandstone parent material. Although some layers in the Amsden shale contain calcareous sandstone, Madison limestone is quite different. All of the geology and soils maps were carefully examined, and the most consistent similar characterization was used to define the draft map unit for the sampling frame.

The BICA vegetation map (Knight et al. 1987) was used to further refine sample units. All riparian and floodplain vegetation units were eliminated from the sampling frame because these sites are either frequently disturbed, too wet, or too heavily vegetated to develop good biological soil crusts. In addition, all Douglas-fir and spruce forest units were excluded because development of good biological crusts is unlikely there due to shade and abundant litter beneath these forested canopies. Due to questions about the projection of the vegetation map, these map units were simply correlated by eye to the units created from the geology and soils maps. The sampling frame, showing these final ecological-type units, is shown in Figure 1.

2.4. Considerations in delineating ecological-type units

Ecological-type units were delineated according to surface-soil characteristics, soil-chemical features, and vegetation properties.

Numerous studies have been undertaken to demonstrate the correlation between surface-soil characteristics and the occurrence and/or abundance of lichens and mosses and cyanobacteria (6b). High clay content prevents moss-lichen crusts from forming, whereas high silt content is associated with high moss-lichen cover (Bowker et al. 2005). Research on the Colorado Plateau has shown that moss-lichen cover and species richness "have approximately six-fold higher cover and approximately two-fold higher species richness on sandy soils than on shale-derived soils" (Bowker et al. 2005). Some researchers have found that high soil concentrations of calcium carbonate and/or gypsum are associated with higher cover of lichens and greater moss-lichen species richness (Ullmann and Büdel 2003). Ponzetti and McCune (2001) concluded that moderately high calcareousness, however, appears to be associated with lower cover and species richness than sites of low or very high calcareous concentrations.

Along with soil-surface texture, the most important soil-chemical features, calcium carbonate and gypsum, can be tentatively discerned from soil mapping units (SMUs), will be used as a covariate in analyses for ecological-type determination and single-site membership within an ecological site. In some cases, SMUs were used intact. In other cases, SMUs were combined or the geologic base map was used to refine or re-draw SMUs to account for attributes of geologic strata that were not necessarily described in the SMU.

Precipitation also will be used as a covariate. Precipitation is likely to affect the YEAR variance component and may affect the RESIDUAL variance by changing the detectability of soil crust organisms, especially cyanobacteria and green algae (Bowker 2006b).

Concentrations of phosphorus, manganese, and zinc in soils (Bowker et al. 2006a) are also positively associated with moss-lichen abundance and composition, but are not discernible in the SMU units or individual soil profile descriptions provided in soil surveys.

Vegetation properties affect the abundance and composition of biological soil crust communities. The most important vegetative community properties are density of perennial plant stems, canopy cover, and amount and longevity of litter produced. As mentioned above, all wetland and riparian vegetation, as well as dense, coniferous forest communities, were excluded from sampling. As such, the ecological types described here generally contain consistent vegetative communities, juniper and/or mountain-mahogany shrublands, sagebrush-steppe shrublands, mixed desert shrublands, or grasslands. Cushion-plant communities are infrequent and were not used to define a particular ecological type.

2.5. Ecological-type descriptions

2.5.1. Gypsiferous dolomite

This unit corresponds to the Goose Egg/Embar/Phosphoria bedrock-geology unit. The vegetation is primarily juniper/mountain-mahogany woodland; some areas are mapped as basin grasslands and windswept plateau (cushion-plant communities). This unit was differentiated because both gypsum (H_2SO_4) and calcium carbonate ($CaCO_3$) content in the soils is high. Biological soil crust communities tend to be very species-rich, especially in lichens and mosses. Crusts are fragile and easily break down with disturbance, but they are also more resilient than other crust communities on other types of soil surfaces.

2.5.2. Gypsiferous siltstone

This unit corresponds to the Sundance/Gypsum Springs bedrock-geology unit. Vegetation is sagebrush-desert shrubland and mixed desert shrubland. This site was differentiated because gypsum content in the soils is high. After initial sampling, it may be determined that natural total biological crust cover and relative cover of moss-lichen crusts does not differ significantly from the gypsiferous dolomite unit.

2.5.3. Limestone bedrock outcrop

This unit corresponds to the Madison limestone bedrock-geology unit. Many areas mapped in the Carbon County, Montana, soil survey as limestone outcrop are not included in this unit, because that report mapped the soil unit rather broadly and did not account for inclusions of sandstone outcrops and shale-derived soils. Vegetation on this unit is primarily mountain mahogany/shrubland and juniper woodland. Soils in this unit tend to be generally shallow and high in calcium carbonate content. The high $CaCO_3$ levels are associated with higher levels of calciphilous lichen species cover. Shallow soils often retain water closer to the soil surface, resulting in dense biological crust communities.

2.5.4. Sandstone shallow soil

This unit corresponds primarily to mapping units for sandstone-outcrop soils and bedrock geology, the latter mainly from hard-copy geology maps (Richards 1955; Stewart 1974). Vegetation is primarily juniper/mountain-mahogany woodland and mountain-mahogany woodland. Except where soils are extremely shallow, natural cover of biological crust communities tends to be lower here than on finer-textured soils. Crusts on these sites are relatively fragile and vulnerable to disturbance because of their coarse-textured soils. Their resilience following disturbance is low, and crust communities may not recover for decades or centuries. When crusts are destroyed on these sites, they are left relatively more vulnerable to exotic invasive plant colonization.

2.5.5. Shallow loamy red shale surface

This unit corresponds to the Shale Outcrop-Abac complex mapping unit of the Carbon County soil survey. The bedrock-geology units are Chugwater mudstones. Primary vegetation is juniper woodland. Soils are loamy and intermediate between the siltier units and the sandstone unit.

2.5.6. Silty limy surface

This unit corresponds to the Carbon County soil mapping unit, Harvey Stony Loam. The geologic parent material is quaternary alluvium. The primary vegetation is juniper woodland. this unit was differentiated because of the combination of its $CaCO_3$ and stoniness at the soil surface. The stoniness may provide greater soil stability under the same disturbance than in other units that have silt- and $CaCO_3$-rich surfaces but lack the additional stones.

2.5.7. Silty surface

This unit corresponds to the Chugwater and Swift-and-Rierdon bedrock-geology units (the latter two usually mapped together). The main soil unit in this type is the Carbon County Spearfish-Shale Outcrop complex. Vegetation is primarily juniper woodland and basin grasslands. This unit was differentiated because of its lack of high gypsum or calcium carbonate content in the surface soil.

2.5.8. Smectific clay

This unit corresponds to the Cloverly and Morrison Formations bedrock-geology units. It is rich in montmorrillonitic clays, which have high shrink/swell properties when soils go through wetting and drying cycles. The natural physical disturbance of these shrinking/swelling soil surfaces generally prohibits the development of mature biological soil crust communities. Often, only cyanobacteria and other microscopic organisms can colonize these sites. The primary vegetation is saltbush-desert shrubland and mixed desert shrubland.

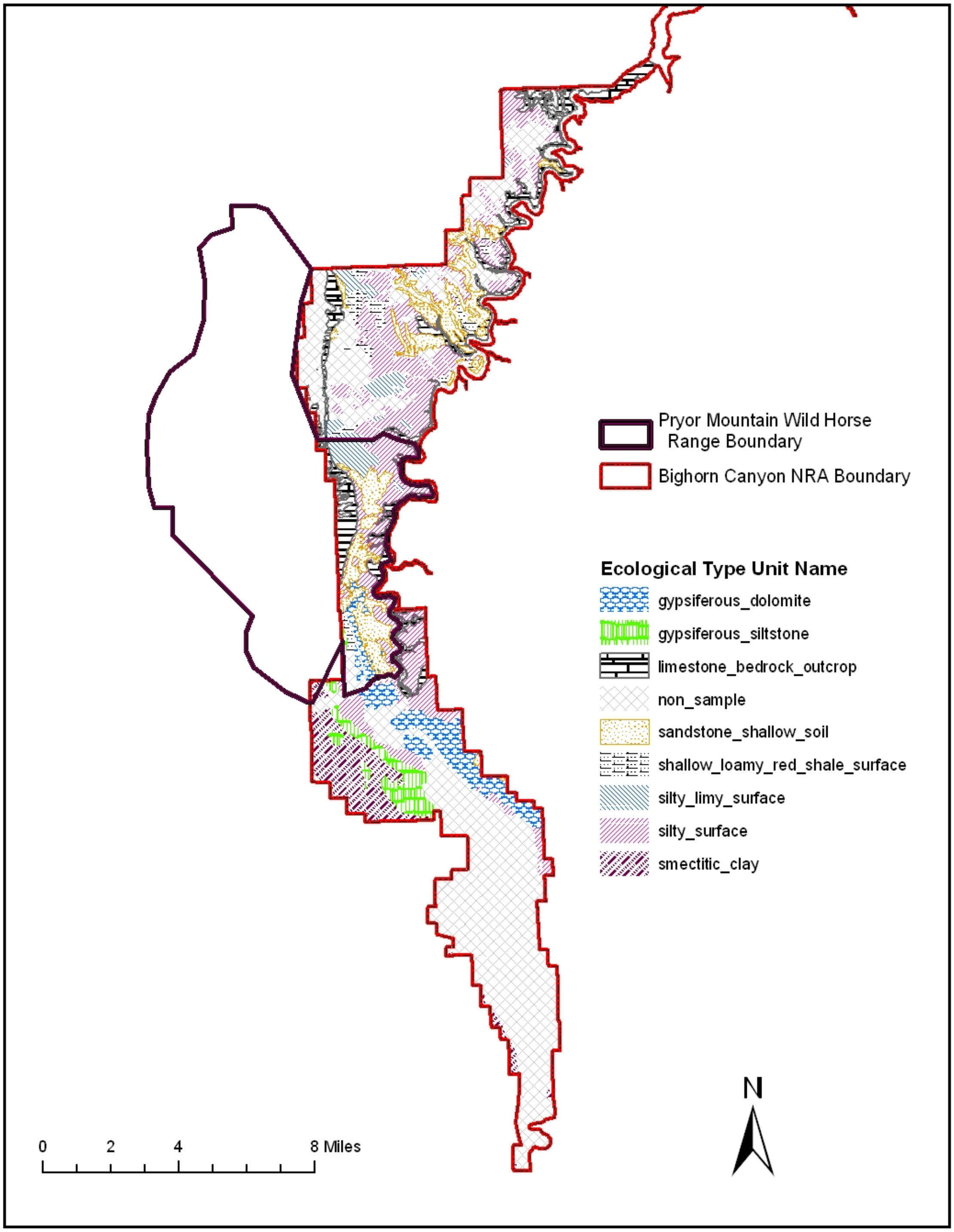

Figure 1. Map of ecological type units/sampling frame.

2.6. Potential changes to sample design

2.6.1. Sampling-unit delineation or sampling frame

Based on soil-laboratory data from samples collected during site establishment, it may be possible and even desirable to combine some ecological types. For example, differences in concentrations of gypsum or calcium carbonate may be negligible between two currently delineated ecological types. It also may be that average soil textures are quite similar between ecological types. If the sand, silt, and clay content of sites in two different ecological types do not differ by more than 5%, then they should be considered for combination. If the ecological types in which gypsum is measured have average concentrations that are less than 5% different than other ecological types, these also should be considered for combination.

