**Draft plan for monitoring effects of geomorphic processes at archaeological sites in Grand & Glen Canyon**

Draft prepared as originally proposed in: Project Element 4.2. of the Glen Canyon Dam Adaptive Management Program Triennial Budget and Work Plan—Fiscal Years 2015–2017

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Prepared by:

Joel B. Sankey, USGS, Grand Canyon Monitoring and Research Center

Helen Fairley, USGS, Grand Canyon Monitoring and Research Center

Joshua Caster, USGS, Grand Canyon Monitoring and Research Center

Amy East, USGS, Pacific Coastal and Marine Science Center

**Monitoring Goals, Objectives, and Questions:**

The USGS Grand Canyon Monitoring and Research Center will implement this plan to monitor effects of dam operations to archaeological sites. Monitoring will focus on whether and how flow and non-flow actions affect the condition of archaeological sites located in the river corridor downstream of Glen Canyon Dam. The GCMRC will intentionally focus on effects of geomorphic processes that are influenced by operations or other non-flow actions which may be undertaken during the next 20 years, with a specific focus on documenting whether and how they affect the physical condition of archaeological sites.

The GCMRC is cognizant that the National Park Service at Grand Canyon National Park and Glen Canyon National Recreation Area and the Hopi, Hualapai, Navajo, Kaibab Southern Paiute, and Zuni Native American tribes have existing programs to monitor cultural resource sites and related resources of interest. Those monitoring programs are in place to assess changes to historic integrity or changes to intrinsic cultural values of historic properties, which differs from the GCMRC focus on quantifying effects of geomorphic processes on the physical condition of historic properties (primarily archaeological sites). The intention of GCMRC is to not duplicate any of the current ongoing monitoring efforts of those other monitoring programs but to complement them, if possible.

The GCMRC is cognizant that aspects of this monitoring plan will have significant and differing relevance to resource managers and stakeholders of the Glen Canyon Dam Adaptive Management Program. For example, some specific aspects of this monitoring plan will be relevant to the requirements of the new Programmatic Agreement for which the Bureau of Reclamation has the lead. As such, the Bureau of Reclamation and other signatories to the PA may wish to cite within that agreement the specific monitoring questions and data interpretations within this GCMRC monitoring plan that are relevant to their stated requirements. Certain aspects of the monitoring implemented with this plan pertain to whether and how dam-controlled flows affect the condition of National Register eligible historic properties in lower Glen and Grand Canyons. Certain aspects of the monitoring will be directly relevant to how flow and non-flow actions implemented by the LTEMP ROD affect the condition of archaeological sites. Some of the monitoring implemented with this plan also will be relevant to the requirements of the Grand Canyon Protection Act.

This monitoring plan is designed to answer the following questions:

1. How do differences in the potential for sites to receive windblown sand from the active river channel and controlled-flood deposits affect site condition over time?
   1. How does (i) the presence and characteristics of rills, gullies and arroyos (drainages), and (ii) overall degree of erosion at the sites change over time relative to the influx and deposition of windblown sand from river deposits?
   2. Do sites where adjacent, upwind fluvial sediment deposits form by high flow events, and unimpeded aeolian sand transport occurs from the flood deposit toward the sites, show different types of surface change and less erosion by gullies and overland flow than other types of sites where either lack of sediment source, presence of transport barriers, or drainage characteristics are limiting factors?
   3. Do sites where aeolian transport barriers are present, but a fluvial source of aeolian sand is also present, show different types of surface change and less erosion by gullies and overland flow than sites without a fluvial source of aeolian sand and/or with differences in drainage characteristics?
   4. At sites with upwind sand sources, do changes in aeolian sand transport barriers -- such as vegetation barriers -- result in measurable changes to the surface characteristics of down-wind archaeological sites?
   5. Are features within archaeological sites being affected by surface change?
2. How do dam-controlled flows directly affect the physical condition of archaeological sites in the downstream river corridor as a result of inundation, bank saturation, flow-related erosion, deposition and other flow-related processes?

