



Protocol Implementation Plan for Monitoring Discharge in Greater Yellowstone Network Parks

Narrative Version 1.0

Natural Resource Report NPS/GRYN/NRR—2017/1534



ON THE COVER

Discharge monitoring in Lower Layout Creek, Bighorn Canyon National Recreation Area, June 2015.
Photography by NPS.

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October 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Ray, A., K. Legg, M. Levandowski, and R. Daley. 2017. Protocol implementation plan for monitoring discharge in Greater Yellowstone Network parks: Narrative version 1.0. Natural Resource Report NPS/GRYN/NRR—2017/1534. National Park Service, Fort Collins, Colorado.

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Executive Summary

The Greater Yellowstone Network (GRYN) is one of 32 Inventory and Monitoring Networks covering 270 national park units within the National Park System. These networks serve an important role in providing park resource managers with important scientific data on the status and condition of vital park resources. This role was established in the Natural Resource Challenge which directed parks to place a great emphasis on natural resource stewardship in meeting the National Park Service mission to “preserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations.”

GRYN includes four national park units: Bighorn Canyon National Recreation Area, Grand Teton National Park, John D. Rockefeller, Jr. Memorial Parkway, and Yellowstone National Park. Combined, these parks span over one million hectares and represent a topographically complex and climatologically heterogeneous region. Park staff and subject matter experts recognized the diversity of ecosystems and, in particular, the ecological and societal importance of water to this region when identifying important park resources for long-term monitoring. Stream flow (or more generally, discharge) was identified as one of the selected vital signs in GRYN’s long-term Vital Signs Monitoring Plan (Jean et al. 2005).

Water resources in GRYN parks are diverse and include alpine lakes, rivers, perennial and ephemeral streams, springs, geysers, wetlands, and natural lakes and reservoirs. In addition, GRYN parks include one designated Wild and Scenic River (the Snake River) and one World Heritage Site (Yellowstone National Park). Yellowstone National Park was recognized as a World Heritage Site, in part, because of its unique aquatic resources; over 200 geysers and upwards of 10,000 geothermal resources are present inside park boundaries.

This protocol implementation plan and the accompanying standard operating procedures (SOPs; Ray et al. 2017), provide the details of how GRYN will use established protocols from the Sierra Nevada Network (Skancke et al. 2017a) and Southwest Alaska Network (Shearer et al. 2015a) as guidance for the implementation of a discharge monitoring protocol for select rivers, streams, and spring outlets throughout GRYN parks. GRYN acknowledges the value of long-term U.S. Geological Survey gaging station flow data and plans to leverage these datasets in a way that enables us to discuss change and quantify trends in river and stream flow for network parks and the public.

We ask readers to recognize that this protocol implementation plan may be revised as new and emerging analytical and monitoring techniques come available. We will be mindful not to modify SOPs unless there is strong justification in doing so. We also recognize that as more data, monitoring tools, and analytical techniques become available, new questions will arise leading to more in-depth analyses and additional considerations.

Acknowledgments

We would like to acknowledge and thank staff from Bighorn Canyon National Recreation Area, Grand Teton National Park, Yellowstone National Park and Greater Yellowstone Inventory & Monitoring Network for their support, feedback, and reviews of prior versions of this protocol implementation plan. Special thanks to Sue Consolo-Murphy, Virginia DuBow, Jennifer Carpenter, and Ann Rodman, who have been extremely helpful and supportive of water monitoring in Greater Yellowstone Network parks. We would also like to acknowledge Robert Al-Chokhachy, Adam Sepulveda, Mike Tercek, and David Thoma for efforts to formalize a regional framework for river and stream flow monitoring throughout the Greater Yellowstone Area. Michael Bozek, Karri Cary, and Staci Stumpf provided helpful comments on earlier versions of the protocol implementation plan. Rob Bennetts provided assistance with conceptual models and Kami Crockatt produced maps contained in the document.

This effort was funded by the National Park Service Greater Yellowstone Inventory & Monitoring Network and the U.S. Geological Survey through the National Park Monitoring Project funding for Integrated Analysis, Modeling, and Synthesis of NPS Inventory and Monitoring Data to inform Condition-based Management. Funding was provided through the following project: Developing a mechanistic understanding between recent climate patterns and Aquatic Vital Signs in the Greater Yellowstone Network (Principal Investigators: Adam Sepulveda and David Thoma).

1 Introduction

Discharge patterns of rivers and streams are dynamic in time and space and reflect characteristics of drainage basins as well as recent and long-term meteorological conditions. Discharge patterns of rivers and streams reflect the annual magnitude and timing of runoff and base flow conditions as well as the more immediate response of rivers to individual precipitation and runoff events. Study of discharge patterns is therefore useful in uncovering spatial and temporal patterns of river and stream flow change across large spatial scales (Rood et al. 2008). Hydrographs are simple but important tools for the study of discharge patterns that reflect stream hydrologic responses over time (typically a calendar or water year but also a season) for a specific river location (Figure 1).

Use of hydrographs in river studies reveals river flows are tightly linked to downstream municipal and agricultural supply, water quality, local and regional meteorological conditions, human recreational use, and overall ecological integrity (see Rood et al. 2008; Al-Chokhachy et al. 2017). Because of these relationships, a clearer understanding of long-term and recent hydrologic change is necessary to direct short and long-term water resource planning to protect important ecosystem services (Brekke et al. 2009). Monitoring features of hydrographs through time can help resource managers better understand both the direction and magnitude of recent and long-term changes to the timing and pattern of river, stream, or spring flows for an individual water body (Figure 2). Moreover, when aggregated, river and stream flow summaries can offer valuable insight on subbasin, regional (see Jean et al. 2005; Rood et al. 2008; Luce and Holden 2009; Leppi et al. 2012; Al-Chokhachy et al. 2017), national (EPA 2016), and global hydrologic trends (Vörösmarty et al. 2010).

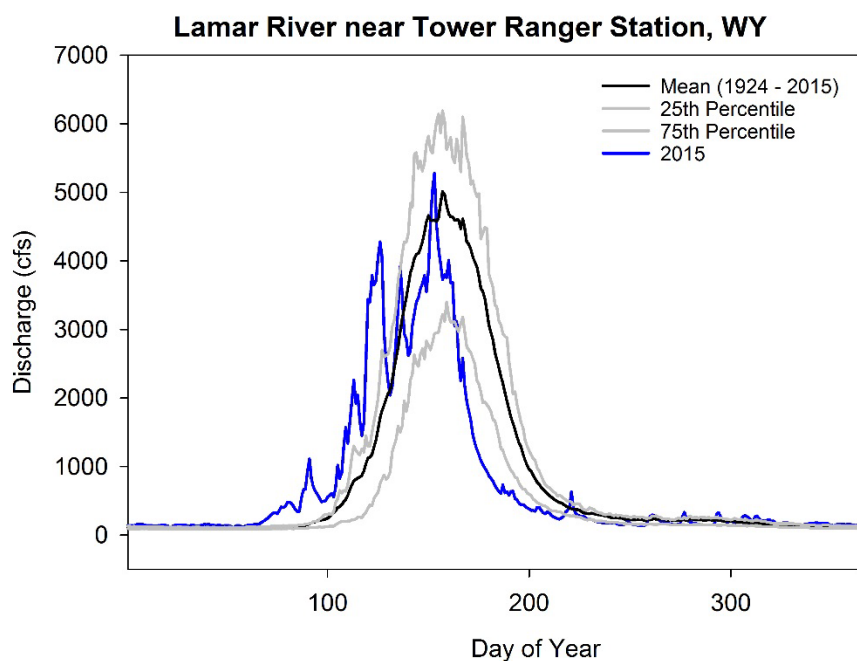


Figure 1. Example of a hydrograph. This flow summary shows annual (2015) and long-term (mean 1923-2015) stream flow patterns for the Lamar River near Tower Ranger Station, Wyoming.

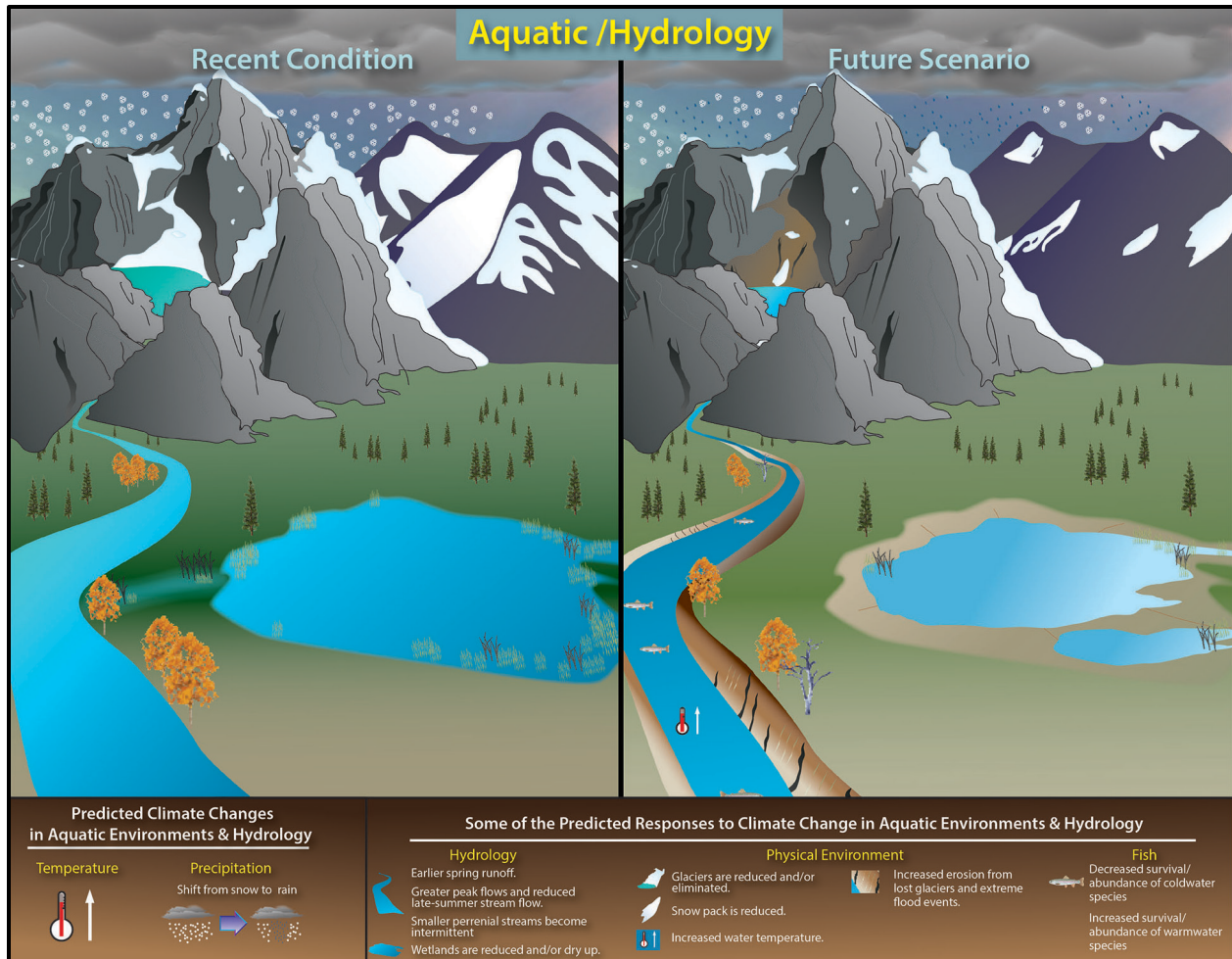


Figure 2. Conceptual model showing meteorologically induced changes to river and pond surface hydrology and the potential physical and ecological consequences of change. (Graphics provided by Rob Bennetts, NPS).

1.1 Global Interest in Stream Flow

Rivers and river-reservoir systems worldwide represent major sources of water supplies for drinking water, agricultural production, and wastewater treatment. Societal links to water are particularly obvious in arid regions of the world. In fact, the distribution of cities are disproportionately tied to rivers and water access. Rivers provide irrigation water for crops, but also prove valuable for facilitating navigation and transport of raw materials and finished products. The timing and patterns of river and stream flow also shape the characteristics of infrastructure (e.g., bridges, roads, and dams), power generation facilities, navigation, communities, agricultural, and business practices worldwide. Now and in the past, water-related infrastructure has been designed around an understanding of historical or longer-term discharge conditions and necessitated monitoring of hydrologic patterns. Global estimates indicate that approximately 45,500 km³/year (1.6×10^{15} ft³/year) of water flows through our global river network (Oki and Kanae 2006). This global river network, and the water it yields, serves as the principal source of renewable water for humans while underpinning habitats that support freshwater biodiversity worldwide (Vörösmarty et al. 2010).

Concerns over global water decline (IPCC 2001) and a determination to deliver clean water to all humans and reliable water for agriculture has led the United Nation's (UN) General Assembly to include water and the characterization of stream flow and water availability as one of the UN's 17 Sustainable Development Goals (Bhaduri et al. 2016). Given this, discharge monitoring stations will significantly contribute to meeting and assessing global Sustainable Development Goals. Importantly, long-term stream flow monitoring will be required to estimate the availability of, and changes in water supply from river and stream ecosystems. The UN formally identified water yield change in freshwater ecosystems as a global monitoring *indicator* of health and sustainability of water-related ecosystems (UN Economic and Social Council 2016). Regional trend monitoring efforts on free-flowing and minimally impaired rivers and streams described in this protocol implementation plan will therefore serve to increase regional and global awareness of climate-related and human-induced (through water regulation) water resource change.

1.2 Stream Flow Monitoring in the U.S.

The U.S. Geological Survey (USGS) has been monitoring and reporting river and stream discharge measurements across the U.S. for more than a century. As of Fiscal Year 2016, the USGS was operating 8,130 river and stream gages (i.e., monitoring locations) nationwide including Puerto Rico and the U.S. Virgin Islands (USGS 2016). The period of record for individual monitoring stations varies dramatically across this national network and ranges from a small number of gages monitored for nearly a century to the majority having less than 30 years of available data (USGS 2005). Variations in the period of record among monitoring stations is not uncommon regionally (see Tables 2 and 3 in Section 3 for a summary of monitoring stations within and surrounding GRYN parks) and this variation sometimes limits our ability to make inferences on the short-term versus long-term changes in discharge (see Al-Chokhachy et al. 2017). On a national basis, approximately 1,600 of these monitoring stations have been described as being 'climate-sensitive' (USGS 2005); climate sensitivity was determined by examining whether meteorological drivers (e.g., temperature, precipitation) explained most of the variation in discharge through time.

