# DEVELOPMENT OF A SPRING ECOSYSTEM MONITORING PROTOCOL IN BIGHORN CANYON NATIONAL RECREATION AREA

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by

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## INTRODUCTION

Aridland seeps and springs in Bighorn Canyon National Recreation Area (BICA) were identified as a vital sign for the Greater Yellowstone Inventory and Monitoring Network (GRYN). This protocol was developed to monitor the ecological condition of BICA springs. Seeps and spring ecosystems have an ecological importance disproportionate to their spatial extent in this desert environment. Protecting seep and spring resources requires in-depth understanding of their ecological character, controlling factors, and natural variability over space and time.

### What is a spring?

A spring is water emanating from geologic contacts or fractures with below surface aquifers as sources. Water from springs may flow across the land surface for some distance. Seeps are areas of saturated soil or seasonal standing water whose flow is generally imperceptible to the casual observer. Springs generally have longer and greater presence of surface water than seeps. Using these as working definitions, BICA springs outnumber seeps. For this reason, the term springs will be used to represent BICA seep and spring resources in the remainder of this protocol.

### Why monitor BICA springs?

Springs directly or indirectly provide the majority of surface water to 19,000 hectares (46,000 acres) of upland, riparian, and lotic ecosystems in BICA. Yet, they encompass less than 1% of the land area. Springs provide seasonal water in some areas and a perennial supply in other areas. Plant and insect populations thrive in spring ecosystems (Perla and Stevens 2003). By supporting the base of the food chain, springs indirectly support upland communities through trophic energy transfer. These areas also provide essential habitat for transient species such as migratory birds, predators, and ungulates.

Springs determine flows in many creeks and streams and in some cases are the sole sources of flow for waterways feeding the Bighorn River/Lake. Through augmenting or directly supplying streams with flow, springs support riparian vegetation downstream. Fluvial processes are driven by storm events. They provide establishment conditions for riparian vegetation. Spring outflow supports the maintenance of riparian vegetation through the dry season (most of the year).

Endemic flora and fauna can be found in spring ecosystems due to their isolation, stable environmental conditions or relict conditions (i.e. paleorefugia) (Hershler and Sada 2002). Sustaining rare or sensitive species make springs particularly significant. *Sullivantia hapemanii* var. *hapemanii* (Hapeman's coolwort) is a rare plant in BICA that occurs in some springs (Heidel 2004).

Pallid, Spotted, and Townsend’s Big-eared bats are listed as Montana Species of Concern by the Montana Hertiage Program. These species are found in caves and on cliffs, which are common geomorphic settings for springs. Water resources are a limiting factor for bats in the Pryor Mountains. Springs provide much of the water resources in the ranges of these species. During a bat survey in the Pryor Mountains, captures of Pallid, Spotted, and Townsend’s Big-eared bats occurred at sites within 5 miles of the BICA boundary. Most captures occurred in association with ponds and springs (Hendricks and others 2004).

Other fauna such as amphibians, reptiles, macroinvertebrates, and migratory birds are potentially strongly dependent on springs in BICA. Macroinvertebrate populations in springs of the Great Basin, Sierra Nevada, and Colorado Plateau are known to support endemic aquatic macroinvertebrates (Erman 2002; Hershler and Sada 2002; Sada and Herbst 2001). Amphibians may use springs for breeding sites and foraging. Rodents are prolific in spring areas due to high forage availability. Robust rodent populations support carnivorous reptiles such as rattle snakes and raptors. Migratory birds benefit from nesting habitat and vegetation sources of food provided by the riparian habitats supported by spring discharge.

Springs are indicators of the groundwater environment in that springs may be fed by local and regional aquifers in which water residence time could range from a few months to hundreds of years. Residence time determines the temporal scale at which impacts to groundwater quality evoke a spring water quality response (Sada pers. comm. 2004). Spring discharge is driven by head pressure in the groundwater environment. Generally, greater groundwater volumes create greater head pressure, and therefore, increase spring discharge. However, the timing and magnitude of the spring discharge response depends on the subsurface distance and flowpath complexity (Manga 2001). Like a person's heart, the volume pumped in a single heart beat translates to a corresponding volume of blood moved through a blood vessel the leg. There is a lag between the time of the heart beat and the pulse felt in the leg. Further, some of the pressure is dissipated along the distance between the heart and the leg. The time lag in spring response is a function, as well as an indicator, of the groundwater environment.

Springs in BICA are essentially undescribed ecologically yet have provided significant ecological function and water supply to people for millennia. BICA springs are known to support a rare plant. Based on studies of desert springs in the Great Basin and Colorado Plateau, BICA springs may support many communities currently unknown to BICA management. Faced with supplying water to historic ranches, visitors and support staff, as well as protecting natural resources, BICA management will need to monitor direct and indirect impacts to its spring ecosystems.

CONCEPTUAL MODEL

Conceptual models were developed to illustrate the synthesis of information regarding desert springs as it potentially relates to BICA springs. They serve three purposes: 1) to provide a foundation for understanding key linkages between spring hydrology and ecosystem function, 2) to hypothesize potential threats to ecological function, and 3) to identify indicators of long-term physical and biological trends. While the models focus on springs within BICA boundaries, many drivers of spring function arise on adjacent private, state, tribal, and federal lands. The primary targets of the BICA spring conceptual models include hydrology, vegetation ecology, and macroinvertebrate ecology.

Physical factors create, sustain, and influence spring ecosystems (Figure 1). Climatic and geologic processes are drivers in the formation of landscape topography, upland vegetation and soils, surface hydrology, and aquifer dynamics. Biological responses to aquatic and riparian physical environments of springs include trophic energy transfer, productivity, biogeographic processes (endemism, dispersal, colonization), habitat development (recruitment, assemblage composition, patch type mosaic), and biodiversity.

Climate (short and long-term) is a major control of spring flow parameters. Recharge rates, freeze-thaw cycles, natural disturbance intensity, and solar radiation are ultimately driven by regional climate patterns (Stevens and Springer 2004). Spring ecosystem extent, plant community composition, and longevity (ephemeral, intermittent, or perennial) are ultimately driven by climate. Climatic cycles which produce long periods of wet, dry, warm and cool influence groundwater recharge and spring discharge as well as spring primary productivity, habitat structure, and pedogenesis. Regional climatic parameters include mean annual temperature, mean annual precipitation, seasonal prevailing wind direction and speed, and seasonal relative humidity.

Aquifer dynamics integrate climatic and geologic factors producing the characteristic patterns in spring discharge, subsurface flow of seeps, and water chemistry. Rock outcrops, faults, fractures, or thickness changes are common places for spring discharge. The geologic layer of the orifice is likely that of the aquifer (and the only geologic information available for BICA springs). However, aquifers of varying geology may be connected by faults and fissures and mix to varying degrees over seasonal, annual, and decadal time scales. Thus, the spatial variability of rock outcrops, faults, fractures, or strata thicknesses may indicate seep and spring locations. Further, geologic forms and processes control geomorphic characteristics of springs such as orifice type and run out morphology. The degree of isolation influences dispersal and colonization of aquatic and riparian species in addition to the spring's relative importance as a source of water, food, and shelter for upland species.

**Indicator**

Water Chemistry (isotopes ($^{18}O$, $^{2}H$ and $^{3}H$) and major ions). Temporal and spatial integration of geo-climatic factors results in a chemical signature of the aquifer(s) which support the springs and seeps. Major cations reflect the character of the aquifer, and isotopes reflect the time since water left the atmosphere and entered the aquifer as well as the recharge area. Water chemistry monitoring can point to changes in aquifer source over time and potential influences on spring ecosystem (aquatic and riparian) characteristics.

**Indicator**

Spring discharge. Interactions among climate, the recharge capture zone, and the groundwater environment control aquifer input, throughput, and output. Spring ecosystem extent, floral and faunal composition, structure, and productivity reflect temporal and spatial variability in spring discharge and water table depth. Surface and subsurface water directly support aquatic and riparian ecosystems. Indirectly, the spring water source supports adjacent riparian and upland ecosystems through trophic energy transfer and provides microhabitat for transient species. In many cases in BICA, springs provide baseflow of streams while storm events and run off drive downstream fluvial and riparian dynamics.

Spring landscape position, topography, and surface hydrology influence the community composition, hydrologic regime, and microclimate of springs. The extent of the spring ecosystem is the area influenced by spring discharge, water quality, and flow dynamics. Elevation, latitude, and longitude affect spring biotic community composition through their relationships to growing season length, temperature, relative humidity, and precipitation. Geomorphology of the spring ecosystem can take many forms. The suite of geomorphic surfaces affects aquatic and riparian community composition and structure through its ability to retain water and the influence of flow velocity, water chemistry, and temperature (Stevens and Springer 2004).

The point at which a spring stops being a spring and becomes a creek, a pond, or an upland environment is an important distinction to identify for monitoring purposes. However, it is not a distinct boundary. The spring ecosystem is that area that is most influenced by the water characteristics as they emerge from underground. This influence extends into the adjacent terrestrial communities dependent on spring water (ground or surface). The point at which the surface environment has a greater influence on water characteristics is considered outside the spring area.

As mentioned above, the boundary between spring and non-spring environments is blurry and variable. The influence of groundwater decreases with distance as the surface environment becomes the dominating influence. Seasonal changes in solar radiation, shading, evaporation rates, surface runoff, and spring discharge (in some cases) cause this boundary to shift up and downstream.

Currently, there is no research documenting the change in spring downstream extent through the seasons. The concept that ecosystem expansion and contraction has been applied to riparian areas in stream systems (Stanley and others 1997). It describes the seasonal effect of drying on terrestrial and aquatic life due solute concentration, reduced habitat availability, and altered ecosystem processes such as primary productivity and nutrient cycling. Applied to BICA springs, the downstream extent of a spring is likely elongated during the late spring and retracted during late summer.

**Indicator**

Spring Downstream Extent. Distinguishing where a spring ecosystem stops and wetland, creek, or pond ecosystems begin is subjective and dynamic. The point at which a change in water temperature of 2°C between the orifice and downstream has been used to mark the downstream extent of a spring ecosystem (Erman 2002). While a temperature difference of 2°C has less if an impact than changes in chemistry, primary productivity, and nutrient cycling due to evaporation, it is an indicator of such changes. Water temperature is an easily measured parameter in the field. Identifying a temperature difference of 2°C during late winter can be used to determine the farthest downstream extent of springs.

Natural disturbances in spring areas such as flooding, sheetflow, rock fall, and fire may kill or scar existing plants, alter microtopography and potentially open new sites for biotic colonization. For example, springs discharging within established stream channels (ephemeral, intermittent, or perennial) are subject to fluvial disturbance regimes. Thus, aquatic and riparian communities within the maximum spring area potentially will have a greater number and abundance of disturbance-dependent species. Fires, sheetflow, and rockfall are upland disturbances that periodically influence spring ecosystems. The timing and magnitude of a disturbance will have varying effects on spring biota depending upon biotic composition, life cycle stages and degree of isolation from suitable habitat. Colonization of invasive, upland, riparian, or aquatic species may occur.

Solar radiation affects the potential evaporation rate of aquatic and riparian ecosystems. Aspect influences the amount and timing of shading and thus, evapotranspiration, productivity, and decomposition, among other processes. Microclimate affects evapotranspiration rates, soil moisture, and ultimately spring and stream flow across the ground surface.

The microhabitats at a given spring emerge from the geomorphic surface types. The mosaic of microhabitats supported by environmental factors at a spring site account for much of the biodiversity and endemism found in spring ecosystems (Cantonati and others 2006). Vegetation community assemblages within each microhabitat are a product of the substrate, geomorphic surface type, and hydrologic regime (Patten and others). Likewise, macroinvertebrate assemblages organize based on geomorphic surface type and zonation of conditions with distance from the spring orifice (Erman 1986; Erman 1998; Sada and Herbst 2001; Sada and Vinyard 2002).

**Indicator**

Microhabitat Spatial Structure. The organization of microhabitats throughout the spring area depend on and, therefore indicate, spring geomorphology, hydrology, and chemistry. The type and proportion of microhabitats at a spring site may respond to changes in spring discharge or disturbance.

The dependence of plant communities on groundwater depth has been known for a long-time (Bryan 1928; Stromberg and others 1996). Cross (1991) found that dominant species shifted depending on hydrologic regime of arid land springs. Plant community composition in vernal pools (ephemeral ponds) respond to water depth and duration. Ground and surface water likely plays a role in plant community composition and structure in BICA springs and seeps. Water chemistry appears to indirectly affect zonation of plant communities through its effect on soil characteristics (e.g. salinity and alkalinity) (Bernaldez and Rey Benayas 1992). Conductivity and alkalinity increase with distance from the orifice (Bernaldez and Rey Benayas 1992). Plant species distribution corresponds to water availability, soil salinity, and soil alkalinity (Bradley 1970; Hunt and Durrell 1966). Thus, some plant species may be used as indicators of flow extent and soil characteristics.

**Indicator**

Spring Vegetation Composition and Structure. Vegetation composition and structure is largely due to the mosaic of microhabitats and long-term flow rates and their stability (Perla and Stevens 2003). Shifts in plant community zonation can occur in response to shifting environmental conditions associated with water availability (Bradley 1970), soil salinity, and soil alkalinity (Bolen 1964) as they vary across a geomorphic surface. While plant communities do not respond to changes in water chemistry gradients in spring environments (Bolen 1964), they have been shown to strongly correlate with soil salinity and soil alkalinity gradients (Bernaldez and Rey Benayas 1992) which respond to long-term water quality trends (Bolen 1964).

**Indicator**

Endemic Vegetation. Aridland springs are known to support endemic vegetation due extreme water quality and stable discharge (Stevens and others 2004). Heidel (Heidel 2004) described *Sullivantia hapemannii* var. *hapemannii* as endemic to calcareous springs and streams of the Bighorn Basin with additional disjunct populations. Distribution and abundance of this and other endemic plant species will likely indicate change in spring ecosystem condition. Further, identification of additional endemics may pose additional indicators.

**Indicator**

Spring Macroinvertebrate Composition and Structure. Aquatic macroinvertebrates make up a substantial proportion of spring biodiversity. Aquatic species in spring ecosystems display species-specific responses to spring environments due to a high degree of endemism (Heino and others 2003; Sada and others 2005). Decreases in specialists and increases in generalist species often occur when variability in environmental conditions increases (Sada and others 2005).

**Indicator**

Endemic Macroinvertebrates. No information on aquatic macroinvertebrates in BICA currently, exists. However, inventories in similar spring landscapes by Erman, Sada, and Stevens have established a high potential for BICA springs to support macroinvertebrates that indicate specific environmental conditions.

Threats to water quantity, water quality, and spring biota are illustrated in FiguresFigure 2,Figure 3, and Figure 4. Major threats to BICA springs include climate change, groundwater withdrawal, water developments, groundwater and surface water pollution, infrastructure expansion, trampling, and increasing non-native species.