**Monitoring Approach and Variables**

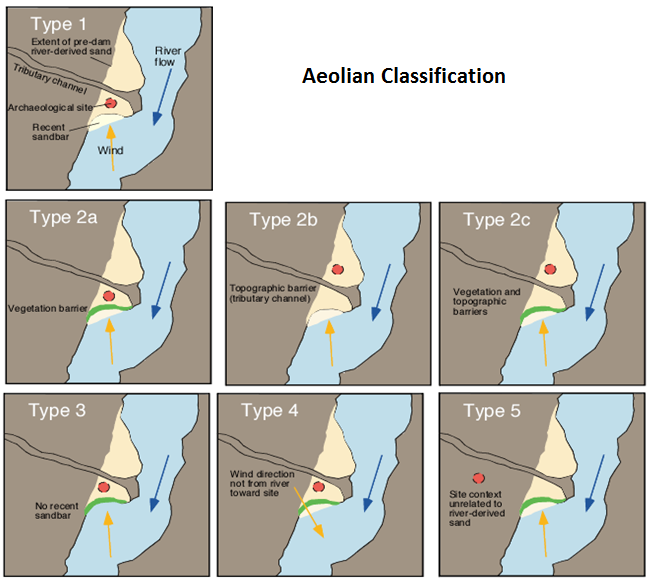
GCMRC will implement this monitoring plan beginning in 2016. Monitoring will focus on two sets of sites: Monitoring Set 1, which is a large number of sites, and Monitoring Set 2, which is a small subset of sites from Monitoring Set 1.

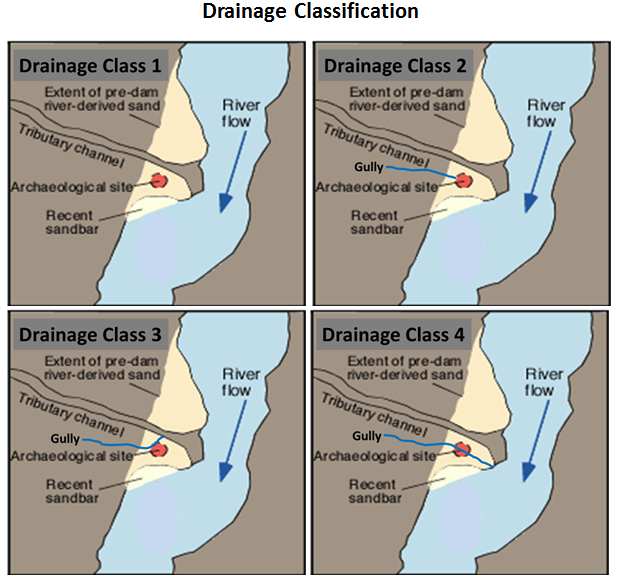
**Monitoring at Set 1**

At the large number of sites, GCMRC will complete and then periodically update the aeolian classification developed by East (2014). The purpose of using the aeolian classification is to monitor the relative potential of archaeological sites to receive windblown sand from the active river channel and controlled floods. The aeolian classification also identifies for each site, whether upwind sand sources and aeolian transport barriers are present or absent. As such, the aeolian classification is instrumental to answering all of the monitoring questions. The aeolian classification is currently (and recently) completed for 358 Grand Canyon archaeological sites, and 0 sites within Glen Canyon (please see the supplementary spreadsheet with this site information, as well as the appendix for the class definitions). GCMRC will complete the aeolian classification for the remaining sites in 2016. GCMRC will then periodically review and update the site classifications in the future at an interval of every 5 years.

The aeolian classification cannot, by itself, be used to monitor how the influx and deposition of windblown sand from river deposits affects erosion and other surface processes that occur at sites. In order to address monitoring questions 1.a.-1.e., changes to drainages (rills, gullies, and arroyos) and changes to the overall degree of erosion must be monitored at each site relative to the aeolian classification. GCMRC will use the drainage classification developed by Leap et al. (2000) to identify whether drainages exist at each site, and if so, whether or not they are integrated with the active river channel. The drainage classification is completed for 241 Grand Canyon sites, and 0 Glen Canyon sites (see the supplementary spreadsheet and the appendix). However, the classification is not current (it was last updated before 2000). GCMRC will update and complete the drainage classifications in 2016 and 2017.

To further assist in assessing possible causes for changes in the aeolian and drainage classifications, GCMRC will also complete the erosion ranking (Pederson and O’Brien, 2014) for Monitoring Set 1 archaeological sites. The erosion ranking is a system most recently published for archaeological sites by Pederson and O’Brien (2014) that uses a qualitative approach to identify the degree to which each site is eroded by hillslope, fluvial, and aeolian processes. The erosion ranking is currently completed for 226 Grand Canyon sites (see the supplementary spreadsheet and appendix), but will need to be completed for the remainder of archaeological sites in Monitoring Set 1. GCMRC will periodically review and update the erosion ranking and the drainage classifications in the future at an interval of every 5 years. GCMRC will collaborate with the NPS in order to complete or update each of the classifications.