Research on the correlation of soil texture and chemistry to biological soil crust abundance, composition, resistance to disturbance, and resilience following disturbance has not produced absolute quantitative ranges matched to particular crust communities. Recommendations about how to decide whether a particular site does not belong in an ecological type based on laboratory results are given below. It should be noted that these recommendations are based on best available knowledge, rather than on sound research about soils and biological crust communities in BICA.

A site should be dropped from the sampling frame if:

- it has a 15% or greater difference in sand or clay content than the average of the remainder of samples in that ecological site;
- it has a 40% or greater difference in silt content than the average of the remainder of samples in that ecological site; or
- it has a 20% or greater difference in gypsum or calcium carbonate concentration (g/kg dry-weight soil) than the average of the remainder of samples in that ecological site.

2.6.2. Number of sites per ecological type unit

The current sample design is based on sampling 10 sites per ecological unit. This number is based on simulations done for piloting similar monitoring in Canyonlands National Park (CANY) (S. Garman, personal communication 2006). CANY and BICA are not equivalent landscapes with equivalent ecological types, but are similar enough to use this simulation as a starting point. Until an initial set of data are collected and site variance can be determined, the power for trend determination for this design cannot be calculated. The number of sites per ecological-type unit may need to be increased or decreased to meet monitoring objectives and the desired analysis timeframe.

2.7. Panel design

Aridland soils, and biological soil crusts in particular, are relatively fragile and can be greatly damaged by frequent foot traffic. Therefore, it is important to sample sites as infrequently as possible and to make every attempt to sample during the spring season (April–June), which is the time of greatest precipitation in BICA. Crust organisms can withstand somewhat greater trampling and compression impacts when they are hydrated.

Following these restrictions, there are two feasible panel designs. Both provide trend estimates, and each emphasizes different status estimates. One design would entail sampling all sites during the first year and then again every 4–5 years. This design would provide better status estimates for all of the PMWHR. The other design would entail sampling all sites during the first year and then all sites in two ecological types each year, rotating through all ecological types every four years. This design would provide better status estimates for individual ecological types. The latter design would provide the most useful management information, because grazing impacts are different for each ecological type. Horse-range expansion probably will be onto areas dominated by one or two ecological types. Thus, having specific information about ecological types will aid in weighing decisions about the best locations for expansion. It would be possible to implement this design during the spring season. After the site-establishment year, only 40 sites would be sampled per year. A crew could probably complete 2–3 sites per field day.

There are more complicated panel designs that involve sampling sets of sites two years in a row and that not only provide good power for trend but also reveal trends more quickly than the panel designs described above. Re-running the GRTS sample selection package in R is not a difficult task.

3. Methodology

Although it would be most efficient and repeatable to use a colorimetric sampling method of ground-cover such as has been developed for the Colorado Plateau parks, there is no such method yet available for BICA soils. Thus, two methods were tested in 2006 for feasibility and inter-observer repeatability. Both methods require three main 30-m transects that are laid out at a 45° angle to the slope fall line. The transects are spaced so that the endpoints do not overlap. These specifications are designed to minimize the effects of disturbance by observers on downslope sampling locations.

Both methods also require the use of 2-m subtransects laid out at an angle perpendicular to the slope, as well as recording of ground-cover measurements for six classes: rock, wood, litter, moss-lichen crust, cyanobacterial crust, and bare soil. The first method entails recording line-intercept lengths of each ground-cover class along a 2-m subtransect. The second method entails recording point intercept of ground-cover classes at 200 points (every 1 cm) along the transect. The second method proved to be much more repeatable between observers.

A third option is to estimate the cover within microplots along the 2-m subtransects or the 30-m main transects. This method, however, is more difficult to carry out in the field and is generally far less repeatable, even for a single observer.

Details of current field methodology are described in SOPs 2, 3, and 4. Pre- and post-field-season preparations are outlined in SOPs 1 and 5.

4. Data management

Field data will be entered into personal data assistants (PDAs) equipped with Excel spreadsheets or Access database forms, then downloaded onto field laptops for storage during field trips. Data will be uploaded to the GRYN server for long-term storage and management. The field crew leader is responsible for data management during the field season. The project manager is responsible for data management after the field season. The two main responsibilities are correcting all data-entry errors and formatting data for use in analyses.

Detailed procedures for data management can be found in SOP 6.

5. Analysis and reporting

Using the GRTS psurvey.analysis package in R, estimates of biological crust cover and aggregate stability will be determined for the following:

- each ecological type within the PMWHR;
- the combined ecological types within the PMWHR;
- each sampled corresponding ecological type outside of the PMWHR; and
- the combined corresponding ecological types outside of the PMWHR.

Using the above estimates, ANOVA or ANCOVA will be run to compare:

- each ecological type inside and outside the PMWHR; and
- the combined ecological types within the PMWHR to the combined corresponding ecological types outside the PMWHR.

Because aggregate stability is a ranked (ordinal) response variable, analysis may require using ordinal logistic regression.

An initial report on status and site characteristics from site-establishment work will be prepared after the first field season. Subsequently, a report on overall status, ecological type status, and trend will be prepared every four years. A smaller report on status of ecological types sampled that year will be prepared every subsequent year. Reports will be written to address three audiences: BICA upper-level management and resource managers, BICA interpretive staff, and the general public.

Detailed procedures for data analysis and reporting are explained in SOP 6.

6. Personnel requirements

Table 2 shows positions, responsibilities, qualifications, and training needed to carry out this protocol.

Table 2. Personnel requirements.

Position	Responsibilities	Qualifications	Training needed
Project manager	1. Conducts pre- and post-field-season activities as described in SOPs 1 and 5. 2. Performs final review and correction of data-entry errors. 3. Delivers data in proper format to ecologist. 4. Reports any data problems (loss of data, difficulties in backing up data, problems using database program) to GRYN data manager.	• Organization • Several years' experience carrying out field activities • Understanding of personnel needs • Problem-solving ability	• Training from GRYN data manager in how to use soils protocol database and how to put data into proper format for analysis
Field crew leader	1. Carries out all planned sampling for field season. 2. Conducts practice run-through using GPS unit and PDA. 3. Conducts practice run-through of downloading data into field PC database program. 4. Is responsible for daily field activities, including vehicle maintenance, communications equipment, contact with BICA, and safety. 5. Performs safe data management during field season, including backing up data on field-data recorder, downloading data onto laptop and backing up, and downloading data onto GRYN server and backing up on CDs. 6. Reports needed equipment repairs and acquires replacements during field season. 7. Reports any data-collection issues to project manager.	• At least two seasons' fieldwork experience • Ability to solve problems and manage field personnel • Availability for entire field season, plus a few days before and after	• Training from project leader in use of PDA, GPS, digital camera, collection of field data
Field crew member	1. Assists field crew leader in collecting field data.	• Available for entire field season	• Training from field crew leader or project manager in how to use PDA, GPS, digital camera, collection of field data
GRYN ecologist	1. Analyzes data to estimate status and trend in biological soil crust cover and soil aggregate stability 2. Performs reporting following SOP #8.	• Advanced skills and experience in statistical analysis; skill and experience using the freeware program R	• Minimal; may need some consultation in operation of GRTS statistical analysis package
GRYN data manager	1. Development and creation of database that will house long-term data; maintenance and changes of database structure; data include numerical transect data; text notes; photos; site sketches; text tables for possible voucher specimen information. 2. Creation of process for downloading data from PDA directly into database. 3. Development and creation of data entry forms for backup in case of problems with PDA. 4. Development of procedures for putting data into format needed for analysis.	• Skill and experience in database development and creation – probably in the Microsoft Access database program	• Minimal; may need some training in use of Visual Basic for Applications if procedures needed that are not already standardized in database program

7. Standard operating procedures

All standard operating procedures are provided as appendices. The following SOPs accompany this protocol:

SOP #1. Pre- and Post-Field-Season Preparations and Procedures

SOP #2. Site Establishment

SOP #3. Field Data Collection for Biological Soil Crust Cover and Aggregate Stability

SOP #4. Data Management

SOP #5. Data Analysis and Reporting

SOP #6. Protocol Revision

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Aridland Soil Structure and Stability Monitoring Protocol for Park Units in the Greater Yellowstone Inventory and Monitoring Network

STANDARD OPERATING PROCEDURE (SOP) #1

Pre- and Post-Field-Season Preparations and Procedures

Version 1.00

November 26, 2006

Revision History Log

Previous version number and date	Revision date	Author(s) of revision (with title and affiliation)	Location in document and concise description of revision	Reason for change	New version number

Add rows as needed for each change or set of changes tied to an updated version number.

Prepared by Elizabeth Crowe ______________________________ Date: November 26, 2006 ______

Reviewed by ____ Date: ______________________

Approved by: ____ Date: ______________________

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1. Pre-Field-Season Preparations

1.1. Set up the field schedule

See Appendix A for the panel schedule. Once the schedule is determined, print out a copy for each field-crew member.

1.2. Notification of BICA staff

Notify Cassity Bromley of the upcoming field season and schedule. Give BICA at least two months' notice of the pending field season and arrival of the field crew.

Contact information for Cassity:

phone: (307) 548-5416
e-mail: Cassity_Bromley@nps.gov

1.3. Accommodations

Accommodations are usually available for research and monitoring crews at BICA. Cassity Bromley (see contact information above) is in charge of accommodations. Call or e-mail her as early as possible before the field season with the schedule and number of people on the crew (generally two). The GRYN Permitting SOP **there isn't one in this set—does this refer to another one somewhere?** also discusses accommodations in GRYN parks.

1.4. Research permit

A National Park Service research and collecting permit must be obtained prior to every field season. See the GRYN Permitting SOP for detailed procedures for obtaining a permit.

1.5. Equipment

1. Radio
   a. Check out a radio from the GRYN data manager, including the instruction book and battery charger.
   b. Make sure the radio is in working order and programmed for use in BICA.
   c. Check re-charger to make sure you can fully re-charge the battery.
   d. If a spare battery is available in the GRYN stash, check one out for the crew.
   e. Include a BICA radio call number card.

2. PDA
   a. Check out a PDA from the GRYN data manager.
   b. Make sure PDAs is in working order.
   c. Check the re-charger to make sure you can fully re-charge the PDA.

3. GPS unit
   a. Check out a GPS unit from the GRYN data manager.
   b. Make sure GPS unit is in working order.
   c. Check the re-charger to make sure you can fully re-charge the GPS unit.
   d. Upload the site coordinates for sites that will be sampled during the upcoming field season into the GPS unit.
   e. Get training in how to use the GPS unit.

4. Field PC
    a. Check out field a PC from the GRYN data manager.
    b. Make sure the PC is in working order, including battery and adapter.
    c. If not already loaded, load the database program and (data entry forms??) **why the question marks?** for the soils monitoring protocol.

5. Digital camera
    a. Check out a digital camera from the GRYN data manager, including instruction manual.
    b. Make sure the camera is in working order.
    c. Check the re-charger to make sure you can fully re-charge the camera.
    d. If the camera takes disposable batteries, purchase two sets of spares for the crew.
    e. Make sure that there are two flash memory cards for the camera, and that both work correctly: try storing, viewing, and downloading photos from the flash memory card.