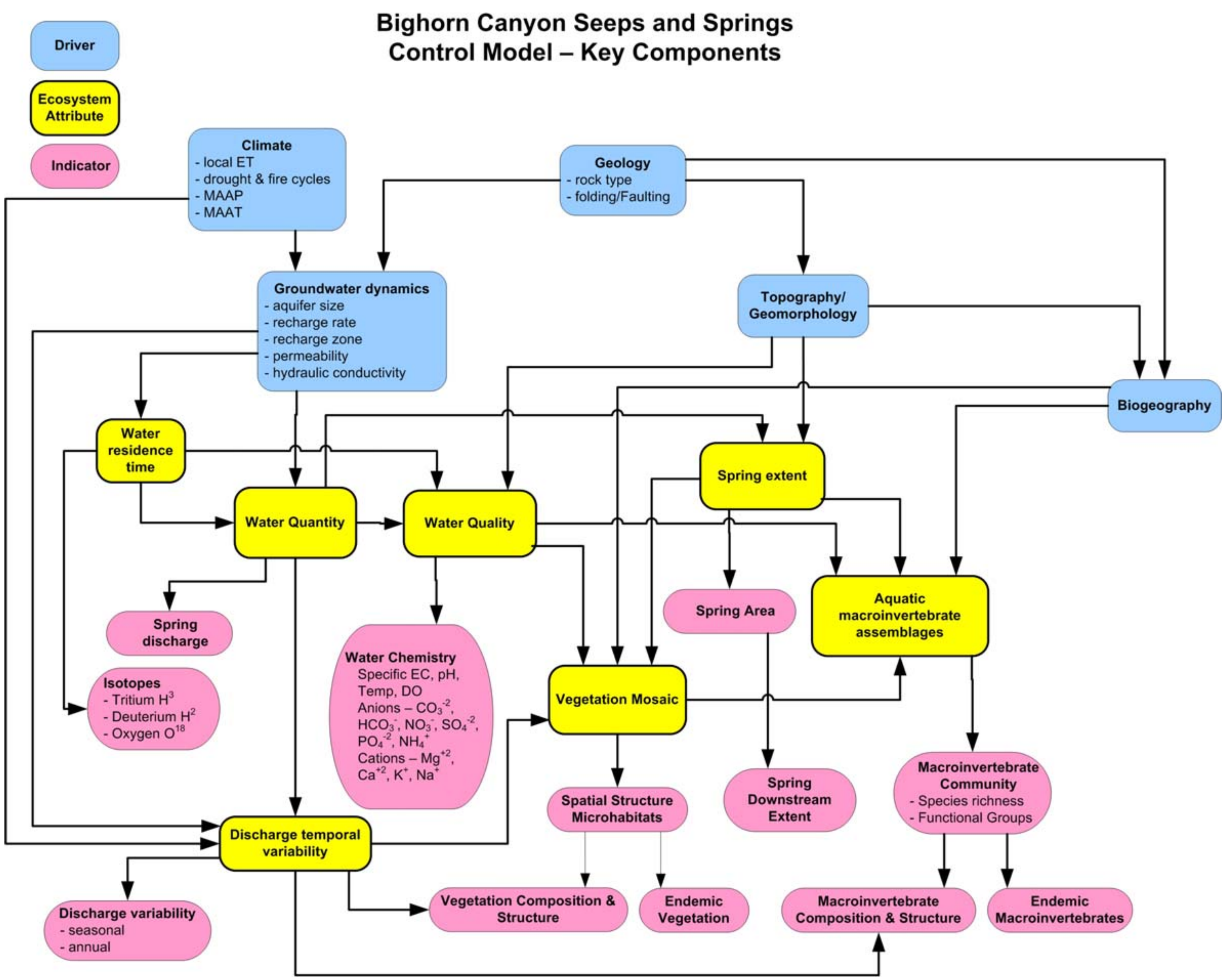


**Figure 1.** Conceptual model of the ecology of BICA springs.

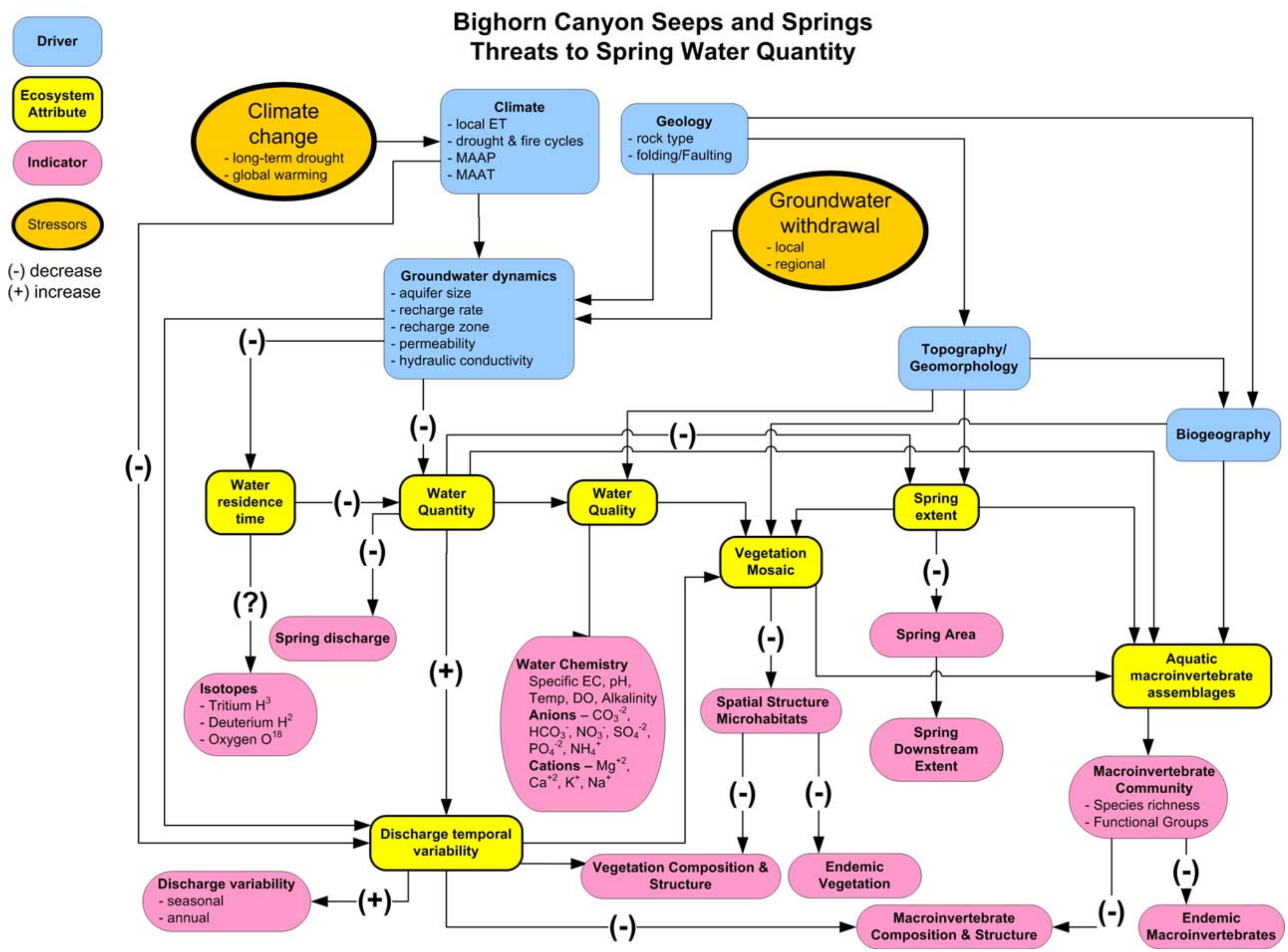


**Figure 2.** Conceptual model of threats to spring water quantity.

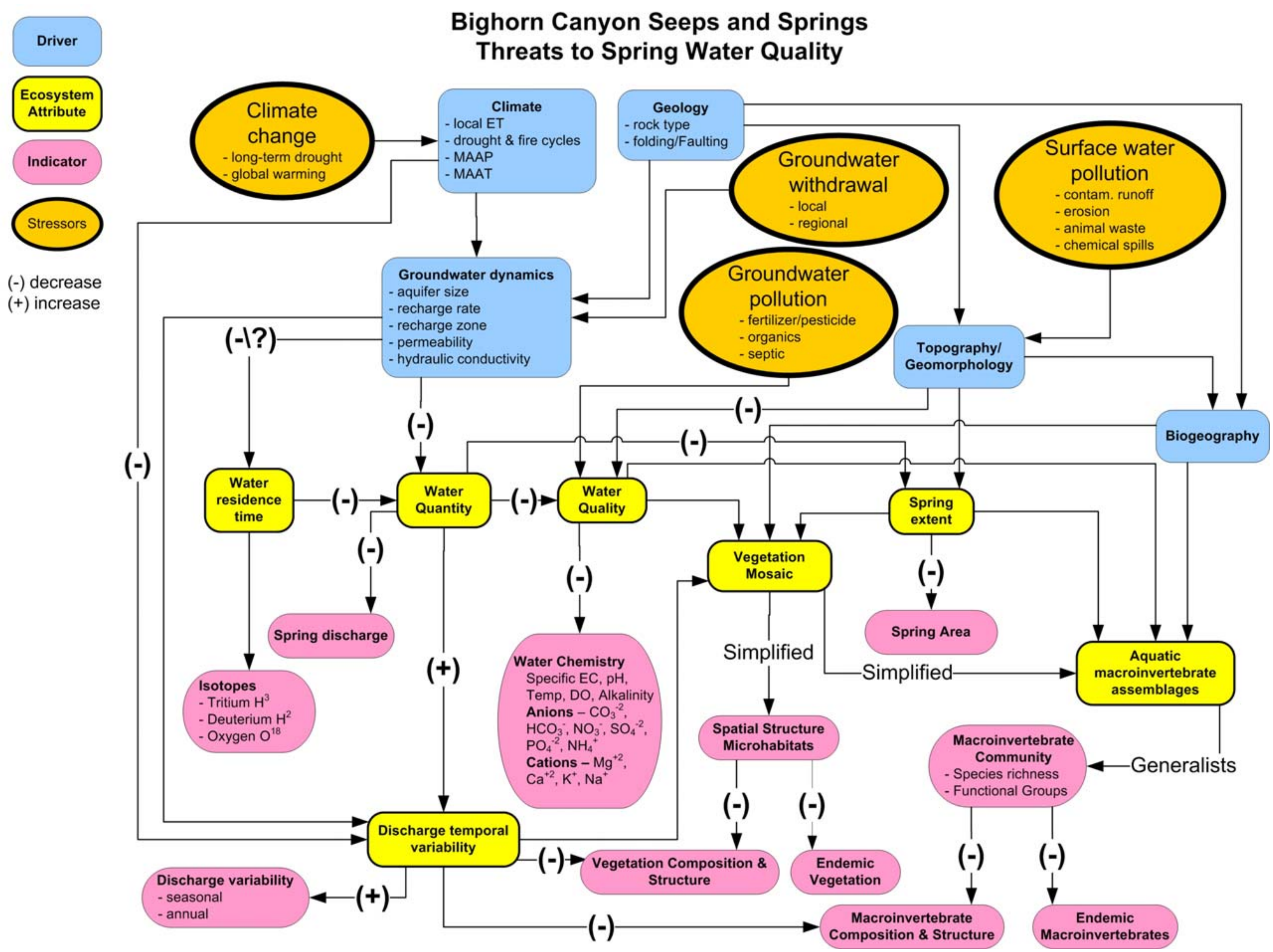


**Figure 3.** Conceptual model of threats to spring water quality.

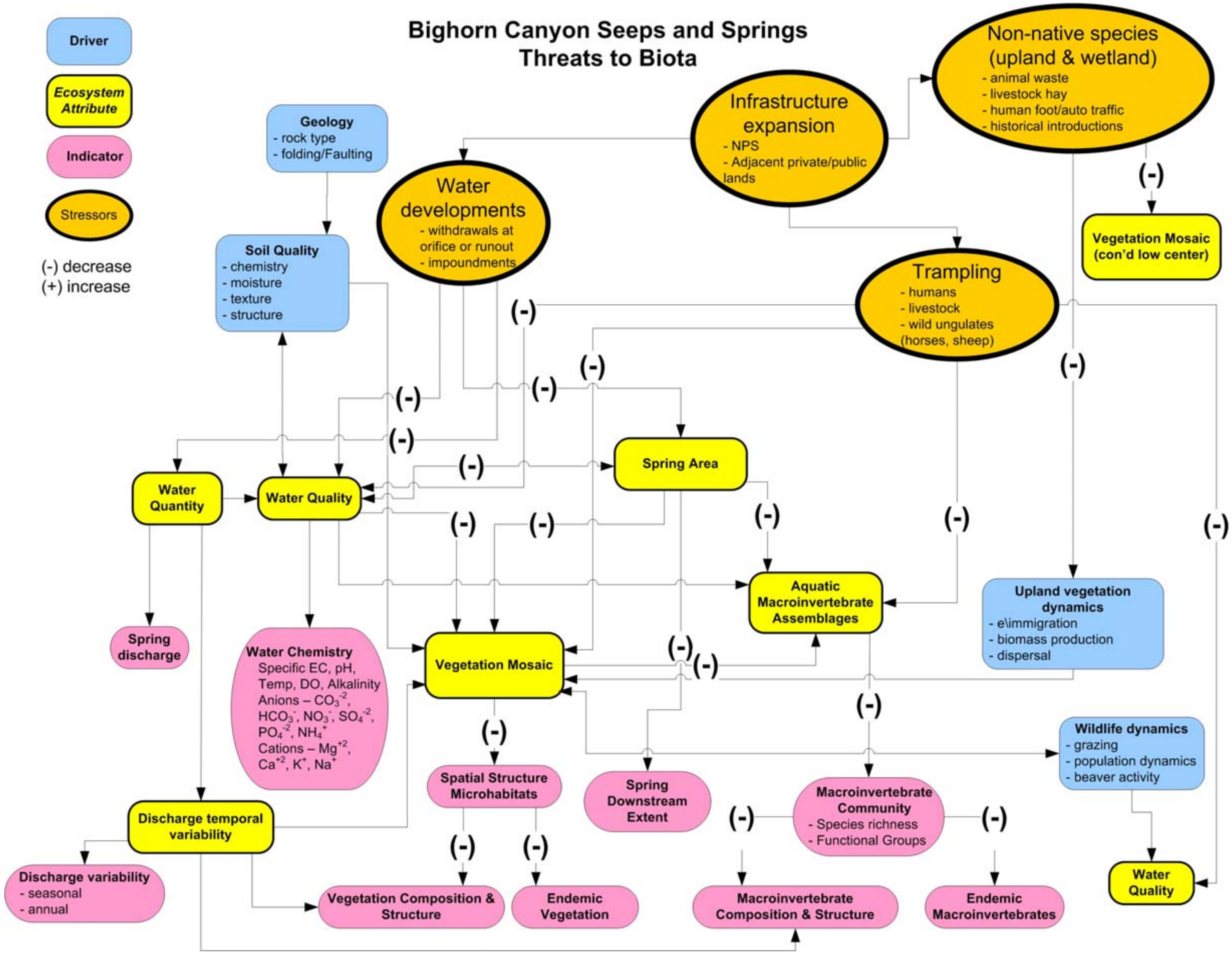


**Figure 4.** Conceptual model of threats to spring biota.

THREATS AND CONCERNS

## Introduction

Springs in Bighorn Canyon NRA (BICA) are essentially unexplored. Some seeps and springs are mapped on USGS topographic maps. Many are associated with historic and prehistoric sites making them culturally significant. BICA springs were simply mentioned in vegetation surveys of the Bighorn Basin and BICA as riparian communities and locations of a rare plant (Heidel and Fertig 2002; Knight and others 1987; Lichvar and others 1985). Information on invertebrates of BICA springs is scant, if it exists at all. Because they are undescribed, the range of natural variability of spring and seep water quantity, ecosystem diversity, and their roles in the greater landscape is currently speculative. There is no baseline assessment or long-term monitoring in place to scientifically assess threats and concerns to spring and seep ecosystems.

We know that prehistoric peoples have used BICA springs for thousands of years (Finley, pers. comm.). However, the amplitude of natural variability of discharge, biotic composition, and water quality cannot be discerned from prehistoric artifacts with sufficient certainty to inform management. Thus, the potential for a monitoring effort to detect changes in spring ecosystem condition outside the historic range of variability is unknown until there are adequate data.

In the absence of natural variability ranges specific to BICA, we can apply information about arid land seeps and springs in regions similar to BICA. We can also use knowledge from disciplines such as groundwater hydrology, wetland and riverine vegetation ecology, and biogeography to build a foundation from which to establish initial thresholds. This section poses potential threats and concerns to BICA seeps and springs based on environmental impact assessments, research, inventories, and monitoring programs related to desert springs of the Great Basin (USA), Spain, and Australia.

Aridland seeps and springs (hereafter termed springs) have three unique features – water, biologically diverse biota (some endemic), and their stability over time. For these reasons they are often historic and prehistoric culturally significant sites, as well as ecological hotspots. It is the combination of these features that synergistically creates aridland spring ecosystems to which surrounding life is drawn. Threats to the water sources, surface ecosystems, and drivers of flow duration of spring ecosystems must be considered in a monitoring protocol in order to manage them in a multi-use setting such as that in BICA.

## Threats to Spring Water Resources

### *General Description*

Spring water resources are tied to climate, groundwater discharge, and water quality. Impacts to these parameters as well as their natural variability will have a corresponding effect on spring ecosystems. Long-term drought, groundwater withdrawal at local and regional levels, and local diversions at or near the orifice are common impacts on water quantity at spring sites throughout the Western United States. Impacts to water quality may occur through groundwater pollution (percolation of sewage, fertilizers, pesticides, herbicides, or toxic chemicals) (Mitsch and Gosselink 1993; Sada and others 2001), surface runoff from contaminated uplands into spring sites (Basnyat and others 1999; Tufford and others 1998), or decrease in water quantity (e.g. drainage, diversion, drought) resulting in wider swings in ionic concentrations (Grootjans and others 1988).

Climate Change

Inputs to local and regional aquifers from which springs discharge are ultimately driven by climate. The last 10,000 years has seen variation in climate. An investigation in the northern Bighorn Basin indicated the early Holocene (10,000 yr B.P.) was cooler and wetter than the present climate and during the middle Holocene a warming trend occurred (Lyford and others 2002). Lyford and others (2002) described wetter conditions between 4400 and 2700 yr B.P. and the last 2700 yr has been increasingly arid. While the direct effects of these climate fluctuations on BICA spring flows are unknown, deductive reasoning leads us to consider that flows have correspondingly varied with changes in climatic input. Because climate is a primary driver of spring flow, and therefore of spring ecosystems, it must be monitored and considered a potential vector of change in spring ecosystem quality and extent.

Anthropogenic Water Use

Water diversion, damming, and groundwater pumping affect water table levels. In an arid climate, water sources are scarce. Use of spring sites for surface or groundwater sources is common. In BICA, every large spring site (e.g. Hillsboro, Sorenson, Lockhart) has been altered for culinary or agricultural uses, many at spring sources (pers. observation). According to Finley (BICA archeologist), historic and prehistoric communities used spring sites for water, food, and shelter material sources, as well. Alterations occur in many forms including 1) capping the orifice and piping water to target areas (Sorenson spring), 2) eliminating spring vegetation around the orifice and building spring houses (Lockhart spring), 3) damming surface flow at the orifice (unnamed spring near Lockhart), 4) diverting surface flow downstream of the orifice (Layout spring), 5) diverting surface flow upstream of the orifice (Mason-Lovell), and 6) groundwater pumping. Water rights policies and disputes regarding water that drains (surface and subsurface) into BICA (Mason-Lovell) are also of concern.

Water Quality

Changes in flow may result in changes in water quality. Solute concentration increases with flow length (Bernaldez and Rey Benayas 1992), creating a gradient of environmental conditions in aquatic and wetted terrestrial areas. Before surfacing, spring water chemistry is indicative of the aquifer through which it flows. Once influenced by the desert climate, evaporation, gases from the atmosphere, evaporites in the substrate, and biological activities alter water chemistry. The dilution effect of discharge decreases over distance. Thus, changes in flow rate that result in expansion or constriction of the wetted area alter salt concentrations, temperature, and pH of spring water on the surface. The effect of water chemistry on soil chemistry produces soil salinity and alkalinity gradients, which affect plant communities of semi-arid land springs (Bernaldez and Rey Benayas 1992).

*Responses of Concern*

1. Decrease in spring discharge. Discharge is related to groundwater flow and aquifer volume. Groundwater withdrawals will potentially lower water tables and decrease spring flow (Brune 1975; Grootjans and others 1988).

2. Increase in spring discharge variability. Constancy in discharge is related to the sustainability of the groundwater environment. Decreases in groundwater aquifer volume or recharge rate will potentially lead to seasonal or storm driven spring flow cycles. Springs that arise from intersections with the water table are particularly sensitive to groundwater volume changes. Once the water table falls below the orifice, spring flow becomes subsurface. Springs will respond to hydrostatic pressure changes in the groundwater environment through changes in discharge (Fetter 1980).
3. Change in water quality. Increases in ion concentrations, specific electrical conductivity, and pH are related to decreases in spring discharge and increases in spring flow variability (Bernaldez and Rey Benayas 1992).
4. Changes in distributions of spring wetlands and riparian areas within spring extents correspond to water flow changes whether natural or anthropogenic. Springs originating from water table intersections with the surface and those influenced by changes in hydrostatic pressure respond to changes in groundwater discharge with a reduction in wetted perimeter reduction. Lowered water tables, decreased flows, and shorter flow duration result in smaller wetted areas and, therefore, smaller spring areas (Thompson and others 2002). Because riparian and wetland plant communities vary with groundwater depth (Meinzer 1927; Stromberg and others 1996), changes in groundwater levels may result in shifts in community composition (Grootjans and others 1988; Hendrickson and Minckley 1985). Numerous studies in arid regions have documented wetland and spring ecosystem shrinkage and losses due to groundwater pumping from shallow aquifers across the West – Nevada (Dudley and Larson 1976); Texas (Brune 1975); Arizona (Bryan 1928); Utah (Bolen 1964). In Colorado's San Luis Valley, a long-term average water table drop of 0.66 m resulted in a shift in wetland species composition. A 5 ft drop resulted in a loss of the entire wetland complex (Cooper 1994). Thus, threats to groundwater translate into potential spring response (Manga 1999).
5. Decrease in macroinvertebrate diversity. Macroinvertebrate diversity decreases are associated with increases in discharge variability (Erman 2002). Macroinvertebrate communities are sensitive to water quality. Their responses to declining flows is partially due to associated water quality changes and partially due to desiccation (Erman 2002). With declining water flow, extent, and duration, as well as degraded water quality, macroinvertebrate communities lose species that have narrow niches and populations of generalists increase (Sada and others 2005).
6. Loss of microhabitats. The mosaic of microhabitats in springs is largely due to the geomorphic surfaces types present (Stevens and others 2004) and long-term flow rates and their stability (Perla and Stevens 2003). Springs may become seasonally variable or quickly respond to storm events ("flashy") in response to water table decreases (drought or groundwater pumping) (Erman 2002). Shifts in plant community zonation occur in response to changes in water availability (Bradley 1970), soil salinity, and soil alkalinity (Bolen 1964) in aridland springs. Changes in flow rate that result in expansion or constriction of spring extents can alter soil salinity and alkalinity gradients (Bolen 1964). While plant communities do not respond to changes in water chemistry gradients in spring environments (Bolen 1964), they have been shown to strongly correlate with soil salinity and soil alkalinity gradients (Bernaldez and Rey Benayas 1992).
7. Loss of amphibian, bird, and mammal habitat. During a bat survey in the Pryor Mountains, captures of Pallid, Spotted, and Townsend's Big-eared bats occurred at sites

within 5 miles of BICA land. Most captures occurred in association with ponds and springs (Hendricks and others 2004). Springs provide habitat for many amphibian species in the Great Basin (Bradford 2002). Nesting, foraging, breeding, and migratory habitat for birds is commonly found in aridland springs (Williams and others 1984). Sada and Vinyard (2002) documented four endemic vole subspecies in Great Basin springs. Most land animals in aridland environments are dependent on surface water, and the springs in BICA provide most of the perennial surface water on the plateaus above the Bighorn reservoir.

*Magnitude of Threat*

Climate changes within the Bighorn Basin are likely to cause changes in spring flow in BICA springs. Anthropogenic impacts to water flow have occurred historically and will likely continue to occur in the future. BICA is managed as a multi-use natural resource. Water developments associated with interpretive sites and resource improvements (e.g. cultural site restoration, cattle trailing operations, wild horse range expansion) are ongoing. Impacts to spring ecosystems can be minimized by withdrawing water (surface or groundwater) from locations more than 100 meters downstream from spring sources. The ecosystem response to reduced spring discharge has not been calibrated. It will probably be commensurate with the severity of the impact. Outside of spring extents, water diversions or developments will have little effect on spring ecosystems, although they will heavily impact downstream riparian habitat.

*Spatial Extent of Threat*

Impacts to spring water sources are greatest in areas where water is scarce and human populations are expanding. All springs in BICA are in jeopardy of being impacted. Increased water use will accompany increased visitorship, development of interpretive exhibits, historical sites, and infrastructure within BICA. Springs will be considered as a water source for such developments. For example, water from the Hillsboro spring province is being used to water an orchard at the Hillsboro ranch site.

*Temporal Scale Over Which Threat Operates*

In BICA, impacts at spring sources are permanent unless developments are removed and ecosystems are restored. Water use impacts outside the spring source (groundwater pumping and diversion) occur during the growing (agriculture) and tourist seasons (Alley and others 1999). In normal water years, aquifers recharge and sustain spring ecosystems. However, in drought years, withdrawals may occur beyond thresholds of recovery for some spring species (Hershler and Sada 2002). In the Great Basin, some specialist species responded within hours of desiccation (Sada 2004). Until BICA springs are described in more detail quantifying such temporal responses is futile. Information from Great Basin springs indicate that sensitive species are impacted in the short-term and require a conservation-minded approach to water developments.

### Threats to Diverse Spring Biota

*General Description*

High rates of natural or anthropogenic disturbance can affect aquatic and riparian species richness (Rosenberg and Resh 1993). Specifically, generalists increase and specialists decrease following high rates or severity of disturbances. Sada and Nachlinger (1996) found a similar phenomenon in spring ecosystems in the Spring Mountains of Nevada suggesting that disturbance plays a similar role in both lotic and spring ecosystems. Further, aquatic species in spring ecosystems appear to display species-specific responses to disturbance due to a high degree of endemism (Heino and others 2003; Sada and others 2005). Many species have narrow environmental ranges (specialists) and therefore are susceptible to changes caused by disturbance (anthropogenic or natural). For example, the dipteran *Fauna liminaria* requires the bordering wet areas of springs which never freeze or desiccate (Wagner and others 1998). The relationship between temperature and dissolved oxygen is tight. Water temperature changes over short distances from spring orifices. There is a narrow zone of environmental conditions in which stone flies can exist. Once disturbed, the potential for stonefly distribution to change or become extirpated is realized. Thus, specialists can be used as bioindicators of particular types of disturbance (e.g. temperature, ionic concentrations, moisture). In springs with long-standing stable flow and water chemistry, specialists have evolved into endemic species (Hershler and Sada 2002; Shepard 1993b). A thorough survey of aquatic and terrestrial biota in BICA springs will likely identify bioindicators of disturbance in the park, as well as expand the lists of endemic flora and fauna.

Anthropogenic Disturbance

Spring biodiversity is related to the stability or constancy of the physical and chemical environment as well as the size of the spring area. Spring ecosystems that are stable through seasonal or annual environmental fluctuations (climate, upland disturbances) retain a diverse biota and many endemic species (Sada and others 2001; Shepard 1993b). A review of anthropogenic changes in the Great Basin concluded that status changes in endemic species in springs coincided with periods of human population expansion and economic growth (Hershler and Sada 2002). Sada and Vinyard (2002) identified ten anthropogenic factors associated with water developments, physical impacts, and biological invasions that affect distributions and abundance of aquatic and invertebrate species in Great Basin springs. The synergy among factors appeared to have a greater affect than any one factor. Sada and Nachlinger (1996) found a negative correlation between spring biodiversity and physical disturbance. Threats to spring biota, especially endemics, in BICA would potentially occur through trampling (human, cattle, and wild horses), water developments, improvements, or expansion of park infrastructure, restoration of historic sites, and increased growth in areas along park boundaries, particularly those requiring travel through the park for access.

*Trampling.* Physical disturbance agents in BICA include cattle trespass, wild horse trampling, and human trampling. Human trampling has the highest potential to impact spring wetlands because development tends to occur around springs. Virtually all cultural sites (Lockhart, Hillsboro, Ewing-Snell, and Mason-Lovell) occur near springs. These historic sites also are sites of prehistoric human activities (Finley, pers. comm.). One spring, perhaps the largest, occurs at the end of Layout trail and serves as the trail's destination. In an arid landscape such as BICA, tourists are drawn to springs as "oases" of lush vegetation, water, and shade. Through curiosity, relief from heat, and thirst, tourists may damage sensitive vegetation, disturb substrate surfaces vital for invertebrates, and introduce sediment, non-native species, and contaminants to spring areas. Because of the millennia of human activity in these areas, the current condition is not pristine. There is evidence of introduced plants, water developments, and denudation. Further impacts due to increases in visitorship, water developments, and introduced species are mounting. Their cumulative impact may threaten to pass ecological thresholds and result in a permanent loss of species and ecosystem processes.

Cattle and wild horse use of springs in BICA can damage spring areas. Cattle-trailing is a long-standing operation in BICA with potential to impact springs along the park road. Cattle need water sources during trailing operations and potentially enter spring areas accessible from the park road. There are three currently known springs along the main park road. Damage to vegetation, breakdown of banks, introduction of pollutants and non-native seed through fecal deposition are common impacts to riparian areas by cattle (Belsky and others 1999). Cattle gravitate to riparian areas for water, forage, and shade, then linger (if only over night) intensifying damage. The Bureau of Land Management has proposed expanding the wild horse range northward into BICA. As proposed, several springs lie within the area to be opened. Wild horses have been documented to preferentially use riparian environments as well as forage on riparian vegetation (Cran and others 1997). Springs on canyon walls, and rock outcrops are not areas traveled to by horses or cattle, in general.