**Monitoring at Set 2**

Monitoring Set 2 will be a smaller subset of sites (n = ~ 30) from Monitoring Set 1. This subset will be used to answer the monitoring questions using change detection from ground-based lidar surveys. The purpose of using the lidar change detection is to monitor the amount of surface change that occurs at each archaeological site due to the influx of windblown sand relative to changes that occur due to gullying and other (including aeolian erosion) processes. The lidar change detection approach provides the ability to measure changes and attribute them to geomorphic processes in a more quantitative manner, albeit at a smaller total number of sites compared to the classification systems. We will map monitored changes in relation to individual features and artifact concentrations within site boundaries, as well as over the site as a whole. The lidar will be used to monitor the cover and structure of vegetation in the immediate vicinity of sites where the vegetation forms barriers to aeolian transport or provides a protective cover that can stabilize sites.

In addition to the lidar acquisition, some important variables will require other monitoring methods during the lidar site visits. Photos taken during the lidar acquisition that are co-registered with the lidar data will be used to confirm vegetation changes by species or association. The same photos will be used to describe changes in the presence and absence of biologic soil crusts within sites and near individual features and artifact concentrations. Biologic soil crusts can stabilize the surface and can be negatively impacted by surface disturbances due to the erosion or deposition of sediment.

Weather data, specifically wind and rainfall, are useful for interpreting surface changes detected with lidar and for attributing changes to specific types of geomorphic processes. We will continue to maintain the existing weather stations with NPS permission at 6 locations within the river corridor, and conduct lidar monitoring at those sites that are located in proximity to those stations. Remote cameras are located at most of the weather monitoring locations and we will retain them for the monitoring program. While weather monitoring data cannot be acquired at all of the lidar monitoring sites, Caster and Sankey (in review) have recently demonstrated how these weather monitoring data from existing, specific locations can be used to most accurately infer weather conditions at other sites along the river.

The ground-based lidar monitoring interval will be 3-4 years, initially. The weather monitoring and remote camera data will be collected at very high temporal frequency due to their autonomous nature and the data will be downloaded from the instruments every 4-6 months.

**Monitoring Methods and Data Integration**

**Monitoring at Set 1**

**Aeolian classification:** We plan to complete this classification for Glen Canyon sites in 2016 with a 2-day field campaign in February or March of 2016. We will visit each site and determine the most appropriate classification using the methods of East (2014).

**Drainage classification:** Beginning in January of 2016 we will review the existing classifications using the methods described in Leap and others (2000) using new aerial imagery (acquired in 2013) combined with the drainage network developed from Sankey and Draut (2014). For each site we will determine whether:

1. the classification is still consistent with current conditions, or
2. the classification is now different based on current conditions, and if so then reclassify the site, or
3. the site requires a field visit to adequately assess and classify/reclassify.

We anticipate that in 2016 we will not be able to complete this review for all sites that need to be classified or reclassified. However, we would like to complete it for all of the sites to be monitored in Glen canyon and approximately half of the sites to be monitored in Grand Canyon. We will generate a list of sites that require field visits, and visit at least half of those sites during a Grand Canyon river trip in May 2016. We will then complete the remaining review and classification/reclassification in 2017 with more site visits as necessary during a Grand Canyon river trip in 2017. The drainage and aeolian classifications of Glen Canyon sites will be completed in the same 2-day field campaign described above.

**Erosion ranking:** The erosion rankings were published recently for 226 Grand Canyon archaeological sites (Pederson and O’Brien, 2014) and the information is typically updated for Grand Canyon sites by the NPS staff during site monitoring. However, there are likely to be some sites in Monitoring Set 1 that currently do not have rankings and for which there is not a plan in place for NPS staff to visit the site and update this information in the immediate future. We will work with NPS in early 2016 to identify such sites and then plan site visits to complete the rankings using the published methods during our river trips in 2016 and 2017.

**Interpretation:** In order to answer the monitoring questions, results of the site classification monitoring will be interpreted for site changes between different classes for each system relative to the other. The following are detailed explanations of how the classification monitoring data will be interpreted to answer each of the monitoring questions.

**Question 1.a.:** We will answer this question at each site by monitoring the changes, if any, in drainage classification and erosion ranking, as a function of the aeolian classification. For example, a type 1 site in the aeolian classification that changes from drainage class 1 to drainage class 4 would indicate that drainages developed at the site during the monitoring period, despite the site’s high potential to receive windblown sand.