The value of long-term discharge monitoring to assess the effects of climate cannot be overstated. In 2016, the U.S. Environmental Protection Agency (EPA) published its fourth edition of Climate Change Indicators in the U.S. (EPA 2016). This report synthesized long-term environmental monitoring records in order to elucidate current understanding of the causes and effects of changing climate. The EPA recognized that long-term river and stream flow records significantly contribute to climate change knowledge and that associated summary metrics of river and stream flow can serve as one of the EPA principal climate indicators (EPA 2016); stream flow is listed as one of 37 climate change indicators used to quantify and communicate climate-induced changes to freshwater ecosystems. The EPA also noted that the stream flow indicator summaries are particularly useful when they are applied to individual or groups of discharge monitoring stations where long-term data records are available (e.g., multi-decade to century-long). The EPA indicates that the USGS National Water Information System (<http://waterdata.usgs.gov/nwis/rt>) serves as the basis of their summary work.

The benefits of using USGS information on river and stream flow are numerous, but a principal benefit is the careful review each discharge record or time series receives prior to its approval. First, continuous discharge records receive careful review by multiple trained hydrographers that screen for gross instrument errors. Site-specific hydraulic and stability characteristics are then incorporated into the analysis and record review. These hydrographers also consider the field protocols employed for site-specific discharge measurements that are used in the development and verification of site-specific rating curves (see <https://water.usgs.gov/osw/pubs/memo.summaries.html> for a list of technical memoranda for surface water monitoring and data review). This step is required for record approval and distribution through public portals (USGS 2010). Although USGS discharge data represents the gold standard for trend analyses, the discharge metrics described by EPA (EPA 2016) and used in this protocol implementation plan, may also be applied to other peer-reviewed and publicly available (e.g., National Park Service) long-term river and stream flow records.

Across the National Park Service (NPS), water resources have long been identified as uniquely and disproportionately threatened by activities occurring inside and outside of park boundaries (Gardner and Dennis, unknown date, circa 1983). Emerging from this understanding of threats to water resources was a description of the need for a NPS-wide inventory and assessment of available water resource data. Shortly thereafter, the NPS launched the Vital Signs Monitoring Program (Fancy et al. 2009; Fancy and Bennetts 2012) and the Inventory and Monitoring (I&M) Division is now a recognized leader among long-term vital sign monitoring programs (Sergeant et al. 2012; Rodhouse et al. 2016). Since its inception, the main goal of this program has been to identify vital signs for long-term monitoring that provided a broad-based understanding of the status and trends of NPS resources. The understanding gained through collaborative vital sign monitoring then, in turn, serves as the basis for science-based decision making needed to protect and sustain vital park resources (Fancy et al. 2009). By design, selected vital signs are intended to help characterize the overall health or condition of important park resources, describe and quantify the effects of dominant stressors, or represent elements of the National Park System that have a clear human nexus.

Water and, particularly, river and stream flow dynamics (Fancy et al. 2009) are regarded as vital to the health of aquatic and terrestrial communities, susceptible to climate and land use impacts, and important to visitor experiences and downstream neighbors (Jones et al. 2010; Madej 2011; Andrews 2012). For these reasons, surface water flows were identified as one of the most common indicators to monitor in the NPS I&M Program nationwide (Fancy and Bennetts 2012). Today, more than half of the 32 NPS I&M Networks actively monitor river, stream, or spring flow as part of their vital sign monitoring programs. Individually, these long-term monitoring programs are helping to identify park-, network-, or regional-scale patterns of hydrologic change and its association with changes in land use and climate. For example, discharge monitoring of springs in Arches National Park is linking changes in winter discharge with important climate drivers (e.g., evapotranspiration; Weissing et al. 2016). In Golden Gate National Recreation Area, Muir Woods National Monument, and Point Reyes National Seashore, base flow of several streams decreased coincident with increases in air temperatures (Madej 2011). Lastly, the Sierra Nevada Network's stream flow monitoring is documenting changes to stream flow in Yosemite, Kings Canyon, and Sequoia national parks and

Devils Postpile National Monument (Andrews 2012). Collectively, these complementary monitoring programs of the NPS I&M Division can offer valuable insight on the hydrologic dynamics of rivers, streams, and spring outlets that are critical to NPS management.

Shifts in temperature and precipitation regimes over the last several decades have already altered discharge patterns of rivers (e.g., Luce and Holder 2009; Pederson et al. 2011a; Leppi et al. 2012). Projected shifts in global and regional climatic conditions are anticipated to further alter the air temperature and precipitation regimes that influence river and stream flow (IPCC 2014). Given this projection and increased demand on surface water resources, it is critical to understand the degree that climate affects stream flows. This is best ascertained from data derived from minimally impaired waters; NPS-managed lands, independent from land-use and other human stresses are an excellent source. Climate-induced changes to hydrographs (e.g., changes in the timing of peak flows and onset of base flow conditions) are anticipated for many western rivers (Stewart et al. 2004). The subsequent consequences to water-dependent species (e.g., amphibians and fish) and the future risk posed by the growing threat of aquatic invasive species and novel diseases are still largely undetermined (Al-Chokhachy et al. 2017). These shifts in climate coupled with rises in human demands for recreation and water consumption (Vörösmarty et al. 2010; McDonald 2010), particularly in arid and semi-arid regions, suggest considerable challenges to the future conservation and management of water resources on NPS lands.

1.3 Stream Flow in the Greater Yellowstone Area and Across GRYN Parks

The USGS has been collecting river and stream discharge measurements throughout the Greater Yellowstone Area and within Grand Teton and Yellowstone national parks for several decades. For example, the USGS has been monitoring discharge in the Yellowstone River near Corwin Springs since 1889. The records for other rivers including the Fall, Gallatin, Lamar, Madison, and Snake rivers began in 1904, 1889, 1923, 1913, and 1984, respectively. These long-term discharge records provide unique opportunities to examine how river and stream hydrographs across the region may be responding to documented changes in air temperatures and snowpacks (*sensu* Luce and Holden 2009).

Rivers and streams in Grand Teton and Yellowstone national parks are threatened by various symptoms of the changing climate including changes to the hydrological cycle. Principal drivers of change for this region are a reduction in precipitation as snow and earlier snow melt (Barnett et al. 2005). Declines in Greater Yellowstone Area snowpacks over the 20th century are well documented. Projections for this region suggest future increases in winter temperatures will rearrange the snow accumulation zones and produce earlier melting and runoff patterns (Pederson et al. 2011b). Some of the effects of these changes have been documented (see Schook and Cooper 2014 as an example) or are predicted throughout Grand Teton and Yellowstone national parks as the duration of low flow conditions increases (Leppi et al. 2012; Al-Chokhachy et al. 2017). Low flow conditions coupled with elevated air temperatures also influence water temperatures. Across the Greater Yellowstone Area, stream water temperature is expected to increase between 0.8 and 1.8 °C (1.4–3.2°F) by 2069 (Al-Chokhachy et al. 2013). Combined changes in discharge patterns and water temperature may influence how visitors experience the parks. For example, popular fishing rivers in this region

include the Lamar River in Yellowstone and upper Snake River in the John D. Rockefeller, Jr. Memorial Parkway. In 2016, unseasonably warm winter and spring air temperatures contributed to earlier runoff and historic low flow conditions across the region. The Snake River near Flagg Ranch and Lamar River near Tower Ranger Station had the lowest average August daily flows in their respective time series (33 years for the Snake River and 75 years for the Lamar River). Temperature-influenced low flow conditions may trigger additional ecological changes including shifting biological communities and increased opportunities for the establishment of invasive species (Woodward et al. 2010). In 2016, a decision to close fishing in the Yellowstone River downstream of Yellowstone National Park (NP) occurred as a result of a large mountain whitefish (*Prosopium williamsoni*) die-off possibly exacerbated by record low flows and elevated stream temperatures (Keller 2016). This die-off and the subsequent closure may portend the novel threats facing water resources as record low flows overlap with increasing air temperatures.

Within Bighorn Canyon National Recreation Area (NRA), river and stream flows originating both outside and inside the park support water levels in Bighorn Lake. By mid-century (2050), significant reductions in snowpack and increases in summer air temperatures are predicted for this region (Hostetler et al. 2011). These changes will likely contribute to declines in river flows that have already been documented throughout the early 2000s (GRYN 2014). In fact, recent analyses show that the Bighorn River contribution to Bighorn Lake has been slowly declining since the 1930s (Figure 3). Total annual flows have dropped from a mean annual flow of 1.85 billion cubic meters (65.5 billion ft³) in the 1930s to a mean annual flow of 1.12 billion cubic meters (39.5 billion ft³) for water years 2000 to 2009. Years since 2010 have been higher and more variable, but long-term trends suggest a mean annual flow reduction of more than 0.7 billion cubic meters (25.5 billion ft³) between the 1930s and the first decade of the 2000s (Figure 3). In lake volume terms, a median reduction between 1930 and the first decades of the 2000s is more than 45% of the total lake volume at full pool. Although several average-to-high flow years occurred since 2010, the dry conditions of the early 2000s may provide important insight on how drier conditions and lower water levels manifest if climate forecasts for the region are realized.

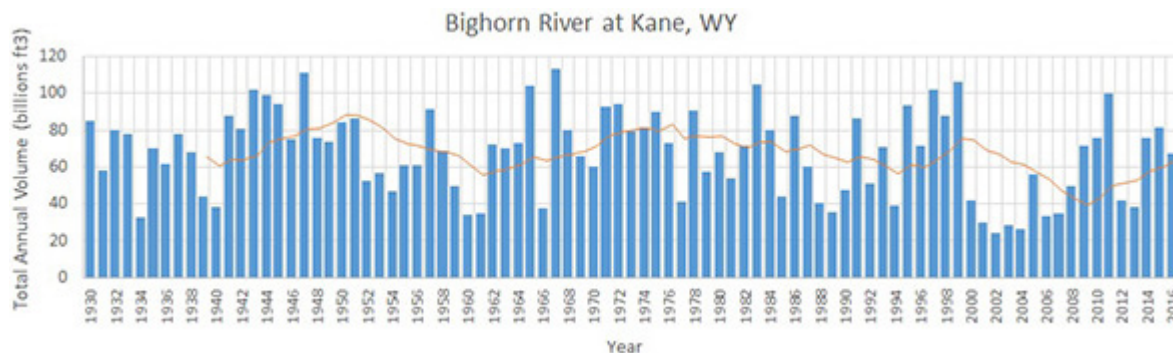


Figure 3. Total annual flow volume for the Bighorn River at Kane, Wyoming. The blue bars show total annual volume of flows and the orange line is the 10-year moving average. The moving average shows how multiple years of drought during the early 2000s contributed to a decline in river discharge in the Bighorn River.

1.4 GRYN's Discharge Monitoring Plan

This protocol implementation plan outlines the means by which river, stream, and spring discharge and reservoir surface elevation data will be acquired from existing USGS or U.S. Bureau of Reclamation (USBR) sources, collected by GRYN staff, and managed and reported for GRYN parks as described in the Vital Signs Monitoring Plan for the GRYN (Jean et al. 2005). GRYN is implementing discharge monitoring methods to track and estimate changes in long-term river, stream, and spring flow from USGS-monitored waters and on representative waters using a combination of manual and automated techniques. Monitored waters included in this plan represent rivers and streams that occur within or are proximal to and influence GRYN parks. While the specific monitoring objectives are designed to understand trends in surface water resources present within and surrounding GRYN parks, they are based on peer-reviewed and approved protocols by the Southwest Alaska Network (SWAN; Monitoring Freshwater Systems in the Southwest Alaska Network [Shearer et al. 2015a]), and Sierra Nevada Network (SIEN; Sierra Nevada Network River Hydrology Monitoring Protocol [Skancke et al. 2017a]), and recommendations from the Southeast Coast Network Surface Water Discharge Monitoring guidance document (Jones et al. 2010) and the EPA's Climate Change Indicators in the United States (EPA 2016). The objectives of this GRYN protocol implementation plan also align closely with recently completed and peer-reviewed methodology already implemented within the Greater Yellowstone Area (see Al-Chokhachy et al. 2017; Evaluating species-specific changes in hydrologic regimes: An iterative approach for salmonids in the Greater Yellowstone Area). Collectively, these peer-reviewed guidance documents provide clear justification for the use of river, stream and spring flow as well as lake and reservoir surface elevation metrics for status and trend monitoring.

The list of primary objectives for the GRYN protocol implementation plan for monitoring discharge are expanded from Jean et al. (2005). Deviations from approved metrics are identified, but represent minor differences in the list of metrics described in Shearer et al. (2015a) and Skancke et al. (2017a). Still, all metrics align with at least one of the peer-reviewed guidance documents cited above. Importantly, river and stream flow data and reservoir surface elevations, along with QA/QC procedures, will rely heavily on existing USGS and USBR operated gages and managed data sets. Methodology to detect trends comes from Skancke et al. (2017a) and Al-Chokhachy et al. (2017). These same metrics will also be applied to existing spring outflow monitoring work carried out by GRYN (see Kaylor et al. 2015).

The principal difference between this GRYN protocol implementation plan and the protocols from SIEN and SWAN involve differences in sites used. GRYN will focus on sites within or surrounding GRYN parks (Figures 4 and 5 below and see Tables 2, 3, and 5 in Chapter 3 for a complete list of USGS and USBR gaging stations). In addition, GRYN will employ, but also, expand on the analytical techniques described in Skancke et al. (2017a). Implementation of the SIEN and SWAN protocols will simplify the incorporation of USGS discharge data into the GRYN vital sign monitoring program. The following modifications to the SIEN and SWAN protocols have been identified:

- 1) Status and trend evaluation approaches will be applied to USGS-gaged streams and rivers and un-gaged GRYN-monitored spring outflows within and surrounding GRYN parks.
 - a) Discharge monitoring at spring outflows will rely on a combination of manual and automated flow measurements (see descriptions in the SWAN Standard Operating Procedures (SOP) for Monitoring Freshwater Systems in the Southwest Alaska Network in Shearer et al. 2015b). In brief, we will employ techniques described in Shearer et al. (2015b) for using the Marsh-McBirney Flo-Mate to estimate discharge in channels below spring outflows (e.g., Layout Creek in Bighorn Canyon NRA; SOP 1 in Ray et al. 2017). In addition, we will follow operating procedures for the use of automated water level loggers to monitor stage at regular intervals (e.g., 30-min to 1-hr frequency) for the development of rating curves for individual un-gaged sites (see Shearer et al. 2015b for details). Where spring outflows yield discharge amounts that can be measured volumetrically, we will take the average of four individual measurements following procedures in Weissinger and Moran (2015).
- 2) Status and trend evaluation approaches will be applied to USBR surface elevation summaries of Bighorn Lake and Jackson Lake (see Table 5 in Section 3).
- 3) In addition to plotting discharge and surface elevation metrics against time, we will also use ordinary least squares regression and quantile regression (see Al-Chokhachy et al. 2017), as well as, the Mann-Kendall test to examine trends in water volume using long-term gaging records.
- 4) Certified, publically available discharge (from USGS gaging stations) and surface elevation (from USBR surface elevation stations) datasets will be used by GRYN for reporting status and trends of gaged rivers, streams, and reservoirs.
 - a) GRYN will maintain a copy of data used for reporting but principal handling of data review and management for USBR- and USGS-managed stations will follow the Quality Assurance Plan (QAP) for each agency.
- 5) For GRYN-managed monitoring sites, manual discharge measurements will be made volumetrically (for developed springs with a piped discharge) or following standard procedures for wadeable streams (see Ray et al. 2017 SOP 1: Discharge Measurement in Wadeable Waters). Water level or flow estimates will be monitored using automated sensors. Data from these sensors will be downloaded from loggers and uploaded to AQUARIUS for review, processing, and storage.
- 6) SOPs have been modified to reflect GRYN-specific changes (see Ray et al. 2017 for additional details).