*Water Developments.* Alterations to spring hydrology impact biota through desiccation and temporal variability in water quantity and quality. These topics were addressed in detail in the previous section.

*Infrastructure Improvement or Expansion.* As BICA deepens its commitment to providing access to cultural and environmental resources, increasing infrastructure for the public is inevitable. Road improvements, additional buildings, restrooms, restoration of historical sites, range and wildlife habitat restoration, and weed management are examples. Because many of the developed resources (and potential future developments) are near spring sites or include use of springs as water sources, springs are at risk to human trampling, water development, non-native plant invasions, and water pollution. Several Great Basin springs are a testimony to the serious threat unchecked development has on spring ecosystems (Hershler and Sada 2002).

*Adjacent Growth.* BICA must accommodate a diverse set of neighbors – public and private. Many private land owners adjacent to BICA must travel through the park for access. This includes cattle trailing operations, transporting feed for livestock, and wear and tear on the road in all seasons. As such, any increases in livestock, building, or other business on private inholdings comes with increased impacts to spring resources along the park road. While changes in land use type and intensity outside BICA are not controlled by BICA management, they must be accounted for in springs monitoring protocol due to their potential affects on water and biological resources.

#### Natural Disturbance

Natural disturbance provides potential for removal of some individuals (e.g. plants, animals, or microbes) and colonization of others (Sousa 1984). Disturbance magnitude and frequency influence development of aquatic and terrestrial community assemblages. Upland disturbances such as fire, rockfall, and overland erosion may impact spring productivity, geomorphology, soil development, and mosaic composition. The direct effects of wildfire on ecosystems surrounding spring orifices are relatively unexplored. Recent studies of the effects of wildfire focus on lotic riparian zones – spring-fed and otherwise – and may be applied to spring ecosystems in some cases. Rockfall produced from freeze-thaw actions may alter spring orifice geomorphology, soil development, microhabitat distribution, and can re-route surface and subsurface flow. Surface runoff into spring areas may be increased due to upland biomass loss through several vectors – fire, ungulate grazing, insect-induced land cover changes, etc. The frequency, severity, and timing of such disturbances potentially influence spring ecosystems, which can be highly evolved to a specific set of environmental conditions.

Fire impacts on fluvial systems are most severe in small watersheds with steep slopes, thin-soils, and potential for high precipitation storm events (Minshall and others 1997). Direct burning reduces biomass and potential seed sources for the year depending on the timing and severity of the fire. Long et al (2003) documented responses of sinkhole spring systems in moderately burned areas in New Mexico. Most regained equilibrium within a few years. However, springs within fluvial channels were impacted more severely and often required more time or active restoration (Long and others 2003). Knowledge derived from these efforts most directly applies to springs discharging into established channels or washes, as well as spring-fed creeks in BICA.

Reduced biomass caused by fire, ungulate grazing, or other disturbances makes riparian areas, including springs, susceptible to erosion storm-related overland flow (Wissmar 2004). Biomass loss in uplands may lead to increased sediment deposition into spring areas resulting in potential community loss due to burial or altered water quality. Incision, head-cutting, and lateral instability are common geomorphic responses to wildfire in fluvial settings (Long and others 2003). Surface runoff due to upland disturbance routed through spring areas may wash away plant communities rooted on rocks (geophytes), and thin soils as well as aquatic and terrestrial invertebrate communities. If a major disturbance impacts an isolated spring ecosystem, there is a risk of local extirpation of individuals or groups of species (MacArthur and Wilson 1965).

Non-native Species

Non-native species can decrease or eliminate native spring plant and animal populations through predation, competition, and hybridization (Hershler and Sada 2002). Non-native introductions could have occurred early in BICA's human history from hunter-gatherer populations inadvertently or intentionally transferring individuals between sites (Hershler and Sada 2002). The rate of non-native species expansion in aridland springs has accelerated over the last 200 years with increases in land management for sport fishing, livestock, and water use (Hershler and Sada 2002). Also, invasion by upland non-native species into desiccated spring areas is a potential threat associated with impacts to spring water resources. Disturbed springs support more exotic plant and aquatic species than undisturbed springs (Sada and Nachlinger 1996). Human impacts (intended or inadvertent) have resulted in considerable numbers of non-native species in springs ecosystems. In BICA, *Rorippa nasturtium* var. *curvipes* (watercress) is an obvious example (personal observation). Other non-native species potentially impacting BICA springs include *Euphorbia esula* var. *uralensis* (leafy spurge), *Tamarix chinensis* (salt cedar), *Eleagnus angustifolia* (Russian olive), *Agrostis stolonifera* (creeping bentgrass), *Poa pratensis* (Kentucky bluegrass), *Bromus tectorum* (cheat grass), *Bromus inermis* (smooth brome), *Potamopyrgus antipodarum* (New Zealand mudsnails), etc.

*Responses of Concern*

1. Decrease in spring biota habitat. Disturbances such as trampling will damage vegetation and alter water quality, soil properties, and substrate surfaces resulting in habitat loss for sensitive species (Stevens and others 2004). It is also possible for disturbances to spring areas to increase habitat heterogeneity by providing new surfaces for colonization (Sousa 1984).

2. Decrease in spring microhabitat diversity. Disturbance to late seral microhabitats will result in a shift in the microhabitat composition to early seral microhabitats (Sousa 1984). It is also possible for disturbance to result in an increase in microhabitat diversity.
3. Decrease in spring-related plant and animal diversity. Sada and Nachlinger (1996) reported a strong correlation between plant and animal diversity along a disturbance gradient. Chemical composition in addition to concentration influenced mollusk species (e.g. clams, snails, slugs) distribution (Sharpe 2002). Erman (2002) found that temporal variability of spring physical and chemical properties such as discharge, alkalinity, calcium, and temperature directly correlated with insect and mollusk diversity in Sierra Nevada cold springs. Decreases in specialists and increase in generalist species often occur when variability in environmental conditions increases (Sada and others 2005). A decrease in spring-related biodiversity would be associated with a corresponding increase in upland species, in the case of dewatering, or exotic species, in the case of increased disturbance.
4. Decreases in extents and population of endemic or rare species such as *Sullivantia hapemanii* var. *hapemanii*. *S. hapemanii* var. *hapemanii* is a wetland obligate. It is often found around calcareous springs, on steep slopes between 4,600 and 8,200 feet elevation. Known populations in BICA occur at Layout, Hillsboro, North Trail Creek Springs, and Little Bull Elk Creek in the Southern district, and several sites on Crow Agency land adjacent to BICA (Heidel and Fertig 2000). Altered hydrology and physical disturbance are the major threats to *S. hapemanii* var. *hapemanii* (Heidel 2004). Physical disturbance agents in BICA include cattle trespass, wild horse trampling, and human trampling. Human trampling has the highest potential to impact *Sullivantia hapemanii* var. *hapemanii* because the known populations occur at developed cultural sites and developed trails that receive the highest visitor traffic. *Sullivantia hapemanii* var. *hapemenii* populations are documented in steep canyons, on canyon walls, and rock outcrops associated with springs and, therefore are not areas traveled by horses or cattle, in general.
5. Increase in number of non-native species and their extents in spring areas. Increased disturbance in Great Basin springs resulted in larger populations of non-native invertebrate and plant species (Hershler and Sada 2002). Humans and livestock are primary vectors for intentional and inadvertent introduction of non-native species to spring areas.

*Magnitude of Threat*

The magnitude of anthropogenic threats to spring biota is difficult to assess without more information on BICA springs. Great Basin springs have high levels of endemism. Springs in this region have lost substantial biotic resources due to anthropogenic disturbance, development and increased human population. BICA springs may suffer a similar fate. However, the population pressure in BICA and surrounding areas is low. The Crow Agency is not likely to develop property adjoining BICA. Federal lands including on the Pryor Mountains are not likely to develop water or mineral resources which might indirectly affect BICA springs. Thus, the greatest pressure originates from NPS management of BICA (particularly future developments around spring areas) and land use within private inholdings. Thus, a conservative estimate of the magnitude of threats to BICA springs is moderate, with greater severity falling on springs near the park road and developed areas.

The magnitude of threat due to natural disturbances depends on climate cycles, fire regimes, rock fall cycles, and large storm events. Such information is currently not available.

*Spatial Extent of Threat*

Springs along the park road and within developed areas are most susceptible to anthropogenic disturbances and non-native invasions. The spatial extent of natural disturbance threats is park-wide.

*Temporal Scale Over Which Threat Operates*

Anthropogenic disturbances such as developments and habitat conversion result in immediate impacts. Trampling by humans or livestock varies in magnitude, frequency, and timing. Therefore, impacts due to trampling will also vary. The Fire Effects Information System sponsored by the USDA Forest Service reports the following fire intervals for uplands surrounding BICA springs; *Artemesia tridentata* 12-43 yr, *Juniperus occidentalis* 20-70 yr, *Cercocarpus ledifolius* 13-1000 yr (Fire Effects Information Center 2005). Thus, the temporal scale for the effects of fire on springs is highly variable due to the number of different upland communities and their varied fire intervals found adjacent to springs.

MONITORING OBJECTIVES

## Spring Water Resources

*Objective 1*

> *Estimate spring discharge and seep water tables and their change over time within BICA, taking into account seasonal, annual, and decadal time scales.*

Justification

Discharge at the orifice is the first parameter to respond to changes in climate, groundwater volume and groundwater flow. Spring ecosystems in desert regions have been described as having evolved under a narrow set of environmental conditions that are dependent on spring discharge (Shepard 1993a). The constancy of discharge has been linked to the unique and often endemic flora and fauna of aridland springs in the Great Basin (Sada and Vinyard 2002). Environmental conditions (temperature, dissolved oxygen, ionic concentrations, and nutrient status) change with distance from the orifice. In turn, plant and animal assemblages respond the zonation in the physical setting. Changes in spring discharge potentially disrupt biotic assemblages and set forth a chain of ecological changes. Thus, discharge at the spring orifice can be used as an indicator of threats to spring biota and ecosystem processes.

While springs in other desert environments have exhibited highly constant discharge, the seasonal, annual, and decadal variation of spring discharge in BICA is unknown. Thus, it will be necessary to establish the natural range of variability at these time scales as reference points by which to determine detectable changes.

Target indicators

1. Seasonal (spring, summer, autumn, winter) spring discharge and seep water tables at spring orifice.
2. Annual (spring) spring discharge and seep water tables at spring orifice.
3. Decadal (spring) spring discharge and seep water tables at spring orifice.

*Objective 2*

> *Determine the status and change over time of water chemistry parameters at seep and spring orifices within BICA.*

Justification

Water quality at spring orifices is a product of climate, the contributing groundwater environment, and the influence of the surface environment. Changes in water quality at the orifice indicate alterations to the groundwater environment. Changes in groundwater flow paths through different rock strata may alter the pH, temperature, specific electrical conductivity, or chemical profile of major ions.

Groundwater pollution will also influence water chemistry in various ways depending on the pollutants. Springs with recharge areas that include developments and agricultural activities are susceptible to pollution from herbicide, fertilizer, and pesticide usage, septic leach fields, and chemical spills from machinery (Mitsch and Gosselink 2000; Sada and others 2001). In BICA, those springs with recharge areas that include roads, buildings, cattle holding pastures, sprayed weed infestations, and historic or current agricultural activities are potentially threatened by groundwater pollution associated with these land uses. Detecting changes in water quality at the orifice will alert BICA staff to consider management actions that alleviate threats to groundwater quality.

Water quality parameters change with distance from the orifice due to interactions with the surface environment (e.g. evaporation, soil chemistry, biological transformations) (Bernaldez and Rey Benayas 1992). Using this concept, monitoring staff can define the spring extent by point at which water temperature downstream is 2°C different from that at the spring orifice. If discharge is stable, then temperature and water quality at a particular distance from the orifice remains relatively stable. Long-term exposure to a particular set of stable aquatic chemical conditions results in specialized, often endemic, macroinvertebrate and plant communities (Hershler and Sada 2002; Sada and others 2005).

<u>Target indicators</u>

| General | Nutrients | Major Cations | Major Anions |
|---|---|---|---|
| pH | Ammonium | Calcium | Bicarbonate |
| Specific Electrical Conductivity | Nitrate | Magnesium | Carbonate |
| Temperature | Phosphate | Sodium | Sulfate |
| Dissolved Oxygen | | Potassium | Chloride |

1. Seasonal (spring, summer, autumn, winter) water chemistry (above list) at spring orifice.
2. Annual (autumn) water chemistry (above list) at spring orifice.
3. Decadal (autumn) water chemistry (above list) at spring orifice.

**Spring Biotic Resources**

The following proposed monitoring objectives require additional inventory before the target plant communities and aquatic macroinvertebrates are identified and sample design and methods can be determined. Such an inventory will require additional resources beyond that which the Greater Yellowstone Network has available through the vital signs monitoring program As such, the following objectives are provided as a starting point for the development of monitoring biotic resources in BICA.

*Objective 3*

*Estimate current status and change over time of indicator plant species abundance within present spring microhabitats.*

A botanist will develop a plant species list (vascular and non-vascular) of BICA springs. The botanist will identify plant species indicative of moisture levels and disturbance, and geomorphology. Indicator species will be chosen based on characterization of microhabitats at BICA springs and knowledge of species in published vegetation literature and databases (The PLANTS Database, Wyoming Diversity Database, and Montana Heritage Program). This is a starting point for monitoring and may be refined with further development.

*Objective 3a*

*Detect a 20% change in indicator plant species density (or frequency) in permanent plots within BICA spring areas.*

The detection level of 20% is a starting point based on peer-reviewed literature on observer and natural variability of vegetation abundance and its measurement. The sample design should allow for the determination of observer and natural variability. The target will be a 5% change beyond the empirically determined observer + natural variability in abundances of indicator plant species.

Justification

Changes in the extent of spring aquatic, wetland and riparian areas within spring extents correspond to water flow changes whether natural (climate) or anthropogenic (water use). Lowered water tables, decreased flows, and shorter flow duration result in smaller spring areas (Thompson and others 2002). Because riparian and wetland plant communities vary with groundwater depth, changes in groundwater levels may result in shifts in community composition of spring ecosystems (Grootjans and others 1988; Hendrickson and Minckley 1985). Numerous studies across the arid West have documented wetland and spring ecosystem shrinkage and losses in biodiversity due to groundwater depletion, regardless of cause. Plant abundance and distribution should remain stable in a spring free of human impacts (Cantonati and others 2006).

Density and frequency have been shown to be more repeatable measures of abundance than cover. While these measures are more time consuming, they will ultimately yield a more informative and robust data set from which to assess resource condition. Mosses tend to be particularly well suited to cold spring environments. In a study of spring vegetation in the Alps, mosses were found to be most indicative of springs than higher plants. Further, 58 taxa of nonvascular plants were found in 18 spring sites (Cantonati and others 2006).

In BICA, we do not know the amount of change in discharge that will elicit a change in spring vegetation composition, nor do we know the natural range of variability for mesic vegetation. This will likely be site specific requiring several years of monitoring to define the relationship.

Target indicators

1. Annual density/frequency of indicator plant species in permanent plots in microhabitats of spring extents.

*Objective 3b*

*Determine the status and change over time of endemic and exotic plant species abundance within spring extents.*

Justification

One of the unique features of aridland seeps and springs is the biodiversity. In many cases endemic species contribute to spring biodiversity. In BICA, *Sullivantia hapemanii* var. *hapemanii* is a rare, obligate wetland plant species. It is often found around calcareous springs, on steep slopes between 4,600 and 8,200 feet elevation. Known populations in BICA occur at Layout, Hillsboro, North Trail Creek Springs, and Little Bull Elk Creek in the southern district, and several sites on Crow Agency land adjacent to BICA (Heidel and Fertig 2000). The potential for finding other rare or endemic plant (vascular or nonvascular) species in BICA springs exists.

Decreases in specialists and increases in generalist species often occur when variability in environmental conditions increases (Sada and others 2005). A decrease in spring-related biodiversity could be indicated by a corresponding increase in upland or introduced aquatic and riparian species. While water quality and aquatic macroinvertebrates respond to acute environmental changes, soil chemistry and spring vegetation composition appear to respond to sustained environmental changes (Bernaldez and Rey Benayas 1992). Monitoring soil conditions in spring systems is fairly destructive which makes it a less appropriate monitoring parameter. Changes in spring vegetation composition indicate potential long-term, if not permanent, damage to spring ecosystems with the least amount of impact to the system.

Non-native species can decrease or eliminate native plant and animal populations through predation, competition, and hybridization (Hershler and Sada 2002). Invasion by upland non-native species into desiccated spring areas is a potential threat associated with impacts to spring water resources. Increased disturbance in Great Basin springs resulted in larger populations of non-native invertebrates and plant species (Hershler and Sada 2002). Human and livestock activity are primary vectors for intentional and inadvertent introduction of non-native species to spring areas. Springs along the park road and within developed areas are most susceptible to anthropogenic disturbances and non-native invasions.

<u>Target indicator</u>

1. Annual density/frequency of endemic and exotic plant species in permanent plots within spring extents. (Multiple site visits may be required to assess species identifiable at different parts of the growing season.)

*Objective 4*

*Determine the status and change over time of aquatic macroinvertebrate community composition and structure spring extents.*

The detection level of 20% is a starting point based on peer-reviewed literature on observer and natural variability of macroinvertebrate abundance and its measurement. The sample design will allow for the determination of observer and natural variability. The target will be a 5% change beyond the empirically determined observer + natural variability in abundances of indicator macroinvertebrate species.

*Objective 4a*

*Detect a 20% change in indicator macroinvertebrate species abundance within spring extents.*

<u>Justifications</u>

Aquatic macroinvertebrates make up a substantial proportion of spring biodiversity. Aquatic species in spring ecosystems display species-specific responses to spring environments due to a high degree of endemism (Cantonati and others 2006; Heino and others 2003; Sada and others 2005). To date, there is no documentation of aquatic macroinvertebrates in BICA springs. Thus, a survey of spring fauna will likely increase the BICA species list and potentially document rare, endemic, threatened, or endangered species. Because the rarity of spring ecosystems is a vital part of the basis for monitoring them, the status of spring-specific species contributes to the knowledge their value.

Target indicators

1. Complete an initial macroinvertebrate fauna of BICA springs followed by an update every five years. Annual richness, abundance, and spatial structure of macroinvertebrate species within spring extents. (Multiple site visits may be necessary to observe species with different emergence times.)

*Objective 4b*

*Determine the status and change over time of endemic aquatic macroinvertebrate species within spring extents.*

Justification

Decreases in specialists and increases in generalist species often occur when variability in environmental conditions increases (Sada and others 2005). Many spring species have narrow environmental ranges (specialists) and therefore are susceptible to changes in water chemistry and habitat quality. Aquatic macroinvertebrates in spring ecosystems appear to display species-specific responses to disturbance due to a high degree of endemism (Heino and others 2003; Sada and others 2005).

Target indicators

1. Annual richness, abundance, and spatial structure of endemic macroinvertebrate species within spring extents. (Multiple site visits may be necessary to observe species with different emergence times.)

## SAMPLING DESIGN

***This component remains in development pending further site investigations planned for June 2006.***

A one time census of all priority springs in Bighorn Canyon is a critical first step towards developing a sample design. The census would included site descriptions of physical and biological parameters such as landscape context, geomorphic surfaces, baseline water chemical and isotopic analyses, habitat types, plant communities, and wildlife observations. This information will be used to classify springs in terms of their hydrologic, geologic, geomorphic, and ecological characteristics. Following the classification process, a decision will be made to determine how the springs (31 known to date) will be stratified and the number of samples per strata.

## METHODOLOGY

Data collection and analyses for monitoring springs focus on site characterizations and regular sampling of physical properties. Site characterizations involve an assessment of geographic, environmental, and ecological traits contributing to the ecological function of each spring. SOP#1 Site Establishment details these methods. Water quantity and quality are considered the most responsive parameters to impacts to springs. SOP#5 Data Collection of Field Parameters contains specific methods used to collect data for these parameters. Further development of vegetation and macroinvertebrate samples procedures may follow initial inventory and refinement of monitoring objectives.

### Water Resources

#### *Water Quantity*

Spring discharge is the volume of water flowing from the spring orifice(s) over a given time. It is a product of regional climate, aquifer volume, and groundwater flow. Discharge is the first spring parameter to respond to changes in the groundwater flow. It influences the zonation of water chemistry and temperature, and, therefore, ecosystem structure and composition (Erman 2002; Sada and Herbst 2001; Shepard 1993a). Quantification of masses of target chemical parameters (e.g. nitrogen) exported (loads), concentrations of target parameters and discharge are needed. For example, the concentration nitrate will vary with discharge due to dilution. Monitoring loads of chemical parameters as mass exported is more indicative of inputs into the system, and therefore, changes in ecosystem condition. As a response variable to impacts on groundwater and a measurable control on spring ecosystems, discharge is an important parameter to monitor in BICA springs.

BICA springs arise from a variety of geologic strata, geomorphologies, and landscape positions. Spring discharge may flow into a channel, spread across rock or hill faces, or flow through soil. For discharge measurement methods to be effective and repeatable, the method must fit the site configuration. In general, measuring discharge may occur in three different ways. 1) Discharge from springs that flow into channels can be measured with a current meter. 2) Discharge from springs with low or shallow surface flows can be measured with temporary weir. 3) Discharge from seeps whose flow is primarily subsurface can be assessed indirectly through measuring water table depth in a network of monitoring wells placed both within the main part of the see and along seep edges. Because each spring arises in a unique setting, these methods may need modification to meet Monitoring Objective #1. To address potential changes in spring hydrology, such as change from surface to subsurface flow, combinations of discharge measuring techniques might be needed.

Expected ranges and variability for spring discharge require several years of monitoring data.

#### *Water Quality*

Water Temperature

Water temperature is an important characteristic of spring ecosystems because it determines the rates of biological and chemical reactions (Penoyer 2003). Groundwater temperatures tend to be stable, and springs commonly have narrow temperature ranges throughout the year (Cantonati and others 2006). The discharge of groundwater to form a spring or contribute to a stream has a moderating affect on stream water temperature (Holmes 2000). For this reason, a water temperature change of 2°C can be used to define the boundary between spring and stream environments (Erman 2002). The stability in water temperature in the spring environment supports endemic species not found downstream where water temperatures fluctuate (Erman 2002). Monitoring spring water temperatures will detect changes in environmental conditions upon which spring biota may depend.

Manga (Manga 2001) used spring water temperature as part of a suite of parameters to estimate mean residence time of groundwater and aquifer characteristics. Spring water temperatures are a product of the mean water temperature across the recharge area, and the conductive and advective properties of the aquifer(s). For these reasons water temperature indicates depth and velocity of groundwater flux (Cantonati and others 2006).