In general, changes from lower to higher numbered drainage classes and/or erosion rankings (henceforth “Surface Erosion Scenario A”) indicate a transition to a more degraded site condition, and the inverse (“Surface Erosion Scenario B”) indicates a transition to a less degraded site condition. Changes from lower to higher numbered aeolian classes (henceforth “Aeolian Scenario A”) indicate a transition to a lower site potential to receive windblown sand, and the inverse indicates a transition to a greater site potential to receive windblown sand (“Aeolian Scenario B”). Table 1 explains how all possible combinations of scenarios will be interpreted in order to answer this monitoring question for each individual site.

Table 1. Explanation of how all possible combinations of change scenarios will be interpreted in order to answer monitoring question 1.a. for each individual site in Monitoring Set 1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | Aeolian Scenario | | |
| A = change from lower to higher numbered aeolian class | B = change from higher to lower numbered aeolian class | C = no change in aeolian class |
| Surface Erosion Scenario | A = change from lower to higher numbered drainage class and/or erosion ranking | Interpretation: transition to more degraded site condition & decreased influx/deposition of windblown sand | Interpretation: transition to more degraded site condition & increased influx/deposition of windblown sand | Interpretation: transition to more degraded site condition & influx/deposition of windblown sand has remained stable |
| B = change from higher to lower numbered drainage class and/or erosion ranking | Interpretation: transition to less degraded site condition & decreased influx/deposition of windblown sand | Interpretation: transition to less degraded site condition & increased influx/deposition of windblown sand | Interpretation: transition to less degraded site condition & influx/deposition of windblown sand has remained stable |
| C = no change in drainage class and/or erosion ranking | Interpretation: stable site condition & decreased influx/  deposition of windblown sand | Interpretation: stable site condition & increased influx/  deposition of windblown sand | Interpretation: stable site condition & influx/deposition of windblown sand has remained stable |

**Question 1.b.:** We will answer this question by comparing the drainage classifications and erosion rankings between sites classified as type 1 aeolian classification and sites of the other aeolian classes. Based on the current scientific understanding, this monitoring is expected to show that type 1 aeolian sites tend to be less affected by surface erosion, and therefore have a less degraded site condition. This monitoring will show where these assumptions are accurate and where they are not valid for specific individual sites or groups of sites.

**Question 1.c.:** We will answer this question by comparing the drainage classifications and erosion rankings between sites classified as type 2 aeolian classification and sites of the other aeolian classes (not including type 1). Based on the current scientific understanding, this monitoring is expected to show that type 2 aeolian sites tend to be less affected by drainages and erosion, and therefore have a less degraded site condition, than type 3 sites (or type 4 or 5 sites). This monitoring will show where these assumptions are accurate and where they are not valid for specific individual type 2 aeolian sites or for type 2 sites as a group.

**Question 1.d.:** We will answer this question by monitoring what changes in the drainage classifications and erosion rankings occur for any sites that transition from aeolian class 1 to aeolian class 2 or vice versa during the monitoring period. Based on the current scientific understanding, this monitoring is expected to show that sites which transition from aeolian class 1 to aeolian class 2 are more likely to be affected by drainages and erosion, and therefore have a more degraded site condition, in comparison to sites which transition from aeolian class 2 to aeolian class 1. This monitoring will show where these assumptions are accurate and where they are not valid for specific individual sites or for certain groups of sites.

**Question 1.e.:** The classification-based monitoring is not designed to answer this monitoring question.

**Question 2.:** The classification-based monitoring is not designed to answer this monitoring question.

**Monitoring at Set 2**

A small sample of approximately 30 sites (and individual features therein) will be monitored with ground-based lidar during site visits. A digital elevation model will be derived from the lidar scans acquired during each, individual site visit. The DEMs will cover the extent of the archaeological site polygon, and wherever feasible, will extend from the site to river channel in order to include the upwind sand source area and topographic barrier(s). A DEM of Difference (DOD) will be determined between each pair of DEMs acquired at successive monitoring dates. Each DOD will depict the topographic change that occurs between two monitoring dates, and the magnitude and rate of topographic changes for that monitoring interval can therefore be determined. Areas of change within the DODs will be mechanistically segregated to attribute each area to a specific geomorphic process (e.g., aeolian, fluvial, or hillslope erosion or deposition). Mechanistic segregation is a data analysis method whereby the contribution of any individual geomorphic process to the total change in a DOD (or to the change in a specific portion of a DOD such as a concentration of archaeological features) is quantified in order to determine where and to what extent that process occurred. (Please see Figure 1 which demonstrates a proof-of-concept mechanistic segregation and interpretation of lidar monitoring data at one proposed site.)