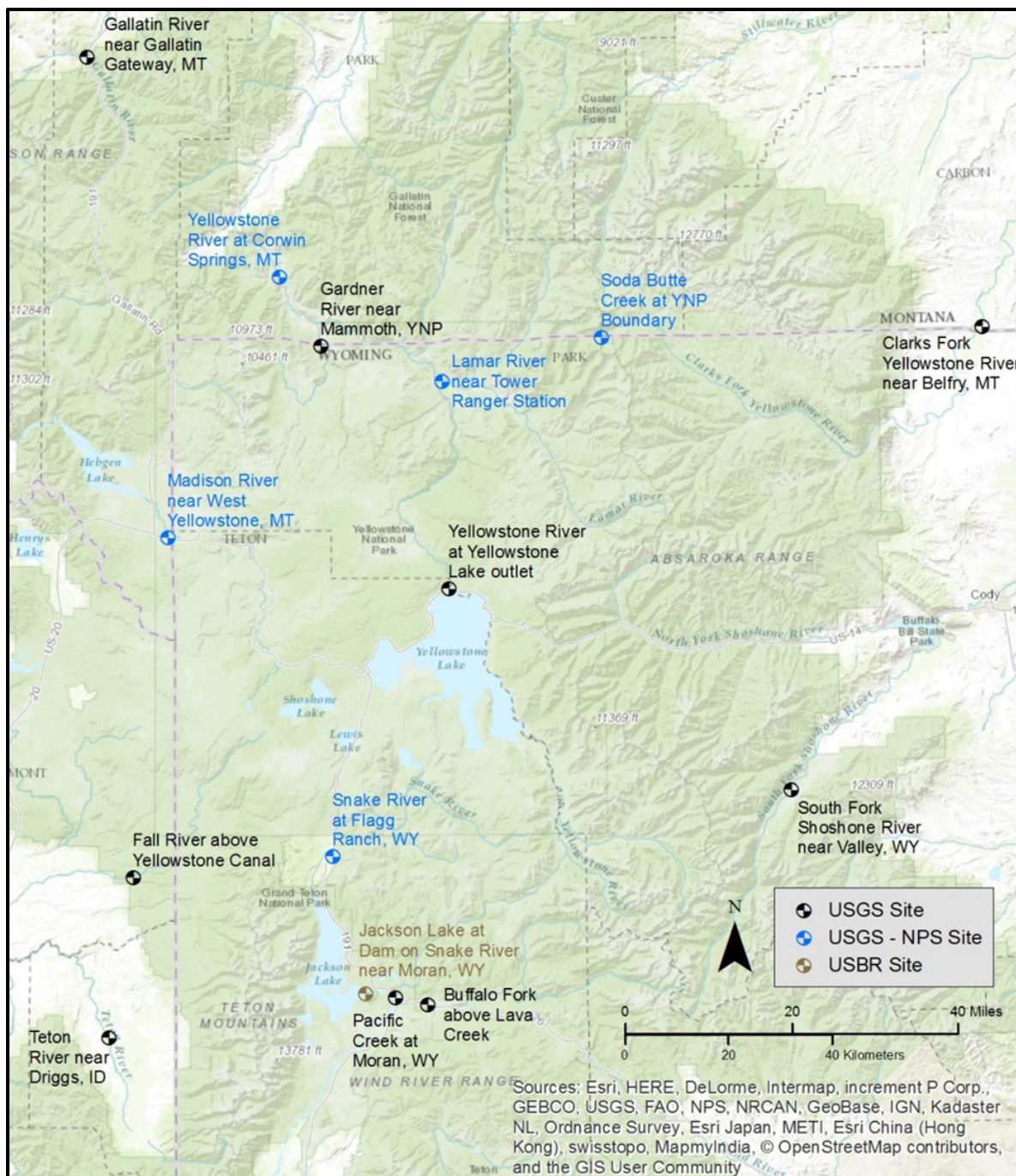


Figure 4. Map of USGS gaging stations in and surrounding Grand Teton and Yellowstone national parks. Black symbols represent USGS maintained stream gages. Blue symbols indicate USGS stations where the NPS Greater Yellowstone Network has co-located water quality monitoring sites. Brown symbols represent USBR operated stage stations that measure reservoir levels.

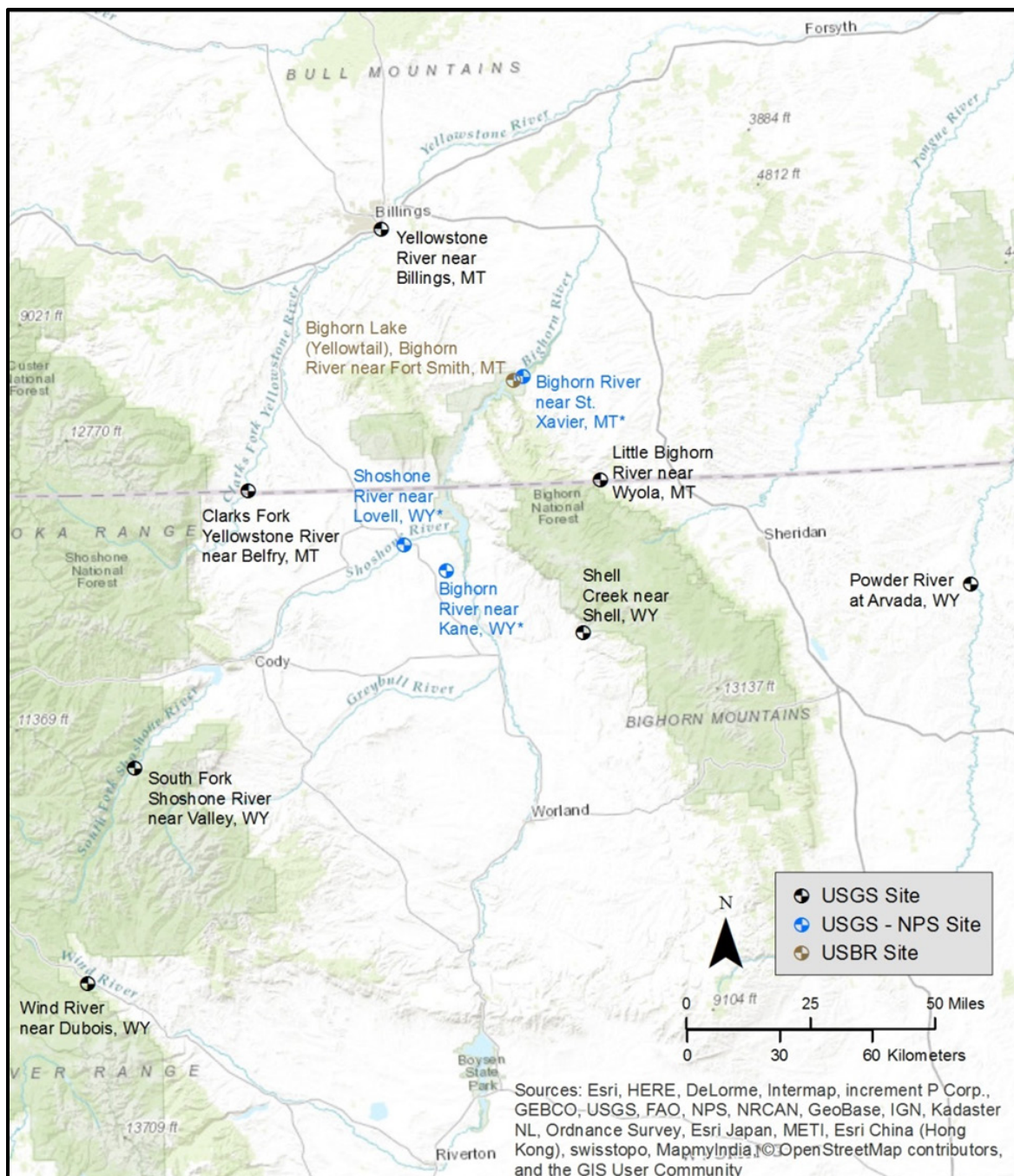


Figure 5. Map of USGS gaging stations in and surrounding Bighorn Canyon NRA. Black symbols represent USGS maintained stream gages. Blue symbols indicate USGS stations where the NPS Greater Yellowstone Network has co-located water quality monitoring sites. Brown symbols represent USBR operated stage stations that measure reservoir levels.

2 Conceptual Framework for Monitoring

Water resources in GRYN parks are diverse and include alpine lakes, rivers, perennial and ephemeral streams, springs, geysers, wetlands, and natural lakes and reservoirs. These resources play a disproportionate role in the function of vital ecosystem processes. Monitoring objectives outlined in this protocol implementation plan will focus on rivers, streams, and outflows associated with spring discharge as well as reservoir surface elevations for Bighorn and Jackson lakes. Understanding the effects of multiple, concurrent stressors that affect river and stream flow, spring discharge, and reservoir levels are an important and ongoing challenge for resource managers in GRYN parks, gateway communities, and downstream users.

As described in Jean et al. (2005), we propose that climate drivers (e.g., temperature, evapotranspiration, and snowpack dynamics) will act as the primary drivers affecting the discharge patterns of surface water resources in and around GRYN parks (e.g., the upper Snake, Lamar, and Bighorn rivers). In brief, changes to the amount of precipitation (snow and rain) will disproportionately affect the total volume of runoff and river, stream, and spring flow. Changes to air temperature will disproportionately influence snowpack dynamics, and in turn, the magnitude and timing of runoff. Specifically, increased air temperatures are expected to contribute to earlier (late winter or spring) runoff and earlier onset of base flows in summer and fall (Barnett et al. 2005; Figure 2).

The predicted changes to the hydrological cycle of rivers, streams, springs, and reservoirs within and around GRYN parks are based on documented responses to warming that are already underway in snow-dominated drainage basins of mid- to high-latitudes (Luce and Holden 2009; Pedersen et al. 2011a; Al-Chokhachy et al. 2017). Documented changes to the timing and abundance of snow cover in mid- to high-latitude regions including GRYN parks directly influences the storage capabilities of mountain snow packs. In some regions, the warming-induced changes to mountain snowpacks are predicted to produce peak flows in 2050 that are one month earlier than conditions present at the beginning of the 21st century (Barnett et al. 2005).

When reduced river discharges are combined with an increasing societal demand for water, conflicts associated with over-allocated water resources should be anticipated (Gleick 2000). Many reservoirs and their associated operations were conceived on the basis of providing a steady and reliable water supply for industry, irrigation, and domestic uses, and importantly, it was historic flows and timing of runoff from decades past that served as the basis for dam construction and operation, and in turn, water allocation (Richter et al. 2003). For this reason, a clearer understanding of long-term trends and current status in river volume and timing of runoff will help inform the management of regulated and unregulated rivers located within snow-dominated watersheds (*sensu* Li et al. 2010). With these ideas in mind, GRYN will employ widely used metrics for discharge patterns of rivers, streams, spring outflow (Jones et al. 2010; Shearer et al. 2015a; EPA 2016; Skancke et al. 2017a; Al-Chokhachy et al. 2017) and reservoirs (Magilligan and Nislow 2005; Shearer et al. 2015a) and will include conceptual models that combine human activities and their associated water demands with anticipated changes in climate (Table 1; Figures 2 and 6). Information revealed from GRYN's vital

sign monitoring activities will supply relevant information on flow patterns of rivers, streams, and springs and elevation dynamics of reservoirs that will be useful to resource managers, gateway communities, and downstream water users.

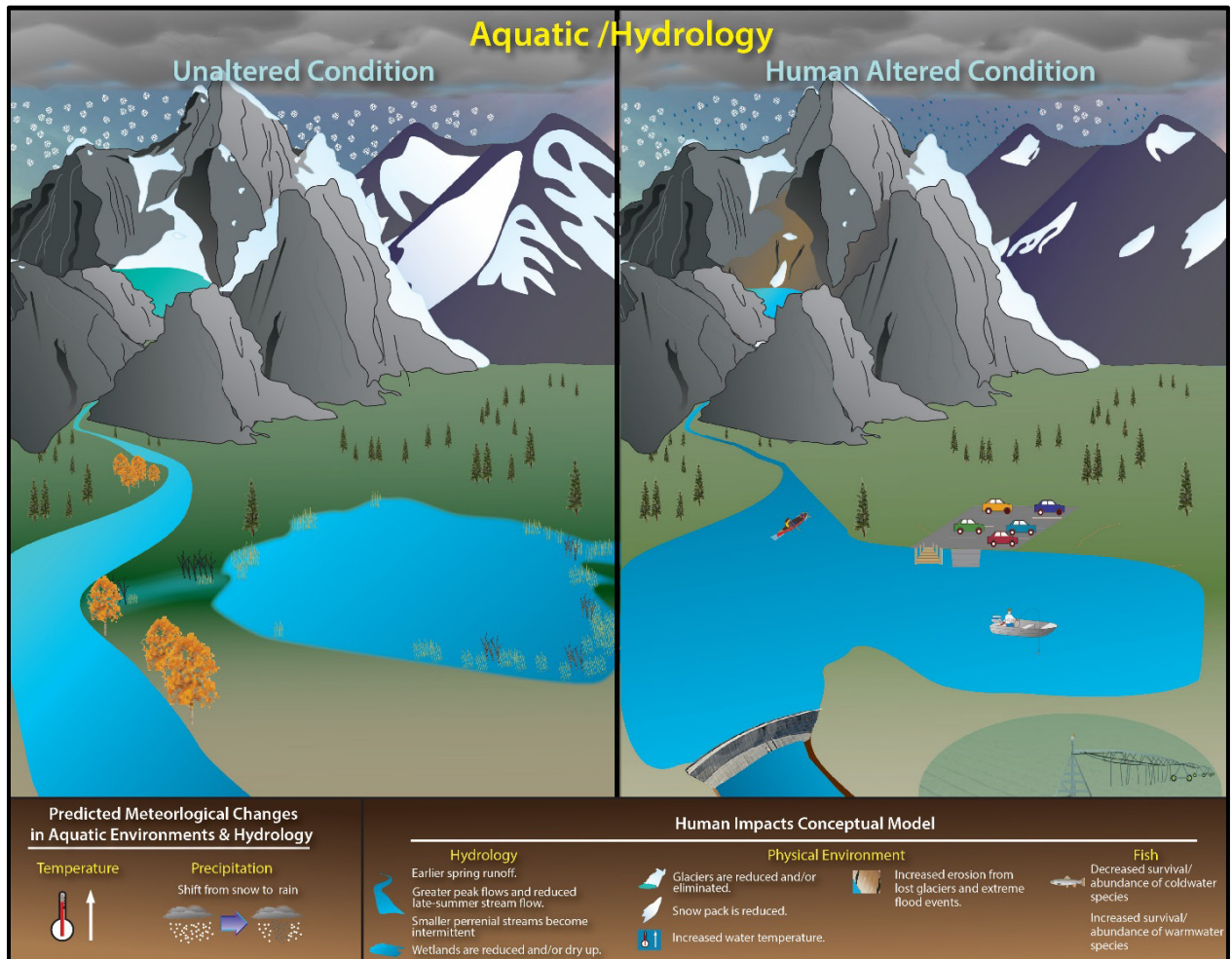


Figure 6. Conceptual model showing meteorologically induced and human induced (i.e., dams and irrigation withdrawals) alterations to surface water resources and associated changes to river and pond surface hydrology. (Graphics provided by Rob Bennetts, NPS).