6. Fiberglass tapes
    a. Check out three 50-meter or 100-meter fiberglass tapes (Keson brand with orange housing) from equipment storage.
    b. Unroll the tapes and make sure they are not broken or torn, and that scale markings are clearly visible.
    c. If necessary, buy replacement tape (easiest to find at Forestry Suppliers or Ben Meadows).

7. Carpenter rulers
    a. Check out four 2-meter wooden carpenter rulers from equipment storage.
    b. Make sure they are not broken and that scale markings are clearly visible.
    c. If there aren't four wooden carpenter rulers, purchase more (easiest to find meter-scaled carpenter rulers at Forestry Suppliers or Ben Meadows).

8. Metal spring clips
    a. Check out at least six metal spring clips for attaching main transect tapes to temporary stakes during sampling.

9. Soil aggregate stability test kit
    a. Check out one soil aggregate stability test kit. Check kit to make sure it contains:
        i. 2 plastic boxes with 18 compartments each
        ii. 18 dry sieves (1" length pieces of 3/4" diameter PVC pipe with screen attached to bottom)
        iii. 1 small soil scoop

1.6. Forms

If site establishment will be conducted during the upcoming field season, make copies of the following forms:

1. Site-establishment form: One for each sampling location, plus ten spare copies

2. Field data collection form: Ten spare copies in case of technical problems with PDA.

3. Rite-In-the-Rain copier paper.

    a. Make five copies of each form on Rite-In-the-Rain copier paper (made by and available from the J. L. Darling Corp. (http://www.riteintherain.com/) or through Forestry Suppliers or Ben Meadows)

    b. AND/OR supply the crew with spare Rite-In-the-Rain copier paper in case of an unexpectedly rainy field season. The crew can make more copies at the BICA office if necessary. Rite-In-the-Rain grid paper is also available.

1.7. Other Supplies

1.7.1. General

1. At least four mechanical pencils (5-mm lead works well, rather than 7 mm) with spare leads and erasers for crew.
2. At least four (these are often lost) thick-point Sharpie pens for labeling Ziploc bags.
3. Flagging for temporary marking of locations.
4. Two squirt bottles for wetting soil when reading ground-cover sub-transects and for wetting samples for aggregate stability test.
5. Five-gallon carboy for carrying distilled or de-ionized water to use in sampling.
6. Metal clipboard with form storage capacity.

1.7.2. For site establishment

1. Six angle-iron stakes for each sample site with the following dimensions:

    - 1" width on each angle
    - approximately 1' length
    - 3/8–1/4" hole drilled into one angle side near the top of the stake. A machine shop should be able to provide the angle iron and drill the holes.

2. One-gallon, freezer-strength (at least 2.7 mm thickness) Ziploc bags for soil samples. Need one bag for each sampling site, plus 10 extra to replace lost or torn bags.
3. Round metal cookie cutter or similar implement for sampling soils. Must be at least 2 cm in height and approximately 8–10 cm in diameter.

1.7.3. For collection of soil ground-cover and aggregate-stability data

1. Bamboo shish-kebab skwers (available in grocery stores).
2. Stopwatch, for timing during aggregate stability test.

2. Post-Field-Season Procedures

2.1. Equipment

1. Turn in radio and related equipment. Report any problems with radio to GRYN data manager, whether mechanical malfunctions or difficulties with use of the radio in the park.
2. Turn in PDA and related equipment to GRYN data manager. Report any problems with the unit or damage to it.
3. Turn in GPS unit and related equipment to GRYN data manager. Report any mechanical problems with the unit or damage to it.
4. Turn in field PC and related equipment to GRYN data manager. Report any mechanical problems with the unit or damage to it. Make sure all field data from the field season's work have been downloaded into the soils protocol database.
5. Turn in digital camera and related equipment to GRYN data manager. Report any mechanical problems with the unit or damage to it. Make sure all photos from the field season's work have been downloaded into the soils protocol database.
6. Store sampling equipment in the GRYN storage unit. There is a specifically marked storage box for equipment used for this monitoring protocol. If this box does not already exist, create one specifically for the equipment for this protocol. All equipment is to be placed in this marked box. This will greatly facilitate pre-field-season activities the following year. Equipment includes measuring tapes, carpenter's rulers, [plot frames], **why the brackets?** and aggregate stability measuring kits.
7. All equipment should be clean and dry before it is stored. Tapes and rulers can be cleaned with a mild dishwashing soap in a very low-concentrate solution. Tree resin can be removed with an organic solvent such as "Goo Gone" available in hardware stores. If any equipment has been broken or damaged during the field season, it should be immediately repaired and/or replaced. If crews are finished working before this is done, the need for repair or replacement should be reported to the project manager.

2.2. Data

Electronic data that have not yet been downloaded should be downloaded into the appropriate folder on the GRYN server and a backup copy made on CD that is stored in the project folder in the office of the GRYN program coordinator or soils project coordinator. Subsequently, consult SOP #5 Data Management.

2.3. Forms

If forms were used during the field season, check to make sure no unexplained blanks are present. Fill in all blank fields where possible. Make photocopies of all originals.

3. Appendix A. Panel Schedule

PENDING

Field Season Year	IDs of Sites to be Sampled	Ecological Type(s)
2007	All	All
2008		

Add additional rows as needed.

Aridland Soil Structure and Stability Monitoring Protocol for Park Units in the Greater Yellowstone Inventory and Monitoring Network

STANDARD OPERATING PROCEDURE (SOP) #2

Site Establishment

Version 1.00

November 26, 2006

Revision History Log

Previous version number and date	Revision date	Author(s) of revision (with title and affiliation)	Location in document and concise description of revision	Reason for change	New version number

Add rows as needed for each change or set of changes tied to an updated version number.

Prepared by: Elizabeth Crowe ______________________________ Date: November 26, 2006 ______

Reviewed by: ____ Date: ______________________

Approved by: ____ Date: ______________________

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1. Introduction

These activities will only occur the first time that a site is established. The site will be permanently marked for future re-visits. It is important not only to follow the directions in this SOP, but also to make any notes deemed necessary about the site. Both subsequent field crews and the GRYN ecologist will benefit greatly from accurate and complete information gathered upon site establishment. Often, a piece of information collected about a site may seem trivial or inconsequential, but prove to be very important in later analysis of data collected on the site.

2. Setting up transects

2.1. Field-checking of GRTS-selected sampling sites

Using the GPS unit containing the UTM coordinates of the sample-site list generated by GRTS, **has this generation already been completed, i.e., should there be instructions for doing it somewhere?** navigate to the first 10 sites in each ecological type within the PMWHR and the first 10 sites in each ecological type outside the PMWHR. The coordinates should guide the crew to the **center** of the sampling site (i.e., the midpoint of the three transects that will be established on the sampling site). Ecological-type units were delineated in GIS and are decidedly imperfect, so sites must be field-checked by the crew for appropriate inclusion in the sample set.

***NOTE*: When using the GPS unit in BICA, the projection should always be set to NAD83 Zone 12 North.**

2.2. Discarding sites

Discard all sites with the following conditions. Replace them with the next sequential site on the selection list that is within that ecological type.

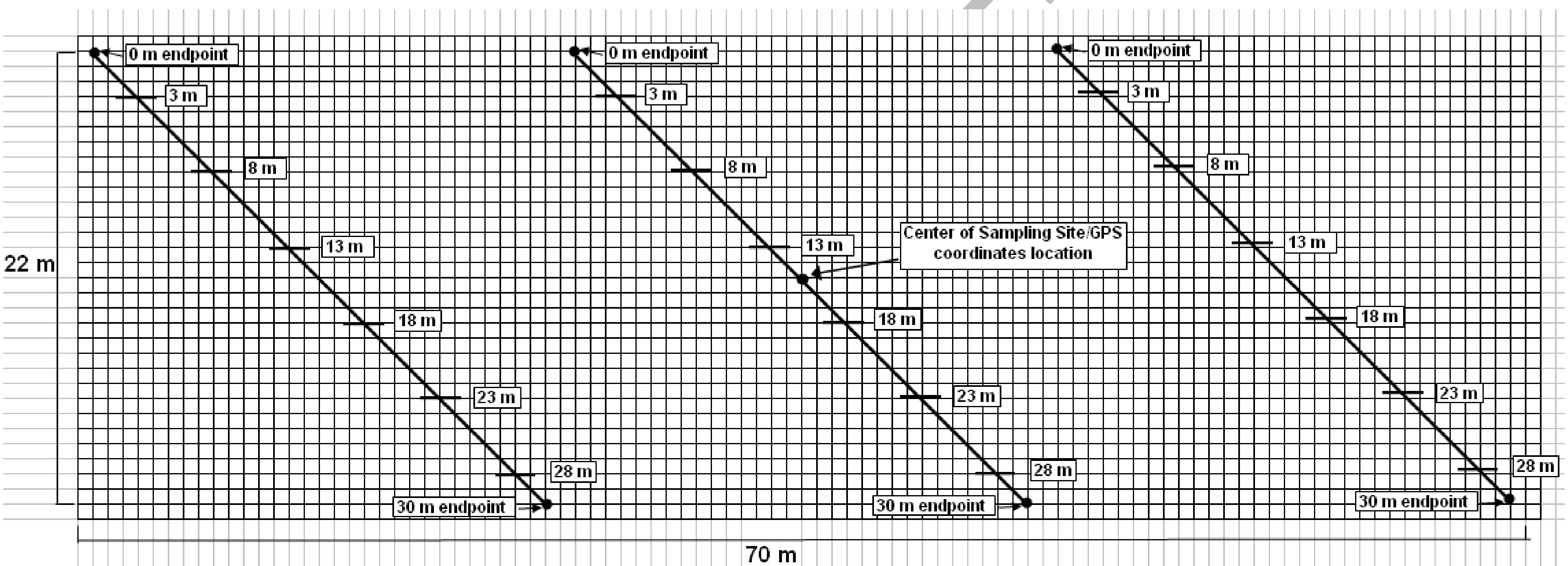
1. Site obviously belongs to a different ecological type than it was originally designated, for example, the site is supposed to be in the silty soil ecological type but is instead on a sandstone rock outcrop. It may not be evident whether the assignment of the sampling site to a particular ecological type is correct. In that case, assume that there is no discrepancy.
2. Site contains a portion of a currently used road or an older, unused road. The protocol is emphasizing the horse-grazing disturbance factor, rather than current or past vehicle disturbance.
3. Site contains more than 20% cover of bedrock outcrop or boulders greater than 1 m at the smallest diameter.
4. Site contains a portion of a dry or ephemeral wash or gully.
5. Site contains a portion of riparian or wetland vegetation or a perennial stream.
6. Site has more than 50% slope.
7. Site contains a trail greater than 20 cm in width.
8. Site contains some type of human-built structure such as a currently maintained fence, a building, or a trough.

9. Site is not large enough to install the three transect layout: must be 70 m wide (perpendicular to the slope) and 22 m long (along the slope fall line or from top to bottom of the site).

NOTE: lab analyses may show that some sites are quite anomalous within an ecological type with respect to a chemical or physical parameter. A decision may be made to discard these sites and establish the next appropriate site on the list during the next field season. However, it may be that the soil physical or chemical parameter can simply be included as a covariate in the statistical analysis of the data.

2.3. Transect layout

Transects are laid out as shown in the diagram below:



There is a two-meter gap (perpendicular to the slope) between the 30-m endpoint of one transect and the 0-m endpoint of the next transect to the right. Six 2-m subtransects are laid out as shown above at the 3-m, 8-m, 13-m, 18-m, 23-m, and 28-m points along the main transects, for a total of 18 subtransects per site.