DODs should be acquired at a monitoring interval that is frequent enough to avoid overprinting of geomorphic processes. Overprinting is where a process produces geomorphic change which is subsequently masked on the ground surface by geomorphic change from a different process. A simple example would be where sediment is deposited by fluvial processes and that deposit is subsequently buried by aeolian deposition. We believe that a 3-4 year monitoring interval is prudent for the ground-based lidar change detection in order to reduce the possibility for mis-attribution of changes to specific geomorphic processes during the mechanistic segregation analysis. In March of 2016 we will implement the lidar monitoring for those Monitoring Set 2 sites that are located in Glen Canyon. In May of 2016 we will further implement the lidar monitoring with a Grand Canyon river trip during which we would produce DEMs for approximately 7-10 of the Monitoring Set 2 sites. We will then complete river trips in 2017 and 2018 where we visit approximately 7-10 additional Monitoring Set 2 sites on each trip. These sites will then be revisited for the first time in 2019-2021. Based on DOD results, it may be prudent to modify the interval of time between the repeated lidar monitoring efforts. It may also be prudent to modify the sample of monitored sites in order to adequately capture the variability of the larger site population. It is therefore important that the plan have built-in flexibility with opportunities to adapt based on feedback from multiple years’ monitoring efforts.

The lidar data will also be used to produce canopy height models (CHM), which are analogous to DEMs for the vegetation canopy. The CHMs will be differenced between each pair of successive monitoring dates in order to quantify any changes that occur in vegetation stature at the site; changes to riparian vegetation transport barriers will be quantified in this way. Photos that are acquired and are co-registered with the lidar will be inspected visually (qualitatively) to determine the type of vegetation that changed at the association or species-level, if possible. The photos will also be inspected to identify locations within sites where biologic soil crust changes from being present to absent, or vice versa. We will consult with botanists and biologic soil crust experts from other related monitoring programs as necessary for photo interpretation.

A very small number of sites (1-2 sites) where aeolian deposition of fluvially sourced sand is known to occur, should initially be monitored at a very high frequency using a combination of ground-based lidar and other tools at GCMRC’s disposal including an autonomous laser scanner, digital monitoring cameras, and automated weather stations. The purpose of this high frequency monitoring is to quantify the frequency and magnitude of interacting aeolian and non-aeolian overprinting events to better inform the use of the 3-4 year monitoring interval for the ground-based lidar change detection. This will allow us to confirm that the 3-4 year interval neither gives too much significance to, nor inadvertently misses, important high or low frequency events that produce significant geomorphic change despite being overprinted by other processes.

**Interpretation:** We will address each monitoring question by evaluating change detection results from ground-based lidar data at each site to determine the rates and magnitudes of topographic changes that occur, if any, that can be attributed to

* (I) any processes other than the influx and deposition of aeolian sand,

relative to those that can be attributed to

* (II) the influx and deposition of aeolian sand.

[We refer to these different types of changes as (I) and (II) throughout the remainder of this section.] The following are detailed explanations of how the change detection results will be interpreted to answer each of the monitoring questions.

**Question 1.a.:** We will answer this question at each site, by determining whether the rates and magnitudes of changes attributed to (I) are greater than the rates and magnitudes of change attributed to (II).

**Question 1.b.:** We will answer the question at each site, by examining the rates and magnitudes of topographic changes attributed to (I) and (II) relative to whether transport from an upwind sand source occurs and/or limiting factors exist at the site. Based on the current scientific understanding, this monitoring is expected to show that the rates and magnitudes of topographic changes related to (II) are greater than those attributed to (I) for those sites where adjacent, upwind fluvial sediment deposits form by high flow events, and unimpeded aeolian sand transport occurs from the flood deposit toward the sites. This monitoring is also expected to show that the rates and magnitudes of changes attributed to (I) are greater than those attributed to (II) for those sites where either lack of sediment source, presence of transport barriers, or drainage characteristics are limiting factors. The monitoring will show where these assumptions are accurate and where they are not valid for specific individual sites.

**Question 1.c.:** We will answer this question at each site, by examining the rates and magnitudes of topographic changes attributed to (I) and (II) relative to whether transport barriers and an upwind source of aeolian sand exist at the site. Based on the current scientific understanding, this monitoring is expected to show that (I) is lower and (II) is greater for sites with transport barriers and an upwind sand source area in comparison to sites without an upwind sand source area. The monitoring will show where these assumptions are accurate and where they are not valid for specific individual sites.