Measuring water temperature is done with a thermistor as close to the spring orifice as possible. The expected range for BICA springs is 1-22°C based on field reconnaissance. A given site will have a narrower temperature range for a given site. Non-geothermal springs with temperatures above 30°C tend to have low biodiversity (Stevens and Springer 2004)

#### pH

The pH of spring water is the negative base-10 log of hydrogen ion activity as refers to the hydrogen ion activity (Hem 1985). Spring water pH is influenced by geology, air pollutants, human impacts, and biological activity (Cantonati and others 2006; Stevens and others 2004). Many BICA springs originate from carbonate geologic strata and can readily buffer changes in hydrogen ions. These springs will have lower seasonal variability than those arising from non-carbonate layers. Sites with stable water chemistry tend to have higher species richness as well as more endemic species (Erman 2002; Erman and others 1992; Sada and Herbst 2001).

Water pH is measured as close to the orifice as possible with a single or multiparameter probe. In general, BICA spring water will range between pH 6 and 8.5, although exceptions may occur in springs influenced by sodic soils, upland erosion, or livestock waste.

#### Specific Electrical Conductance

Specific electrical conductance (SpEC) is the measure of the capacity of a volume of water to conduct a current at a given temperature (Hem 1985). The SpEC of a spring is a function of dissolved gases and ions in groundwater and surface water near the orifice. Ions dissolved from geologic strata represent the natural state of spring water. Groundwaters with shorter flow paths or residence times will have lower SpEC values than those flowing through the same geologic units with longer flow paths and residence times (Hem 1985). Further, springs with shorter residence times will be flushed by storms leading to more variable SpEC values (Cantonati and others 2006). Deviations from expected SpEC ranges may indicate human impacts such as upland erosion, diversion, or livestock trampling.

Measurement of SpEC occurs at the spring orifice with a single or multiparameter probe. Expected ranges for BICA springs are wide for the population of springs (100 - 2000 µS/cm). However, a given spring site SpEC range will be narrower.

#### Dissolved Oxygen

Dissolved oxygen (DO) refers to the amount of gaseous oxygen dissolved in water. It is required by biota in spring environments and affects many chemical and biological reactions (Radtke and others April 1998). Sources of DO include dissolution of atmospheric oxygen and photosynthesis of aquatic or submerged autotrophs. Sinks of DO include respiration of aquatic biota and chemical reactions such as oxidation. The solubility of oxygen in water varies with temperature (Penoyer 2003).

Most surface water investigations of water quality measure DO. Low DO can be detrimental to aquatic life. Conditions leading to low DO include warm water temperatures, stagnation, high respiration rates, and eutrophication (Penoyer 2003). Subterranean waters are generally low in dissolved oxygen due to lack of interaction with the surface and, if biota are present, the dominance of respiration and decomposition (Cantonati and others 2006).

Dissolved oxygen is an NPS WRD core parameter and will be monitored at BICA springs. However, DO measurements are problematic to interpret. DO is a naturally and highly variable parameter. It changes with water temperature, photosynthesis and respiration rates (diurnal and seasonal), turbulence (Penoyer 2003), salinity, and, for springs, time since discharge from the subsurface environment (Cantonati and others 2006). Detecting a meaningful change in DO that would inform a management decision requires a combination of intensive short term and long term sampling (Nagorski and others 2003). The NPS Water Resources Division describes DO as a core water quality parameter for many of the reasons stated above. However, they also rank DO as the "most problematic and prone to failure and erratic or false out of range measurement" due its sensitivity to environmental conditions (Penoyer 2003). DO is a core parameter in the Regulatory and Integrated Water Quality protocols. Monitoring staff may find DO data on BICA springs useful to maintain a consistent set of water quality data for landscape scale analysis of NPS water resources.

In general, DO levels in surface waters range from 2 to 10 mg/L, although most aquatic life requires average DO levels of at least 5 mg/L to survive. Supersaturation (above 100% saturation) of DO can occur due to cold water temperatures, turbulence, and an imbalance between sources and sinks. As a general rule of thumb, DO maxima and minima occur in early afternoon and early morning (just before sunrise), respectively. Standards for natural streams describe dissolved oxygen and temperature as relatively stable even during weather extremes (Karr and Dudley 1981). Quantitative standards must be established for a given site through nested short term and long term sampling (Nagorski and others 2003).

Field methods for measuring dissolved oxygen commonly use an amperometric probe with temperature compensation (Penoyer 2003). Dissolved oxygen must be measured in situ. This is the recommendation for this protocol.

Inorganic Analytes

For the purpose of this study, inorganic analytes include major ions and three isotopes in the water column. The significance of each is described below. In general, the chemical make up of spring water is the product of everything that comes in contact with it – geology, atmosphere, biota, upland inputs, and residence time. In turn, the chemical make-up (major cations and anions) of spring water influences spring biota (Bradley 1970; Cantonati and others 2006; Sada and Herbst 2001). Isotopic levels ($^{18}O$, $^{2}H$ and $^{3}H$) in combination with major ions (calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride), temperature, and discharge variability are used to assess residence time and recharge zone (Manga 2001).

Understanding the chemical profile of a spring lends insight into the character of the spring ecosystem (see Data Analysis for an example). The subsurface environment has the greatest influence (Bakalowicz 1994), and therefore serves as a baseline reference point for monitoring. If endemic species are present, water chemistry may be linked to their presence (Hershler and Sada 2002). Well buffered systems will be less impacted by chemical pollutants. Residence time indicates the temporal scale at which changes occur at the spring (Bakalowicz 1994).

Seasonal variability of flow and chemical levels generally correspond to short residence times (see Data Analysis for an example). Consequently, stable flow and chemical profiles correspond to long residence times. Extending this concept to groundwater impacts (natural or anthropogenic), short residence times lead to short lag periods between groundwater impact and spring response. Similarly, long residence times lead to long lag periods.

The variability in the subsurface environments of BICA springs produces a wide range of inorganic analyte levels (Table 1). Further, depending on residence times, seasonal variability may be high or low. Several years of monitoring are needed to establish baseline levels for each ion and ion profile, as well as for expected ranges for BICA springs. Table 1 shows existing data for groundwater samples from several geologic strata in the BICA area. The variability within a stratum and among strata is high. Sources of this variability include sampling location, sampling depth, effect of other strata along the subsurface flow path, subsurface mixing where flow paths converge, and pollutants (pers. comm. Montana Bureau of Mines and Geology, 2004). The geologic strata applicable to BICA can be viewed in Appendix A.

Inorganic analytes are measured through lab analyses from samples collected in the field as close to the orifice as possible. Acid neutralizing capacity (carbonate and bicarbonate) is an exception due to the loss of carbon dioxide during storage and transport to an analytical lab (Rounds and Wilde September 2001). While the analyte levels are commonly reported in concentrations (mg/L), monitoring nutrient loads (mass exported) lends insight into changes in the amount of an analyte entering and exiting the system.

**Table 1.** Groundwater data collected from the Pryor Mountains and surrounding area. Adapted from Pryor Mountain Groundwater Characterization (Montana Bureau of Mines and Geology 2004) and *Water Resources of the Bighorn Basin (Lowry and others 1976) and #development of this protocol.

| | BICA Spring | pH | SpEC µS/cm | Na mg/L | K mg/L | Ca mg/L | Mg mg/L | Cl mg/L | HCO3 mg/L | CO3 mg/L | SO4 mg/L | NO3 mg/L | Alkalinity mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kootenai (215255) | | 7.4 | 798 | 24.40 | 1.7 | 80.5 | 43.3 | 6.97 | 306.2 | 0.0 | 202.00 | 0.25 | 251 |
| Ellis (215232) | | 7.3 | 1857 | 17.50 | 1.1 | 393.0 | 67.7 | 1.25 | 189.8 | 0.0 | 1085.00 | 0.25 | 156 |
| Rierdon (207508) | | 8.0 | 1617 | 4.04 | 1.5 | 308.0 | 73.4 | 2.50 | 219.6 | 0.0 | 886.00 | 0.25 | 180 |
| Rierdon (207523) | | | 2240 | 16.00 | 3.0 | 570.0 | 58.0 | 3.00 | 225.0 | 0.0 | 1450.00 | 0.18 | 185 |
| Chugwater (215233) | | 7.5 | 1014 | 7.93 | 1.1 | 169.0 | 44.8 | 1.27 | 166.4 | 0.0 | 443.00 | 0.27 | 136 |
| Chugwater (215248) | Lockhart Middle | 7.4 | 1226 | 34.40 | 2.1 | 161.0 | 70.3 | 3.70 | 251.8 | 0.0 | 523.00 | 0.60 | 207 |
| Chugwater (7944) | | 7.5 | 1420 | 7.40 | 3.6 | 206.0 | 61.3 | 4.30 | 214.0 | 0.0 | 587.00 | 0.08 | 176 |
| Chugwater (215246) | Lockhart South | 8.3 | 1330 | 34.60 | 2.1 | 179.0 | 75.2 | 4.00 | 251.3 | 0.0 | 611.00 | 0.25 | 206 |
| Chugwater (215252) | | 8.1 | 1846 | 9.38 | 4.0 | 382.0 | 60.0 | 2.50 | 169.6 | 0.0 | 1085.00 | 0.25 | 139 |
| Chugwater (212183) | | 7.6 | 2190 | 15.80 | 2.4 | 474.0 | 93.9 | 2.50 | 208.2 | 0.0 | 1448.00 | 0.25 | 171 |
| Tensleep (215312) | | 7.5 | 443 | 1.39 | 0.8 | 65.0 | 27.5 | 1.02 | 282.1 | 0.0 | 36.00 | 0.56 | 231 |
| Tensleep (215281) | | 7.7 | 426 | 1.52 | 0.8 | 59.1 | 29.5 | 0.65 | 288.7 | 0.0 | 14.10 | 0.415 | 237 |
| Tensleep (215234) | Sorenson | 7.7 | 412 | 3.22 | 0.6 | 55.4 | 21.7 | 0.25 | 217.8 | 0.0 | 54.60 | 0.18 | 179 |
| Tensleep (215240) | South Trail Creek | 7.7 | 535 | 6.39 | 0.7 | 78.8 | 28.7 | 1.02 | 239.4 | 0.0 | 111.00 | 0.20 | 196 |
| Tensleep (215235) | North Trail Creek | 8.1 | 1827 | 31.00 | 2.8 | 330.0 | 97.0 | 2.50 | 237.9 | 16.8 | 1033.00 | 0.63 | 223 |
| Tensleep (215280) | Pete’s | 7.7 | 746 | 27.90 | 1.7 | 92.4 | 40.2 | 6.90 | 253.8 | 0.0 | 231.00 | 0.96 | 208 |
| Tensleep | Hillsboro | 7.5 | 512 | 7.00 | 1.0 | 58.0 | 31.0 | 0.01 | 200.0 | 0.0 | 126.00 | 0.09 | 181 |
| Amsden (215238) | | 7.6 | 375 | 0.49 | 0. 5 | 48.6 | 23.8 | 0.25 | 262.3 | 0.0 | 1.25 | 0.18 | 215 |
| Amsden (215231) | | 8.2 | 364 | 0.70 | 0.4 | 57.1 | 18.3 | 0.25 | 255.0 | 0.0 | 1.25 | 0.66 | 209 |
| Amsden (215227) | | 8.2 | 346 | 1.10 | 0.8 | 47.0 | 20.2 | 0.50 | 221.4 | 0.0 | 9.49 | 0.11 | 182 |
| Madison (215249) | | 8.1 | 250 | 0.44 | 0.3 | 33.2 | 10.7 | 0.25 | 158.6 | 0.0 | 1.25 | 0.25 | 130 |
| Madison (188523) | | 7.8 | 384 | 1.18 | 0.6 | 43.3 | 22.6 | 0.65 | 255.5 | 0.0 | 2.71 | 0.13 | 210 |
| Madison * | | 7.6 | 1270 | 2.30 | 2.0 | 192.0 | 72.0 | 0.00 | 200.0 | 0.0 | 595.00 | 0.30 | — |
| Madison # | Layout | 7.7 | 226 | 1.00 | 1.0 | 24.0 | 14.0 | 0.01 | 200.0 | 0.0 | 9.00 | 0.09 | 110 |
| To be determined | North Davis | 6.9 | 1218 | 35.00 | 2.0 | 152.0 | 85.0 | 0.01 | 24.0 | 0.0 | 620.00 | 0.14 | 206 |
| To be determined | Headgate | 7.2 | 266 | 4.00 | 2.0 | 38.0 | 26.0 | 0.01 | 200.0 | 0.0 | 37.00 | 0.08 | 175 |

### *Carbonate and Bicarbonate (Acid Neutralizing Capacity)*

Acid neutralizing capacity (ANC) is the ability to neutralize hydrogen ions. The most common constituent contributing to ANC is bicarbonate. Less common contributors include carbonate (above pH 8.5) hydroxide, silicate, and borate and are not separated out in reported values. Errors associated with this assumption are minimal unless pH values exceed 9.5 (Hem 1985). ANC levels are indicators of geologic strata, aquifer typology (porosity, flow patterns), and buffering capacity (Table 1). Springs discharging from limestone aquifers usually have higher ANC levels than those from sandstone or shale. Aquifers recharging water over wide areas have longer residence times and higher ANC levels than those that flow through fissures. Spring waters with bicarbonate levels below 50 meq/L are consider sensitive to impacts leading to a change in pH (nutrients, organic inputs, acid deposition) – between 50 and 200 sensitive; and above 200 not sensitive (Camarero and others 1995).

Carbonate and bicarbonate are measured at the spring orifice using inflection point titration with sulfuric acid. Measurements that represent current conditions must be made at the time of sampling (Wood 1991). Laboratory alkalinity measurements tend to underestimate bicarbonate concentrations. This results from bicarbonate loss in the form of carbon dioxide between sample collection and laboratory analysis. A charge balance is performed on every sample as a QAQC measure error in the lab analyses. Measuring carbonate or bicarbonate in the lab may introduce error sufficient enough to render a sample result unusable. If titration is done on an unfiltered sample the result is called acid neutralizing capacity. If done on a filtered sample, alkalinity (Rounds and Wilde September 2001).

### *Nutrient Status*

Spring water nutrient status is influenced by impacts in the recharge zone, groundwater depth and upland inputs of erosion, surface runoff, and animal waste. Farming, feed lots, septic tanks, and atmospheric deposition in spring recharge zones are common sources of groundwater pollution (Bakalowicz 1994). Nutrient status tends to decrease with groundwater depth (Anderson 1993). The recharge zone of BICA springs is the area covered by the Pryor Mountains (pers. comm. Montana Bureau of Mines and Geology). There is little input of nutrients to this area. The depth of groundwaters feeding BICA springs is likely over 100 ft. Nitrate and ammonium are generally low in poorly oxygenated sources such as groundwater. Expected levels in BICA springs based on literature are quite low compared to drinking water standards or common levels found in surface waters. Initial targets include: nitrate < 100 μg/L; ammonium < 30 μg/L; total phosphorus < 10 μg/L (Cantonati and others 2006).

Nitrite is an oxidized form of nitrogen naturally produced by nitrifying soil bacteria. It is unstable in aerated waters and is generally used as an indicator of pollution from the disposal of sewage or organic waste. Nitrite is generally not present in concentrations to significantly contribute to the ionic balance of natural waters. Nitrite is generally not reported separately in water studies (Hem 1985).

Ammonia nitrogen is often used in fertilizers and may be a threat to BICA spring condition. However, ammonia nitrogen is difficult to attribute to a particular human source because it is naturally variable. It is unstable in aerated waters and is common in rainwater. Ammonia strongly adsorbs to mineral surfaces and is often filtered out during preparation of water quality samples (Hem 1985). If ammonia nitrogen is suspected as an impact to BICA spring condition, a sampling design should be developed to establish background levels and those associated with the suspected source.

Sulfate is a nutrient common in organic pollution. However, given the presence of gypsum in BICA, natural sulfate levels may be very high (Table 1). Therefore, background levels will need to be established through long term monitoring.

### *Calcium and Magnesium*

Calcium is a common ion in igneous, metamorphic, and sedimentary rock. BICA has a substantial amount of limestone, dolomite, and gypsum-rich bedrock, all of which are high in calcium. Also, magnesium is common in dolomite rock. Dissolved calcium and magnesium are the products of many complex chemical reactions involving sodium, sulfate, pH, alkalinity, and temperature (Hem 1985). Calculations to account for these influences are beyond the scope of this monitoring protocol. However, in the event that NPS needs to track the intricacies of calcium chemistry, the influencing parameters are tracked.

### *Sodium and Potassium*

Natural sources of sodium and potassium include fine grained sedimentary rock strata such as those found in BICA (Hem 1985). What is important about sodium and potassium levels is their molar (mg/L) ratio. Potassium: sodium molar ratios may be high in dilute waters where the sum of their concentrations is less than 10 mg/L. In waters with sodium levels above 0.44 meq/L (10 mg/L), potassium levels are generally less than half the sodium concentration or less (Hem 1985). Sources of sodium or potassium contamination are fertilizers, pesticides, and road salting.

### *Chloride*

Chloride levels are generally low and constant because it used by neither biological nor chemical processes between recharge and discharge (Bakalowicz 1994). For this reason, chloride levels are the same when it leaves the atmosphere as when it emerges at a spring. Thus, it can be used as an indicator of recharge area. When used in conjunction with regional geology, distance from oceans and cities, water chemistry, and isotopic composition, chloride content of spring water can give a good estimate of recharge zone (Bakalowicz 1994). In halite or gypsum strata, chloride levels will be higher than in non-chloride containing strata. However, chloride levels should remain constant over time (Hem 1985). Elevated levels may indicate runoff from salted roads or fertilized uplands (Cantonati and others 2006).

*Isotopes*

For monitoring the condition of BICA springs, stable and unstable isotopes can be used to estimate recharge area and water age. Water age is the time of entry of a water molecule into an aquifer to the time it discharges at a spring (some would call this travel time through the aquifer). The recharge area loosely estimates the region of water percolation into an aquifer that potentially influences BICA spring discharge. Recharge area will be estimated using the ratio of 18-oxygen ($^{18}O$) to deuterium ($^{2}H$). Water age will be estimated using tritium ($^{3}H$).

*A note about isotopes adapted from USGS Isotope Tracers Project (USGS 2006)*

Isotopes are atoms of the same element that have the same number of protons and electrons but a different number of neutrons. Stable isotopes are not radioactive on geologic time scales. Unstable isotopes are radioactive and decay into other isotopes at constant rates. The difference in neutron number leads to an atom with a different atomic weight but the same charge. Isotopes are communicated by atomic number and chemical abbreviation. For example, normally oxygen has atomic number 16. Isotopic oxygen has two extra neutrons and atomic number 18. It is written $^{18}O$ or 18O and pronounced "O 18". Radioactive hydrogen takes two forms – $^{2}H$ (deuterium = hydrogen with one extra neutron) and $^{3}H$ (tritium = hydrogen with 2 extra neutrons).

An isotopic composition of hydrogen (or oxygen) is reported as a ratio of ratios (δ). The ratio of heavy to light isotopes is measured in a sample ($R_{sample}$) compared to a standard of known composition ($R_{standard}$). Delta (δ) is calculated from a formula with the ratio of $R_{sample}$ to $R_{standard}$ and is expressed in parts per thousand (‰). More positive (less negative) δ values mean that a sample contains more of the heavy isotope compared to the standard. A $\delta^{18}O$ value of -19‰ means that there are 19 parts per thousand (or 1.9%) fewer $^{18}O$ atoms in the sample compared to the standard. Similarly, a $\delta^{18}O$ value of -25‰ contains 6 fewer parts per thousand $^{18}O$ atoms than the previous sample.

Delta values change with each turn of the hydrologic cycle. As water goes through a phase change heavy isotopes concentrate in the heavier phase and lighter isotopes concentrate in the lighter phase. For example, during evaporation of water from a pool (liquid to gas) heavier isotopes tend to remain in the pool while lighter isotopes tend to move into the vapor phase. The resulting $\delta^{18}O$ and $\delta^{2}H$ values for vapor are more negative than those for condensate (rain, dew, fog, etc.). Likewise increasing altitude, latitude, inland distance, and decreases in temperature contribute to more negative $\delta^{18}O$ and $\delta^{2}H$ values.

See Appendix B or (http://wwwrcamnl.wr.usgs.gov/isoig/res/funda.html.) for further background on isotopes.

Recharge Area (Location). Recharge area is the geographic footprint over which recharging of aquifer(s) that support a spring occurs. Recharge area can be estimated from the ratio of $\delta^{18}O$ to $\delta^2H$. This ratio indicates two conditions at the time water recharges into an aquifer: temperature at which condensation occurred (rain vs. snow) and the amount of evaporation prior to infiltration. A regional representation of $\delta^{18}O$: $\delta^2H$ values was derived from precipitation collected from a series of regional sites ($r^2$=0.98) (Benjamin and others 2004). This regional relationship is called a local meteoric water line. It identifies $\delta^{18}O$: $\delta^2H$ values from waters recharging from rain versus snow (Figure 5). Values that plot high on the line arise from rain water. Values that plot low on the line arise from snow. Because the $\delta^{18}O$: $\delta^2H$ values for the local meteoric water line were derived directly from precipitation, regional values that plot below the line represent waters subject to evaporation prior to infiltration.

Plotting $\delta^{18}O$: $\delta^2H$ values from BICA springs with data from the local meteoric water line can be used to deduce the environment from which the source water transferred from atmosphere to groundwater (Figure 5). Recall that increasingly negative $\delta^{18}O$ and $\delta^2H$ values occur at larger distances inland, lower temperatures, and higher latitudes and altitudes. Further, departures from the local meteoric water line indicate evaporation prior to recharge. BICA spring $\delta^{18}O$ and $\delta^2H$ values are highly negative and plot low on the local meteoric water line. This suggests that BICA spring water arose from snow pack and at higher altitudes in the region. The climate and topography surrounding BICA indicate that spring water likely originated from the Pryor Mountains during winter snow.