2.4. Marking transects

1. To mark transect endpoints, steel or aluminum angle-iron stakes are highly recommended (aluminum is lighter to carry but more expensive to buy; steel will rust but will last for many decades).[1] The stakes should have the following dimensions:

    - 1" width on each angle
    - approximately 1' length
    - 3/8–1/4" hole drilled into one angle side near the top of the stake. A machine shop should be able to provide the angle iron and drill the holes.

2. To label sites, use round, blank aluminum tags of 1¼"–1½" in diameter with a thickness of at least 0.05" (any thinner and tags will bend and potentially break; these markers must remain intact and readable for many decades). These tags are available from Forestry Suppliers for about $10–13 per 100 tags, depending on diameter. **These are not on the SOP 1 equipment list; should they be added? If so, how many?**

3. Tags can be written on with a metal scribe, **This is not on the SOP 1 equipment list; should it be added?** available at most hardware stores for about $8–10.

4. Tags can be affixed to stakes with 9–12-gauge metal wire **not on the list**. Wire cutters **not on the list** will be needed to cut and bend this heavy wire. Both are available at hardware stores.

5. DO NOT mark tags with permanent markers (such as Sharpie pens). These markings WILL NOT LAST.

6. Tags should be placed at the 0-m end of each of the three transects established at a sampling site. It's quite possible that a stake will be pulled out or washed away in a severe erosion event. The more stakes that are marked, the more likely a future crew can re-establish the three-transect layout.

7. Stakes should be driven into the ground until they are flush with the soil surface.

3. Site Sketches

A location sketch must be made for each site, including the following features: **What kind of paper should be used for this? Should paper be included on the SOP 1 equipment list?**

1. All three transects, from beginning to end. Mark locations of subtransects along main transects.

2. Landscape features that are noticeable and useful for re-location, such as
    - Rock outcrops
    - Large boulders

---

[1] Although rebar is cheaper than angle-iron, it is not recommended for marking long-term transect layout, for two important reasons:

1. Rebar is used to mark many different projects on the landscape. Using angle iron will help crews to distinguish soil monitoring sites when they overlie other marked project sites or when crews are simply trying to re-locate a site within a particular vicinity.

2. Rebar endcaps that can be marked on-site can be difficult to find. Using pre-numbered endcaps can be confusing and ambiguous to future crews. Being able to write specifics on a marker tag is very helpful for crews who have not been to a site before.

- Single or clumps of trees (e.g., limber pine) or tall shrubs (e.g., Utah or western juniper). Tree species should be written on sketch; don't just draw in tree location.
- Roads
- Trails; note whether trail is designated hiking trail or animal trail
- Fences; be sure to include location of gate(s)
- Streams/drainageways, whether perennial or ephemeral
- Cliffs/rock walls
- Other human-made structures, such as pastures, exclosures, signs, water troughs, buildings, etc.

3. Scale marks
4. North arrow
5. Locations of photo points (see below) with compass bearings and distances from one transect endpoint location, i.e., a permanent marker.
6. Locations of soil samples

On the site-sketch form, also record:

- the site identification
- first initials and full last names of the field crew
- ecological-type unit
- date
- general slope of site, and
- general aspect of site.

4. Photo Points

Photo points should be established from which photos are taken that provide a general view of the site and show landmarks for future site re-location only. Photo points are not recommended for monitoring purposes. If they are to be taken, a publication should be consulted for proper installation and re-shooting. It is very difficult to interpret anything but very major changes in a landscape from photo-point monitoring. The subtleties of changes in ground-cover will be impossible to quantify in photos.

1. One photo point can be established at the site center. Because the GPS coordinates are already available, no coordinates need be re-taken.
2. Take photos at an oblique angle of the site in the four cardinal directions.
3. Take at least four photographs in four directions with the horizon showing. These latter photos are quite useful in re-locating hard to find sites.
4. If the horizon can't be photographed and/or there are large, visually obvious features that would be useful for re-location, photograph these.
5. Take and record a compass bearing for every photograph.
6. Record these bearings in the proper section on the site-establishment form. If photo points are established at other locations on the site, record the GPS location at that site.

7. Record the distance (in meters) and compass bearing from the site center to this/these other photo points. These measurements are much more accurate than the GPS locations that can be recorded by the current GRYN GPS units. Make notes about any unusual features photographed.

5. Soil Samples: Collection and Lab Analyses

5.1. Collection of soil samples

Samples should be collected along the main transect line at whole-meter markings between subtransects. Soils are collected from only the top two cm of soil.

1. Use an 8-cm-diameter metal cookie cutter (available at grocery, baking, and some hardware stores) for efficient collection of soil samples. **Should we provide some more detail about how the sample should be collected? To my mind, the fact that a cookie cutter has no bottom begs more information about how to use it to collect a soil sample. Do you press it in the ground up to the top and then scoop out what's inside?**

2. Remove all moss and lichen crust organisms, litter, rocks, and pieces of wood from the sample before bagging it.

3. Collect enough small samples to total the mass that meets the requirements of the analysis laboratory used. A small, handheld scale with a hook or clip that can be affixed to the bag can be used to periodically weigh the bag until the proper amount of sample has been collected.

4. Using a permanent marker, clearly mark the bags with the
   a. collection date,
   b. site identification,
   c. GPS coordinates,
   d. collector's first initial and last name, and
   e. ecological type. This information may seem excessive, but often at the end of a day, week, or field season, one or several bags are missing identification information. If bags are labeled with all of this information, it is much easier to re-identify them properly.

5. Mark each sample location on the site sketch.

5.2. Lab analyses

Soils should be tested for the following:

1. Physical attributes
   a. Particle-size distribution (***required***)
   b. Sand fractions (***required***)

2. Chemical attributes

a. Gypsum ($CaSO_4$) (***required*** on sites in the gypsiferous dolomite and gypsiferous siltstone ecological types **unless** there is an obvious gypsum evaporate layer on the soil surface. This evaporate layer will appear as a very white coating on the soil surface. In that case, the gypsum concentration can be assumed to be quite high).

b. Available P, Mn (*optional*)

c. Ca, Mg, K, Na (exchangeable cations) (*optional*)

6. Labs

Numerous soil laboratories across the country were contacted for pricing information and analysis capabilities. Three contacted labs could do all of the required analyses (Table 1. Soil lab analyses prices as of summer 2006.

1. Utah State University Analytical Laboratories
   http://www.usual.usu.edu/
2. University of Idaho Analytical Sciences Laboratory
   http://www.agls.uidaho.edu/asl/.
   Contact Steve McGeehan, Chief Chemist. Phone: 208-885-7900; fax: 208-885-8937
3. Colorado State University Soil Water and Plant Testing Laboratory
   http://www.colostate.edu/Depts/SoilCrop/soillab.html
   Contact: Mary C. Schumm, Assistant to Lab Manager. Phone: 970-491-5061; fax: 970-491-2930

Should there be instructions about how often the analyses are done, e.g., all together at the end of the season or after each site is established, and about getting information about how to properly package the samples from the lab?

Table 1. Soil lab analyses prices as of summer 2006.

Analysis	Utah State University	University of Idaho	Colorado State University
Prep – drying and grinding	$2.50	$4.00	$3.85
Particle size distribution	17.00	20.00	13.50
Sand fractions	11.50	10.00	6.00
Particle size and sand fractions w/sample prep	31.00	34.00	23.35
Gypsum content	15.00???	15.00	30.00
Available P	6.00	18.00	9.10
Mn (DTPA-extractable	9.00	26.00	50.00
Exchangeable cations (Ca, Mg, K, Na)	50.00	40.00	53.00
Costs for Entire Set of Sample Sites			
Set 1[a] - p.s.d. and sand fractions	$5,580.00	$6,120.00	$4203.00
Set 2[b] - p.s.d. and sand fractions	11,160.00	12,240.00	8406.00
Set 3[c] - p.s.d. and sand fractions	16,740.00	18,360.00	12,609.00
Set 1 [a] - p.s.d./sand fractions; gypsum on 50 sites	–	6870.00	5703.00

[a] Set 1: 9 SMUs, sample 10 sites within each, inside and outside the horse range, totaling 180 samples.

[b] Set 2: 9 SMUs, sample 20 sites within each, inside and outside the horse range, totaling 280 samples.

[c] Set 3: 7 SMUs, sample 30 sites within each, inside and outside the horse range, totaling 420 samples.

7. Initial Data Collection

Collect soil ground-cover and aggregate stability data using methods described in SOP #3, Field Data Collection for Biological Soil Crust Cover and Aggregate Stability_v1.

Aridland Soil Structure and Stability Monitoring Protocol for Park Units in the Greater Yellowstone Inventory and Monitoring Network

STANDARD OPERATING PROCEDURE (SOP) #3

Field Data Collection for Biological Soil Crust Cover and Aggregate Stability

Version 1.00

November 26, 2006

Revision History Log

Previous version number and date	Revision date	Author(s) of revision (with title and affiliation)	Location in document and concise description of revision	Reason for change	New version number

Add rows as needed for each change or set of changes tied to an updated version number.

Prepared by: Elizabeth Crowe ______________________________ Date: November 26, 2006 ______

Reviewed by: ____ Date: ______________________

Approved by: ____ Date: ______________________

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1. Safety and Personal Protection

1. Always wear appropriate clothing and sunscreen to protect yourself from the sun. Wear a wide-brimmed hat, long sleeves, long pants, and sunglasses that protect from both UVA and UVB rays. Apply sunscreen in the morning before starting field work. Re-apply as recommended on the sunscreen bottle. Many field workers ignore the damage that sun exposure has on the skin. Protecting yourself from the sun now is the best prevention against skin cancer in the future.

2. Always bring plenty of water. Few reliable sources of water are available, and all have to be filtered. It is recommended that you drink ½ to 1 quart of water or sports drink for every hour that you hike in summer heat.

3. Bring a two-way radio that has been programmed for BICA, and a radio charger. Make sure the battery is fully charged each field day. The field crew leader should check in with BICA headquarters in the morning when leaving to do field work and in the evening when finished. This ensures that the radio operators at the BICA visitor center know who you are, are aware of your activities, and can send out help if necessary.

4. Bring a cell phone if one is available. There is limited reception in BICA (try Devil's Canyon Overlook).

5. Wear shoes that have enough protection for your feet but as little crust-damaging tread as possible. Crust crews on the Colorado Plateau wear nearly smooth-soled shoes. Light hikers are probably suitable for most hiking conditions in BICA.