**Question 1.d.:** We will answer the question at each site, by examining the rates and magnitudes of topographic changes attributed to (I) and (II) relative to changes to transport barriers over time. Based on the current scientific understanding, this monitoring is expected to show that (I) increases and (II) decreases over time for sites where transport barriers increase over time. Conversely this monitoring is expected to show that (I) decreases and (II) increases over time for sites where transport barriers decrease over time. The monitoring will show where these assumptions are accurate and where they are not valid for specific individual sites.

**Question 1.e.:** The topographic change detection with ground-based lidar can also target more localized areas of features within archaeological sites. We will answer this question by summarizing topographic changes and attributing those changes to specific geomorphic processes at the localized areas of features within archaeological sites. We will determine at the localized areas of features within archaeological sites whether the rates and magnitudes of topographic changes attributed to: (I) exceed (II), (II) exceed (I), or do not differ for (I) and (II).

**Question 2.:** The topographic change detection with ground-based lidar can target areas where the physical condition of sites is directly affected by dam-controlled flows. We will answer this question using topographic change detection for at least one location in Glen Canyon where repeated inundation of the toe of a terrace – on which an archaeological site resides – has been observed to result in erosion of the terrace bank, which could in turn destabilize features on and within the terrace. We will determine the rates of topographic change attributed to erosion or deposition for: the area of the terrace toe that is directly inundated by dam-controlled flows; the higher elevation area of the terrace bank; and the area of the tread (top) of the terrace.



**Figure 1 (previous page): Example monitoring results from proof-of-concept mechanistic segregation and change detection of lidar from site AZ C:05:0031 for the period between spring 2013 and spring 2014. In the maps and pie charts, changes are color coded by one of six possible mechanisms (geomorphic processes) to which the change is attributed. Pie charts show volumetric contributions to the sediment budget from each possible mechanism within (i) the total survey area and (ii) the archaeological site for the monitoring period. Areas with high potential for overprinting are noted with hatching; overprinting is where a process produces geomorphic change which is subsequently masked on the ground surface by geomorphic change from a different process. For this example monitoring interval, deposition slightly exceeded erosion in the total survey area, which includes the site and the area between the upwind sand bar that is considered the source for windblown sand on the site. In the total survey area, the greatest volume of sediment was deposited by the fluvial mechanism (maps and pie chart), presumably as a result of the 2013 high flow experiment. Aeolian deposition produced the next largest volume of sediment deposition, which is expected as this site is currently classified as Type 1 in the Aeolian Classification system. Within the site boundary, erosion from the combination of aeolian and alluvial processes exceeded aeolian deposition (inset B. and pie chart). If the concentrations of features within the archaeological site are mapped, it is possible to calculate volumetric contributions to the sediment budget for those specific areas.**

**Data Management**

We will store the results of the classification-based monitoring by appending the data tables previously produced for the aeolian classification with the drainage classification data and erosion ranking data.

We will store all of the past and future lidar and other related topographic surveys and survey control data in a single combined project directory per site. These data will be stored on a server at GCMRC to which only members of the monitoring staff and select IT staff have access. We will store all raw lidar files and survey control files. We will store important files from the intermediate processing steps. For each site, we will maintain a single Geomorphic Change Detection (GCD) GIS project file with related data layers and change detection products, statistics, and maps for all historical lidar surveys. The GCD GIS projects could be shared at the discretion of the NPS if other stakeholders want to use these data for their monitoring efforts.

**Reporting**

A detailed report focusing on the monitoring questions (1a-1e) will be produced following the completion of updates to the classification systems or the ground-based lidar survey set, with the first reports scheduled for completion during FY18 and FY19. The first reports will present the completed aeolian and drainage classifications as well as the erosion rankings for the sites in Monitoring Set 1, and will present the initial bare surface DEMs and CHMs created from the ground-based lidar surveys conducted during FY16-18. The purpose of these reports is to establish a point of reference by which to assess future changes in order to answer the monitoring questions for Monitoring Sets 1 and 2.

Following FY18, detailed monitoring reports will be provided at 4 and 6 year intervals. At the 4 year interval, the results of ground-based lidar change detection between the most recent repeat surveys and the initial survey (FY19 report) will be presented for each site in which data was collected. The purpose of this report will be to provide answers to the monitoring questions from the first monitoring interval and to provide detailed information on the range of surface change rates and magnitudes observed for features, sites, and types of sites.

At the 6 year interval, a monitoring report will present the results of the completed updates to the aeolian and drainage classifications as well as the erosion rankings for the sites in Monitoring Set 1. The purpose of this report will be to provide answers to the monitoring questions for the monitoring interval. The monitoring work and reporting schedule is summarized in Table 2.