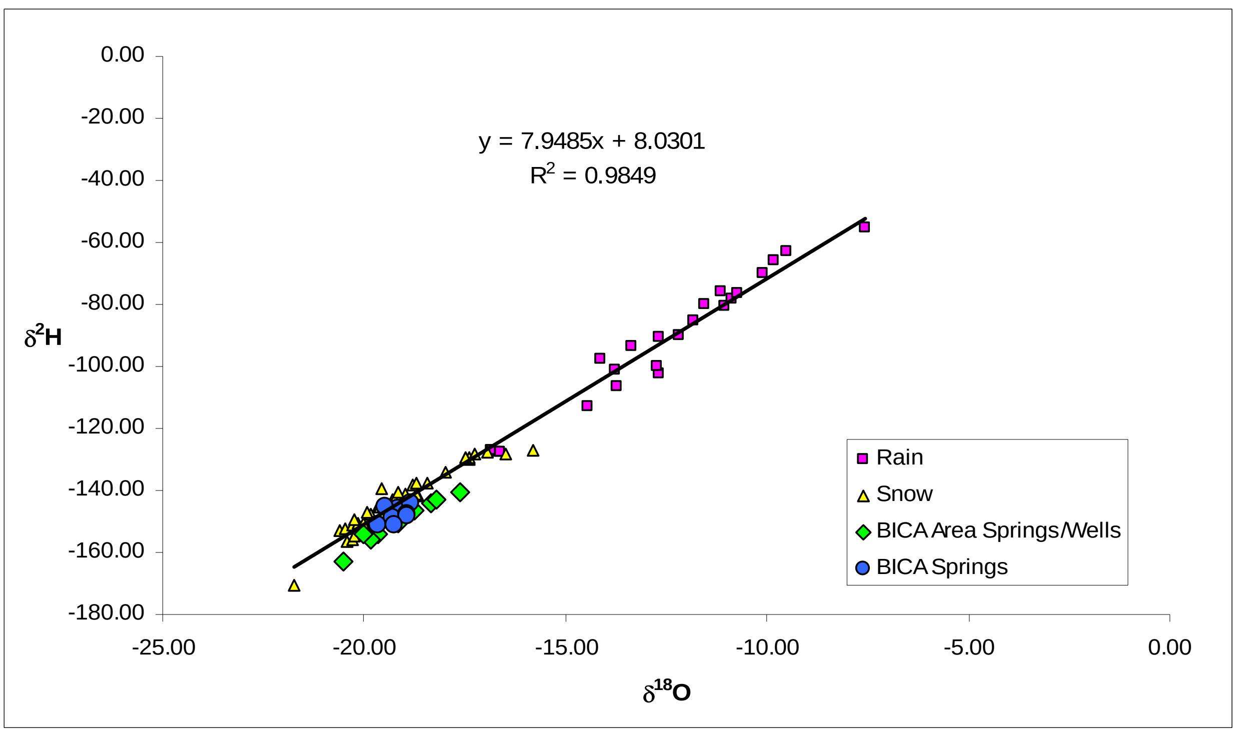


**Figure 5.** Springs from BICA and surrounding areas are plotted on the local meteoric water line developed for the Montana, Idaho, and Wyoming region (Benjamin and others 2004). Clustering low on the local meteoric water line indicates snow as the spring water source and negligible evaporative enrichment.

**Table 2.** Isotope data from groundwater samples in the Pryor Mountain and surrounding areas. Adapted from Pyror Mountain Groundwater Characterization (Montana Bureau of Mines and Geology 2004) and BICA Springs protocol development.

| Geology (MBMG#) | BICA Spring | $^{18}O$ | $^{2}H$ | $^{3}H$ | ± $^{3}H$ |
|---|---|---|---|---|---|
| Kootenai (215255) | | -17.63 | -140.32 | 9.6 | 0.9 |
| Chugwater (215233) | | -19.67 | -153.99 | 3.5 | 0.7 |
| Chugwater (215246) | Lockhart South | -19.67 | -150.98 | 5.4 | 0.8 |
| Rierdon (207508) | | -18.35 | -143.84 | 2.4 | 0.5 |
| Chugwater (215252) | | -19.14 | -150.38 | 4.7 | 0.7 |
| Ellis Group (215232) | | -19.25 | -149.59 | 10.2 | 1.0 |
| Chugwater (212183) | | -19.85 | -156.07 | 0.8 | 0.6 |
| Tensleep (215312) | | -18.91 | -144.60 | 20.4 | 1.6 |
| Tensleep (215234) | Sorenson | -18.95 | -147.83 | 10.8 | 1.0 |
| Tensleep (215240) | South Trail Creek | -18.95 | -148.14 | 13.8 | 1.2 |
| Tensleep (215235) | North Trail Creek | -19.23 | -151.13 | 2.2 | 0.7 |
| Tensleep (215280) | Pete's | -20.51 | -162.70 | 7.1 | 0.9 |
| Tensleep | Hillsboro | -19.46 | -145.48 | 11.8 | 1.1 |
| Amsden (215231) | | -18.75 | -146.66 | 15.0 | 1.3 |
| Amsden (215227) | | -18.21 | -142.85 | 18.1 | 1.4 |
| Madison (215249) | | -20.02 | -154.23 | 12.6 | 1.0 |
| Madison | Layout | -19.18 | -146.17 | 11.1 | 0.9 |
| To be determined | North Davis | -19.29 | -148.95 | 7.5 | 0.7 |
| To be determined | Headgate | -18.86 | -143.92 | 14.1 | 1.1 |
| | | | | | |

Water Age. Tritium is an unstable isotope used to date water recharge that occurred less than 100 years ago (Kendall and McDonnell 1998). It is ideal for aging water because it is integral to the water molecule, not simply dissolved in water. It is well suited for age dating over the last 100 years because of the infusion of tritium into the atmosphere through nuclear weapon testing in the 1950s and 1960s. Tritium levels peaked in 1963 (often called the bomb peak), and returned to background levels in the 1990s (Figure 6). Water recharging into aquifers between 1950 and 1995 have signature levels of $^{3}H$. An estimate of $^{3}H$ levels in the BICA region from 1953 to 1983 was created based on tritium data collected in Ottawa, Canada (the longest tritium dataset for North America) and regional precipitation data (Michel 1989) (Figure 6). From the regional estimates, $^{3}H$ from a BICA spring can be used to broadly date when the water left the atmosphere and entered the aquifer supplying the spring.

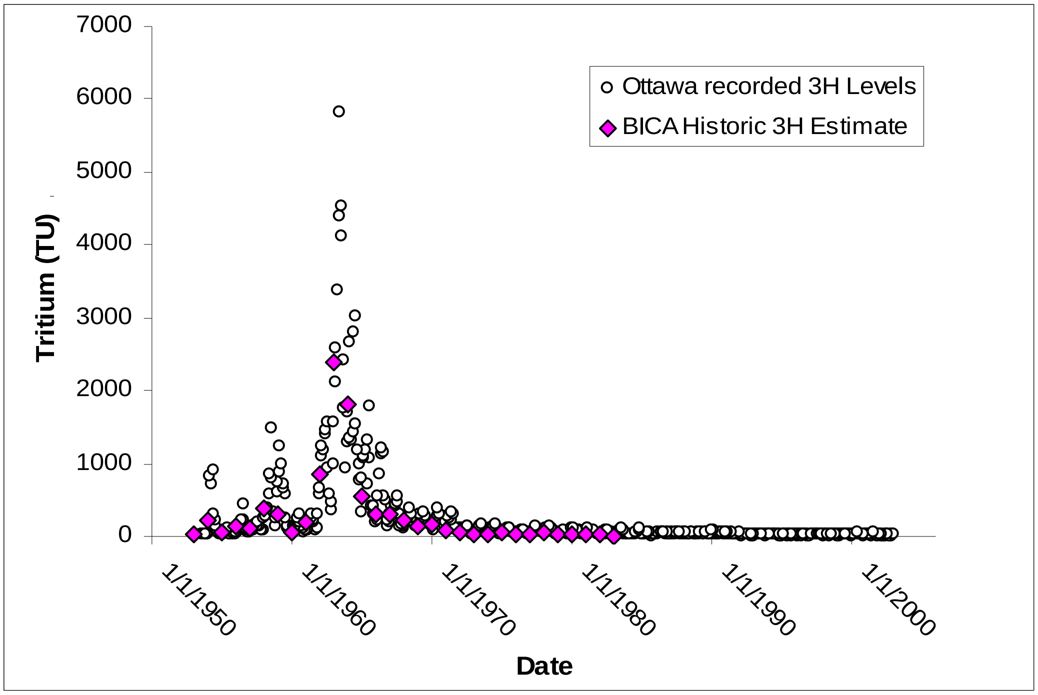


**Figure 6.** Tritium levels measured in Ottawa, Canada from 1953 to 2002 were used to estimate historic tritium levels in BICA.

## Biotic Resources

### *Geomorphology*

The Northern and Southern Colorado Plateau Networks (N/SCPN) spring inventory protocol serves as a model and starting point for describing geomorphic characteristics relevant to the BICA spring monitoring protocol (Stevens and others 2004; Stevens and Springer 2004). Geomorphic surface type, the physical structure and size of a spring ecosystem, can take many forms. Spring surface types are a product of interactions between climate, geology, and aquifer dynamics operating over several spatial and temporal scales. The microhabitats at a given spring emerge from the geomorphic surface types of the spring. Table 3 lists the surface types used the N/SPCN inventory. Many BICA spring surface types will fit one or more of these type descriptions, some will not. Monitoring staff may need to create surface type descriptions that fit a given spring. For example, Alkaline Seep does not fall into the descriptions in Table 3. A detailed site visit is required to fully understand the factors characterizing the geomorphic surface of Alkaline Seep.

**Table 3.** Geomorphic surface types. Adapted from (Stevens and others 2004).

| Surface Type | Physical Description | BICA example |
|---|---|---|
| Cave | Emergence in a cave | Not observed |
| Limnocrene | Emergence in pool(s) | Layout minor orifice |
| Rheocrene | Flowing spring, emerges into one or more stream channels | Hillsboro |
| Helocrene | Emerges from low gradient wetlands; often indistinct or multiple sources; Hillslope springs with little geologic structure | Pentagon |
| Hillslope | Emerges from a hillslope (30-60o slope); often indistinct or multiple sources; Debris slope, but little geologic structure | Pentagon |
| Gushet | Discrete source flow gushes from a wall; Debris slope, madicolous, bare rock | Not observed |
| Hanging garden | Dripping flow emerges usually horizontally along a geologic contact; May have little debris slope | Pickett’s Wall Seep |
| Fountain | Artesian fountain form; Orifice usually small | Not observed |
| Exposure springs | Cave or rock shelter fractures, ground water exposed at the land surface; Cave apertures | Layout |
| Hypocrene | A buried spring where flow does not reach the surface; Hillslope springs with little geologic structure | Headgate |

### *Habitat Structure*

The mosaic of microhabitats supported by environmental factors at a spring site account for much of the biodiversity and endemism found in spring ecosystems (Cantonati and others 2006). The variety of geomorphic surface types at a spring has bearing on the microhabitats present (Stevens and others 2004). As with geomorphic surfaces, the suite of microhabitat descriptions from the N/SCPN spring inventory protocol will serve as a starting point for describing those in BICA. However, monitoring staff may need to revise or create descriptions of microhabitats as they exist in BICA to improve the function of the protocol. Table 4 shows the microhabitats associated with geomorphic surfaces as observed by N/SCPN spring inventory staff (Springer and Stevens 2004).

**Table 4. Microhabitats potentially associated with geomorphic surfaces (Table 3). C = commonly found; L = less common; U = uncommon. Adapted from (Springer and Stevens 2004)**

| Microhabitat Type | Springs Type:<br>Microhabitat Description | Cave | Limnocrene | Rheocrene | Helocrene | Hillslope | Gushette | Hanging garden | Fountain | Exposure Springs | Hypocrene |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cave habitats | Permanently dark, twilight | C | L | L | L | L | C | U | L | C | L |
| Orifice | Springs vent or portal, cave entrance zone | U | C | C | L | L | C | C | C | C | U |
| Hyporheic | Habitat beneath the floor of the stream | C | C | C | L | L | L | U | U | L | L |
| Wet wall | Wet , seeping, or dry (precipitate) wall | C | U | L | U | L | C | C | U | U | U |
| Madicolous | Falling or fast flowing stream water | C | U | L | U | L | C | L | U | U | U |
| Spray zone | Slopes wetted by spray or subsurface flow | C | U | L | U | U | C | L | C | U | U |
| Open-water pool(s) | Mud, ooze, sand, gravel, boulder, or bedrock-floored pond | C | C | L | L | L | L | L | L | C | U |
| Spring stream(s) | Fine-grained (sand or silt), gravel, cobble-boulder, bedrock floors | C | C | C | L | L | C | L | C | U | U |
| Cienega | Low slope marsh, meadow, shrubland, woodland, forest | U | C | C | C | C | L | L | L | U | L |
| Hillslope meadow | High slope marsh, meadow, shrubland, woodland, forest | U | U | C | L | C | L | U | L | U | L |
| Riparian | Fluvial marsh, meadow, shrubland, woodland, forest | U | C | C | C | C | C | C | L | U | C |
| Adjacent barren dry rock | Cliffs, slopes, or relatively flat bedrock exposures adjacent to springs flows | C | L | C | L | L | C | C | L | C | L |
| Adjacent uplands | Meadow, shrubland, woodland, forest | U | C | C | C | C | C | C | C | C | C |

*Adjacent Cover Types*

The landscape context of a spring site describes the cover types adjacent to the spring site. The potential for trophic transfer between spring sites and uplands sites is high. The spring provides a water source for insects, reptiles, birds, and mammals that travel between upland and spring sites. Also, debris transported from uplands such as wood, organic matter, and rocks provide habitat structure. The high biota at a spring site increases the food source for species traveling between spring and upland habitats. Also, disturbed cover types influence spring sites. For example, bare ground from agriculturally altered areas may result in increase sediment in spring sites. Or, irrigation may supplement discharge. Knight and others (1987) have described cover types in BICA. Cover type nomenclature will follow this work (Table 5).

**Table 5.** Upland vegetation communities found in BICA. Adapted from (Knight and others 1987).

| Community | Description | Indicator Species | Physical Environment |
|---|---|---|---|
| **Marsh** | found along the Bighorn and Shoshone Rivers | sedges rushes, cattails, and emergent species | standing water most of the year |
| **Riparian** | found near water resources | | |
| **Floodplain meadow/mudflat** | | *Tamarix chinensis*, *Eleagnus angustifolia*, *Artemisia biennis*, *Chenopodium berlandieri*, *Halogeton glomeratus*, *Kochia scoparia* | high water table; often flooded |
| **Floodplain shrubland** | openings in floodplain woodlands | *Rhus trilobata*, *Tamarix chinensis* | |
| **Floodplain woodland** | along big rivers; mature trees form groves | *Populus deltoides*, *Salix amygdaloides* | |
| **Creek woodland** | found along tributaries to Bighorn and Shoshone Rivers | *Populus angustifolia*, *Betula occidentalis*, *Rhus trilobata* | |
| **Desert Shrubland** | found in the southern district | | |
| **Saltbrush** | | *Atriplex gardneri* | Shale, alluvium, flat topography |
| **Sagebrush** | | *Artemisia tridentata*, *Artemisia spinescens*, *Oryzopsis hymenoides*, *Stipa comata* | <1150 meters above mean sea level; low cover |
| **Greasewood** | | *Sarcobatos vermiculatus*, *Halogeton glomeratus* | Moist soils with high salt content (whitish salt crust) |
| **Mixed Desert** | Horseshoe bend and east of causeway; low cover | *Chrysothamnus nauseosus*, *Atriplex confertifolia, Agropyron spicatum* | |
| **Sagebrush Steppe** | | *Artemisia tridentata*, *Artemisia nova*, *Gutierrezia sarothrae*, *Bouteloua gracilis*, *Agropyron spicatum* | >1200m/ higher cover; well-drained soils |
| **Grassland** | low shrub cover | *Andropogon scoparius* and *Bouteloua curtipendula* | |
| **Mixed-grass prairie** | | *Andropogon scoparius*, *Bouteloua curtipendula*, *Agropyron spicatum* | Shallow soils on sandstone |
| **Basin grassland** | | *Agropyron spicatum*, *Bouteloua gracilis*, *Stipa comata* | |
| **Windswept plateau** | | cushion plants | Mesa tops; sparse cover |
| **Great Plains shrubland** | | *Prunus americana*, *Prunus virginiana*, *Symphoricarpos* spp. | Moist areas in grasslands |
| **Juniper/Mountain Mahogany** | occur on shallow soils and fractured bedrock | *Juniperus osteosperma* and *Cercocarpus ledifolius* | |
| **Juniper woodland** | | *Juniperus osteosperma* | |
| **Mountain mahogany shrubland** | | *Cercocarpus ledifolius*, *Cercocarpus montanus* | Rocky shallow soils/ lower tree line |
| **Coniferous forests** | occur in moist habitats found in high elevations and in the northern district of BICA | *Pinus flexilis*, *Pseudotsuga menziesii*, and *Abies lasiocarpa* | |
| **Limber pine** | | *Pinus flexilis* | Lower elevations; within Juniper woodlands |
| **Douglas fir** | | *Pseudotsuga menziesii*, *Spiraea betulifolia*, *Shepherdia canadensis* | |
| **Ponderosa pine** | only known occurrences are in the northern district of BICA | *Pinus ponderosa*, *Pseudotsuga menziesii*, *Bouteloua gracilis*, *Agropyron spicatus* | |
| **Spruce-fir** | Coolest of BICA habitats | *Picea engelmanii*, *Pseudotsuga menziesii*, *Vaccinium scoparium* | |
| **Agricultural Areas** | Actively managed for crops or livestock | | |
| **Developed Areas** | Areas with roads, buildings, water developments | | |

DATA ANALYSIS

## Water Resources

### *Chemical Profile*

A chemical profile of a site includes a summary table and a Piper plot. The summary table includes pH, temperature, SpEC, DO, water quantity and ion molar ratios. It provides a snapshot of the site in terms of its size and potential to support life (e.g. Table 1). Chemical analysis results are evaluated for significant error by calculating the ionic balance. The current analytical methods utilized by commercial laboratories are accurate enough to give ionic balances lower than 5%. Therefore, samples with ionic balances below 5% will be maintained for data analysis. Others will be discarded.

The calcium: magnesium molar ratio is commonly used as an indicator of flow path and source area (e.g. (Jensen and others 1997). Ca: Mg near 1.0 indicates water flow paths through dolomitic formations; 1.0-3.0 indicates a combination of limestone and dolomitic formations; >3.0 indicates primarily limestone formations.

The Piper plot (e.g. trilinear, ternary) is a visual reference for describing the chemical character of the water sample. A Piper plot of major ions can be used as a diagnostic for determining if water from two different sites arose from the same source. Water from two sites may differ due to geology, flow rate, flow patterns, or subsurface mixing. Figure 7 is a classification system for natural waters based on a Piper plot of major ions (Fetter 1980). In Piper plots, cations and anions are plotted in the left and right lower triangles, respectively. A composite is projected into the diamond region. Cation concentrations are plotted as percent equivalents/L (eq/L) of sodium + potassium, calcium, and magnesium. Separately, anion concentrations are plotted as percent eq/L carbonate + bicarbonate, sulfate, and chloride (Maidment 1993). Equivalents per liter are calculated by multiplying the concentration (g/L) by the valence of the ion and dividing by the molecular mass (g). See Appendix C for a table of valences and molecular masses for ions used in the analysis of BICA spring water.

Data from four BICA springs acquired during protocol development are used as an example (Figure 8a-c). Headgate and Layout are calcium/magnesium/bicarbonate types. North Davis is a calcium/magnesium/sulfate type. And, Hillsboro is a calcium/magnesium/bicarbonate/sulfate type.

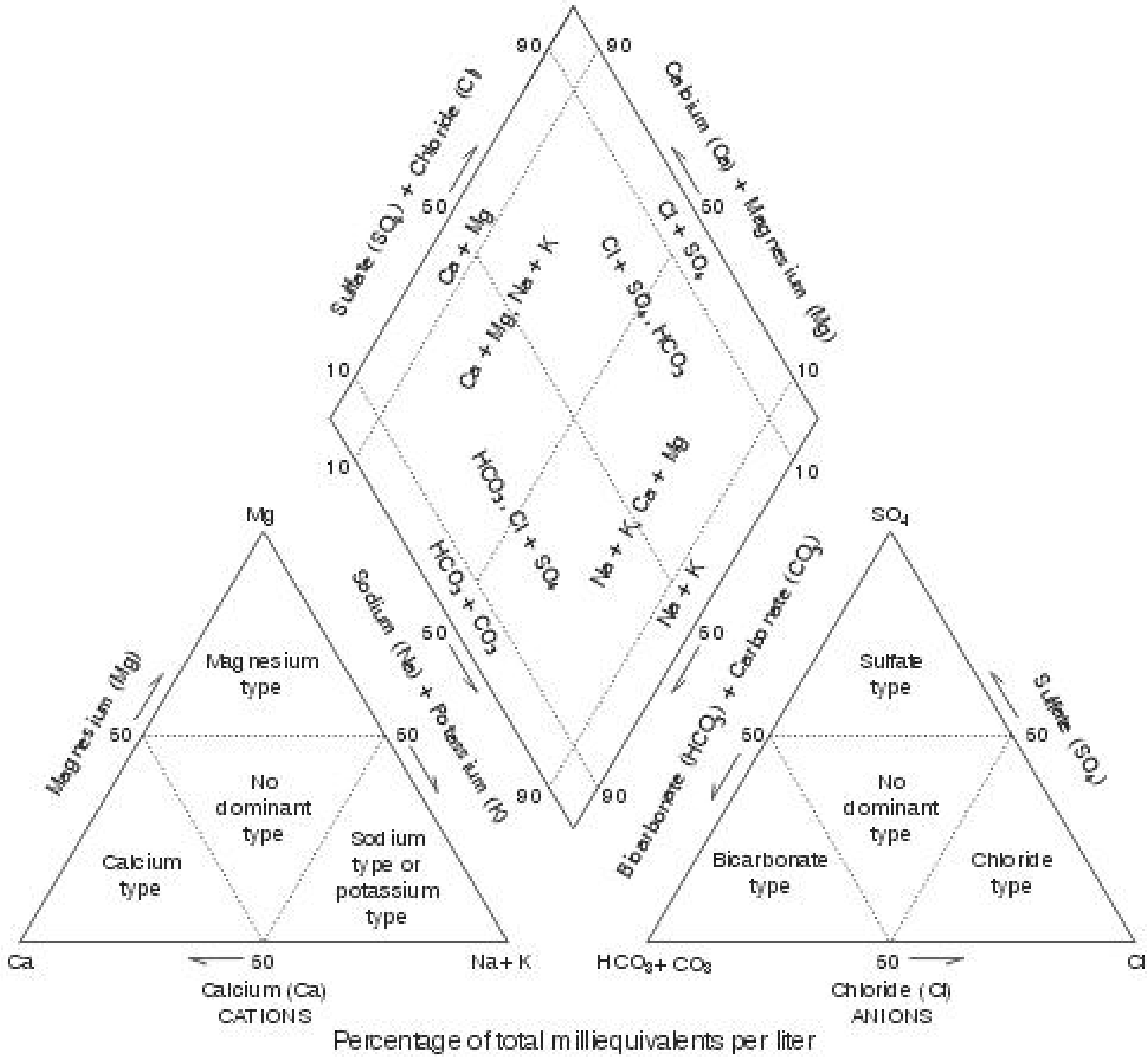


**Figure 7.** Piper plot showing chemical characteristics of groundwater. Cation and anion concentrations (meq/L) are plotted in the lower triangles and their locations are projected into the upper diamond to specify hydrochemical characteristics of the groundwater sample. Adapted from (Freeze and Cherry 1979; Maidment 1993).