Table 1. Dominant drivers contributing to changes in long-term discharge patterns and reservoir levels within and surrounding Greater Yellowstone Network parks and potential measures for vital sign monitoring.

Category	Management Concerns	Potential Measures
Changing climate conditions	Projected increases in air temperatures and evapotranspiration rates are likely to have the largest impact on snowpack dynamics	Monitoring the date and magnitude of peak and low flow, duration of ice cover
	Changes in amount of precipitation (rain and snow) are likely to affect the total volume of flow and timing of half flow	Monitoring total annual river volume, timing of half flow, annual average stream flow
Dams/Impoundments	Dams decrease the magnitude and duration of peak and extreme flows, increase discharge of minimum flows, change the shape of the hydrograph, and change the timing of peak and base flows in river channels below them	Monitoring timing of annual and peak events, number of high and low pulses each year, monitoring mean annual maxima and minima (e.g., 3-, 7-, and 30-day)
Water diversions	Water diversions and withdrawals reduce in-channel flow particularly during the summer	Monitoring annual minima means (e.g., 3-, 7-, and 30-day minima).

3 Measurable Objectives

The primary goal of GRYN's discharge monitoring is to track and estimate changes in long-term river and stream flow from USGS-monitored waters. These techniques will also be employed on a small number of representative springs monitored using manual or automated techniques (see Kaylor et al. 2015). In addition, we will employ complementary metrics to track and estimate changes in surface elevation dynamics of two reservoirs (Bighorn and Jackson lakes) that are central features in GRYN parks. Monitoring data will be useful for understanding the effects of multiple meteorological processes and human forces influencing discharge patterns across GRYN parks. While the specific monitoring objectives are designed to understand trends in aquatic resources present within and surrounding GRYN parks, they are also intended to complement broader NPS, USGS, and EPA regional and national scale objectives and complement ongoing water quality (O'Ney 2006; O'Ney et al. 2009) and amphibian/wetland (Bennetts et al. 2013) vital sign monitoring.

The list of primary objectives for the GRYN protocol implementation plan for monitoring discharge are taken from Jean et al. (2005). These objectives will be met using flow-specific metrics described in Al-Chokhachy et al. (2017) for the Greater Yellowstone Area, Skancke et al. (2017a) for the SIEN network, Shearer et al. (2015a) for SWAN parks, and by the EPA (2016) for national application. Objectives 1 through 3 will apply to USGS-gaged rivers and streams in or near Bighorn Canyon NRA, Grand Teton NP, John D. Rockefeller, Jr. Memorial Parkway (MP), and Yellowstone NP (Tables 2 and 3) and un-gaged streams and spring outfalls in Bighorn Canyon NRA (Table 4). Objective 4 will be applied to USBR-gaged stations on Bighorn and Jackson lakes (Table 5).

3.1 Objective 1

Evaluate status and trends in base or low flow characteristics of selected USGS-gaged rivers and streams within or adjacent to GRYN parks (Tables 2 and 3) and un-gaged spring outflows in Bighorn Canyon NRA (Table 4).

We will use **3-day, 7-day, and 30-day average low flow discharge** each year to estimate long-term trends in low flow conditions. Because the biological and societal impacts of low flows differ in summer and winter (Novotny and Stefan 2007), we will estimate the long-term trends for the **3-day and 7-day low flow in summer** (May to September) and **3-day and 7-day low flow in winter** (November to March).

3.1.1 Justification/Rationale for Objective 1

Flow variability and low flow conditions are believed to be one of the primary abiotic factors structuring fish and other aquatic life in streams (Jackson et al. 2001; Fisher et al. 2012). As climatic conditions shift, base flow conditions are predicted to occur earlier in the year and persist longer as increases in regional air temperatures affect snowmelt and runoff patterns in mountainous rivers and streams. Changes in summer base flows can affect fish and other aquatic biota. For example, summer low flows often coincide with periods of increased water temperatures and decreased dissolved oxygen levels. Specifically, lower summer flows and warmer water temperatures can alter the growth and survival of salmonids (Xu et al. 2010) and other aquatic life. Summer flows are also important for recreational activities (e.g., boating) and for downstream water users (Hamlet and Lettenmaier

1999). Similarly, winter flow levels could affect recreational opportunities during fall and winter, impose management considerations for downstream storage facilities (which typically evacuate floodwaters in winter; Hamlet and Lettenmaier 1999), and alter ice dynamics in winter months.

3.2 Objective 2

Estimate status and trends in the timing of annual peak or non-peak high flow conditions of USGS-gaged rivers and streams within or adjacent to GRYN parks (Tables 2 and 3) and ungaged spring outflows in Bighorn Canyon NRA (Table 4).

We will evaluate trends in the timing (**date of peak flow or the single highest one-day annual event**) and **magnitude of annual peak flow** to consider long-term trends in these important annual events. In addition to the single largest daily event, we will examine the annual average **3-day and 7-day continuous high flow** events. Lastly, we will estimate changes in the **magnitude of winter peak flow** (maximum winter flow or single highest 1-day event between November and March).

3.2.1 Justification/Rationale for Objective 2

River and stream flows shape almost every attribute of rivers and streams (Hart and Finelli 1999). When flow conditions are pushed beyond the boundaries of the post-glacial history of a system, parts of the system (e.g., biological communities and river channel properties) are likely to change. For example, the timing and magnitude of annual and seasonal maximum flows are likely to occur earlier in the year as increases in temperature affect snowmelt and runoff patterns in rivers and streams of the Rocky Mountains (Pedersen et al. 2011a). Moreover, climate forecasts predict an increase in the number and intensity of extreme meteorological events (Easterling et al. 2000). The biological and societal effects of short and long duration high flow events and floods are still unclear (Messner and Meyer 2006), especially when flow conditions outside the evolutionary history of organisms are experienced on a more regular basis (Hart and Finelli 1999). Trends in high flow events will be evaluated using 1-day, 3-day, and 7-day high flow and maximum winter flow metrics.

3.3 Objective 3

Estimate status and trends in socioeconomically important hydrologic conditions of USGS-gaged rivers and streams within or adjacent to the GRYN parks (Tables 2 and 3) and ungaged spring outflows in Bighorn Canyon NRA (Table 4).

We will evaluate long-term trends in **total annual river volume** (based on a water or calendar year), the **timing** (i.e., date) **of half flow**, and **annual average stream flow** or discharge rate.

3.3.1 Justification/Rationale for Objective 3

Water delivery to consumptive users and water-related infrastructure (e.g., boat launches, diversion channels, and dams) were designed around quantitative estimates of historical flow conditions. Shifts away from long-term conditions could pose unique problems for water resource managers, irrigators, and the public. Trends in long-term annual flows and the timing of half-flows within GRYN parks will be evaluated using the following annual metrics: total annual flow volume, annual average stream flow, and timing of half flow.

Table 2. USGS Monitoring Station ID and the elevation, latitude, and longitude for USGS stream gages (sites) in the Greater Yellowstone Area, USA.

USGS Site ID	Site	Years of Record	Elevation (m)	Water area (km ²)	Latitude	Longitude
13011900	Buffalo Fork above Lava Creek, WY	1965-2016	2,064	837	43.8381	-110.4408
06207500	Clarks Fork Yellowstone River near Belfry, MT	1921-2016	1,215	2,984	45.0097	-109.0653
13046995	Fall River above Yellowstone Canal, ID	1993-2016	1,762	837	44.0619	-111.1519
06043500	Gallatin River near Gallatin Gateway, MT	1930-1981 1985-2016	1,575	2,121	45.4972	-111.2707
06191000	Gardner River near Mammoth, WY (YNP)	1938-2016	1,714	513	44.9923	-110.6910
06188000	Lamar River near Tower Ranger Station, WY ^a	1923-1969 1988-2016	1,829	1,730	44.9282	-110.3943
06037500	Madison River near West Yellowstone, MT ^a	1913-1973 1983-1986 1988-2016	2,027	1,127	44.6571	-111.0680
13011500	Pacific Creek at Moran, WY	1917-2016	2,048	438	43.8503	-110.5178
13010065	Snake River at Flagg Ranch, WY ^a	1983-2016	2,073	1,259	44.0989	-110.6675
06187915	Soda Butte Creek at Yellowstone NP Boundary, WY ^a	1998-2016	2,237	80	45.0028	-110.0019
06280300	South Fork Shoshone River near Valley, WY	1956-2016	1,890	769	44.2078	-109.5553
13052200	Teton River near Driggs, ID	1961-2016	1,814	872	43.7819	-111.2092
06191500	Yellowstone River at Corwin Springs, MT ^a	1889-1893 1911-2016	1548	6,775	45.1121	-110.7937
06186500	Yellowstone River at Yellowstone Lake outlet, WY	1926-1982 1984-1986 1988-2016	2,355	2,577	44.5671	-110.3804

^a Indicates locations where GRYN's water quality monitoring is co-located.

Table 3. USGS Monitoring Station ID and the elevation, latitude, and longitude for USGS stream gages (sites) near Bighorn Canyon NRA.

USGS Site ID	Site	Years of Record	Elevation (m)	Water Area (km ²)	Latitude	Longitude
06279500	Bighorn River near Kane, WY ^a	1928-2016	1,116	40,823	44.7586	-108.2642
06287000	Bighorn River near St. Xavier, MT ^a	1934-2016	945	50,950	45.3169	-107.9189
06207500	Clarks Fork Yellowstone River near Belfry, MT	1921-2016	1,215	2,984	45.0097	-109.0653
06289000	Little Bighorn River near Wyola, MT	1939-2016	1,326	471	45.0071	-107.6154
06317000	Powder River at Arvada, WY	1930-2016	1,103	15,669	44.6500	-106.1269
06278500	Shell Creek near Shell, WY	1940-2016	1,332	376	44.5650	-107.7122
06285100	Shoshone River near Lovell, WY ^a	1966-2016	1,173	6,086	44.8386	-108.4344
06280300	South Fork Shoshone River near Valley, WY	1956-2016	1,890	769	44.2078	-109.5553
06218500	Wind River near Dubois, WY	1945-2016	2,191	601	43.5786	-109.7592
06214500	Yellowstone River near Billings, MT	1904-2016	939	30,580	45.8001	-108.4680

Table 4. Un-gaged spring outflow locations monitored by GRYN within Bighorn Canyon NRA.

Site ID	Site	Years of Record	Elevation (m)	Latitude	Longitude
M-L	Mason-Lovell , WY	2011-2016	1120	44.8292	-108.1585
LCR1	Layout Creek (Upper) , MT	2011-2016	1697	45.0982	-108.2955
LCR2	Layout Creek (Lower) , MT	2011-2016	1228	45.0774	-108.2544
LH	Lockhart Ranch , MT	Intermittent since 2011	1344	45.1354	-108.2471

3.4 Objective 4.

Estimate status and trends in lake level (and commensurate pool volume) of USBR-gaged reservoirs within GRYN parks (Table 5).

We will evaluate status and trends in the **timing** and **magnitude of maximum and minimum elevations** (single highest and lowest readings within a year) to consider long-term trends in these important annual events. In addition, we will examine the annual **3-day and 7-day maximum elevation** and **3-day and 7-day minimum elevation**.

3.4.1 Justification and Rationale for Objective 4

Lake levels are fundamental to maintaining ecological processes in and along lakes and reservoirs and evaluating the response of regulated waters to changing upstream conditions and climate drivers is becoming increasingly important to water resource managers. In regions where winter snowpack and the timing of spring snowmelt strongly influence the management of reservoirs and water delivery systems, future changes in meteorological conditions are likely to alter filling and drawdown patterns of reservoirs (Barnett et al. 2005). Specifically, a reduction in the storage of water as snow means changes to the timing and magnitude of runoff necessary to fill reservoirs. Warmer climatic temperatures also likely contribute to increased evaporative losses from reservoirs. When these patterns are combined with earlier and increasing societal demands for water, disputes for already over-allocated water resources (like those in the Western U.S.) may follow (Li et al. 2010). Given the increasing concerns over changing flow patterns and loss of water storage as snow, there is a growing need to understand changes in the status and trends in reservoir levels – particularly in snow-dominated regions (Li et al. 2010). Trends in long-term reservoir levels in Bighorn Lake (Bighorn Canyon NRA) and Jackson Lake (Grand Teton NP) will be evaluated using the metric described under this objective.

Table 5. USBR-gaged reservoir elevation stations located within GRYN parks.

Site ID	Site	Years of Record	Max Pool Elevation (m)	Max Water Storage (acre-ft)	Dam Latitude	Dam Longitude
BHR MT00576	Bighorn Lake (Yellowtail), Bighorn River near Fort Smith, MT	1967-2016	1,116	1,381,189	45.3069	-107.9578
JCK WY01385	Jackson Lake at Dam on Snake River near Moran, WY	1910 - 2016	2,069	847,000	43.8594	-110.5899

4 What's being Measured and How

GRYN will monitor stream, river, and spring discharge and the surface elevation of two reservoirs (Bighorn and Jackson lakes) using the general methods described in peer-reviewed and approved protocols by SWAN (Monitoring Freshwater Systems in the Southwest Alaska Network [Shearer et al. 2015a]), and SIEN (Sierra Nevada Network River Hydrology Monitoring Protocol [Skancke et al. 2017a]), and peer-reviewed methodology already evaluated for the Greater Yellowstone Area (Al-Chokhachy et al. 2017).

Data on river and stream discharge will come principally from established USGS monitoring stations (see Tables 2 and 3 for a list of USGS-gaged waters). These data will be downloaded from the USGS National Water Information System server at: <https://waterdata.usgs.gov/nwis>. Data on reservoir surface elevation and estimated pool volume will be downloaded from the USBR Hydromet online portal: <https://www.usbr.gov/pn/hydromet/>. Individual, real-time summaries for Bighorn Lake (BHR – MT00576; https://www.usbr.gov/gp-bin/arcweb_bhr.pl) and Jackson Lake (JCK – WY013085; <https://www.usbr.gov/pn-bin/arcread.pl?station=JCK>) are also available.