2. Equipment

The project manager already should have put together a box of the supplies and equipment needed for the upcoming field season. This box should include:

- Radio programmed for BICA frequencies with battery charger and BICA radio call number card
- PDA for recording field data
- GPS unit with coordinates of sample sites ***(NOTE: projection in GPS unit should be set to NAD83 ZONE12N)***
- Field PC with adapter for re-charging battery
- Digital camera with spare batteries (or charger), two flash memory cards, and manual.
- Three 50-m fiberglass tapes
- Four 2-m wooden carpenter rulers
- Metal spring clips for attaching tape ends to temporary stakes
- One soil aggregate stability testing kit. Check to make sure it includes
  - 2 plastic boxes with 18 compartments each;

- 18 sieves (1" length pieces of 3/4"-diameter PVC pipe with screen attached to bottom
- 1 small soil scoop

- Several sets of paper forms in case of technical difficulties with PDA. Forms should be on Rite-in-the-Rain paper if working in the rain.
- Mechanical pencils and permanent markers
- Flagging for temporary marking of sites
- Two plastic squirt bottles filled with de-ionized or distilled water
- Six pieces rebar or angle-iron stakes for marking temporary ends of transects (rebar is ok for temporary marking)
- Wooden bamboo shish-kebab skewers for conducting point counts along subtransects
- Stopwatch, for timing during aggregate stability test
- Metal detector for re-locating permanent transect
- Small sledgehammer **Like many items in SOP 2, these last two items are not listed anywhere in SOP 1. Should it be? *Suggestion*: it seems like it would be helpful to include an SOP-specific equipment list in each SOP that requires equipment, and an all-encompassing list by implement type (e.g., electronics, hardware-store stuff, etc.) in SOP 1. Yes?**

3. Measuring Biological Soil Crust Cover

3.1. Transect setup

Set up main transects as shown in the diagram below. Endpoint locations should already have been established through the site-establishment process. Stakes may need to be re-located using a metal detector. Rebar or angle-iron stakes may be used to temporarily mark transect endpoints and to attach main transect tapes. Tapes should be attached with clips.

NOTE: When setting up transect tapes, **do not** wrap the tape around an angle-iron stake, tree, shrub, or any other object. This will quickly degrade the tape, and **it will eventually break**. Tapes are expensive (~$50) to replace. Always use spring clips to hold tape ends taut along the transect line.

Subtransects are not permanent. The 2-m wooden carpenter rulers are laid out for subtransects and moved to the next subtransect point when point-reading for one subtransect is finished.

3.2. Method

It is most efficient for one crew member to read all subtransects and the other to record point data on the PDA. Reading the transects can be quite tedious, however, so the crew may decide to trade off duties for each main transect.

1. Subtransects are read at the 3-m, 8-m, 13-m, 18-m, 23-m, and 28-m points along each main transect (Figure 1. Main and subtransect layout at a sampling site.Starting at the upper end of the main transect, the subtransect reader should lay out a fully extended 2-m wooden carpenter ruler at the appropriate location along the main transect. **The**

subtransect should be laid out perpendicular to the slope fall line rather than to the transect direction.

2. At each whole centimeter mark, line up a wooden bamboo skewer vertically with the mark and look straight down over the skewer to see where its point has landed on the soil surface. Tell the recorder which category of ground cover is at that point.

Table 1. Ground-cover categories and coding.

Field form code	Ground-cover categories
ML	Moss-lichen biological crust
C	Cyanobacterial crust
L	Litter (including wood)
R	Rock (greater than 1 cm in diameter)
B	Bare soil (which includes gravel less than 1 cm in diameter)
BV	Basal vegetation (this refers to a plant stem that is rooted at the measurement point)

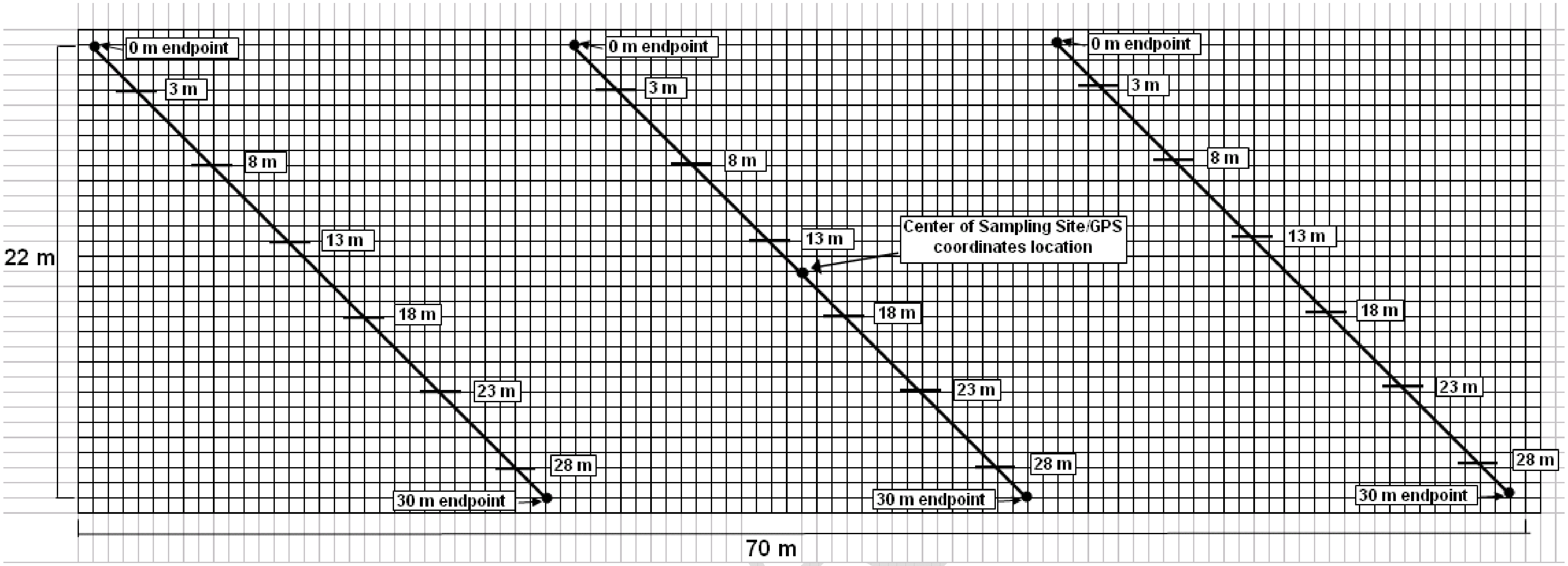


Figure 1. Main and subtransect layout at a sampling site.

3. Record moss-lichen crust (ML) any time a moss or lichen species that is attached to the soil surface is contacted by the point of the skewer. Cyanobacterial crust (C) is harder to recognize because its appearance is similar to bare soil.

4. When a bare-soil (B) area is reached along a subtransect, use the skewer to lightly tap the soil surface. It the soil maintains resistance and does not easily crumble into sand and silt particles, it should be recorded as cyanobacterial crust. To double-check the existence of cyanobacteria, pick up a small piece of surface soil outside of the transect but contiguous with the point being examined. Lightly break it into two pieces and then hold it up to the light and look for dangling "threads" that attach to both pieces or that have smaller soil particles attached to them (Figure 2. Two photos showing binding of soil particles by cyanobacterial sheaths.).

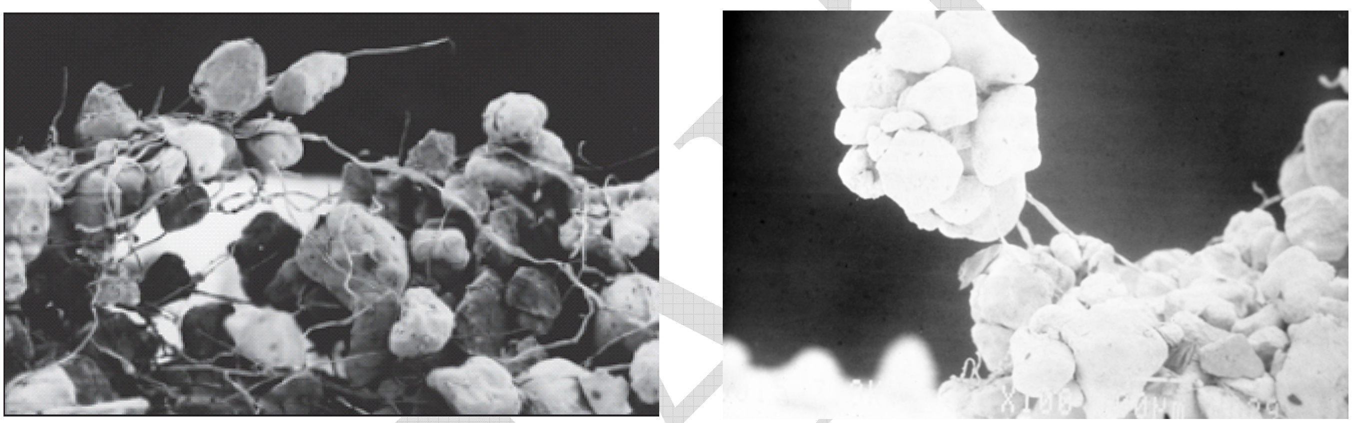


Photo credit: http://www.soilcrust.org (Belnap 1999) *Photo credit: http://www.soilcrust.org (Belnap 1999)*

Figure 2. Two photos showing binding of soil particles by cyanobacterial sheaths.

5. Continue reading at each whole-cm mark until you reach the end (200 cm). Two hundred points should have been read. Be careful not to bump the subtransect ruler and to always look down at the same angle over the subtransect when reading points. Obviously, this method is not perfect and observers will not look at exactly the same point each time the subtransect is read. Preliminary work, however, using different observers showed that this method produced the best consistency in ground-cover characterization.

6. When finished with one subtransect, pick up the carpenter ruler, move to the next location down the main transect, and repeat the above steps.

7. The recorder and observer may have to figure out a good pace for reading transects. It is easy for the observer to get ahead of the recorder and end up having to repeat and sort out recorded data. A good pace will keep the crew happier and more efficient.

4. Measuring Soil Aggregate Stability

4.1. Selecting sites

Within the overall sampling unit, 18 sites must be chosen from which to collect samples for the soil aggregate stability test. Using the PDA, open Excel and use the **=RAND()** function to generate 18 random numbers. **Will they need any more specific information on how to accomplish this?** Using the first two digits to the right of the decimal, add that number of centimeters to each subtransect location to create the 18 sampling locations for aggregate stability. If the first two digits are zero, use the third and fourth digits to the right of the decimal. For example, if the first random number is 0.423199339, go to 3 m 42 cm (or 342 cm) on the first main transect and collect the first aggregate stability sample. ***NOTE:*** If the site was sampled previously (this should be obvious because it will take at least a few years for the soil to recover from this disturbance), generate another random number for that site and proceed from there.

4.2. Method

The following instructions, including figures, tables, and forms, have been copied and/or edited to fit this protocol from Herrick and others (2005).

4.2.1. Collecting sample

1. Determine the dominant vegetative-cover class over the random point and enter this into the "Veg" column on the data form (although data should be entered into a PDA form, a copy of the paper form is shown below). The area to be classified is effectively as large as the sample area (6–8 mm).

Table 2. Vegetative-cover categories and coding.

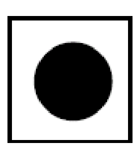
Field form code	Ground-cover categories
NC	No perennial grass, shrub, or tree-canopy cover
G	Perennial grass canopy and grass/shrub canopy mixture
F	Perennial forb
Sh	Shrub canopy
T	Tree canopy

2. Excavate a small trench (10–15 mm deep) in front of the area to be sampled (Figure 3. Excavate small trench). **Using what?**

Lift out a soil fragment and trim it (if necessary) to the correct size (Figure 4. Ensure correct sample size.

3.). **Using what?**

4. The soil fragment should be 2–3 mm thick and 6–8 mm in diameter (Figure 4. Ensure correct sample size). This is the diameter of a wood pencil eraser. Try to fit sample in this dot.