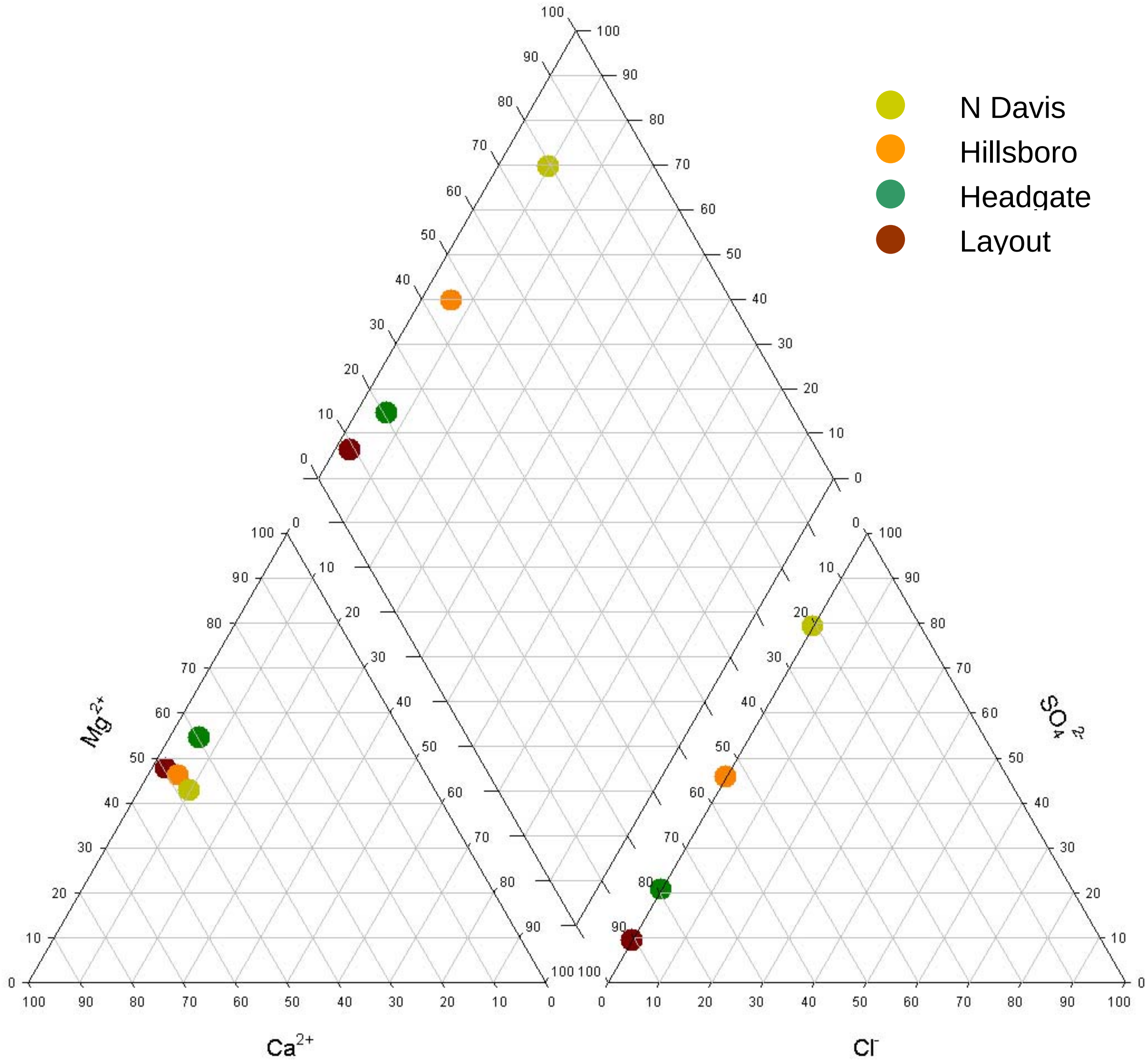


**Figure 8a.** Piper plot of spring 2004 water chemistry from Layout, Hillsboro, North Davis, and Headgate.

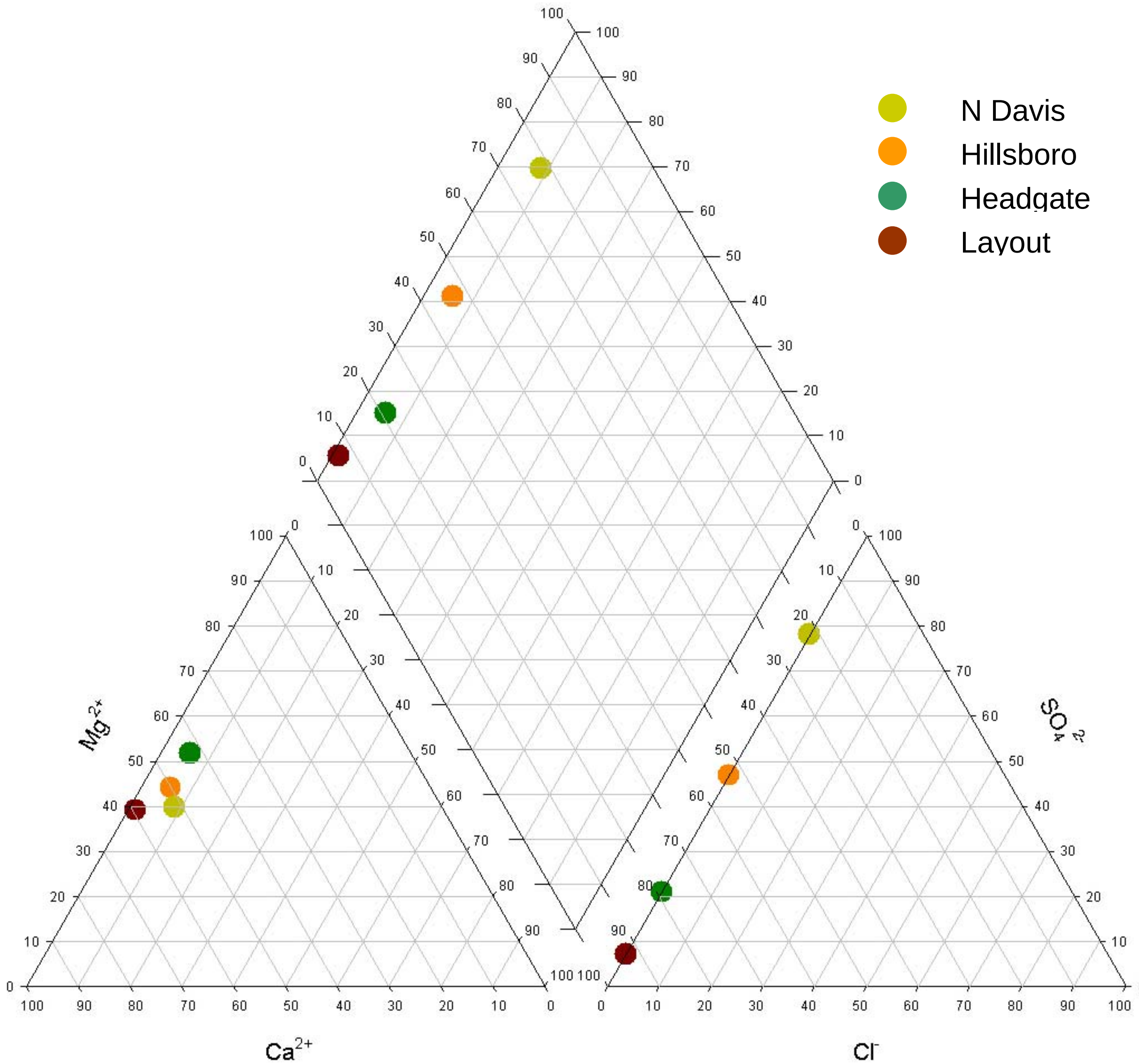


**Figure 9b.** Piper plot of fall 2004 water chemistry from Layout, Hillsboro, North Davis, and Headgate.

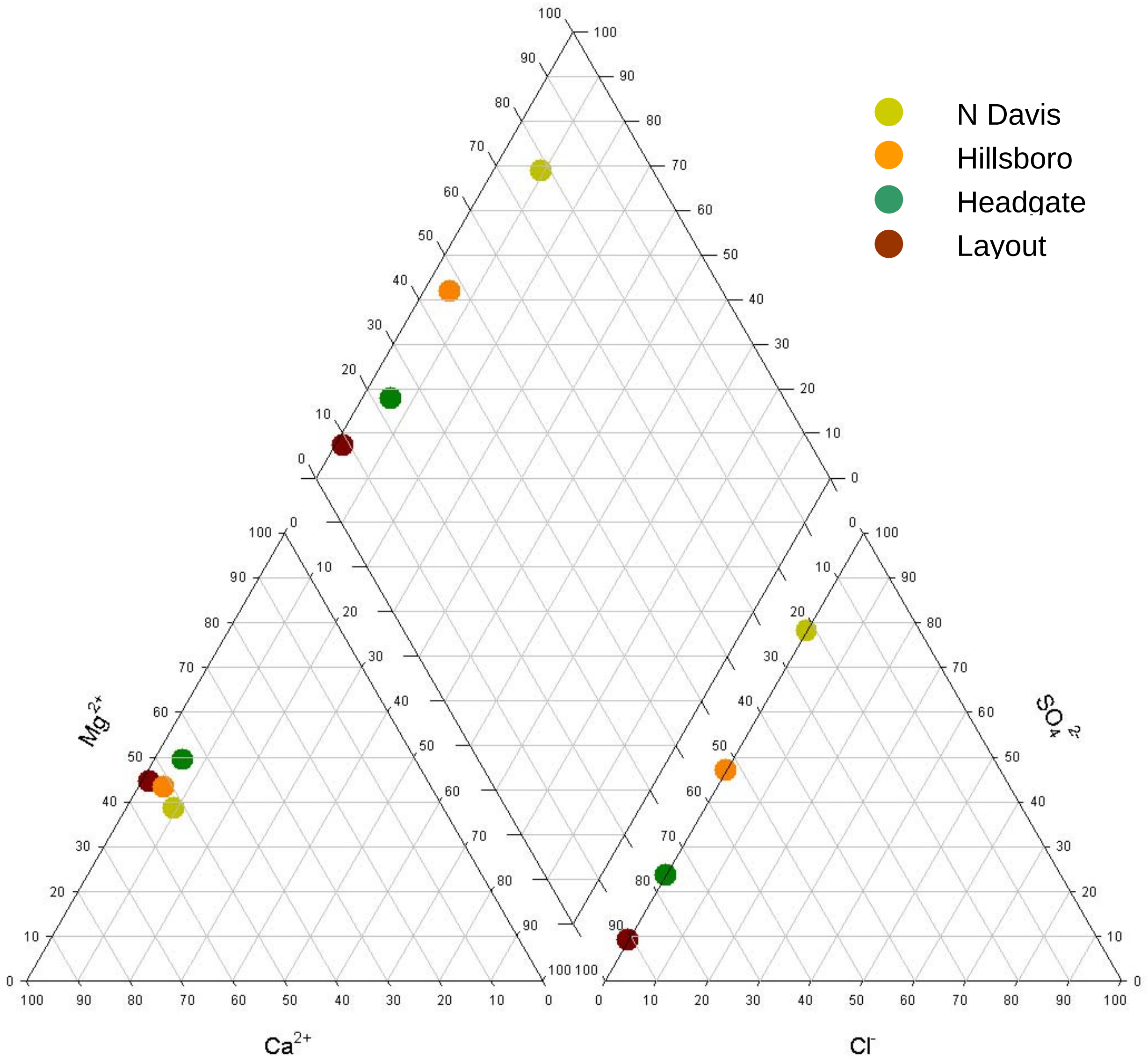


**Figure 10c.** Piper plot of winter 2005 water chemistry from Layout, Hillsboro, North Davis, and Headgate.

*Chemical Loads*

Chemical loads are often calculated for nutrients and other pollutants. They indicate the mass of a chemical species exported. Load is calculated by multiplying the concentration by the discharge and applying appropriate conversion factors to obtain the units kg/yr.

*Residence Time*

Residence time can be estimated with four independent parameters. Seasonal variability of flow and chemical levels generally correspond to short residence times. Consequently, stable flow and chemical profiles correspond to long residence times. For example, Figure 8 shows seasonal water chemistry from North Davis, Hillsboro, Headgate, and Layout springs. The spring, fall, and winter plots show no discernable variation suggesting residence times greater than two years. Discharge data is somewhat variable suggesting response to precipitation within the last 30 days Table 6.

Enriched tritium levels can be used to identify an age range. Tritium has a half life of 12.34 years. That is, half of the current amount decays in 12.34 years according to the radioactive decay equation:

$$A = A_{\circ}\, 2^{-t/T}$$

Conversely, twice the current amount of $^{3}H$ occurred 12.34 years ago in 1993. By applying this relationship to $^{3}H$ levels measured in BICA and surrounding area springs, an age range for spring water was estimated (Figure 11 and Table 7). Lastly, the $\delta^{18}O$: $\delta^{2}H$ values indicate the type of water source, and the recharge environment.

To assess residence time at a single site, consider seasonality of flow and chemical composition in combination with $\delta^{18}O$: $\delta^{2}H$ values and tritium levels. Layout will serve as an example. Chemical composition is stable across seasons suggesting an age greater than the time frame sampled – two years. Flow varies across seasons suggesting that at least part of the source water arises from recent precipitation. A tritium level of 11.1 TU (Table 2) indicates water age is less than 30 years with the potential to arise from the current year's precipitation (Table 7). Also, the $\delta^{18}O$: $\delta^{2}H$ value indicated the water source was snow. Considering the dataset covers one year, only an initial estimate can be made. The majority of water discharging from Layout spring is less than one year old and arises from the past season's recharged snow pack.

**Table 6.** Seasonal discharge (L/s) data for springs assessed during protocol development.

| | North Davis | Hillsboro | Headgate | Layout |
|---|---|---|---|---|
| **Spring** | 0.0320 | 11.40 | 0.0* | 5.819 |
| **Fall** | 0.0447 | 3.90 | 0.0* | 5.040 |
| **Winter** | 0.0600 | 11.36 | 0.0* | 1.760 |

*Indicates water table depth 100 meters downstream from orifice.

**Table 7.** Age ranges for BICA tritium levels. Spring response may represent impacts that occurred decades ago. Similarly, current impacts in the recharge area may not be detected in current spring conditions.

| Tritium Units | Age Range (years) |
|---|---|
| 0 – 5 | > 50 |
| 5 – 15 | < 30 likely current year's precipitation |
| 15 – 20 | > 30 |

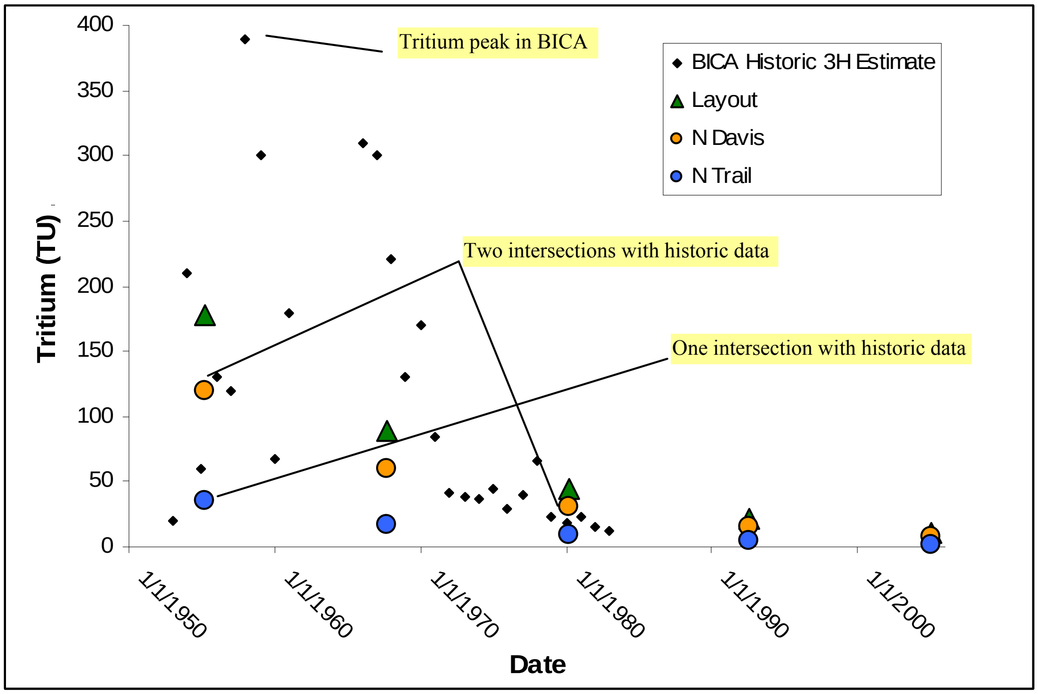


**Figure 11.** Tritium levels were projected back in time to determine potential date of recharge. Data from two BICA springs cross the historic tritium data at 1955 and 1980 indicating that samples collected at shown sites more than 30 years ago. Data from a third spring (Montana Bureau of Mines and Geology 2004) crosses the historic tritium data at 1955 only and indicates the water recharged over 50 years ago.

*Trend Analysis*

Once five years of baseline data have been collected, assessments of natural ranges of variability, identification of exceedance values pertinent to BICA springs, and trend analyses should be done.

### Biotic Resources

Data analysis of biotic resources will be determined pending completion of SOPs for biotic resource data collection.

DATA MANAGEMENT

### Existing Water Quality Data

Existing water quality data for BICA springs originated from 3 sources. Together these sources make a discontinuous dataset for water quality in BICA springs. The methods, detection limits, and units vary. Each is described in Appendix D.

### BICA Spring Database

A database created by the N/SCPN for spring ecosystem inventory has been evaluated and modified for BICA springs monitoring data (Figure 12a -f). This database was designed around the parameters germane to spring ecosystems including geomorphologic surfaces and their arrangement, microhabitat structure and types, and spring biota. It is an efficient structure for entering, maintaining, storing, and retrieving data that is tailored to the specific data common to desert spring ecosystems. *This database requires further modification of water quantity and quality fields as well as design of output features to facilitate data analysis and reporting.*

NPSTORET is another available database designed for water quality data (Figure 13a-e). All NPS water quality data must be entered into NPSTORET. It serves as a vehicle for uploading water quality data into the EPA national database STORET and allows for tracking water resources on a national scale. The output features are well designed to interface with common water quality statistical analyses and reporting. *However, more training is required to use NPSTORET. Further, NPSTORET would require additional development to accommodate the ecological data collected for the spring protocol and its output for data analysis and reporting.*

It is recommended that the N/SCPN database be further modified to accommodate BICA spring monitoring data and desirable output for data analyses and reporting on spring ecosystem condition. In addition, to meet NPS water quality monitoring needs, water quality data from the N/SCPN database should be imported to NPSTORET.