Data for un-gaged stations tracked using automated water level loggers (e.g., water level survey data described by Skancke et al. 2017b) or magnetic or ultrasonic flow meters operated by GRYN will be downloaded quarterly and stored using AQUARIUS software following procedures described in SOPs 11 and 12 from SWAN (Shearer et al. 2015b). At un-gaged sites, manual discharge measurements will be used to develop rating curves of daily flow (see USGS guidance as an example in Rantz et al. 1982a and 1982b). For developing those curves, manual measurements of stream and spring outflow discharge will be measured six to eight times annually. In channels, discharge measurements will be made at an established and georeferenced cross-section. When possible, transient objects such as woody debris that interfere with laminar flow will be removed from the vicinity of the transect area prior to beginning measurements. A measuring tape will be stretched perpendicular to the stream flow and used to divide the stream into a minimum of 20 increments. This attempts to ensure that no more than 5% of the cross sectional area will be represented by each velocity measurement. If hydraulic irregularities are detected, additional increments will be established to account for noticeable anomalies (Gore 1996).

Under wadeable conditions (see Lane and Fay 1997), velocities will be measured using an electromagnetic Marsh McBirney velocity meter affixed to a graduated, stainless steel, top-set wading rod (Nolan and Shields 2000). Velocities are measured at a depth of 0.6 times the total depth with the rod resting on the bottom. The depth of the velocity meter probe is automatically adjusted to 0.6 times the depth when the vernier scale converter on the rod is set to the correct water depth. During elevated flows when wading is either unsafe or not possible, measurements will not be made. When water depths exceed 2.5 feet (0.75 m), measurements will be taken at 0.2 and 0.8 times the depth, and average velocity is reported. Likewise, at depths greater than 2.5 feet (0.75 m), an additional velocity measurement is taken at 0.6 times the water depth when one the following conditions exist: 1) when water velocity at 0.8 times water depth is greater than water velocity at 0.2 times water depth, or 2)

when water velocity at 0.2 times water depth is more than twice the water velocity at 0.8 times water depth.

For springs where discharge is estimated using an automated magnetic or ultrasonic flow meter, manual volumetric (see Weissinger and Moran 2015) spring flow measurements will be used in tandem to develop a rating curve between the automated measurements and the manual volumetric discharge measurements. Volumetric discharge measurements will be made by placing a 1-L graduated cylinder under the down-stream end of the spring discharge pipe (see photograph below) and documenting the time required to fill the cylinder. Discharge is expressed as volume per unit time. During each site visit, four individual measurements will be collected and the average of these measurements will be used to calculate the final flow at the site in liters per second (L/s).



Discharge measurement location for the Mason-Lovell spring at Bighorn Canyon NRA. December 2012.

Daily estimates of discharge (for rivers, streams, and spring outflow) and surface elevation and estimated pool volume (for reservoirs) will be used to summarize the metrics described in Tables 6 and 7 and used to characterize the status and long-term trends in discharge (rivers, streams, and springs) and surface elevation and corresponding pool volumes (reservoirs). At USBR- and USGS-gaged locations, only USBR or USGS ‘approved’ surface elevation or discharge information will be

used for reporting purposes. Provisional data (see <https://help.waterdata.usgs.gov/policies/provisional-data-statement>) may be used for preliminary analyses or for special or time sensitive resource purposes, but GRYN will not use data flagged as ‘provisional’ for trend reporting. For GRYN-maintained gages, discharge records will be plotted against time and data points that represent unexplained outliers or that appear unrepresentative of actual flow (e.g., due to a runoff event, channel modification, icy conditions, or unreliable equipment readings) will be eliminated from the analyses (see Weissinger and Moran 2015).

Table 6. Monitoring metrics, objectives, and methods for GRYN parks based on conceptual models for river, stream, and spring ecosystems. All metrics will be based on daily estimates of discharge from USGS or from GRYN managed spring locations.

Discharge Metric	Objective Number	Sampling Method	Data Collected
Instantaneous Discharge	1,2,3	Manual measurement of discharge, estimated from rating curve	Depth and velocity for discharge estimates from channels; volumetric estimates from springs; USGS data summaries from National Water Information System (NWIS)
Date of peak flow	2	Estimated from rating curve	USGS daily data summaries from NWIS; daily discharge summaries GRYN produced rating curves
Magnitude of peak flow	2	Estimated from rating curve	Same as above
Magnitude of winter peak flow	2	Estimated from rating curve	Same as above
3-day, 7-day, and 30-day high flow	2	Calculated	Same as above
3-day, 7-day, and 30-day low flow	1	Calculated	Same as above
3-day and 7-day low flow (in summer)	1	Calculated	Same as above
3-day and 7-day low flow (in winter)	1	Calculated	Same as above
Total annual river volume	3	Calculated	Same as above
Timing of half flow	3	Calculated	Same as above
Annual average daily stream flow	3	Calculated	Same as above

Table 7. Monitoring metrics, objectives, and methods for GRYN parks based on conceptual models for reservoir ecosystems. All metrics will be based on daily estimates of surface elevation and pool volume from USBR managed monitoring locations.

Elevation Metrics (Reservoirs)	Objective Number	Sampling Method	Data Collected
Instantaneous surface elevation (and associated pool volume)	4	Manual measurement of stage, estimated from rating curve	USBR data summaries from HYDROMET Data System
Annual elevation maximum	4	Estimated from rating curve	Same as above
Date of maximum elevation	4	Estimated from rating curve	Same as above
Annual elevation minimum	4	Estimated from rating curve	Same as above
Date of minimum elevation	4	Estimated from rating curve	Same as above
3-day and 7-day maximum elevation	4	Calculated	Same as above
3-day and 7-day minimum elevation	4	Calculated	Same as above

5 Sampling Design and Monitoring Schedule

GRYN's overall discharge monitoring approach is USGS/USBR-based; the approach simply utilizes existing USGS gaging stations to characterize the status and long-term trends in the timing and quantity of discharge in flowing waters in and surrounding GRYN parks and surface elevation dynamics of two reservoirs. Our reliance on a sampling design that uses existing long-term USGS and USBR gage records is consistent with efforts across NPS I&M networks (Jones et al. 2010; Madej 2011; Andrews 2012; and Skancke et al. 2017a). This approach leverages the century- to decades-old records that already exist for many gaged rivers throughout the U.S. Given the high seasonal and among-year variability in discharge data, the existence of long-term USGS discharge and USBR surface elevation records will be particularly valuable for trend analyses of surface water resources (see Skancke et al. 2017a). Pre-existing gages that predate the I&M program allow an even longer term data series to be evaluated for trends and allow for spatial comparisons to be made for patterns occurring regionally or even nationally.

5.1 Sampling Design

In order to select a subset of rivers and streams for status and trend monitoring, GRYN assembled all USGS river and stream monitoring station locations and available records that could be used to describe the discharge patterns of river and stream flow in and immediately surrounding GRYN parks. The available discharge records varied dramatically in length (see Tables 2 and 3 and Appendix A) and some records contained gaps (i.e., monitoring was suspended) of few to many years. To assess the trends in river and stream flow conditions over the past century, we prioritized waters that were co-located with our existing water quality monitoring stations (see Tables 2 and 3). All criteria considered for USGS station inclusion are listed below and a list of stations included in this GRYN protocol are summarized in Tables 2 and 3.

Selection Criteria:

- 1) River/stream sites that are co-located with GRYN water quality monitoring locations
- 2) River/stream sites that are physically located within or just outside the park boundaries
- 3) River/stream sites that integrate conditions of multiple tributaries (e.g., the Madison River at West Yellowstone integrates conditions in Gibbon and Firehole rivers that also have USGS gages)
- 4) River/stream sites that represent the least altered conditions (e.g., Snake River at Flagg Ranch does not have the types of upstream manipulations that the Snake River at Moose station does)
- 5) River/stream sites that support the longest record of flow

In addition to the streams and rivers that were selected, two reservoirs (Bighorn Lake and Jackson Lake) are included in this GRYN protocol as these reservoirs were described as important indicators by resource managers to GRYN during initial monitoring scoping sessions/documents (see Jean et al. 2005). Lastly, from greater than 28 identified springs in Bighorn Canyon NRA, three representative springs (Kaylor et al. 2015) were selected for discharge monitoring. To identify representative

springs, we first considered residence times and chemical profiles of identified springs. Clustering approaches of geochemical signatures identified three dominant spring types (see Schmitz et al. 2007) and from these, spring suitability for long-term monitoring was based on ability to accurately collect discharge measurements (e.g., presence of a downstream channel or existence of a discharge pipe) and proximity to one another (Schmitz et al. 2007). Layout Creek below Layout Spring, Mason-Lovell Spring, and springs associated with the Lockhart Ranch were identified and are included in this protocol.

5.2 Monitoring Schedule

Data on river and stream discharge will come principally from USGS stations (see Tables 2 and 3 for a list of USGS-gaged waters). These data will be downloaded from the USGS National Water Information System server. Data on reservoir surface elevation and estimated pool volume will be downloaded from the USBR online portal for Bighorn and Jackson lakes. Data will be downloaded annually after provisional flags from the reviewing agency (USBR or USGS) have been removed.

For Bighorn Canyon NRA spring monitoring, discharge will be measured manually six to eight times annually for the development and maintenance of site-specific rating curves. Quarterly, GRYN will download data from automated water level loggers (e.g., level survey data described by Skancke et al. 2017b) or from magnetic or ultrasonic flow meters operated by GRYN. Quarterly downloads will be loaded into and stored using AQUARIUS software following procedures described in SOPs 11 and 12 from SWAN (Shearer et al. 2015b).

6 Data Management, Analysis, and Reporting

The types of data to be collected and the requisite processing steps as part of the GRYN protocol implementation plan for monitoring discharge (and surface elevation) are described below and in accordance with the GRYN generalized Annual Project Information Cycle (see Figure 7). Data used for discharge summaries represent two distinct source types: GRYN-generated data and provider-certified data from USGS and USBR. Consistent with Skancke et al. (2017a), the data management activities and Annual Project Information Cycles for these two data sources are shown separately to distinguish the differences, but also to highlight the similarities in the information cycle. To that end, annotated versions of the Annual Project Information Cycles for GRYN-generated discharge and provider-certified data are included here (see Figures 8 and 9 in sections 6.1 and 6.2 below). Please note that data from USGS and USBR will be downloaded and processed annually only after all provisional flags from the providing agency have been lifted.

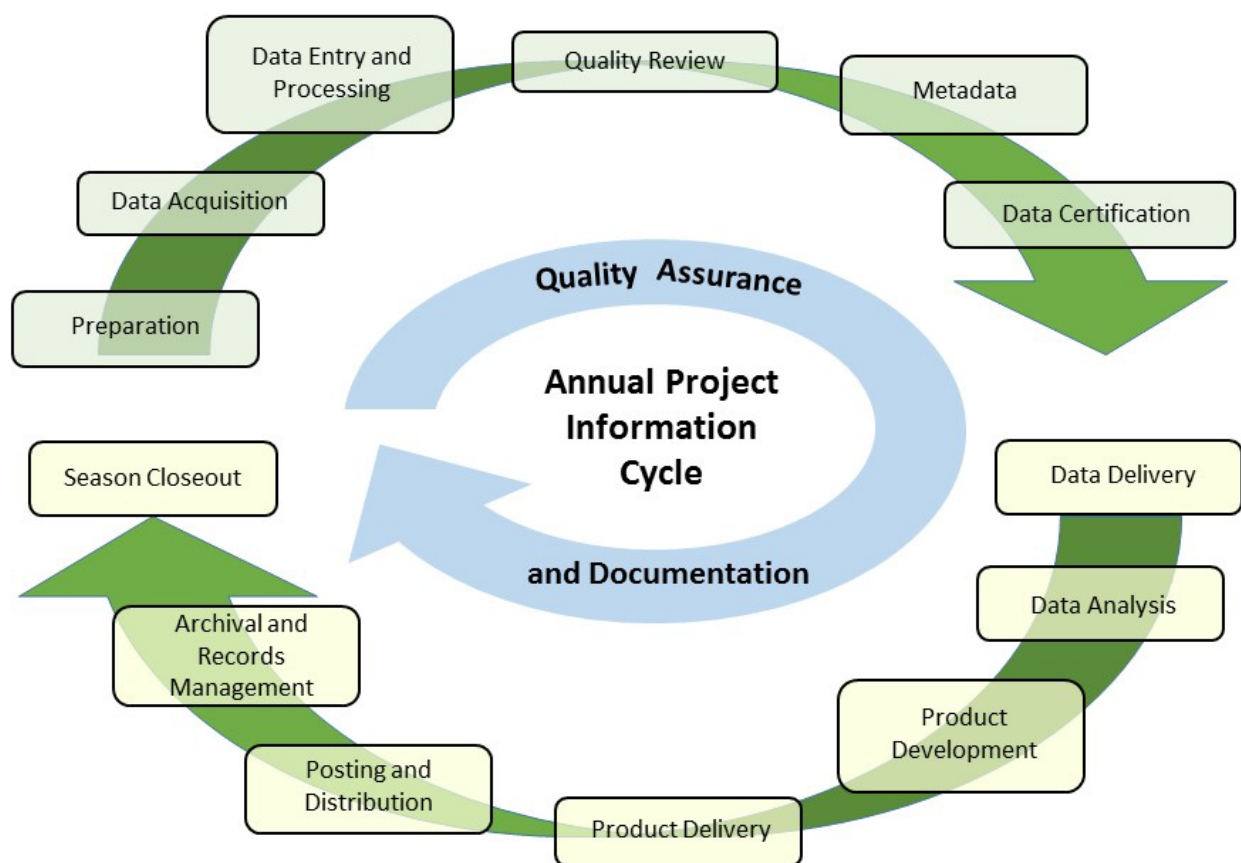


Figure 7. GRYN generalized Annual Project Information Cycle showing the annual start (i.e., preparation stage) and end (i.e., season closeout) points for data associated with GRYN protocols.

6.1 GRYN-generated Data

The Annual Project Information Cycle for manually collected data and associated automated data collection is shown in Figure 8 and summarized below.

- 1) Our annual discharge monitoring campaign will be initiated by a careful review of the GRYN Protocol Implementation Plan for Monitoring Discharge in the Greater Yellowstone Network Parks and its associated standard operating procedures (see Ray et al. 2017).
- 2) Manual discharge measurements will follow standard procedures for wadeable waters (see SOP 1: Discharge Measurement in Wadeable Waters and SOP 2: Volumetric Discharge Measurements in Developed Springs in Ray et al. 2017). Necessary readings will be documented on each sampling trip using field forms (Figures 1-2 and 2-1 in SOPs 1 and 2 from Ray et al. 2017). Copies of field forms and field notes from previous visits will be used to help confirm the results. Results of the previous year's discharge estimates will also be available digitally on-site to provide context for the current estimates.
- 3) Raw water level (stage) or flow datalogger files will be downloaded from loggers and stored as a comma-delimited text (.csv) file. All data files will be viewed graphically along with the record from the previous year in AQUARIUS.
- 4) Manually collected data will be entered into standardized spreadsheets (Figure 1-2 in SOP 1).
- 5) An independent reviewer will perform a 100% quality control check on data from paper forms. Any associated field notes will be reviewed by an independent reviewer for completeness.
- 6) Downloaded data will be uploaded to AQUARIUS as a Data Set to identify data gaps or erroneous data.
- 7) Successfully uploaded data originating from automated loggers and from discrete discharge measurements will be independently reviewed in AQUARIUS.
- 8) Erroneous/suspect data will be flagged and investigated. If flagged data are determined unusable, they will be annotated with documentation to support the decision to exclude them from the analyses. After the review of flagged data, remaining data will be flagged as certified in AQUARIUS.
- 9) The Rating Curve tool in AQUARIUS will be used to develop stage-discharge relationship for GRYN-generated data.
- 10) Daily discharge will be calculated from continuous stage or flow data in AQUARIUS.
- 11) Daily discharge metrics summarized in Table 6 will be calculated from raw certified data.
- 12) Certified data will be uploaded to NPS Data Store and these data are used in analyses.
- 13) Report will be prepared using results of discharge analyses. Once complete, the report, data sets, statistical code, and any other derivative products will be uploaded to NPS Data Store and GRYN's website and managed as a long-term program records.
- 14) Paper field forms will be archived locally, scanned, and uploaded to NPS Data Store annually. On a routine schedule, paper field forms will be sent to national archives.