5. Collect samples at the exact sample point. Move the sample point only if it has been disturbed during previous measurements or the soil surface is protected by a rock or embedded litter. Move the point a standard distance (1 m) **in which direction? Also, is 1 m correct? That seems really far away.** and note this change on the data form.

6. Minimize shattering by: a) slicing the soil around the sample before lifting **Using what?**; b) lifting out a larger sample than required, and trimming it **Using what?** to size in the palm of your hand; or c) misting the sample area **Using what?** before collection.

7. If the soil sample is too weakly structured to sample (falls through the sieve), mist it lightly with deionized water **from the squirt bottle? How do you "mist it lightly" with that?** and then take a sample. If the sample still will not hold together, record a "1" on the data form.

8. If the soil surface is covered by a lichen or cyanobacterial crust, include the crust in the sample. If the sample is covered by moss, collect the sample from under the moss.

9. Gently place the sample in a dry sieve (Figure 6. Place sample in sieve); place sieve in the appropriate cell of a dry sample box (starting with upper left corner of box).

10. Soils must be dry before testing. If samples are not dry after collecting, allow to air dry with the lid off.

11. Do not leave lid closed on samples for more than one minute on hot/sunny days. Excessive heat can artificially increase or decrease stability.

Figure 3. Excavate small trench.

Figure 4. Ensure correct sample size.

Figure 5. Collect surface sample.

Figure 6. Place sample in sieve.

4.2.2. Testing samples

1. Fill each compartment of the empty box to the top with deionized or distilled water that is approximately the same temperature as the soil.

2. Lower the first sieve with the sample into the first water-filled compartment (upper left corner of sample box to upper left corner of water box) (Figure 7. Place first sample in water.).

Figure 7. Place first sample in water.

3. From the time the sieve screen touches the water surface to the time it rests on the bottom of the box, one second should elapse.

4. Start the stopwatch when the first sample touches the water. Use Table 3 to assign samples to stability classes.

Table 3. Stability-class ratings.

Stability class	Criteria for assignment to stability class
1	50% of structural integrity lost (melts) within 5 seconds of immersion in water, **OR** soil too unstable to sample (falls through sieve).
2	50% of structural integrity lost (melts) 5-30 seconds after immersion.
3	50% of structural integrity lost (melts) 30-300 seconds after immersion, **OR** < 10% of soil remains on the sieve after five dipping cycles.
4	10–25% of soil remains on the sieve after five dipping cycles.
5	25–75% of soil remains on the sieve after five dipping cycles.
6	75–100 % of soil remains on the sieve after five dipping cycles.

5. After five minutes, follow the sequence of immersions on the data form, adding one sample every 15 seconds. Beginners may want to immerse a sample every 30 seconds. This allows nine samples to be run in 10 minutes, so it takes 20 minutes to test one box of 19 samples. **I don't get this math. If it's ok, fine—just thought I should point it out.**

6. Observe the fragments from the time the sample hits the water to 5 min (300 sec) and record a stability class based on Table 1. **Shouldn't this be Step 5, and Step 5 be Step 6? Also, Table 3 and Figure 8 indicate that you're supposed to have a look after 5 seconds, but I don't see that here.**

7. Raise the sieve completely out of the water and then lower it to the bottom without touching the bottom of the tray. It should take one second for each sieve to clear the water's surface and one second to return to near the bottom of the box.

8. Repeat this immersion a total of five times. Do this even if you have already rated the sample a 1, 2 or 3 (you are allowed to change your rating if, after sieving, >10% of soil remains on sieve).

9. Hydrophobic samples (float in water after pushed under) are rated 6.

10. The photos in Figure 8. Photos illustrating key steps of testing a soil sample for four different stability rankings.illustrate the key steps of testing a soil sample for four different stability rankings. Important note: Some of the fragments shown in these samples map appear large. They are for illustration only. Be sure to follow the size guidelines (6–8 mm) described above.

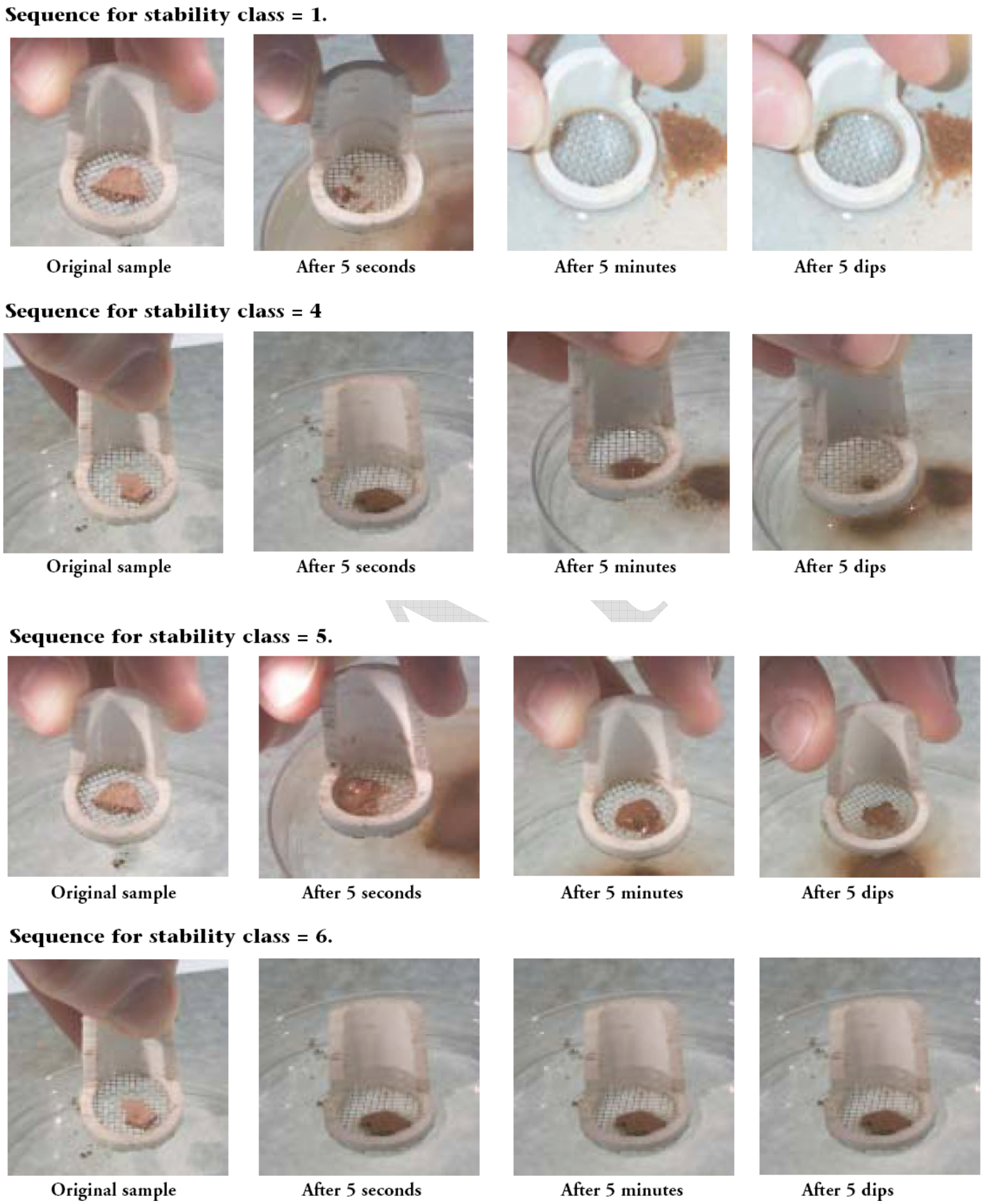


Figure 8. Photos illustrating key steps of testing a soil sample for four different stability rankings.

4.2.3. Calculating soil stability indicators

1. Add together all stability values. Divide this sum by the total number of samples taken. Record this value as the average stability for “All samples” on the data form.

2. Add together all values that were protected by canopy (Veg = G, F, Sh, or T). Divide this sum by the number of samples in this group. Record this value as the average stability for “Protected samples” on your data form.

3. Add together all stability values that were classified as no canopy (Veg = NC). Divide this sum by the number of samples in this group. Record this value as the average stability for “Unprotected samples”.

An example of raw data and calculation of indicators is shown in Figure 9. Example of data form and summary table with raw data and indicator calculations. The original form for recording aggregate stability data (Herrick et al. 2005) is shown in Figure 10. Soil stability test form.

What should they do with the samples after all this is done?

Surface

Line 1										Line 2									
Pos	Veg	In time	Dip time	#	Pos	Veg	In time	Dip time	#	Pos	Veg	In time	Dip time	#	Pos	Veg	In time	Dip time	#
7	NC	0:00	5:00	3	28	NC	0:45	5:45	3	6	G	1:30	6:30	5	24	G	2:15	7:15	6
14	S	0:15	5:15	5	35	S	1:00	6:00	4	12	NC	1:45	6:45	1	30	S	2:30	7:30	3
21	G	0:30	5:30	6	42	G	1:15	6:15	5	18	S	2:00	7:00	4	36	NC	2:45	7:45	1

Avg. Stability = Sum of Stability Rankings (i.e., #) / Total No. Samples Taken

Line	All samples		Protected samples (Samples w/Veg = G, F, Sh, or T)		Unprotected samples (Samples w/o Veg = NC)	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
1	4.3		5.0		3.0	
2	3.3		4.5		1.0	
Plot Avg.	3.8		4.75		2.0	

Figure 9. Example of data form and summary table with raw data and indicator calculations.

Soil Stability Test Data Form

Monitoring plot: ______________________________ **Observer:** ______________________ **Date:** ____________________

Recorder: ______________________ **Page** _____ **of** ________

Veg = NC (no perennial canopy), **G** (grass or grass/shrub mix), **F** (forb), **Sh** (shrub), **T** (tree). **# = Stability value** (1-6). Circle value if samples are hydrophobic.

Surface

Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip	
Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#
		0:00	5:00				0:15	5:15				0:30	5:30				0:45	5:45				1:00	6:00				1:15	6:15	
		1:30	6:30				1:45	6:45				2:00	7:00				2:15	7:15				2:30	7:30				2:45	7:45	
		3:00	8:00				3:15	8:15				3:30	8:30				3:45	8:45				4:00	9:00				4:15	9:15	

Notes: ____

Subsurface

Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip		Line ___		In	Dip	
Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#	Pos	Veg	time	time	#
		0:00	5:00				0:15	5:15				0:30	5:30				0:45	5:45				1:00	6:00				1:15	6:15	
		1:30	6:30				1:45	6:45				2:00	7:00				2:15	7:15				2:30	7:30				2:45	7:45	
		3:00	8:00				3:15	8:15				3:30	8:30				3:45	8:45				4:00	9:00				4:15	9:15	

Notes: ____

Avg. Stability = Sum of Stability Rankings (i.e., #) / Total No. Samples Taken

Line	All samples		Protected samples (Samples w/Veg = G, Sh, or T)		Unprotected samples (Samples w/ Veg = NC)	
	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
Plot Avg.						

Figure 10. Soil stability test form.

5. Photo Points

Photo points should already have been established during the site-establishment process. The crew may want to establish more photo points in the future to show results of erosion or deposition events or other major disturbances. Photo points are not recommended for monitoring purposes (see SOP 2).