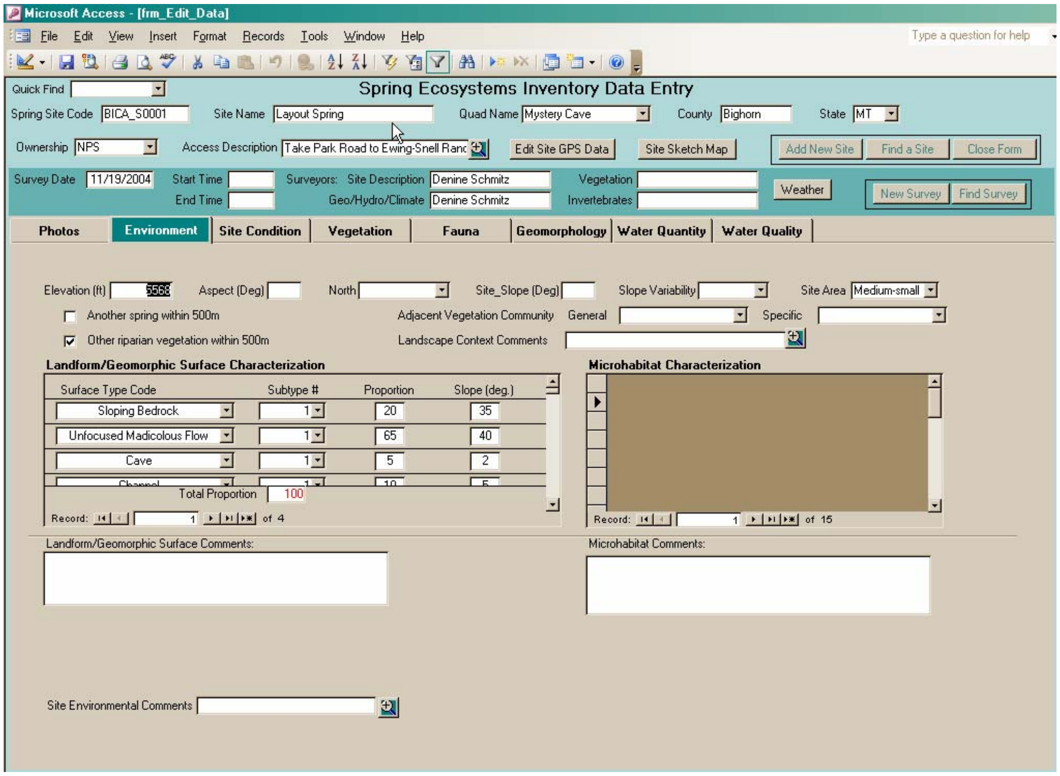


**Figure 12a.** Modified database designed for spring ecosystem data.

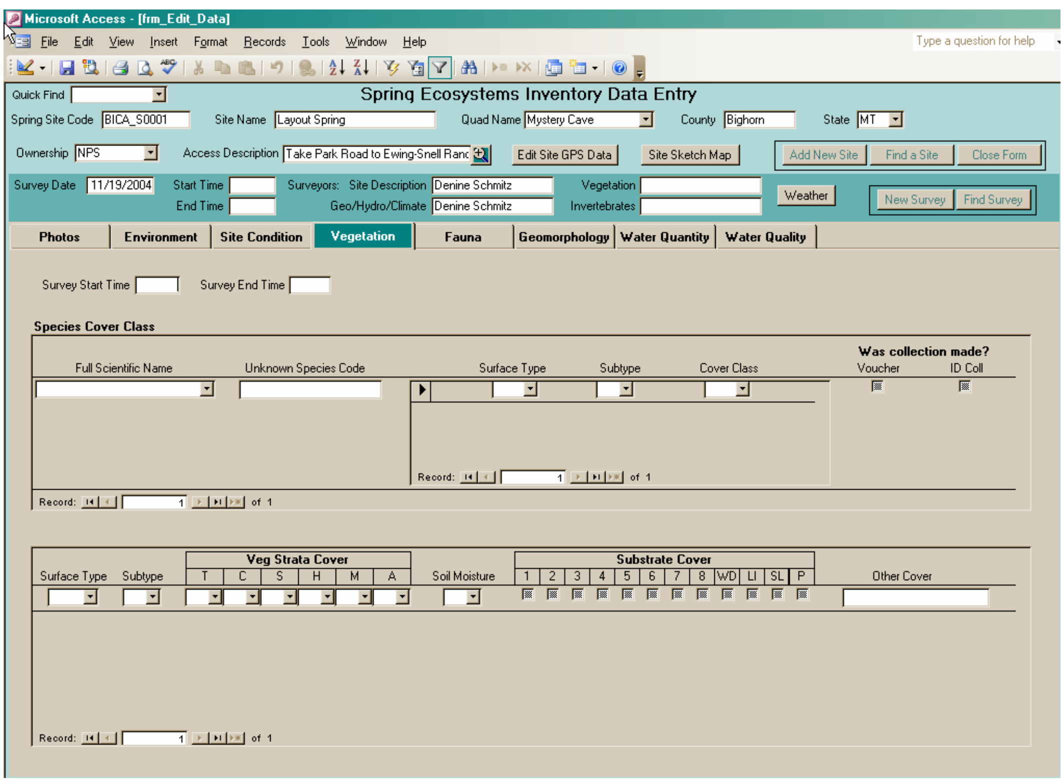


**Figure 7b.** Modified database designed for spring ecosystem data.

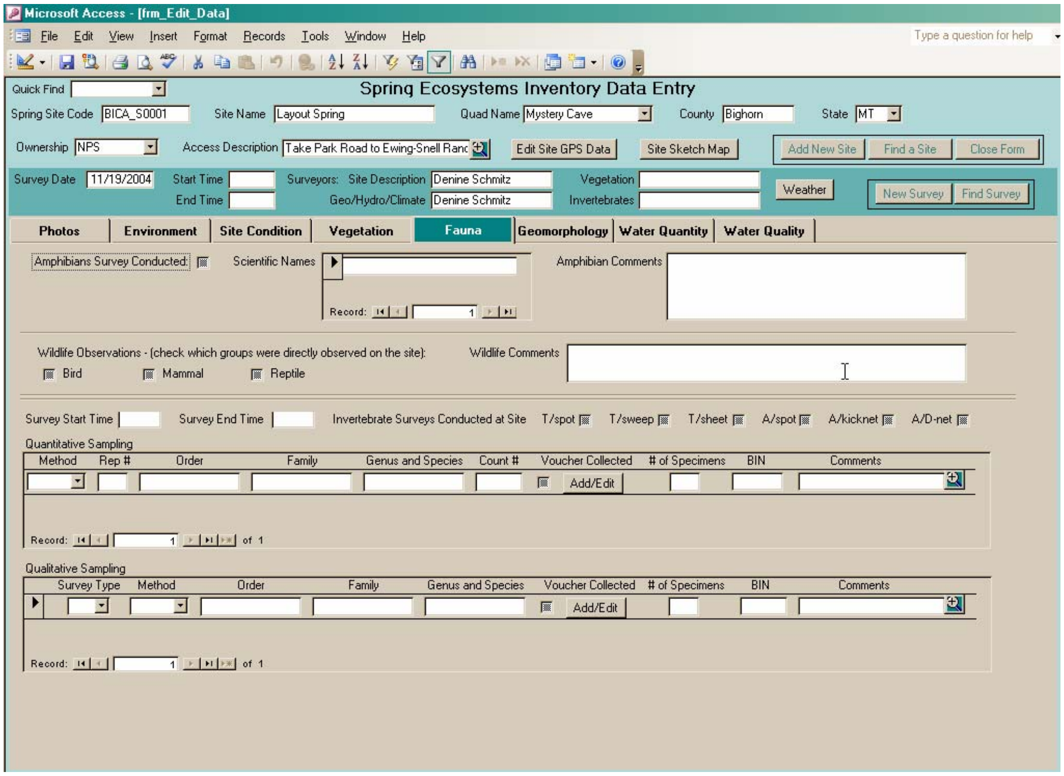


**Figure 7c.** Modified database designed for spring ecosystem data.

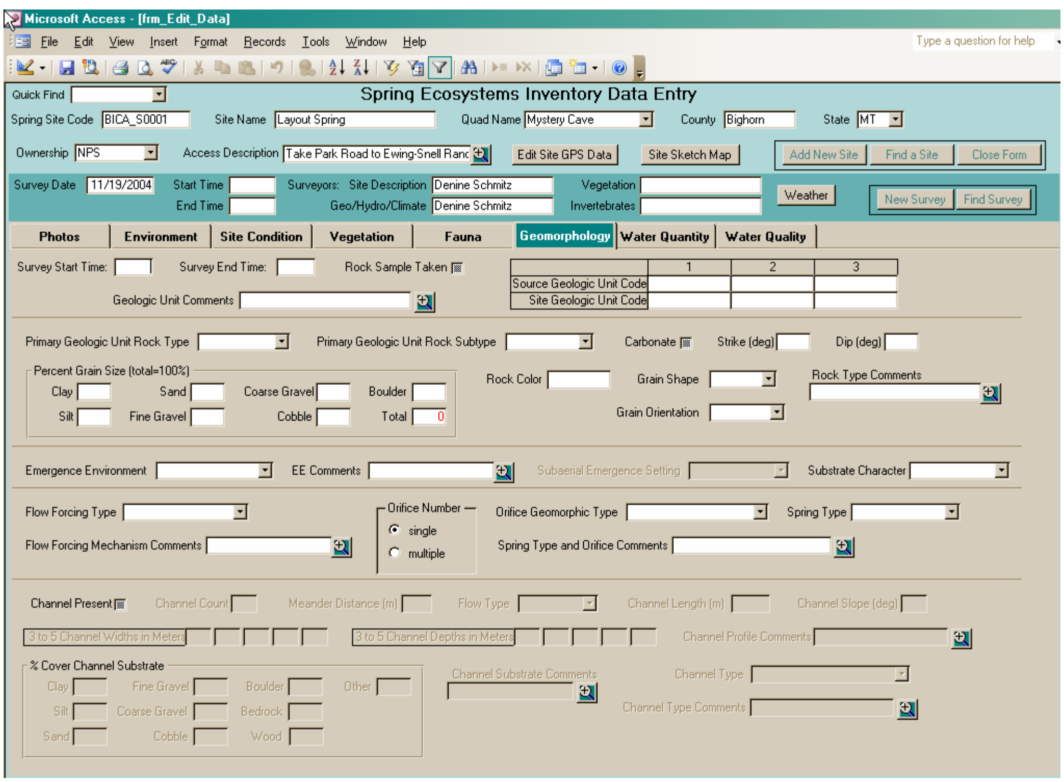


**Figure 7d.** Modified database designed for spring ecosystem data.

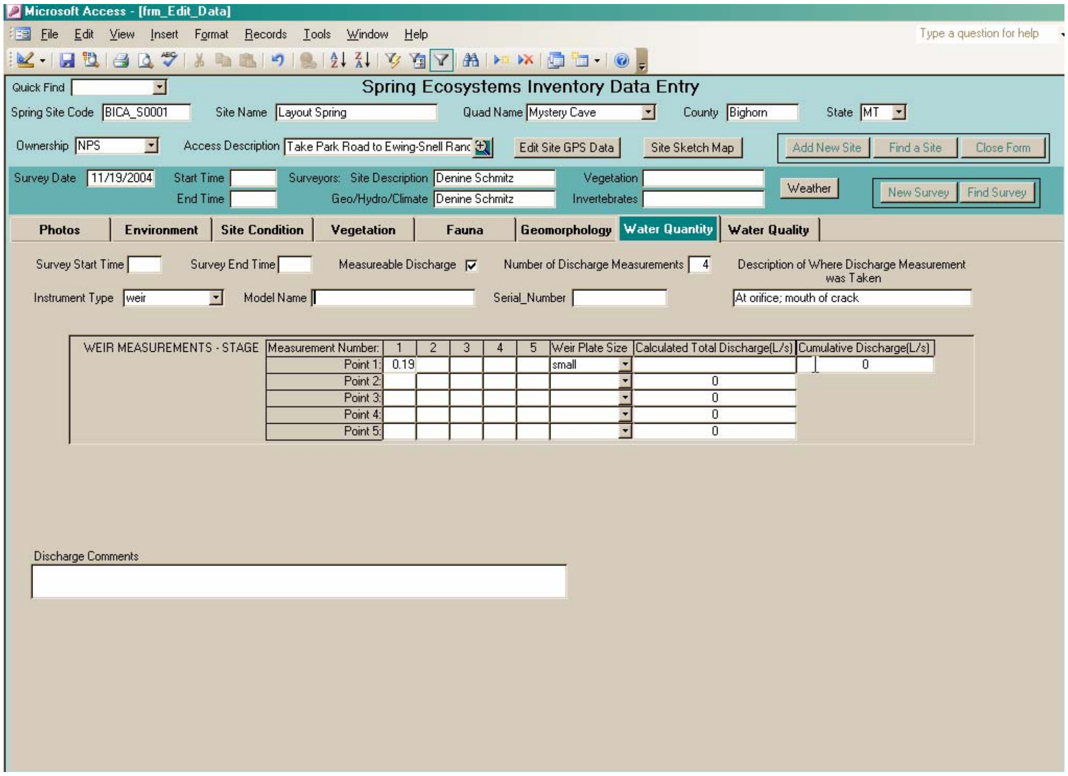


**Figure 7e.** Modified database designed for spring ecosystem data.

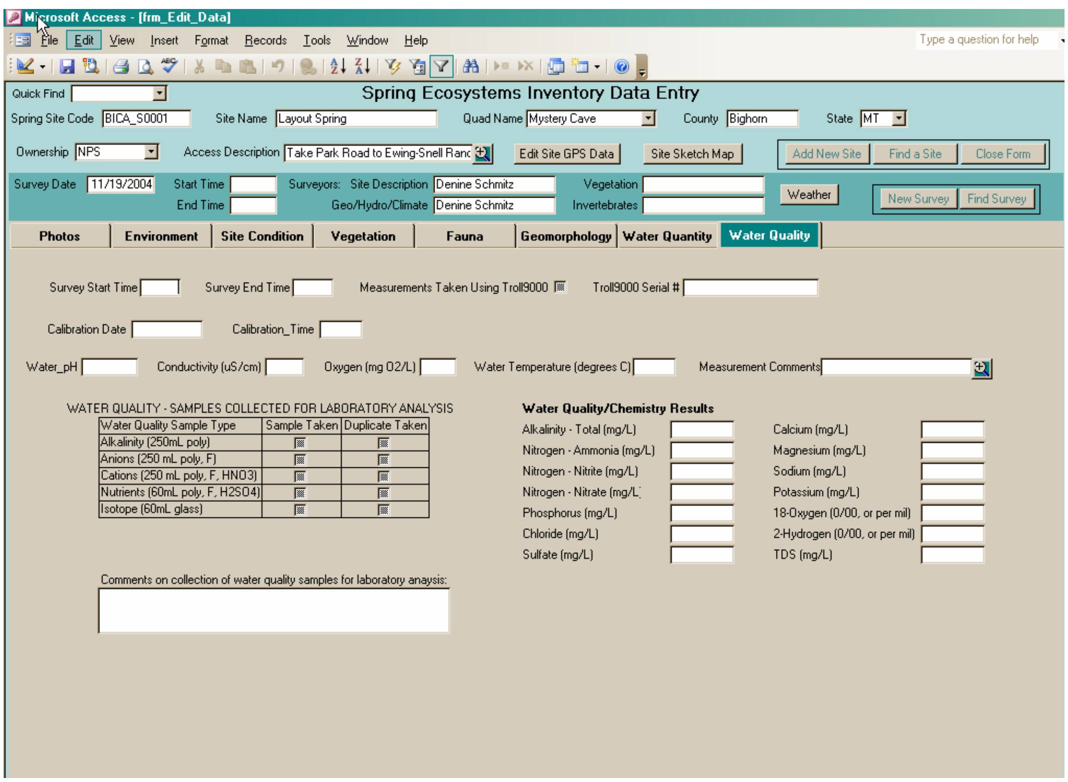


**Figure 7f.** Modified database designed for spring ecosystem data.

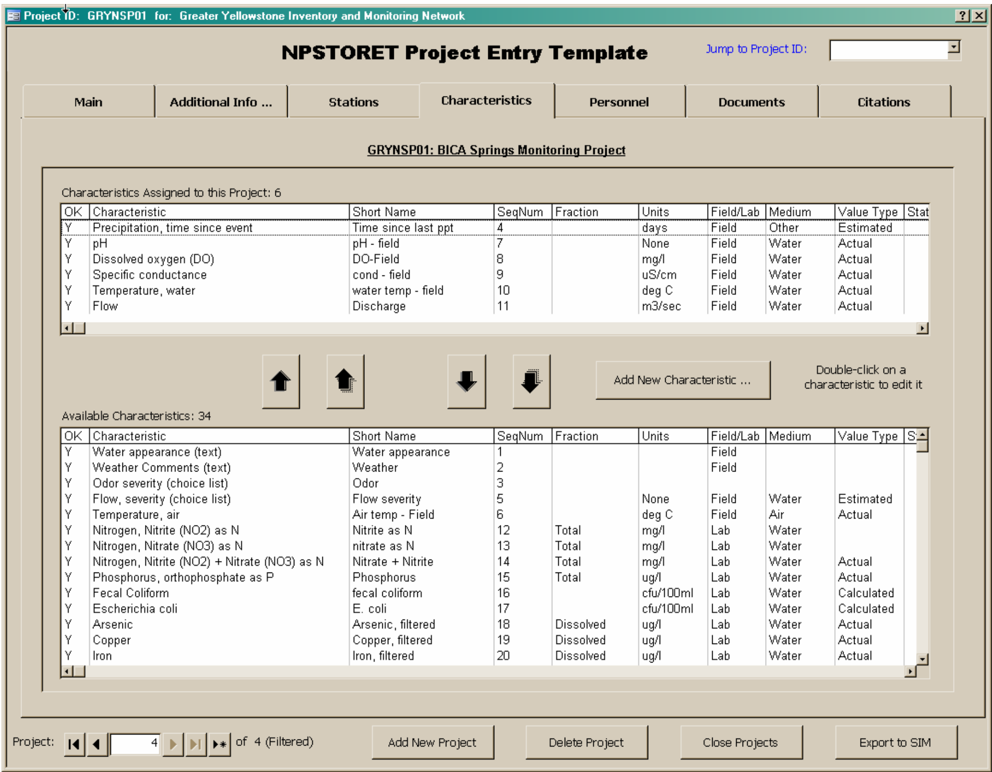


**Figure 13a.** NPSTORET database designed for water quality data.

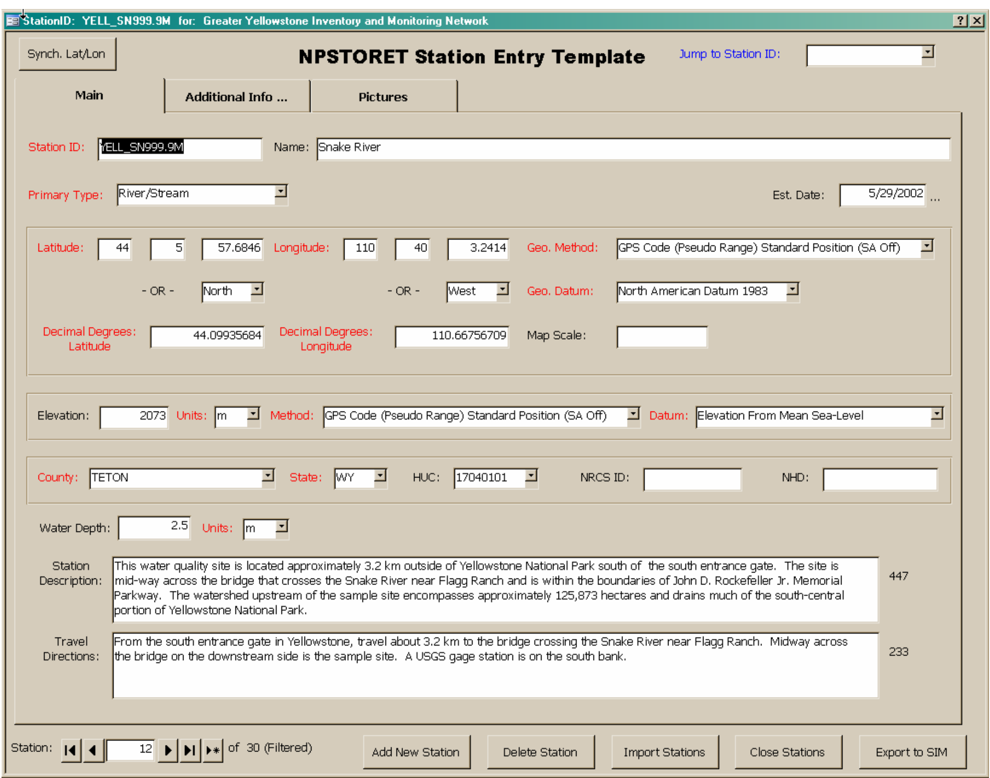


**Figure 8b.** NPSTORET database designed for water quality data.

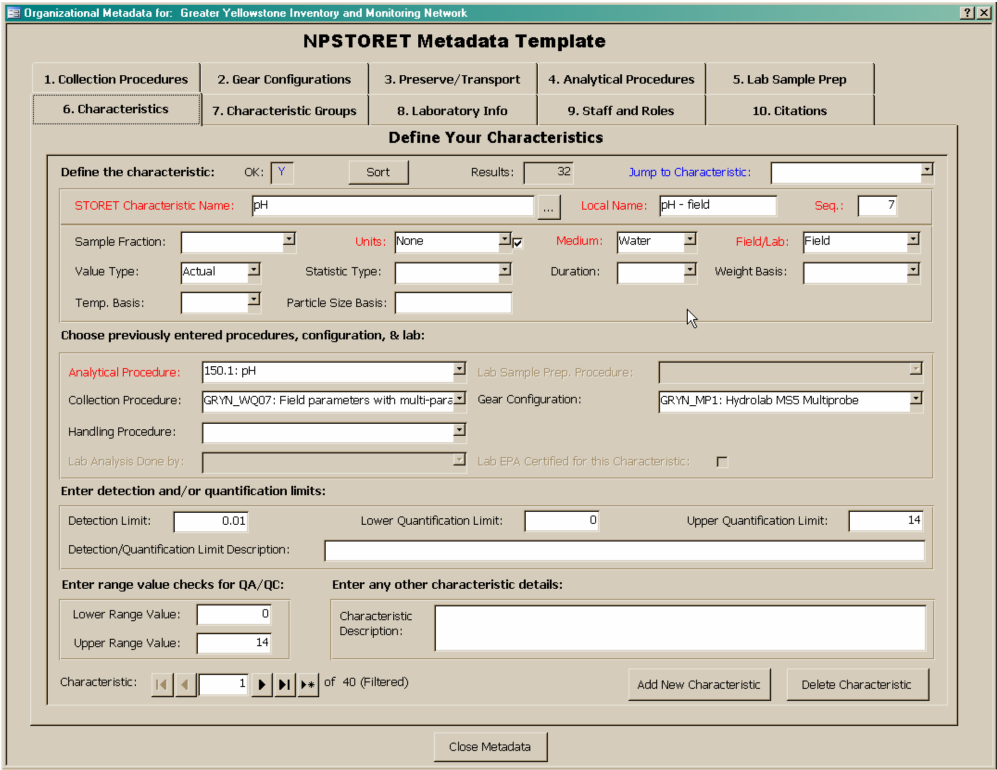


**Figure 8c.** NPSTORET database designed for water quality data.

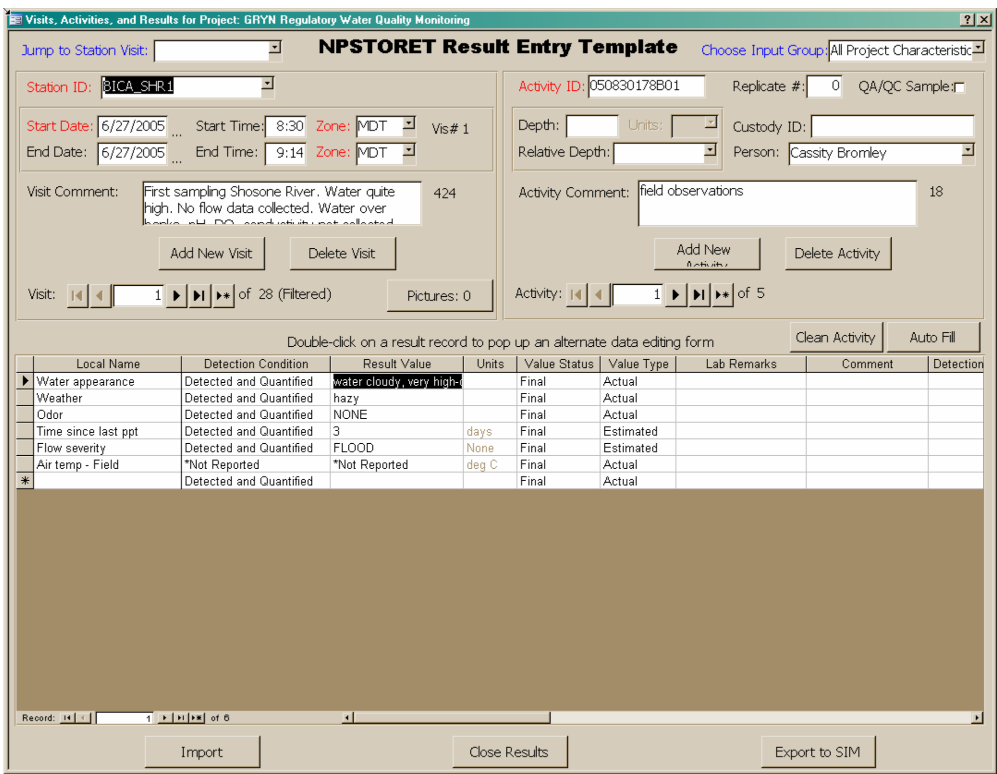


**Figure 8d.** NPSTORET database designed for water quality data.

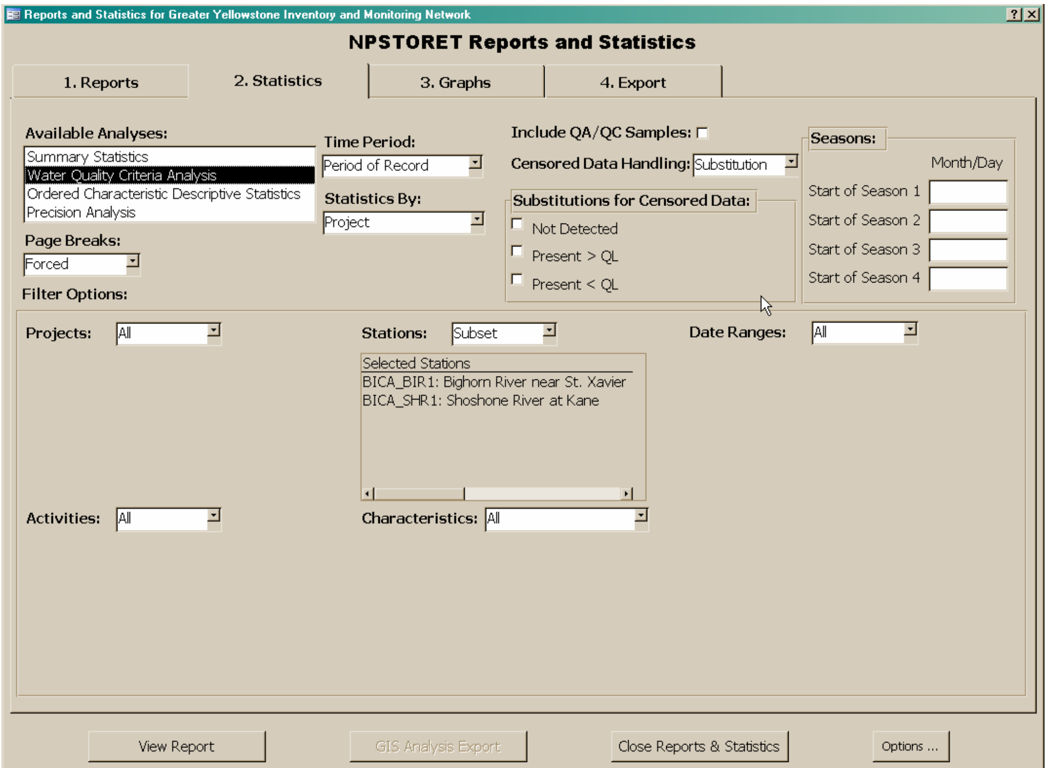

**Figure 8e.** NPSTORET database designed for water quality data.

## Existing GIS data

There is a suite of GIS files relevant to monitoring BICA springs (Appendix E). Shapefiles for spring locations and current water quality have been updated with historic records, Montana Bureau of Mines and Geology records, and field surveys. Shapefiles for boundaries, geology, infrastructure, soils, vegetation, and water exist on the BICA Spring Protocol Resources cd, however, few have metadata. It is assumed that supporting spatial data are projected in UTM, with a NAD83 datum and use a UTM Zone 12 coordinate system. Deviations exist.

Background images include color infrared aerial photos taken in 2005 and 2002, and black and white aerials from 1994. 2005 images include the Montana portion of BICA, only. They can be downloaded from the Montana Natural Resource Information System web site (http://nris.state.mt.us/nsdi/orthophotos/naip_2005.asp). 2002 and 1994 images are named and partitioned according to the USGS quadrangles. These images can be found on the BICA Aerials and Dems cd. The Wyoming images are also available on the Wyoming Geographic Information Advisory Council web site (http://wgiac2.state.wy.us/html/index.asp).

## Existing Content Resources

Several government publications, protocols, and reports provide useful reference when faced with situations requiring adaptation. They can be found on the BICA Spring Protocol Resources cd. They are listed in Appendix F.

OPERATIONAL REQUIREMENTS

## Personnel

To complete the monitoring of BICA springs a project leader and crew members are required. The responsibilities and minimum qualifications for the positions are described below.

*Project Leader*

Responsibilities

1. Implements all aspects of the protocol – management, data collection, analysis, reporting, and protocol revision.
2. Serves as a liaison among GRYN staff, BICA staff, contracted experts, other related projects (i.e., water quality, amphibians, birds), and other staff (crew members).
3. Networks with project leaders of similar efforts to build relationships and cooperation and to learn from the experiences of others (e.g. springs ecologists in the N/SCPN)
4. Hires and trains crew members.
5. Coordinates and maintains field schedules, equipment, and supplies stores.
6. Maintains a current understanding of the state of the science regarding spring water and biotic resources as they apply to BICA springs.
7. Maintains the data resource including data entry, quality assurance/quality control, and backups.
8. Reports data to water quality specialists, GRYN staff, and BICA staff as necessary. Forms include reports, tables, and maps.

Qualifications

The project leader must have or have to ability to obtain the following qualifications:

1. Basic understanding of water quality monitoring including quality control/quality assurance, stream discharge characteristics, chemistry, water quality data collection, and wetland vegetation
2. Basic understanding of geology, geomorphology, vegetation dynamics, aquatic biology, and their interactions as they apply to spring ecosystems.
3. GIS skills to build maps and perform basic spatial analyses.
4. A working knowledge of relational database, spreadsheet, and statistical software
5. Prior field experience
6. Familiarity with NPSTORET.
7. Physical ability to lift 50 pounds, walk long distances over rough terrain, and withstand inclement weather.

*Crew Members*

Responsibilities

1. Assist the project leader in data collection, analysis, and reporting.
2. Informs project leader of needs for equipment maintenance, supply ordering, and data entry.

Qualifications

1. Basic environmental science background including coursework in biology, ecology, botany, geology, hydrology, geomorphology, and chemistry or equivalent experience.
2. Prior field experience is preferred
3. Physical ability to lift 50 pounds, to walk long distances over rough terrain, and withstand inclement weather.

## FUTURE DIRECTIONS

An SOP for spring vegetation communities is recommended. It requires a botanist to identify plant species indicative of moisture levels and disturbance and characterize spring microhabitats. The monitoring objectives in this document provide a starting point for including vegetation in the set of ecological parameters.

An SOP for spring aquatic macroinvertebrates is also recommended. There are ongoing efforts to secure funding for an aquatic ecologist from the Montana Heritage Program to complete an inventory and site characterization of aquatic macroinvertebrates in BICA springs.

Status surveys that determine the presence and distribution of amphibians, invertebrates (aquatic and terrestrial), birds, mammals, non-vascular plants, and algae are needed. Detection of endemics, rare species, and species of special concern is vital to managing the natural resources of BICA. Results of such surveys will prompt monitoring efforts appropriate to the statuses of important species and their roles in community dynamics in the greater landscape.

Potentially useful research directions include:

1. Determine the response of spring vegetation communities to inundation period, seasonality of flow, and expansion/contraction during seasonal flow fluctuations.
2. Identify indicators of impacts to springs including plants, terrestrial and aquatic invertebrates, flow variability, and water chemistry.
3. Test the idea that the order of response to spring groundwater depletion (natural or anthropogenic) is discharge, water chemistry, aquatic macroinvertebrates, and plant communities.
4. Identify drivers of endemism of spring plants and macroinvertebrates.

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APPENDIX A

GEOLOGICAL SURVEY | BULLETIN 1026 PLATE 2

| System | Series | Group | Formation and member | Section lithology | Thickness, in feet | Description |
|---|---|---|---|---|---|---|
| CRETACEOUS | Upper Cretaceous | | Hell Creek formation | | | Sandstone, massive, soft; and greenish-gray sandy shale |
| | | Montana | Bearpaw shale | | 850 to 1,100 | Shale, dark-gray, concretionary; upper unit<br>Shale, dark-gray, with many bentonite beds; middle unit<br>Shale, dark-gray, concretionary; lower unit |
| | | | Parkman sandstone | | 250 | Sandstone, massive, brown, with hard nodular limonitic concretions; upper unit<br>Shale, dark-gray sandy and silty; lower unit |
| | | | Cody shale 2600±: Claggett shale member | | 350 | Shale, dark-gray with bright orange- and brown-weathering fossiliferous concretions; upper unit. Shale, dark-gray, concretionary; middle unit<br>Shale, dark-gray, with many bentonite beds; lower unit |
| | | | Shale member equivalent to Eagle sandstone | | 375 to 425 | Shale, sandy, gray, with many beds of thin hard rusty-weathering ironstones; thin bed of ledge-forming sandstone about 170 ft above base; thick bentonite zone about 280 ft above base |
| | | | Telegraph Creek member | | 750 to 850 | Shale, sandy, gray; weathers to yellowish sandy soil |
| | | Colorado | Niobrara shale member | | 400 | Shale, dark-gray, with numerous gray septarian concretions and thin bentonite beds; a thin calcareous shale zone about 80 ft above base forms light-colored band of soil |
| | | | Carlile shale member | | 275 | Shale, dark-gray, sandy in middle; a 25-ft zone of thin hard ironstones 100 ft. above base; a 10- to 20- ft zone of large concretions 180 ft above base |
| | | | Greenhorn calcareous member | | 60 to 100 | Shale, dark-gray, white-weathering, calcareous; limonitic bentonite at base |
| | | | Lower member | | 200 | Shale, dark-gray, concretionary; thick bentonite bed 60 ft above base |
| | | | Frontier formation | | 275 | Shale, dark-gray, sandy, with sandstone lenses; thick Soap Creek bentonite bed at top |
| | Lower Cretaceous | | Mowry shale | | 345 to 400 | Shale, gray, siltstone, and sandstone, partly siliceous; weathers silvery gray to bluish gray; Clay Spur bentonite bed at top |
| | | | Thermopolis shale | | 425 | Shale, dark-gray, with several beds of bentonite; zone of sandstone dikes about 250 ft below top |
| | | | Cloverly and Morrison formations, undifferentiated | | 225 to 650 | Sandstones, thin at top underlain by shale, siltstone, "rusty beds", variegated shales, and the lenticular Pryor conglomerate member of the Cloverly formation. Mostly variegated shale and greenish siltstone and sandstone below Pryor conglomerate member |
| JURASSIC | Upper Jurassic | Ellis | Swift formation | | 90 to 170 | Sandstone and siltstone, fossiliferous, glauconitic; and calcareous shale; has ledge-forming very fine grained calcareous sandstone at base |