In addition to the formal detailed monitoring reports, annual oral presentations of preliminary results and new insights derived from data analysis will be provided at either the GCDAMP Annual Reporting Meeting, the annual PA meeting or both. These presentations and informal discussions will be intended to provide opportunity for stakeholder feedback. Stakeholder feedback will be used to assess the effectiveness of the monitoring plan to meet the needs of stakeholders.

Table 2. 12-Year Monitoring Schedule

|  |  |
| --- | --- |
| **Fiscal Year** | **Activity** |
| FY16 | 1.) Complete Aeolian Classification for Monitoring Set 1  2.) Work on Drainage Classification  3.) Work on Erosion Ranking  4.) Complete ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY17 | 1.) Complete Drainage Classification  2.) Complete Erosion Ranking  3.) Complete ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY18 | 1.) Report on initial classification monitoring dataset  2.) Complete ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY19 | 1.) Report on initial lidar monitoring datasets  2.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY20 | 1.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY21 | 1.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites  2.) Begin updating Aeolian Classification  3.) Begin updating Drainage Classification  4.) Begin updating Erosion Ranking |
| FY22 | 1.) Complete first ground-based lidar monitoring report  2.) Complete Aeolian Classification update  3.) Complete Drainage Classification update  4.) Complete Erosion Ranking update  5.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY23 | 1.) Complete first classification monitoring report  2.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY24 | 1.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY25 | 1.) Complete second ground-based lidar monitoring report  2.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites |
| FY26 | 1.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites  2.) Begin updating Aeolian Classification  3.) Begin updating Drainage Classification  4.) Begin updating Erosion Ranking |
| FY27 | 1.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites  2.) Complete Aeolian Classification update  3.) Complete Drainage Classification update  4.) Complete Erosion Ranking update |
| FY28 | 1.) Complete third ground-based lidar monitoring report  2.) Complete second classification monitoring report  3.) Repeat ground-based lidar surveys for 7 to 10 Set 2 sites |

**Plan Flexibility and Adaptability**

One goal of this monitoring plan is to provide the most useful information to stakeholders and managers so that informed decisions can be made. To effectively accomplish this goal, flexibility and adaptability are necessary components of the monitoring plan. All reporting will provide an opportunity for review and feedback from stakeholders, including the stakeholders involved in cultural resource monitoring by the NPS and Tribes. This feedback and ensuing discussion will then be used by GCMRC to adapt our monitoring program, as appropriate. While the core monitoring questions will not change, concerns over sample size, recent changes in a specific site condition, site selection, and sampling intervals will be periodically evaluated. Where appropriate based on scientific sampling strategies and GCMRC resources, the monitoring plan will be adapted to address these comments and concerns for the next monitoring cycle.

**Personnel Considerations and Monitoring Limitations**

This monitoring plan requires USGS-GCMRC staff, including traditional geoscientists and scientists with cultural resource management backgrounds, to carry out monitoring that focuses on the effects of geomorphic processes related to flow and non-flow actions at archaeological sites. At present, the GCMRC maintains staff with appropriate geoscience backgrounds to develop and implement the proposed monitoring plan. While GCMRC also employs two individuals (H. Fairley and J. Caster) with advanced degrees in archaeology and cultural resources management who will be actively involved in implementing the plan, the GCMRC will not provide interpretations on changes to the NRHP eligibility criteria and site integrity. These aspects of monitoring are deferred to the appropriate land managers and stakeholders of the Glen Canyon Dam Adaptive Management Program. The methods and reporting strategies in this plan are designed to inform land managers and stakeholders on observed site and landscape changes to make judgements on effects related to flow and non-flow actions that can be used to assess best management practices during the monitoring period.

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**Appendix I: Background for Site Classification systems**

**Geomorphology-based Archaeological Site Classification Systems:**

A portion of this monitoring plan focuses on geomorphic processes observed at a large number of archaeological sites by evaluating changes in site classifications at individual sites from one monitoring interval to the next. The principle classification system evaluates the potential for aeolian transport of fluvially-sourced sand from the active river channel to higher elevation sites (the Aeolian Classification System; East, 2014[[1]](#footnote-1)). To interpret the implications of changes in the aeolian class between monitoring intervals at any given site, two other classification systems are used. The Drainage Classification System is based on water flow paths within and/or adjacent to an archaeological site (Hereford, 1993[[2]](#footnote-2); Leap and others, 2000[[3]](#footnote-3)), and the Erosion Ranking is a semi-quantitative assessment of geomorphic impact to a site by erosion (Damp and others, 2007[[4]](#footnote-4); Obrien and Pederson, 2009[[5]](#footnote-5); Pederson and Obrien, 2014[[6]](#footnote-6)). All three systems have an intuitive numeric class designation. Tables 1a – 3a provide a summary of the class designations for each of the three systems.