15) Year-end meeting will be scheduled to review annual activities and products in preparation for next information cycle (Figure 8).

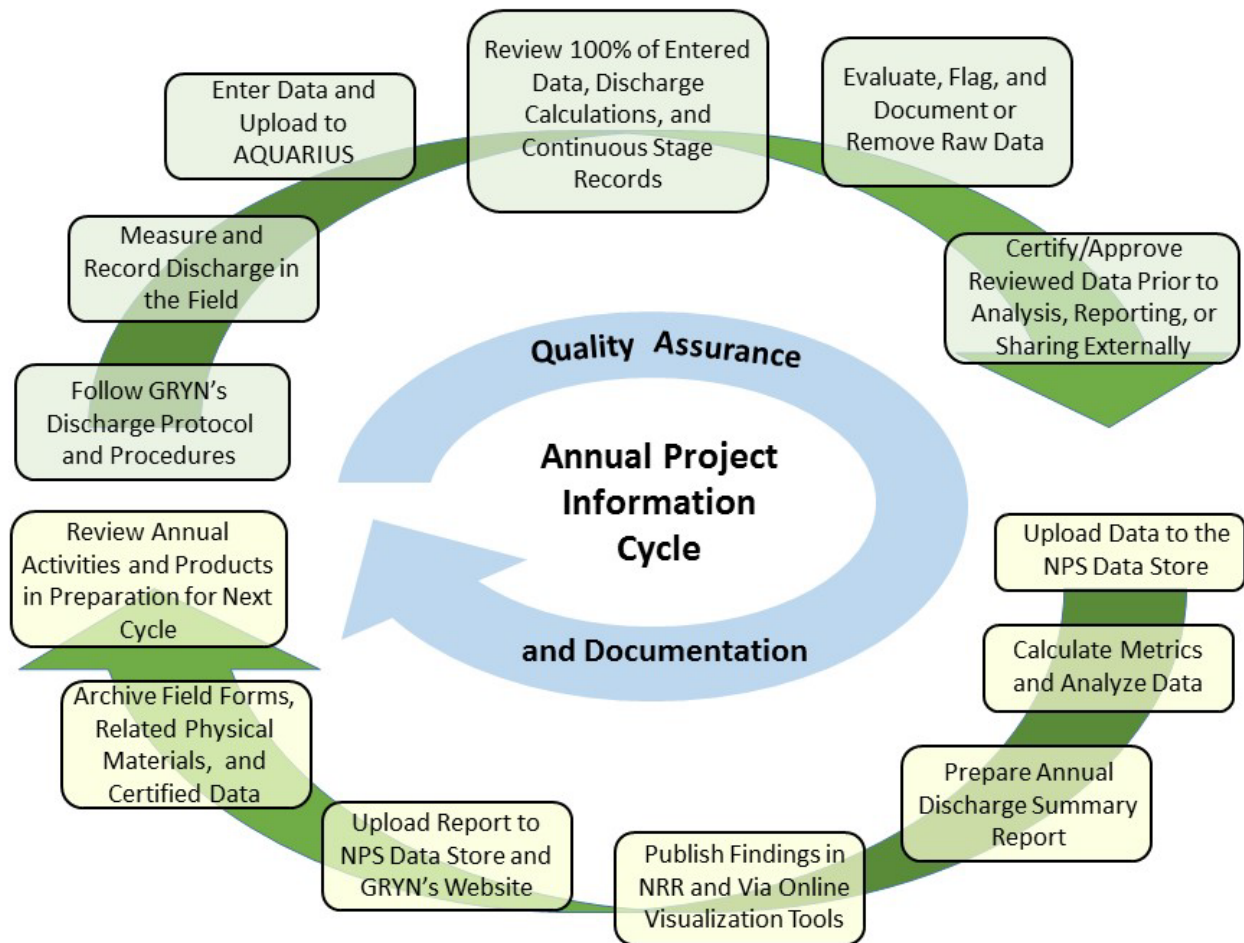


Figure 8. GRYN Annual Project Information Cycle for manual and automated discharge data collection.

6.2 Provider-certified Data

The Annual Project Information Cycle for provider-certified discharge and surface elevation data is described below and in Figure 9. The information cycle for the provider-certified data will be identical to the GRYN-generated data for steps 1 and 12-15 above. However, the use of certified data simplifies the intermediary steps.

- 1) Certified USGS daily discharge and USBR daily surface elevation and pool volume data will be acquired from NWIS and HYDROMET for use in analyses.
- 2) Daily discharge and surface elevation metrics summarized in Tables 6 and 7 will be calculated and analyzed from provider-certified data.

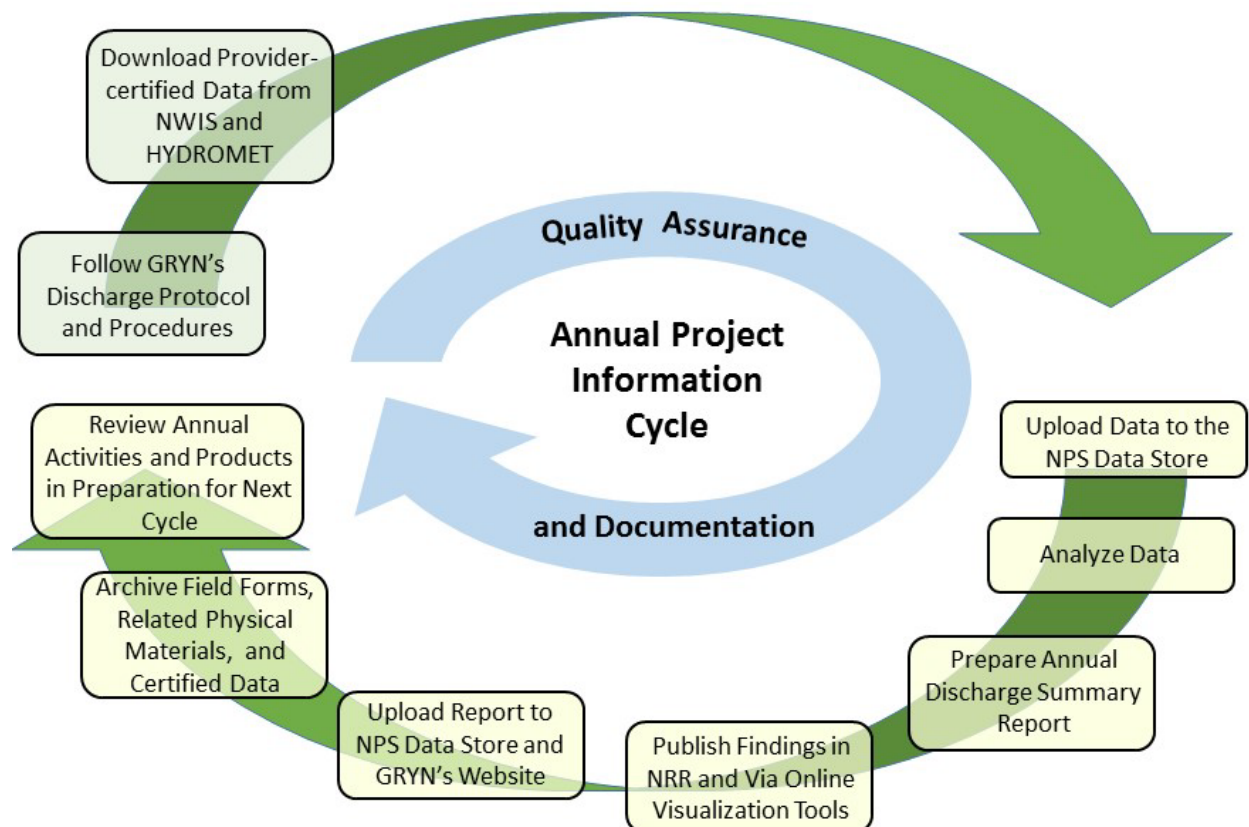


Figure 9. GRYN Annual Project Information Cycle for discharge data downloaded from provider-certified sources (i.e., USGS and USBR).

7 Budget

The estimated annual cost for GRYN's Protocol Implementation Plan for monitoring discharge is presented in Table 8. The workload associated with the protocol implementation plan is predominantly office-based and requires only limited fieldwork at Bighorn Canyon NRA. In addition, there will be startup costs associated with monitoring previously un-gaged systems at the park. We anticipate these costs to be around \$5,000 including equipment and supplies, ecologist and hydrotech time to establish sites, and initial data collection. Once initial costs are incurred, we estimate that the total annual cost to implement this protocol will be between \$31,000 and \$37,000. This includes field time at Bighorn Canyon NRA and personnel time to manage, analyze, and report data collected in the field and downloaded from other sources. In addition GRYN also currently provides \$8,000 annually to support the USGS gaging station on the Snake River at Moose, WY. For the five-year analysis and reporting effort for the protocol, there would be an increased labor cost of approximately \$30,000 for additional time: for the ecologist (0.1 FTE), data manager (0.05 FTE), hydrotech (0.15 FTE), Program Manager (0.02 FTE), and Writer/Editor (0.02 FTE).

Table 8. Estimated annual operating cost (based on FY 2016 dollars) for monitoring discharge. Budget does not reflect matching support provided by parks and partners.

Category	Item Detail	Costs (FY 2016)	Notes
Personnel	Ecologist	\$12,456	0.12 FTE or 3 pp GS-12
	Data Manager	\$4,710	0.04 FTE or 1 pp GS-12
	HydroTech	\$8,456	0.15 FTE or 4pp GS-7
	Program Manager	\$2,500	0.02 FTE or 0.5 pp GS-13
	Writer/Editor	\$1,500	0.02 FTE or 0.5 pp GS-9
	Total Personnel Costs	\$29,622	–
Equipment and Supplies	Water level loggers (3)	\$900	One time purchase with periodic replacements
	Ultrasonic flow meters (2)	\$3,000	One time purchase with periodic replacements
	Total Equipment Costs	\$3,900	–
Annual Service	Flo Mate Calibration	\$300	–
	Ultrasonic Flow meter calibration	\$1,000	–
	USGS Snake River Moose gage	\$8,000	–
Travel to BICA for monitoring (4 trips annually ~ 3 days each)	Travel to BICA for monitoring (4 trips annually ~ 3 days each)	–	–
	Vehicle Travel (450 miles/trip @ \$0.54/mile)	\$972	–
	Accommodations (winter only; 2 people x 2 nights @ \$80/night)	\$320	–

Table 8 (continued) Estimated annual operating cost (based on FY 2016 dollars) for monitoring discharge. Budget does not reflect matching support provided by parks and partners.

Category	Item Detail	Costs (FY 2016)	Notes
Travel to BICA for monitoring (4 trips annually ~ 3 days each) (continued)	Per diem (2 people x 3 days @\$20/day)	\$480	–
	Total Annual Travel Costs	\$1,772	–
Total Annual Protocol Costs	–	\$39,000 - \$44,594	Range depends on equipment purchased, replaced, or calibrated

8 Safety

Implementation of the discharge protocol has few added risks for GRYN's operations since the principal data sources are available online from USGS and USBR. On the other hand, the work conducted at Bighorn Canyon NRA that is specific to spring monitoring is complementary to currently ongoing water quality monitoring work and will be completed during our regularly scheduled quarterly monitoring visits.

The Job Hazard Analyses (JHAs) for GRYN's Water Resources Monitoring program applies to all water related monitoring activities including activities described in this protocol implementation plan that will be carried out at Bighorn Canyon NRA. The Water Resource Monitoring JHA and other relevant JHAs associated with fieldwork and driving apply to all personnel who will assist in the implementation of portions or all of the protocol. To that end, we have identified the principal risks (below and in the JHAs) and the risk abatement strategies (including training needs) in each JHA.

Specific safety concerns and potential hazards related to this protocol implementation plan include:

- 1) Traveling to and from field locations
- 2) Hiking to field sites
- 3) Crossing rivers and streams
- 4) Encountering noxious plants, dangerous animals, disease, and people
- 5) Sampling springs and seeps
- 6) Sampling during high flows or following a storm event
- 7) Exposure to environmental variables

Based on the JHA and associated risk abatement/mitigation actions described in the JHAs it was determined that this GRYN protocol can be safely implemented provided that GRYN and partner staff implement it in accordance with the referenced SOPs and recommended risk abatement actions. Personnel involved with GRYN discharge monitoring must review the relevant documents, SOPs, and JHAs (Table 9) annually. They must sign the JHAs associated with this GRYN protocol implementation plan (see below). In addition, all NPS GRYN personnel will follow the Safe Practices Manual and Emergency Operations Plan specific to the parks where we are working.

Table 9. Relevant JHAs and location on the GRYN server.

JHA	Location on the GRYN Server
Water Resource Monitoring JHA	U:\Admin\Safety\GRYN_safety_plan\GRYN_Job_Hazard_Analysis
Driving Safety JHA	U:\Admin\Safety\GRYN_safety_plan\GRYN_Job_Hazard_Analysis
GRYN Safety Plan	U:\Admin\Safety\GRYN_safety_plan

9 List of Associated Standard Operating Procedures

The following four discharge monitoring standard operating procedures (SOPs) can be found in the accompanying SOP document (Ray et al. 2017).

SOP 1. Discharge Measurement in Wadeable Waters

SOP 2. Volumetric Discharge Measurements from Developed Springs

SOP 3 Rating Curve Development in AQUARIUS from Automated Water-Level Measurements

SOP 4 How to Analyze, Track, and Report USGS Discharge Data

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Appendix A. Job Hazards and Risk Assessment

(Updated May 2016)

This appendix contains the current GRYN Job Hazard Analyses (JHAs) for Water Resource Monitoring, Driving, and Office Work.

In addition, GRYN has considered the application of the GREEN-AMBER-RED (GAR) Risk Assessment Model as outlined in the NPS Operational Leadership Student Manual (Version 2; July 2011) for water-related and other field activities in Bighorn Canyon NRA, the park where the bulk of the manual and automated discharge monitoring work described in this GRYN protocol implementation plan will take place. The GAR model is a general assessment of a task or operation and generates communication concerning the risks of an activity (in this case, carrying out discharge measurements in the field – the field-based activities associated with this protocol implementation plan). The most important part of the process is the team discussions prior to potentially hazardous activities or tasks that will lead to a better understanding of the risks and how they will be managed.

A GAR assessment for all GRYN fieldwork including water quality and discharge monitoring of spring outflows and seeps in Bighorn Canyon NRA was conducted on 6 March 2013 and involved GRYN and park staff. We have integrated the results of this GAR assessment into the JHAs associated with the Protocol Implementation Plan for Monitoring Discharge in the Greater Yellowstone Network Parks.

JOB HAZARD ANALYSIS	JOB TITLE (and number if applicable): GRYN Water Resource Monitoring	DATE: 02/06/2013	NEW REVISED 5/2016 EKS	X
	Title of Person Who Does the Job: Aquatic Ecologist, field technicians, and others (i.e. university interns/students) assigned to field work	Analysis By: Andrew Ray		
	Supervisor: Kristin Legg	Reviewed By: Cathie Jean (2/28/2013)		
Park: Greater Yellowstone Network Parks	Division: Inventory and Monitoring	Approved By: Kristin Legg (last reviewed 2017)		
REQUIRED AND/OR RECOMMENDED PERSONAL PROTECTIVE EQUIPMENT:				
1. Sturdy hiking boots 2. Person flotation Device (U.S. Coast Guard Type I) 3. Waders (chest-high with a belt) 4. Walking/wading staff 5. Long pants 6. Sun hat, sunscreen and polarized sunglasses 7. Personal water bottles 8. First aid kit 9. Communication equipment 10. Safety whistle		11. Insect repellent (head net) 12. Compass / GPS unit 13. Maps 14. Emergency contact information 15. Extra warm clothing 16. Rain gear 17. Food 18. Throw rope/throw bag 19. Bear spray		
SEQUENCE OF BASIC JOB STEPS	POTENTIAL HAZARDS	RECOMMENDED ACTION OR PROCEDURE		
Calibrating Water Quality Monitoring Equipment	Exposure to sharp objects when cleaning and calibrating equipment.	• Carefully inspect equipment for sharp objects (e.g. sharp edges to probes or broken glass bulb on pH electrode) or foreign objects that may have been collected in instruments that occurred during previous use. • Follow manufactures recommendations for proper cleaning of instruments and probes.		
	Exposure to calibration chemicals	• Review and display MSDS sheets for all calibration standards. • Know proper storage, handling, and disposal recommendations for each calibrant. • Wear safety goggles, rubber gloves, and a water proof apron when calibrating equipment. • Locate rinse and eye wash stations prior to initiating		

		- calibration. - Emergency contact information should be displayed in the event of exposure or spills.
Travel to and from Field Locations In Vehicle	Refer to GRYN Driving Safety JHA	Refer to GRYN Driving Safety JHA
Communication (please follow check-in, check-out procedures and emergency contact in Safety Plan)	Loss of contact with field partner(s)/team member(s)	- Stay together. Do not leave work partner (maintain a distance of no more than 50 yards); if hiking on a trail, stop at regular intervals to let partner catch-up; if hiking off trail, stay within visual distance of one another. - Communicate off trail routes prior to continuing. - Make sure radios are charged and on the correct channel. - Use cell phone (if available and coverage), as this may be more reliable for communication in remote locations. - Establish regular contact/meeting times where failure to contact triggers emergency procedures. - Clearly establish triggers for emergency procedures, avoid false alarms. - Separate communication devices so that they are not held by the same person. - Carry SPOT Locator beacon and use it if partner can't be found and there is an emergency situation. - Sound safety whistle to help others locate your position.
	Unable to reach a radio repeater in a remote location	- Check to make sure radio is on the correct channel. - Make sure radio is charged- try to contact someone on the radio to inform him/her of your predicament; if you are unable to reach a repeater from your location, seek higher grounds by climbing upslope toward a ridge top or knoll and try again; try at regular intervals, meandering around may help in getting a signal. - Use cell or satellite phone (if available), as this may be more reliable for communication in remote locations. - Using SPOT locator beacon to check in regularly and if needed to contact Search and Rescue personnel to initiate a rescue. - If unable to make contact, return to front-country ASAP & contact project coordinator, program manager or safety officer.
	SPOT locator beacon does not work; cannot make verbal contact with GRYN staff	- Use radio to contact Park dispatch to relay message on safety status and to notify project coordinator about SPOT malfunction. - If unable to make contact, return to front-country ASAP & contact project coordinator, program manager or safety officer.
Hiking to Field/Sampling Sites	Steep, rugged, and slippery terrain	Assess terrain conditions to find safe route and modify sampling plans to avoid unsafe areas; proper footwear is VERY important- wear boots with slip-resistant soles with toes well above the ankle. broken in before the field

		season, plus extra socks, NO TENNIS SHOES or open toed sandals. • Maintain an erect posture when contouring steep slopes; avoid walking below another person due to the potential for rocks to dislodge from above. • Avoid walking across waterfalls or spring discharge points when possible. • Avoid walking or hiking routes that have extended sections with wet, moss covered substrates. • If you knock a rock off call out "rock" to notify those below you that a rock is falling. • No glissading allowed through snow fields or sliding down waterfalls or moss covered slopes.
	Undergrowth	• Wear safety glasses (or other glasses) when hiking in brushy areas to protect eyes from protruding objects.
	Rocks/climbing	• Vertical climbing should be avoided unless outfitted with proper rock climbing gear and you are trained. • Avoid routes that require extensive scrambling or climbing up waterfalls or moss covered rocks. • Be aware of loose debris when moving up slope. Test rocks that may be used as holds, stay out of their path when testing. When below someone stay out of way of falling debris.
	Crossing fences	• When possible use gates (leave them open or closed depending on how you find them) if no gate is available cross under or over with caution. • Assist other crew members by holding fence wire apart, pass pack over first to help with balance.
	Blisters and/or foot problems, sprained knees or ankles	• Exchange wet socks with dry socks to mitigate blisters. • Treat immediately to prevent increased damage. • Turn around and return home if ankle or knee is sprained.
Backpacking with Heavy Loads to Field Sites	Heavy, excessive loads and load instability	• Carry no more than 1/3 of your body weight but not more than 60 lbs while traveling in the backcountry. • When carrying heavy loads, pack the gear so that heavy equipment is carried low on your back to increase stability. • Consider using hiking poles (especially when crossing rivers and streams). • Assess equipment needs to ensure only required equipment is being carried. • Use good backpack with hip belt to better distribute weight.
	Muscular pain & soreness	• Stay in condition by using callisthenic exercises that focus on body strength, endurance and flexibility. Start slowly to ensure muscle groups are given adequate time to warm up. Use stretching exercises before starting.

		- Don't continue if a problem is encountered that could lead to an accident. - Turn around if there is a sprained knee/ankle, back, etc.
	Fatigue	Take frequent breaks for food and water. Plan trips such that hiking distance is reasonable.
	Back strain	Lift loads with your legs to avoid back injuries.
Crossing Rivers & Streams	Falling and being swept downstream	- Review "Back and Beyond" safety video. - Don't cross moving water more than waist deep or where velocity is so fast that safe footing is impossible. - Use the "floating stick" method to determine if water is moving too quickly to cross --- toss a stick into the water, if the floating stick moves faster than you can walk, waters are potentially unsafe to cross. - Choose a safe location for crossing streams. Usually, ripples and/or wider stretches indicate shallower water. The area should be free of large debris. - Assess terrain downstream for a safe place to get out should you fall in and for downstream hazards. - Pack away excess clothing, as wet clothing increases weight and can drag a person down if swept into the water. - Use appropriate footwear or chest waders when crossing; waders should already be part of gear. - Unbuckle pack so that it can be shed in case of a fall. - Cross one at a time; always watch your partner while they are crossing. - Use pole or wading staff for added stability. - When crossing, move and look upstream to identify any objects that may be floating downstream. - Lean slightly into the current and shuffle sideways at a slight angle in an upstream direction. - If swept downstream, float with feet downstream to bounce off obstacles and protect head. - If helping someone who has fallen make sure you are in a safe spot and will not be pulled in. - Use a throw rope to provide an emergency line to someone that is in the water and in need of emergency assistance. Make sure to tie the rope to a secure structure immediately after contact is made with the target.
Encountering noxious plants, dangerous animals, disease, and people	Bees/Wasps/Hornets	- Determine if any field crew are allergic to bee stings. - Notify other crew members and the supervisor if you know you are allergic to bee stings. - Ensure that individual carries prescribed medication to prevent anaphylactic shock and that they know how to use and safely handle the EpiPen; carry a bee sting kit or Benadryl or other antihistamine. - Be aware of the ground where you step- some hornets

		build nests in the ground at the base of trees or shrubs, or in rotten logs- watch for bees buzzing in and out of holes or around ground level.
	Ticks	• Avoid tick bites by wearing protective clothing (long pants and shirts with long sleeves). • If bitten by a tick, remove it (grasp tick with tweezers at head and pull straight out); keep in plastic container (if possible) or tape it to a piece of paper, and keep it in the event of illness. Notify supervisor you were bitten by a tick. Fill out an accident report in the event that symptoms of Lyme disease or other tick related disease appear later.
	Mosquitoes	• Wear bug repellent and long sleeve shirt to prevent bites; be aware of West Nile Virus symptoms. • At the height of the bug season, use mosquito head nets (bed nets for cabins too).
	Mountain lions/wolves	• Avoid mountain lions/wolves; if you encounter a lion that doesn't run from you- leave the area; if attacked- fight back using rocks and sticks or whatever you may have! Stay big and try not to crouch down. • Be aware during dawn and dusk time periods. • Always work in groups of two or more. • Report all mountain lion/wolves sightings to supervisor. If there is an incident, report as soon as possible. • Use bear spray if you have to.
	Bears (Black and Grizzly)	• Work in groups of two or more. If necessary post a look out who can watch for bears and let others know the bears location if spotted. • Prevent surprise encounters by making plenty of noise, especially when working near running water. • When working in Grizzly bear habitat, carry bear spray on your body where it is accessible at all times. Do not leave behind with your pack. • Be extremely careful with bear spray so that you don't accidentally spray yourself or a member of your group. • Select travel routes to avoid walking in ecotones (edge of forest/meadow) where bears take naps/daybeds or where they may feed on carcass. • Keep bears at a distance; detour as far as possible behind and downwind of the bear. • Don't leave food or beverages unattended. • Follow safety food storage orders. Properly store food, thoroughly wash dishes and keep a clean camp area. Set up camp to keep sleeping and cooking areas separate. • Continue to make noise while working at the sampling site. • Participate in annual bear safety training.

		- Report all bear sightings to supervisor. - Any incidents with a bear need to be reported immediately to a park ranger or staff.
	Zoonotic Disease (bubonic plague, Hanta Virus, rabies)	- Stay away from dead rodents and rodent feces, especially in closed buildings. - Do not handle any species of dead animal unless trained to do so. Larger animals can carry disease as well. - Use a solution of bleach/water to spray feces for clean up. - Beware of symptoms, if you have been in an area or feel that you might have been exposed tell your supervisor. If you feel at all sick go to a doctor and notify them of potential exposure. Tell the doctor what you do if you get sick during the field season.
	Encounters with strangers	- Report uncomfortable encounters with strangers to the law enforcement, agency Lead or Dispatch and supervisor as soon as possible. - Report apparent illegal activity to a NPS park ranger or USFS law enforcement officer. - Do not get into a confrontation with others on the trail or campgrounds, leave the area as quickly as possible without alerting the individual. - If not able to get to a vehicle or safe location and an incident is occurring try to find a safe place to take cover until you can move to safety and reach help.
	Treatment of general injuries	- All field crew members should have current first aid and CPR certification. - Remain calm if there is an injury. - Call for emergency help if needed do not feel the need to self-rescue. - Report any injury no matter how minor to supervisor.
Collecting Water from Rivers and Streams	Wading in flowing water	- Wear a U.S. Coast Guard approved Type I or Type II Personal Flotation Device when working in water that is over knee deep. - Always use intact, properly fitting waders with a belt strap, when sampling water that is above knee deep. - Even with PFD, don't wade into water that is more than waist deep especially when turbidity limits your ability to see into the water column or when the current is swift. - Avoid wading through areas with large accumulations of woody debris (i.e. downed trees or near beaver lodges). - Pack away excess clothing, as wet clothing increases weight and can easily hang up on branches or downed materials hidden just beneath the water surface. - If wearing a pack while wading, unbuckle pack so that it can be shed easily in the event that you lose your footing. - Use pole or wading staff for added stability when

		surveying in flowing water or in backwaters with soft substrates. - Wade into flowing water one at a time; always watch and listen for your partner while they are collecting water in streams. - If helping someone who has lost their footing or is mired in soft substrates, make sure you are in a safe spot or on firm ground; use a staff or throw rope to provide a line that your survey partner can use to self-extract.
	Drowning	- Wear a U.S. Coast Guard approved Type I or Type II Personal Flotation Device when working in water that is over knee deep. - Always wear chest waders with a waist belt when wading in rivers and streams; waist belts will trap air in lower part of waders and allow you to float in the event of a fall. - Use a wading staff to aid in travel through standing water. - Use polarized sunglasses to help identify debris and other materials below the water surface. - Stay within earshot and sight of your survey partner. Be sure to check on partner every few minutes visually or verbally if you can't see them. - Have a throw rope available in the event that an emergency line can aid in safe extraction of someone working in standing water. - Be familiar with using CPR and other first aid techniques in case partner has fallen/drowned in water.
Sampling during High Flows or Following a Storm Event	Exposure to High Flows	- Never wade into water that is more than waist deep especially when turbidity limits your ability to see into the water column or when a storm is approaching. - Wear a U.S. Coast Guard approved Type I or Type II Personal Flotation Device when working in water that is over knee deep. - Always use intact, properly fitting waders with a belt strap, when sampling water that is above knee deep. - Use a wading staff. - Have a partner watch as water is collected; have a throw rope ready for use in the event that the sampler loses footing. - Be familiar with using CPR and other first aid techniques in case partner has fallen/drowned in water.
	Sampling During a Storm Event	- If heavy precipitation occurs or is approaching; leave the stream/river immediately. - If lightning is seen, exit the water immediately and get into vehicle or seek a safe, protected location. This may mean moving to lower elevations away from isolated trees and

		crouch down on the balls of your feet to reduce ground contact. • Make sure you are not in a stream drainage that could have a flash flood.
Sampling Springs and Seeps	Mired in soft substrates	• Don't wade into water that is more than waist deep especially when turbidity limits your ability to see into the water column. • Avoid wading through areas with large accumulations of woody debris (i.e. downed trees). • Pack away excess clothing, as wet clothing increases weight and can easily hang up on branches or downed materials hidden just beneath the water surface. • Use waders when surveying springs/seeps. • Unbuckle pack so that it can be shed easily in the event that you become caught in soft substrates. • Use pole or wading staff for added stability when surveying in springs, seeps, or sampling locations with soft substrates. • Wade into springs, seeps, or areas with soft substrates one at a time; always watch and listen for your partner while they are surveying in springs, seeps, or areas with soft substrates. • If helping someone who is mired in soft substrates, make sure you are in a safe spot or on firm ground; use a staff or throw rope to provide a line that your survey partner can use to self-extract from the mud.
	Drowning	• Wear a U.S. Coast Guard approved Type I or Type II Personal Flotation Device when working in water that is over knee deep. • Always wear chest waders with a waist belt when wading in springs and seeps; waist belts will trap air in lower part of waders and allow you to float in the event of a fall. • Use a wading staff to aid in travel through standing water. • Use polarized sunglasses to help identify debris and other materials below the water surface. • Stay within earshot and sight of your survey partner. Be sure to check on partner every few minutes visually or verbally if you can't see them. • Have a throw rope available in the event that an emergency line can aid in safe extraction of someone working in standing water. • Be familiar with using CPR and other first aid techniques in case partner has fallen/drowned in water.
Exposure to environmental variables	Hypothermia	• Always anticipate bad weather and dress accordingly, and carry warm clothes with you. • Keep clothing as dry as possible; use synthetic fleece and

		non-cotton outdoor clothing in inclement weather. • Eat high energy nutritional supplements between meals. • Cover the head and neck to prevent heat loss. • Keep active to maintain the body's metabolism. • Drink plenty of liquids to prevent dehydration (even when you are not thirsty). • Drink warm liquids not cold; understand the effects of cold and wind; most hypothermia cases develop between 30F and 50F. • If cold, take actions to warm your body to prevent hypothermia.
	Hyperthermia	Hyperthermia may occur during high temperatures (extreme risk @ temperatures > 120 degrees F), monitor for: • dehydration, heat exhaustion, heat cramps, and heat stroke; symptoms include nausea, headache, and flushed, red skin. • Drink plenty of water (even when you are not thirsty), supplement water with energy drink to help prevent salt loss. • As heat increases, take frequent breaks in cool locations. • Wear a light shirt and a hat with a good brim. • When starting to work in hotter conditions than your body is acclimated to, start slowly to build up your resistance to the heat. • Get out of the heat and stop fieldwork if necessary.
	Exposure to <i>giardia</i> , <i>E. coli</i> , or other pathogens caused by drinking contaminated water	• Consider all streams contaminated and avoid drinking unless purified. • Carry plenty of water on outings; also carry water treatment tablets. • On long outings, carry a water filter.
	Sunburn	• Field work takes place in full sunlight so use 30+ or greater SPF sunscreen and lip balm; use 45+ SPF when working above 10,000 feet. • Wear a hat, sunglasses, and shirt. Keep an eye out for your partner, let them know if they look like they are getting too much sun.
	Adverse weather such as thunderstorms, lightning and wind	• Check weather before heading into the field. If there are significant storm warnings consider delaying trip. Don't go. • Avoid exposed ridge tops and being on or near lakes, meadows or other exposed areas if thunderstorms are approaching or developing nearby. • Move to lower elevations away from tall trees as storms approach. • If hair begins to stand up, immediately minimize exposure by moving to lower elevations away from isolated trees

		and crouch down on the balls of your feet to reduce ground contact. • Watch for hazard trees and listen for falling trees. • Find a safe spot in a wind event or if possible, leave the area. Seek refuge in a building or car if possible.
Collecting Waters at Multiple Sampling Locations	Complacency	• Keep in visual sight (or sound) of coworker. • Keep bear spray with you at all times on your body. • Keep note of where you drop your pack so that you can quickly reach food/water (remember food cannot be left unattended on the ground). • Continue to make noise while working across multiple locations. • Continue to watch the weather. • Watch for hazard trees. • Watch for footing and tripping hazards. • Be as vigilant leaving the sampling location as you are going to the sampling location. • Make noise while preparing gear and materials to leave. • Review possible safety concerns and mitigations even for repetitive tasks to avoid complacency and increase awareness.
	Repetitious movement (looking down into the water)	• Exchange between observer and recorder to minimize repetitious movement. • Take breaks as needed to stay alert and fresh. • Take time to stretch periodically.
Bottling and Preserving Samples	Exposure to Preservation Chemicals	• Always wear protective glasses and laboratory gloves when handling preservatives or acidification agents (e.g. H_2SO_4, HNO_3). • Dispose of spent preservative containers into a properly labeled bag. • Maintain MSDS sheets in vehicle. • Have a field portable eyewash station in vehicle with sterile isotonic solutions for washing or irrigating eyes. • Maintain an emergency contact list in work vehicles that identifies individuals to contact in the event of chemical exposure. • Seek medical attention immediately if chemical exposure to eyes or skin occurs.

Packaging, Carrying, or Shipping Water Samples	Back strain associated with carrying large volumes of water or heavy coolers	• Lift with the legs; use a dolly or similar device to carry heavy loads (when possible). • Take multiple trips or use multiple coolers to keep loads at or below 40 lbs. • Use the buddy system to carry large or awkward gear/coolers.																								
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JOB HAZARD ANALYSIS	JOB TITLE (and number if applicable): Driving Safety	DATE: 05/14/2013	NEW 05/15/2016	X
	Title of Person Who Does the Job: All GRYN employees	Analysis By: Erin Shanahan		
	Supervisor: Kristin Legg	Reviewed By:		
Park: Greater Yellowstone Network Parks	Division: Inventory and Monitoring	Approved By: Kristin Legg (last reviewed 2017)		
REQUIRED AND/OR RECOMMENDED PERSONAL PROTECTIVE EQUIPMENT: 20. Two or more high-visibility safety road vests 21. Functioning seatbelts for all passengers				
SEQUENCE OF BASIC JOB STEPS	POTENTIAL HAZARDS	RECOMMENDED ACTION OR PROCEDURE		
Vehicle Maintenance including pre-driving inspections	- Vehicle malfunctions leading to breakdown, injury or accident - In the event of a breakdown, lack of crucial equipment that might be needed - Accidents or injuries caused from unsecured items	- Take the vehicle in for regular scheduled maintenance or when any problem arises with vehicle performance - Familiarize yourself with the tire jack, spare tire, tools and other vehicle equipment. - Check that the vehicle has appropriate equipment such as a first-aid kit, safety vests and cone, snow or fire shovel and an ice scraper. - Do a walk around of vehicle. Inspecting for damage and potential hazards. - Ensure tires are inflated to proper psi - Secure all items that might become projectiles in the event of a crash. - Always drive with headlights on (be sure to turn off when not driving).		
Driving to and from destination on paved roads	- Accidents from following a vehicle too closely or driving too fast for conditions - Collisions with other vehicles or animals and/or driving off road surface due to inattention or impairment (e.g. tired or sleepy) - Collisions due to driving when visibility is impaired due to elements (rain, fog, smoke, snow, sun in eyes, etc). - Other motorists' errors	- Obey speed limits and slow down if road conditions become slick, rough, or congested with traffic - Pay attention at all times. Do not talk on a cell phone or text while driving. Keep eyes facing forward and check mirrors frequently. - Choose the safest route such as a road with a divider stripe and passing lanes - Be especially careful on curves and stay within your lane - If you must drive a road without a lane divider, reduce		

		speed and allow at least 4 seconds between you and the vehicle ahead of you. • Ensure adequate rest. Have the passenger stay alert and communicate hazards with driver. • Drive defensively. Assume everyone you encounter on a roadway as a potential threat. • Make sure to have a clean windshield to improve visibility • Drive with two hands on the wheel in the 10 and 2 position.
Driving to and from destination on unpaved, dirt, or damaged roads,	• Accidents (collisions, sliding off road) • Getting stuck in the mud • Falling hazards on road way • Road becomes impassible following afternoon rain shower • Rocks being thrown from passing vehicles • Blind corners with oncoming traffic	• Reduce speed • On very bad roads, scout ahead if in doubt. • Park and walk. • Report hazards such as fallen rocks or trees to park or forest service dispatch • Carry a hand saw, Pulaski and tow strap • On blind corners proceed slowly, stay as much as possible on your side of the road and honk the horn if necessary • Drive with two hands on the wheel in the 10 and 2 position.
Driving to and from destination on slippery roads (rain, ice, snow, mud)	• Accidents (collisions, sliding off road)	• Reduce speed • Engage proper equipment such as snow tires, 4-wheel drive, or tire chains • Don't continue if conditions are bad. Find an alternate route or wait for the conditions to clear. • Drive with two hands on the wheel in the 10 and 2 position.
Driving to and from destination at night	• Potential for collisions with pedestrians, animals and other obstacles that are not visible • Accidents due to fatigue	• Turn headlights on; keep windshield and headlights clean • Use high beams when able • Reduce speed • Schedule trip to ensure driver is well rested and during daylight hours when possible. • Pull over and rest if sleepy • Drive with two hands on the wheel in the 10 and 2 position. • Passenger remains engaged and pays attention
Towing trailer	• Collisions due to extra weight of load, extra length and greater stopping distances • Back-up problems • Wind shear • Wide turns create conditions where tires are on curb and/or trailer touches obstacles outside the regular road prism	• Reduce speed • Allow 6 or more seconds between you and the vehicle ahead of you to allow stopping time. • Practice backing up with a trailer in a safe environment such as an empty parking lot. • Lengthen your turns & watch side-view mirrors • Make sure there are enough hands available to attach

	• Getting pinched or injured while attaching trailer to vehicle • Inoperable trailer lights causing accidents • Trailer comes off hitch	the trailer to the vehicle. • Check trailer lights once connected to the vehicle • Drive with two hands on the wheel in the 10 and 2 position. • Use hazard lights when ascending and descending grades at low speed • Make sure the hitch and ball match. • Attach safety chains from trailer to vehicle.
Emergency / breakdown	• Exposure due to being stranded • Being hit by passing vehicles • Injury while changing flat tires or other vehicle equipment and jumping a vehicle to get started	• If possible, pull off road • If there is risk of being hit by passing traffic, turn on four-way hazard flashers. Use cones or flares 200-300 ft from car to provide a buffer around your vehicle. • If you need to stand on or near roadway, wear a safety road vest. Stay on road shoulder away from the moving traffic • Carry extra water, food and clothing • Do not leave the vehicle unless you know you are able to reach help or being transported by someone. • Follow instructions on how to replace flat tires or jumping a vehicle. Do not do if uncomfortable or do not have experience/training.
Parking and backing	• Collision with rocks, pedestrian or other hazard while backing into or out of a parking site • Exhaust system igniting a grass fire • Parked vehicle moving on its own.	• Back into parking spots instead of pulling straight in. Park off of the road or in a designated parking area. Find a safe location to park that will provide safe exiting • Put transmission in Park or in low gear. If parking on a slope, set parking break. • Ensure that fuels (e.g. tall grass) are clear beneath vehicle so as not to start a fire. • Use a backer to guide you into a safe place that will be easy to pull forward out of later. Use mirrors and/or look over your shoulder. If no backer is available, walk around the vehicle before moving from a parked position and tap horn. • On grades, use chalk blocks on downhill side of tires to keep vehicle from moving forward or backwards.
Driving – physical and mental fatigue; chemical fatigue (e.g. allergy medicine)	• Accidents results from falling asleep at the wheel or from poor judgment • Co-pilot (passenger) falls asleep.	• Get needed rest. Avoid driving when tired and take breaks as needed. Be particularly cautious when driving late at night or early in the morning. • If a replacement driver is available, trade off driving when you start to feel tired. • If no replacement driver is available, pull off the road and take a break, stretch and/or a short nap. • Plan the trip so that no person will be driving more than 10 hours.

		• Plan the work day so that no person will be driving after a combined total (work & driving) of 12 hours in a single day and 10 hours if by yourself. • Passenger is alert and communicating with the driver before sleeping.																								
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JOB HAZARD ANALYSIS	JOB TITLE (and number if applicable): Office Safety	DATE: 03/01/2017	NEW	X
	Title of Person Who Does the Job: All GRYN employees	Analysis By: Andrew Ray		
	Supervisor: Kristin Legg	Reviewed By:		
Park: Greater Yellowstone Network Parks	Division: Inventory and Monitoring	Approved By: Kristin Legg (last reviewed 2017)		
REQUIRED AND/OR RECOMMENDED PERSONAL PROTECTIVE EQUIPMENT:				
SEQUENCE OF BASIC JOB STEPS		POTENTIAL HAZARDS	RECOMMENDED ACTION OR PROCEDURE	
Computer Use Fatigue	• Back pain/musculoskeletal disorders • Tendonitis • Carpal Tunnel	• Switch positions throughout the day • Be intentional about maintaining good posture • Consider use of ergonomically designed desks and chairs • Take regular exercise breaks • Educate oneself and co-workers about the risk factors associated with musculoskeletal disorders • Encourage early reporting of signs and symptoms of computer use fatigue • Use ergonomically designed mouse and keyboard pads		
Computer Use Eye Strain	• Eye stress • Blurred vision • Headaches • Dizziness	• Use proper lighting in work environment • Do not sit too close to computer screen • Use a non-glare computer screen • Take regular breaks and encourage the use of screen prompts as a reminder of the importance of breaks		
Carpal Tunnel Syndrome	• Stiffness in wrists and hands • Numbness and loss of dexterity	• Use ergonomically designed mouse and keyboard pads • Encourage early reporting of signs and symptoms • Take regular breaks • Allow rest days by varying activities		
Electrical Cords and Electrical Hazards	• Fire • Shocks • Trips • Falls • Sprains	• Do not overload outlets • Use surge protectors for computer equipment • Keep cords organized and free from walking paths • Never use personal space heaters in government buildings without approval from supervisor and facility manager		

Indoor Supplies and Activities	• Trips • Falls • Slips • Sprains • Hit by falling/overhead objects • Burns	• Keep work areas clean and organized • Keep drawers closed when not in use • Use step ladders for out-of-reach supplies. Never use a chair as a step ladder • Use proper containers and storage for supplies • Follow MSDS rules and recommendations for use of any chemicals. • Walk around office -- do not run • Watch out for potential tripping hazards. Follow good housekeeping practices, including closing drawers, properly disposing of wasted, and properly storing materials and equipment when not in use. • Make sure office chairs are in good working order • Report maintenance issues/concerns to building supervisors immediately (e.g. wet floor or leaky toilet, torn carpet)
Inadequate Lighting and Poor Air Circulation	• Eye strain • Dry and irritated eyes • Headaches • Fatigue • Shortness of breath • Hypersensitivity to allergens • Sinus congestion • Coughing/sneezing • Dizziness • Nausea	• Take regular breaks • Keep office/lab door open • Alternate indoor and outdoor activities • Turn lights on and off
Lacerations and Punctures	• Paper lacerations • Lacerations from scissors or paper cutters • Punctures from staplers	• Carefully use office equipment and be mindful of sharp edges • Do not use equipment that is not completely functional/operational (e.g., do not use paper cutters with a missing or broken guard) • Keep fingers and hands away from contact points
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The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 101/140432, 617/140432, 136/140432, 642/140432, October 2017

National Park Service
U.S. Department of the Interior



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