| | Middle Jurassic | | Rierdon formation | | 175 to 390 | Shale, light-brown, fossiliferous, calcareous |
| | | | Piper formation | | 150 to 180 | Siltstone, red, and shale; upper unit. Limestone, gray; middle unit. Shale, red, above gypsum; lower unit |
| PERMIAN AND TRIASSIC | | | Chugwater formation | | 375 to 675 | Siltstone, red, and sandstone; thin limestone 40 to 100 ft below top may be Alcova limestone member; basal gypsiferous and limestone unit is equivalent to Embar formation |
| | | | UNCONFORMITY | | | |
| PENNSYLVANIAN | | | Tensleep sandstone | | 0 to 115 | Sandstone, gray to yellowish-gray; few chert and dolomite beds |
| | | | Amsden formation | | 230 to 280 | Shale, red, siltstone, and sandstone and thin beds of dolomite and limestone. Chert predominates near middle; red siltstone and shale at base |
| | | | UNCONFORMITY | | | |
| MISSISSIPPIAN | | | Madison limestone | | 705 to 740 | Brecciated zones and channels filled with limestone fragments and redbeds; 150 ft. Limestone, light-gray, and limestone, dolomitic; 315 ft. Limestone, fossiliferous, purplish-gray; 85 ft. Limestone, light-gray, with chert beds from 40 to 80 ft above base; 155 ft |
| DEVONIAN | Upper Devonian | | Three Forks shale and Jefferson limestone, undifferentiated | | 300 | Limestone, light brownish- and greenish-gray, shaly and sandy; upper 200 ft. Dolomite, very light-gray, and dolomitic limestone; lower 100 ft |
| ORDOVICIAN | Upper Ordovician | | Bighorn dolomite | | 285 to 480 | Dolomite, light-gray to white, and dolomitic limestone; upper unit. Limestone, dolomitic, massive, cliff-forming, light-brown is 180 ft thick in Bighorn Canyon lower unit |
| CAMBRIAN | Middle and Upper Cambrian | | Gallatin limestone and Gros Ventre formation, undifferentiated | | 1,000± | Limestone, with thin siltstone and shale partings; upper part. Limestones, thin-bedded, flat-pebble, and green shale; lower part. About 700 ft exposed in Bighorn Canyon but largely concealed by talus |

Geology by G. E. Prichard

GENERALIZED COLUMNAR SECTION OF ROCKS EXPOSED BETWEEN THE BIGHORN MOUNTAINS AND HARDIN, MONT.

334328 O - 55 (In pocket) No. 1

**Figure 14. BICA Geologic Strata adapted from (Richards 1955).**

APPENDIX B

Isotope Background Information can be found at
http://wwwrcamnl.wr.usgs.gov/isoig/res/funda.html

APPENDIX C

Equivalent weight (meq/L) = Concentration (mg/L) * Valence / Molecular Mass (g)

**Table 8.** Valences and molecular masses of ions used in spring water analyses.

| Ion | Valence | Molecular Mass |
|---|---|---|
| **Ca** | 2 | 40.1 |
| **Mg** | 2 | 24.3 |
| **Na** | 1 | 23.0 |
| **K** | 1 | 39.1 |
| **$HCO_3$** | 1 | 61.0 |
| **$CO_3$** | 2 | 60.0 |
| **$SO_4$** | 2 | 96.1 |
| **Cl** | 1 | 35.5 |
| **$NO_3$** | 1 | 62.0 |
| **$NH_4$** | 1 | 18.0 |
| **$PO_4$** | 3 | 95.0 |
| **F** | 1 | 19.0 |

Digital copy can be found on the BICA Springs Protocol Resources cd in ..\Data\BICA Spring WQ Data.xls on the Equivalent weights sheet.

APPENDIX D

## Existing Water Quality Data

*BICA Aridland Seeps and Springs Protocol Development 2004-2006*

During the protocol development between 2004 and 2006, four springs were selected to determine the suitability of various sampling and analytical techniques for water quality data. Layout, Hillsboro Main, and North Davis Creek springs and Headgate seep were sampled from November 2004 to March 2006. Data for these springs can be found on the BICA Spring Protocol Resources cd (Table 9).

**Table 9.** Files related to data collected during protocol development.

| Data Type | File Path |
|---|---|
| Water Chemistry | ..\Data\BICA Spring WQ Data.xls<br>..\Data\BICA Springs Data by Site.xls |
| Isotopes | ..\Data\BICA D and O Isotopes.xls<br>..\Data\BICA Tritium vs Local Estimate.xls |
| GIS | ..\BICA_Springs_GIS\Water\BICAareaSpringWQ76-06.shp<br>..\BICA_Springs_GIS\Water\BICAnpsSprings.shp |
| Photos | ..\Pix*.jpg |

*Pryor Mountains Groundwater Characterization 2004*

Montana Bureau of Mines and Geology conducted a groundwater survey of springs and wells within the foot print of the Pryor Mountains. For this study the Pryor Mountains are bounded by the Bighorn River to the east; the Shoshone River to the south; Sage Creek to the west; and the town of Pryor to the north. Four of these sites were BICA springs. One site was Pete’s spring less than 100 meters beyond the BICA boundary. Data for these springs can be found on the BICA Spring Protocol Resources cd (Table 10).

**Table 10.** Files related to data collected during the Pryor Mountains Groundwater Characterization (Montana Bureau of Mines and Geology 2004).

| Data Type | File Path |
|---|---|
| Water Chemistry | ..\Data\Pryor Mtns WQ data.xls<br>..\Data\BICA Spring WQ Data.xls |
| Isotopes | ..\Data\BICA D and O Isotopes.xls<br>..\Data\BICA Tritium vs Local Estimate.xls |
| GIS | ..\BICA_Springs_GIS\Water\BICA_PryorMtnGW.shp<br>..\BICA_Springs_GIS\Water\BICAareaSpringWQ76-06.shp<br>..\BICA_Springs_GIS\Water\BICAnpsSprings.shp |

*Baseline Water Quality Data for Bighorn Canyon NRA 1967 – 1978*

Baseline water quality data for many water resources within BICA were compiled from STORET records by NPS Water Resources Division (National Park Service 1998). Eight of these records pertain to BICA springs. Eight additional records pertain to springs within one kilometer of the BICA boundary. Data for these springs can be found on the BICA Spring Protocol Resources cd (Table 11).

**Table 11.** Files related to historic baseline water quality data (National Park Service 1998).

| Data Type | File Path |
|---|---|
| Water Chemistry | ..\Data\BICA Spring WQ Data.xls |
| GIS | ..\BICA_Springs_GIS\Water\Hist_Baseline_WQ_1998.shp<br>..\BICA_Springs_GIS\Water\BICAareaSpringWQ76-06.shp<br>..\BICA_Springs_GIS\Water\BICAnpsSprings.shp |
| pdf | ..\Data\BICAWQinvAnal1998.pdf |

APPENDIX E

## GIS resources relevant to BICA.

**Table 12.** GIS resources relevant to BICA springs monitoring protocol.

| Data Type | File Path |
|---|---|
| **Springs** | ..\GIS\Water\BICAareaSprings.shp<br>..\GIS\Water\BICAnpsSprings.shp<br>..\GIS\Water\BICAareaSpringWQ76-06.shp<br>..\GIS\Water\BICA_PryorMtnGW.shp<br>..\GIS\Water\Hist_Baseline_WQ_1998.shp<br>..\GIS\Water\PryorMtnGW.shp<br>..\GIS\Water\SpringAccess.shp<br>..\GIS\Water\SpringPhoto.shp |
| **Vegetation communities** | ..\GIS\Vegetation\rare_plants.shp<br>..\GIS\Vegetation\Spring_Up_Veg.shp<br>..\GIS\Vegetation\veg.shp<br>..\GIS\Vegetation\wetlands\nwi_wy.shp |
| **Geology** | ..\GIS\Geology\geology_clip.shp |
| **Surface water** | ..\GIS\Water\creeks_clip.shp<br>..\GIS\Water\SorensonPond.shp<br>..\GIS\Water\full_lake.shp |
| **Roads** | ..\GIS\Infrastructure\all_roads.shp |
| **Boundaries** | ..\GIS\Boundaries\BICAboundary.shp<br>..\GIS\Boundaries\mt_wy_county.shp<br>..\GIS\Boundaries\MTCounty.shp<br>..\GIS\Boundaries\WYCounty.shp |
| **Quad index** | ..\GIS\Boundaries\bica_quad_index.shp |
| **2005 Aerials** | Available from MT NRIS<br>5039.sid<br>5139.sid<br>5038.sid<br>5138.sid<br>5037.sid<br>5137.sid<br>5237.sid |
| **2002 CIR aerial photos** | Available from MT NRIS<br>grapevine dome.sid<br>yellowtail dam.sid<br>east pryor.sid<br>dead Indian hill.sid<br>little finger ridge.sid<br>mystery cave.sid<br>hillsboro.sid<br>Available from WY GIAC<br>sykes spring.sid<br>natural trap cave.sid<br>kane.sid<br>spence.sid |
| **1994 BW aerial photos** | Available from GRYN Data Manager |
| **USGS 7.5 minute quads** | Available from GRYN Data Manager |
| **10 meter DEM** | Available from http://data.geocomm.com |

APPENDIX F

## Content Resources relevant to BICA

**Table 13.** Documents relevant to monitoring BICA springs ecosystems that can be found on the BICA Springs Protocol Resources cd.

| Data Type | File Path |
|---|---|
| **BICA Springs Protocol** | ..\Springs Monitoring Protocol\Conceptual Models<br>..\Springs Monitoring Protocol\Forms<br>..\Springs Monitoring Protocol\Narrative<br>..\Springs Monitoring Protocol\SOPs |
| **Other Spring I & M Protocols** | ..\Other Protocols\Colorado Plateau\Stevens, Springer, Sada SCPN springs protocol 2004.pdf<br>..\Other Protocols\AZ Strip\GCWC AZ strip springs inventory assessment 2001.pdf<br>..\Other Protocols\AZ Strip\GCWC Bio inv&ass 10 S rim springs.doc<br>..\Other Protocols\Mojave\Mojave Level 1 Protocol.pdf<br>..\Other Protocols\Mojave\Sada et al nps mojave im spring survey protocols 2003.pdf |
| **Water Quality** | ..\Springs SOP info\WQ\Fishman WQ chem Methods.pdf<br>..\Springs SOP info\WQ\Hem Study & Interpretation of Chem Char.pdf<br>..\Springs SOP info\WQ\Alkalinity*.*<br>..\Springs SOP info\WQ\Discharge*.*<br>..\Springs SOP info\WQ\Dissolved Oxygen*.*<br>..\Springs SOP info\WQ\EC*.*<br>..\Springs SOP info\WQ\Equipment*.*<br>..\Springs SOP info\WQ\pH*.*<br>..\Springs SOP info\WQ\Sample Collection*.*<br>..\Springs SOP info\WQ\Temperature*.* |
| **Macroinvertebrate** | ..\References\Erman Biodiversity Cold Springs Sierras 1992.pdf<br>..\References\Erman Phys Chem Profiles of Sierra Springs 1992.pdf |
| **Vegetation** | ..\References\Heidel & Fertig BICA Plant list_Jan02.pdf<br>..\References\Heidel & Fertig Rare plants of BICA.pdf |
| **Bibliography** | ..\References\BICA Springs Protocol.enl |
| **Springs Ecosystems** | ..\References\Stevens_Springer_Conceptual model springs ecosystem ecology.pdf<br>..\References\Arid wetland BIBLIOGR annotated.doc<br>..\References\Patten et al gb-spring-short.doc |
| **Disturbance** | ..\References\Perla and Stevens Seaman Spring MS 030220.doc |
| **Databases** | NPSTORET (Available from GRYN Data Manager)<br>N/SCPN Seeps_Springs (Available from GRYN Data Manager)<br>BICA_Springs database (partially revised N/SCPN database)<br>..\Data\BICA_Springs.mdb<br>..\Data\BICA_Springs_be.mdb |
| **Photos** | ..\pix*.jpg |