If photo points are established at new locations on the site, record the GPS location at that site. ***NOTE*****: When using the GPS unit in BICA, the projection should always be set to NAD83 Zone 12 North.** Take and record a compass bearing for every photograph. Record these bearings in the proper section on the site-establishment form. Also, record the distance (in meters) and compass bearing from the site center to this/these other photo points. These measurements are much more accurate than the GPS locations that can be recorded by the current GRYN GPS units. Make notes about any unusual features photographed.

6. References

Belnap, J. Biological soil crusts. 1999. http://www.soilcrust.org.

Herrick, J. E., J. W. Van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume 1: Quick start. Las Cruces, N. M.: USDA-ARS Jornada Experimental Range.

Aridland Soil Structure and Stability Monitoring Protocol for Park Units in the Greater Yellowstone Inventory and Monitoring Network

STANDARD OPERATING PROCEDURE (SOP) #4

Data Management Procedures for Monitoring Soil Structure and Stability in Bighorn Canyon National Recreation Area

Version 1.00

November 26, 2006

Revision History Log

Previous version number and date	Revision date	Author(s) of revision (with title and affiliation)	Location in document and concise description of revision	Reason for change	New version number

Add rows as needed for each change or set of changes tied to an updated version number.

Prepared by: Elizabeth Crowe ________________________________ Date: November 26, 2006 ______

Reviewed by: ____ Date: ________________________

Approved by: ____ Date: ________________________

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List of Tables

1. Data Model

The data model in Microsoft Access follows the NPS Natural Resource Database Template (NPS 2006a) format. One table stores location data, and separate tables store survey data such as ground-cover parameter values and aggregate soil-stability data within sites. Primary and secondary key values are included in each table to support the relationship between parameter values associated with each site. Associated lookup tables contain known values that facilitate data entry by providing pick lists, and promote high-quality data by controlling the consistency of data entry for these parameters. Refer to the attached data dictionary for a complete list and description of data fields and value domains.

2. Data Stewardship Roles and Responsibilities

The stewardship of data and materials for this project is shared among the field-crew members, project leader, and GRYN staff, as listed in Table 1. To successfully catalog, organize, structure, archive, and make available relevant soil structure and stability monitoring data and results, project staff should expect to spend approximately one third of their time, overall, on activities related to the stewardship, analysis, and reporting of project data.

Table 1. Data stewardship roles and responsibilities.

Data stewardship responsibility	Responsible party	Organization	Contact information
Master copy of protocol	Soils monitoring project leader	NPS-GRYN	(406) 994-7530
Master copy of database	GRYN data manager	NPS-GRYN	(406) 994-4124
Master copy of database and protocol (backup person)	Soils monitoring project leader	NPS-GRYN	(406) 994-4124
Security and backup plan for primary database	GRYN data manager	NPS-GRYN	(406) 994-4124
Verification and validation of data in master database	Soils monitoring project leader		(406) 994-7530
Original data sheet/field forms	Soils monitoring project leader		(406) 994-7530
Documentation for data structure and database application	GRYN data manager	NPS-GRYN	(406) 994-4124
Maintenance of documentation for data structure and database application	GRYN data manager	NPS-GRYN	(406) 994-4124
Annual storage and long-term archiving of physical project materials	GRYN data manager	NPS-GRYN	(406) 994-4124

3. Data Entry and Quality Assurance

3.1. Data entry

3.1.1. Electronic data collection

Handheld computers may be used to record some or all required data values during a site survey. The project leader and network data manager will work together to design a data-entry process. The process includes developing electronic forms for the handhelds that match the workflow in the field, documenting a standard method and schedule for uploading data from one or more handheld computers to a seasonal working database and the master project database, and setting expectations, building awareness, and training users. Paper copies of data forms must always be carried as a backup to electronic equipment. Field-crew members will back up field data at least once each day to a secondary device or memory card.

3.1.2. Paper field forms

If paper field forms are used, data will be entered in the computerized database as soon as possible, either at the end of the field day or at the end of the field trip. The project leader will provide instructions to field-crew members for accessing a computer application to enter survey data. In most cases, the field-crew leader will enter the data. If necessary, a qualified person appointed by the field crew leader and approved by the project leader will enter the data.

3.1.3. Digital images

Digital photos taken at sampling sites will be stored in a folder called BICA_SOILS_Images within the parent folder where the database is stored. File size for digital photos should normally be at least 100 kb but less than 300 kb. Project staff will resize original image files larger than 300 kb. Photos taken of things other than the sampling site will not be stored in the project's file structure.

3.2. Data verification

Crew members are responsible for creating legible, accurate, written entries on field forms when they are used. As a first step to verify data, crew members will visually check and double-check the recorded values either on field forms or in the handheld computer on the day of data collection. On a daily or weekly basis, as allowed by the schedule and duration of field visits, the crew leader will check field forms for completeness, accuracy, and legibility prior to entering data into a computer database.

3.3. Data validation

After data are either downloaded from handheld computers or entered into computer database from paper forms, the project leader or a qualified person designated by the project leader will validate the accumulated data for logical accuracy. Data validation will include an assessment of data content and structural integrity (e.g., data types, table relationships, consistency of values within fields).

All errors identified during quality-control procedures (e.g., data verification and validation) must be corrected on the original data source (paper or electronic), with a complete log file explaining all corrections stored with the master database.

4. Metadata

Documenting the soil structure and stability dataset, the data source(s), and the methodology by which the data are acquired establishes the basis for interpreting and appropriately using data and results from the soils monitoring project. The project leader is responsible for developing and maintaining database documentation as well as National Park Service and Federal Geographic Data Committee metadata for spatial data related to the monitoring sample design and project operation. The GRYN data manager is responsible for annually reviewing the content and structure of the metadata to ensure that it meets NPS requirements. The NPS Metadata Tools and Editor (NPS 2006b) application and/or ArcCatalog extension should be used to develop and maintain metadata for project files, databases, and GIS layers.

5. Archiving

The GRYN data manager maintains an archive copy of the GRYN soils database on the GRYN server for access by network staff. All data on the GRYN server receive comprehensive, redundant backups stored on-site and quarterly backups stored off-site. At the end of each field season all physical project materials, including site sketches and any paper field-data collection forms used are submitted by the project crew leader to the GRYN data manager.

6. References

National Park Service. 2006a. Natural resource database template. <http://science.nature.nps.gov/im/apps/template/>. Last accessed March 8, 2007.

National Park Service. 2006b. NPS Metadata Tools and Editor. <http://science.nature.nps.gov/nrdata/tools/>. Last accessed March 8, 2007.

7. Appendix A. Soil structure and stability data dictionary

Table: (fill in when database created)							
Site Location Attributes							
Field Name (label) on hardcopy data collection form	**Database Field Name**	**Database Field Caption**	**Field Description**	**Valid Field Values**	**Entry Required During Field Survey**	**Entry Required in Database**	**Database Quality Control Procedure**
Site ID	Site_ID		User-generated identifier from sampling site selection process	Positive integer value	Required	Required	Cross check
Date Established	Date_Established		Date of site establishment	Valid date	required	required	cross check
Field Crew Members	Observer		First initial and full last name of people establishing site and transects	Full name of crew member(s). NOT initials.	required	required	cross check
Ecological Type Unit	Eco_Type_Unit			limestone_bedrock_outcrop silty_surface silty_limy_surface sandstone_shallow_soil shallow_loamy_red_shale_surface gypsiferous_dolomite smectitic_clay gypsiferous_siltstone	required	required	cross check
Site UTM Easting (NAD83 Zone 12N)	SiteUTME_12_83		Easting coordinate at center of sampling site, UTM zone 12, NAD 83	Integer value within a range of values represented by a bounding rectangle of the overall study area.	Not required. Target center point of site pre-loaded in GPS from GIS		

Table: (fill in when database created)							
Site Location Attributes							
Field Name (label) on hardcopy data collection form	**Database Field Name**	**Database Field Caption**	**Field Description**	**Valid Field Values**	**Entry Required During Field Survey**	**Entry Required in Database**	**Database Quality Control Procedure**
Site UTM Northing (NAD83 Zone 12N)	SiteUTMN_12_83		Northing coordinate at center of sampling site, UTM zone 12, NAD 83	Integer value within a range of values represented by a bounding rectangle of the overall study area.	Not required. Target center point of site pre-loaded in GPS from GIS		
Site Comment	Site_Comment		Pertinent and brief comments about the site, such as safety concerns, access considerations, etc.				

Table: (fill in when database created)							
Photo Points							
Field Name (label) on hardcopy data collection form	**Database Field Name**	**Database Field Caption**	**Field Description**	**Valid Field Values**	**Entry Required During Field Survey**	**Entry Required in Database**	**Database Quality Control Procedure**
Site ID	Site_ID	Site_ID			Required	Required	Cross check
Photo Point ID	Photo Point ID				Required	Required	Cross check
Photo Point UTM Easting (NAD 83 Zone 12N)	PPUTME_12_83			Easting coordinate at location of photo point, UTM zone 12, NAD 83	Required	Required	Cross check
Photo Point UTM Northing (NAD 83 Zone 12N)	PPUTMN_12_83			Northing coordinate at location of photo point, UTM zone 12, NAD 83	Required	Required	Cross check
Distance from Site Center (m)				Distance measured with meter-scaled tape in field from sampling site center to photo point	Required	Required	Cross check
Azimuth from Site Center (deg)				Azimuth measured with compass from sampling site center to photo point	Required	Required	Cross check
Azimuth of Photo Point				Azimuth measured from photo point of direction of photo taken	Required	Required	Cross check
Notes about photo				Description of photo taken	Optional	Required	Cross check

Table: (fill in when database created)							
Soil Ground-Cover Data							
Field Name (label) on hardcopy data collection form	**Database Field Name**	**Database Field Caption**	**Field Description**	**Valid Field Values**	**Entry Required During Field Survey**	**Entry Required in Database**	**Database Quality Control Procedure**
Date	Date		Data of ground cover transects read	Valid date	required	required	cross check
Subtransect #	Subtransect #		Subtransect Number	1,2,3,4,5,6	already on field form	required	cross check
Cover Class	Cover Class		Ground cover class encountered at sampling point along subtransect	ML = moss-lichen biological crust C = cyanobacterial crust L = litter (including wood) R = rock (greater than 1 cm in diameter) B = bare soil (including gravel less than 1 cm in diameter) BV = basal vegetation (refers to a plant stem that is rooted at the measurement point)	required	required	cross check
Endpt	Endpoint		Endpoint , i.e. last cm marking on subtransect ruler to which cover class extends	1-2000	required	required	cross check

Table: (fill in when database created)							
Soil Aggregate Stability: Raw Data							
Field Name (label) on hardcopy data collection form	**Database Field Name**	**Database Field Caption**	**Field Description**	**Valid Field Values**	**Entry Required During Field Survey**	**Entry Required in Database**	**Database Quality Control Procedure**
Monitoring plot	Site ID	Site_ID	Site ID generated during site establishment	positive integer	required		
Observer	Observer		crew member collecting soil samples and testing aggregate stability		required	optional	not applicable
Recorder	Recorder		field crew member recording data from aggregate stability tests		required	optional	not applicable
Date	Date		Data of aggregate stability tests	Valid date	required	required	cross check
Line	Main Transect #		main transect number on sampling site along which aggregate stability sample taken	1,2,3	required	required	cross check
Pos	Position		cm location along main transect		required	required	cross check
Veg	Vegetative cover		type of protective vegetation exactly on aggregate stability sampling location	NC = no perennial canopy G = grass or grass/shrub mix F = forb Sh = shrub T = tree	required	required	cross check
In time					required	required	cross check
Dip time					required	required	cross check