**Table 1a:** Aeolian Classification System.

[This table provides a summary of the Aeolian Classification System. For a detailed explanation see East, 20141)

|  |  |
| --- | --- |
| **Type/Class** | **Description** |
| **1** | Sites with an adjacent, upwind fluvial sediment deposit formed by a recent high flow event, and no evident barriers that would hinder aeolian sand transport from the flood deposit toward the archaeological site. |
|  |  |
| **2** | Sites with an upwind sediment deposit formed by a recent flood, but with a barrier separating the flood deposit from the archaeological site. |
| **2a** | Vegetation barrier present. |
| **2b** | Topographic barrier present. |
| **2c** | Both vegetation and topographic barriers present. |
|  |  |
| **3** | Sites at which a recent flood did not deposit sediment upwind of site, even though flood water had been present at an upwind location relative to the archaeological site (where an upwind shoreline exists for a recent controlled flood). |
|  |  |
| **4** | Sites at which there is currently no upwind shoreline with sand deposited from a recent controlled flood, thereby precluding the possibility of upwind sand transport, but whose geomorphic context does involve river-derived sand deposited by pre-dam floods. |
|  |  |
| **5** | Sites in the river corridor whose geomorphic context is not dependent on Colorado River-derived sand, such as those situated on bedrock or talus. |

**Table 2a:** Drainage Classification System.

[This table provides a summary of the Drainage Classification System. For a detailed explanation see Leap and others, 20003. To make the numeric system more intuitive, sites were renumbered from Leap and others, 2000)

|  |  |
| --- | --- |
| **Type/Class** | **Description** |
| **1** | Sites are not dissected by gullies or arroyos. |
| **2** | Sites are dissected by gullies and arroyos that grade to a surface that is higher in elevation than the active river. |
| **3** | Sites are dissected by gullies and arroyos that grade to the channel of a tributary to the Colorado River. |
| **4** | Sites are dissected by gullies and arroyos that grade to the active channel of the Colorado River. |

**Table 3a:** Erosion Ranking System.

[This table provides a summary of the Erosion Rankin System. For a detailed explanation see Pederson and O’Brien, 20146)

|  |  |
| --- | --- |
| **Type/Class** | **Description** |
| **1** | Stable (little to no documented erosion) |
| **2** | Mild erosion |
| **3** | Intermediate erosion |
| **4** | Serious erosion |
| 5 | Severe erosion |

1. East, A.E., 2014, Summary of Methods Analyzing Potential Aeolian HFE Sediment Supply to Individual Archaeological Sites: U.S. Geological Survey Administrative Report, 11 p. [↑](#footnote-ref-1)
2. Hereford, R., Fairley, H.C., Thompson, K.S., and Balsom, J.R., 1993, Surficial geology, geomorphology and erosion of archeologic sites along the Colorado River, eastern Grand Canyon, Grand Canyon National Park, Arizona. Grand Canyon National Park in cooperation with the Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Ariz.: U.S. Geological Survey Open-File Report 93-517. [↑](#footnote-ref-2)
3. Leap. L.M., Kunde, J.L., Hubbard, D.C., Andrews, N., Downum, C.E., Miler, A., and Balsom, J.R., 2000, Grand Canyon Monitoring Project 1992-1999: Synthesis and Annual Monitoring Report FY99: Grand Canyon National Park River Corridor Monitoring Project Report No. 66, submitted to Bureau of Reclamation, Upper Colorado River Region Office, Salt Lake City, UT. [↑](#footnote-ref-3)
4. Damp, J., Pederson, J., and O’Brien, G., 2007, Geoarchaeological Investigations and Archaeological Treatment Plan for 151 Sites in the Grand Canyon, Arizona: Unpublished report prepared for Bureau of Reclamation, Upper Colorado River Region, Salt Lake City. 502 p. [↑](#footnote-ref-4)
5. O’Brien, G., & Pederson, J. (2009). Geomorphic attributes of 232 cultural sites along the Colorado River in Grand Canyon National Park, Arizona: Report to the U.S. Geological Survey, Grand Canyon Monitoring and Research Center, 194 p. [↑](#footnote-ref-5)
6. Pederson, J.L., O’Brien, G.R. (2014), Patterns in the Landscape and Erosion of Cultural Sites Along the Colorado River Corridor in Grand Canyon, USA: Geoarchaeology, v.29, p. 431-447. [↑](#footnote-ref-6)