Table: (fill in when database created)							
Soil Aggregate Stability: Raw Data							
Field Name (label) on hardcopy data collection form	**Database Field Name**	**Database Field Caption**	**Field Description**	**Valid Field Values**	**Entry Required During Field Survey**	**Entry Required in Database**	**Database Quality Control Procedure**
#	Stability Index Value		Relative aggregate stability value of soil sample	1 = 50% of structural integrity lost within 5 seconds of immersion OR soil too unstable to sample (falls through sieve) 2 = 50% of structural integrity lost (melts) 5-30 seconds after immersion 3 = 50% of structure integrity lost (melts) 30-300 seconds after immersion OR <10% of soil remains on the sieve after five dipping cycles 4 = 10-25% of soil remains on the sieve after five dipping cycles 5 = 25-75% of soil remains on the sieve after five dipping cycles 6 = 75-100% of soil remains on the sieve after five dipping cycles	required	required	cross check

Table: (fill in when database created)							
Soil Aggregate Stability: Summary Data							
Field Name (label) on hardcopy data collection form	**Database Field Name**	**Database Field Caption**	**Field Description**	**Valid Field Values**	**Entry Required During Field Survey**	**Entry Required in Database**	**Database Quality Control Procedure**
Line	Main Transect #		main transect number on sampling site along which aggregate stability sample taken	1,2,3	required	required	cross check
Avg. Stability – All Samples			Average stability = sum of stability rankings/total # of samples taken on main transect	1-6	required	required	cross check
Avg. Stability – Protected samples			Average stability = sum of stability rankings/samples taken under protective vegetation on main transect	1-6	required	required	cross check
Avg. Stability – Unprotected samples			Average stability = sum of stability rankings/samples taken under unprotective vegetation on main transect	1-6	required	required	cross check
Plot Avg.			Average stability = sum of stability rankings/total # of samples taken on entire site	1-6	required	required	cross check

Aridland Soil Structure and Stability Monitoring Protocol for Park Units in the Greater Yellowstone Inventory and Monitoring Network

STANDARD OPERATING PROCEDURE (SOP) #5

Data Analysis and Reporting

Version 1.00

November 30, 2006

Revision History Log

Previous version number and date	Revision date	Author(s) of revision (with title and affiliation)	Location in document and concise description of revision	Reason for change	New version number

Add rows as needed for each change or set of changes tied to an updated version number.

Prepared by: Elizabeth Crowe ______________________________ Date: November 26, 2006 ______

Reviewed by: ____ Date: ______________________

Approved by: ____ Date: ______________________

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1. Analysis

1.1. Estimators

Because the sample design was developed in R (R Development Core Team 2005) using the GRTS design package, psurvey.design (Olsen and Kinkaid 2005b), the corresponding GRTS analysis package, psurvey.analysis (Olsen and Kinkaid 2005a), should be used to calculate estimators of mean ground-cover components (especially biological soil crust cover) and aggregate stability. These estimators can be used to evaluate status of these soil properties. The code to estimate trend for different panel designs is currently being developed within the I&M program.

1.2. Analyses of interest

Because the design of this monitoring protocol is similar to traditional experimental design, that is, two "treatments" inside and outside the horse range, and eight variables of interest within each treatment, the ecological types analyses can be ANOVA and/or ANCOVA. ANOVA would be a simpler analysis that would compare the variables of interest, ground-cover or aggregate stability. ANCOVA would incorporate covariates of interest such as soil texture, soil calcium carbonate content, soil gypsum content, and yearly precipitation. Aggregate stability is a ranked (ordinal) response variable and can be analyzed using ordinal logistic regression.

Analyses of interest include:

1. Status and trend of ground cover and soil aggregate stability within ecotype inside horse range;
2. Status and trend of ground cover and soil aggregate stability within ecotype outside horse range; and
3. Comparison of status and trend of ground cover and soil aggregate stability within ecotype between inside and outside groups.

Depending on the variance of the estimators, the following analyses may also be performed:

1. Overall status and trend of ground-cover and soil aggregate stability inside horse range;
2. Overall status and trend of ground-cover and soil aggregate stability outside horse range; and
3. Comparison of overall status and trend of ground-cover and soil aggregate stability between inside and outside groups.

Do they need information on how to run these analyses?

Because the panel design emphasizes sampling all sites within a set of ecological types each year, overall status and trend estimates for inside and outside of the horse range may not have enough precision to be useful to managers.

Analysis of status within the ecotypes sampled in a given year should be performed the fall/winter following the field season. Analysis of trends should occur each time a new set of data for an ecotype is added to the previous set. Thus, because all sites will be sampled the first year, trend analysis can be performed for the ecotypes sampled the following year. Given only two sampling events, this trend will not have much power, but it will be a start on which subsequent sampling events can build. After the first six years of sampling, a new sampling event for a given ecotype will occur only every five years, and trend analysis will follow accordingly.

2. Reporting

Reports will be written to target three main audiences: BICA upper-level managers; BICA natural resource managers; and the general public and BICA interpretive staff. Four types of reports will be prepared:

1. Synthesis report (provided to BICA upper-level managers)
    - Used to inform park decision- and policymakers about status and management options with regard to soil surface stability.
    - Should contain only summary information that can be read in an hour or two.
    - Should provide a source of accountability for such mandates as the NPS Natural Resource Challenge and the Government Performance and Results Act (GPRA).
    - Produced every four years; should provide a synthesis of the previous four years of data, including status and trends of soil surface stability.
2. Detailed synthesis report (provided to BICA natural-resource managers)
    - Should help park natural resource managers to make on-the-ground decisions about managing the effects of soil disturbance on soil-surface stability.
    - Should contain all details of analysis, including information about anomalous data, tables of results from ANOVA/ANCOVA analyses, which include all relevant statistics as would be shown in a scientific journal article.
    - Should provide a source of accountability for such mandates as the NPS Natural Resource Challenge and the Government Performance and Results Act (GPRA).
    - Produced every four years; should provide a synthesis of the previous four years of data, including status and trends of soil surface stability.
3. Annual progress report (provided to BICA upper-level management and natural-resource managers)
    - Synthesizes the activities that occurred during the year and provides information on the status of ecological types sampled.
    - Should be similar to the synthesis reports in showing detailed analysis results of the years work and the trend analysis for the ecological types sampled that year.
4. Periodic brochures with general information **about what? Resources? Status and trends? What's the goal of these/what do you want to tell the public?** (provided to BICA interpretive staff and the general public)

Because of the nature of the variables being examined, data can be presented in straightforward formats such as bar graphs with error bars.

The GRYN website will all house all reports mentioned above as well as more information, and be oriented to a more general audience.

3. References

Olsen, A. R., and T. Kinkaid. 2005a. psurvey.analysis. Corvallis, Ore.: U.S. Environmental Protection Agency. [cited Oct. 1, 2006]. http://www.epa.gov/nheerl/arm/designpages/design&analysis.htm.

Olsen, A. R., and T. Kinkaid. 2005b. psurvey.design. Corvallis, Ore.: U.S. Environmental Protection Agency. [cited Oct. 1, 2006]. http://www.epa.gov/nheerl/arm/designpages/design&analysis.htm.

R Development Core Team. 2005. R: A language and environment for statistical computing. Version 2.2.1. Vienna, Austria: R Foundation for Statistical Computing. [cited Oct. 1, 2006]. http://www.R-project.org.

Aridland Soil Structure and Stability Monitoring Protocol for Park Units in the Greater Yellowstone Inventory and Monitoring Network

STANDARD OPERATING PROCEDURE (SOP) #6

Protocol Revision

Version 1.00

November 28, 2006

Revision History Log

Previous version number and date	Revision date	Author(s) of revision (with title and affiliation)	Location in document and concise description of revision	Reason for change	New version number

Add rows as needed for each change or set of changes tied to an updated version number.

Prepared by: Elizabeth Crowe ______________________________ Date: November 26, 2006 ______

Reviewed by: ____ Date: ______________________

Approved by: ____ Date: ______________________

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List of Tables

The following is modified from Northern Colorado Plateau Network Climate Monitoring Protocol.

1. Review

Users of any standard operating procedure will promptly notify the project leader and/or the GRYN data manager about recommended and required changes. Modifications should be reviewed **by whom?** for clarity and technical soundness. Small changes or additions to existing methods will be reviewed in-house by GRYN staff. The project leader must review, incorporate, and communicate all changes, complete the revision history log, and change the date and version number on the title page and in the document footer.

2. Recordkeeping

All edits and amendments to an SOP document since its original publication date, as well as updated protocol versions, must be recorded in the Revision History Log that accompanies the protocol. Information entered in the log must be complete and concise. Version numbers will increase incrementally by hundredths (e.g., version 1.01, version 1.02, etc.) for minor changes that do not require a change in analytical methods. Major revisions that will require a change in analytical methods will be designated with the next whole number (e.g., version 2.0, 3.0, 4.0). Record general information about the change, including the author, changes made, and a short explanation of the reason for the change, in the Revision History Log. More specific information about the location and reason for the change should be recorded in the Master Version Table.

Narrative and SOP updates may occur independently. That is, a change in one SOP will not necessarily invoke changes in other SOPs; a narrative update may not require SOP modifications. However, all narrative and SOP version changes must be noted in the Master Version Table. Any time a narrative or an SOP version change occurs, a new version key number must be created and recorded in the MVT, along with the date of the change and the versions of the narrative and SOPs in effect. **Who is responsible for doing this?** The version key number increases by whole integers (e.g., 1, 2, 3, 4, 5). The version key number is essential for project information to be properly interpreted and analyzed. **Fancy et al. say that "The revision procedure should also specify the need for and appropriate duration of an overlap period before new methods are adopted," but I don't see that here.**

3. Posting

New versions of the protocol narrative and SOPs must be posted on the GRYN web page. Previous versions of the protocol narrative and SOPs must be archived with the GRYN.

Table 1. Revision History Log

Previous version number and date	Revision date	Author(s) of revision (with title and affiliation)	Location in document and concise description of revision	Reason for change	New version number

Add rows as needed for each change or set of changes tied to an updated version number.

Table 2. Master Version Table

Version Key #	Date of change	Reason for change	Background and justification	Issues and threats	Sampling design	SOP #1 Pre- and post-field-season preparations and procedures	SOP #2 Site establishment	SOP #3 Field data collection	SOP #4 Data management	SOP #5 Data analysis and reporting
VK1	11.30.06	XXX	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The U.S. Department of the Interior (DOI) is the nation's principal conservation agency, charged with the mission "to protect and provide access to our Nation’s natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities." More specifically, Interior protects America’s treasures for future generations, provides access to our nation’s natural and cultural heritage, offers recreation opportunities, honors its trust responsibilities to American Indians and Alaska Natives and its responsibilities to island communities, conducts scientific research, provides wise stewardship of energy and mineral resources, fosters sound use of land and water resources, and conserves and protects fish and wildlife. The work that we do affects the lives of millions of people; from the family taking a vacation in one of our national parks to the children studying in one of our Indian schools.

NPS D-XXX, Month Year

National Park Service
U.S. Department of the Interior

Natural Resource Program Center
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov