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Oblique view showing reaches of preliminary reconnaissance along the upstream reach of Battle Creek (Map data ©2016 Google).

Application of Paleoflood Surveys for the Southern Black Hills of South Dakota

Study SD2010-04

Final Report

Prepared by:

U.S. Geological Survey

Dakota Water Science Center

Rapid City, South Dakota

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DISCLAIMER

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16. Abstract

Flood-frequency analyses for the Black Hills area have especially large uncertainties and are especially important for planning purposes because of a history of extremely large and damaging floods, such as the extreme floods of June 9–10, 1972. Geology, topography, and climatology are additional complicating factors for flood-frequency characterization for the area. Two previous paleoflood studies for the Black Hills area indicated good potential for improving flood-frequency analyses through implementation of paleoflood investigations. The objectives of this study (SD2010-04) for the southern Black Hills were to (1) develop long-term flood chronologies and associated peak-flow frequency analyses for selected stream reaches by applying paleoflood hydrology approaches; and (2) develop flood-frequency information regarding “high-elevation” stream reaches to help address questions regarding differential potential for generation of exceptionally strong rain-producing thunderstorms across elevation gradients in the area. Neither objective was accomplished because the study was terminated before planned completion.

Substantial efforts could be applied for only 2 of the 12 research tasks prior to study termination. These were task 3 (preliminary reconnaissance) and task 4 (activities associated with Section 106 of the National Historic Preservation Act). Field reconnaissance conducted along 10 candidate streams indicated that conditions in the southern Black Hills appear quite favorable for conducting paleoflood investigations. All 10 candidate streams had moderate to good potential for favorable paleoflood evidence, and in general are well constrained in relatively narrow canyon reaches, which provides good sensitivity for changes in stage, relative to discharge.

Task 4 (Section 106 activities) was needed because alcoves and rock shelters that are well suited for deposition and preservation of paleoflood evidence may have been used as shelters or cache locations by indigenous inhabitants and thus may be eligible for consideration as historic properties because of possible archaeological or cultural materials. The complexity of the Section 106 concerns and issues became progressively more apparent as the study evolved. The study eventually was terminated when it became apparent that the resources needed to address the Section 106 issues would overwhelm the resources available for study implementation. In the event of consideration of future re-implementation, approaches that might help expedite Section 106 issues could include (1) a partnership with another Federal agency that has substantial experience with the Section 106 process; (2) securing assistance from a consultant that could help with both the Section 106 process and the required archaeological component; and (3) partnering with a tribal college with archaeological or earth science/hydrology programs, which could help make this study become part of a learning exercise.

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Acronym	Definition
FEMA	Federal Emergency Management Agency
SDDOT	South Dakota Department of Transportation
Section 106	Section 106 of the National Historic Preservation Act
SHPO	State Historic Preservation Office
SWD	Slack-water deposit
USGS	U.S. Geological Survey

1.0 EXECUTIVE SUMMARY

Paleoflood hydrology is the study of previously unmeasured floods (paleofloods), whether relatively recent or ancient, and has been used in various settings to investigate the magnitudes and timing of large and infrequent floods. An initial reconnaissance-level paleoflood study for the Black Hills area (O'Connor and Driscoll, 2007) was completed as a cooperative effort between the Office of Research of the South Dakota Department of Transportation (SDDOT) and the U.S. Geological Survey (USGS). That study (SD2005-12) indicated good potential for improvement of flood-frequency analyses for the Black Hills area by conducting full-scale paleoflood studies and resulted in implementation of a second study (SD2008-01) for the central Black Hills (Driscoll and others, 2011; Harden and others, 2011). A third study (SD2010-04) described in this report was subsequently implemented for the southern Black Hills; however, the study was eventually terminated before planned completion because of issues described in section 1.3 of this Executive Summary.

1.1 Problem and Background

Flood-frequency analyses for the Black Hills area have especially large uncertainties and are especially important for planning purposes because of a history of extremely large and damaging flood events, such as the extreme floods of June 9–10, 1972 (Schwarz and others, 1975), in which at least 238 lives were lost (Carter and others, 2002). Development of meaningful flood-frequency analyses for especially large (low-probability) floods is particularly challenging because of large outliers in the relatively short-term peak-flow records available for many area streamgages (Sando and others, 2008). The largest flood peaks for many streamgages are an order of magnitude (or more) larger than the next largest observed peaks. The potential for extreme property damage and loss of life from exceptional flood events poses risks that go substantially beyond those associated with highway infrastructure. Thus, issues associated with improved flood-frequency characterization have widespread relevance.

Large floods can leave various forms of evidence that can be used to infer maximum flood stage. Some flood evidence can be preserved for hundreds, or even thousands of years, and various methods can be applicable for dating of paleoflood evidence (Benito and O'Connor, 2013; O'Connor and others, 2014). Detailed site investigations for the two previous paleoflood studies in the Black Hills area primarily involved stratigraphic analysis of sequential deposits of flood sediments, along with radiocarbon dating of entrained organic materials. Those studies demonstrated the regional applicability of paleoflood studies for improving flood-frequency analyses for the Black Hills and resulted in implementation of this most recent study for the southern Black Hills.

1.2 Research Objectives

This study involved two research objectives. The first objective was to develop long-term flood chronologies and associated peak-flow frequency analyses for selected stream reaches in the southern Black Hills, based on application of paleoflood hydrology approaches demonstrated within previous SDDOT Research Projects SD2005-12 and SD2008-01. The second objective was to develop flood-frequency information regarding "high-elevation" stream reaches within the southern Black Hills to help address questions regarding differential potential for generation of exceptionally strong rain-producing thunderstorms across elevation gradients in the area. Neither objective was accomplished because the study was terminated before planned completion.

1.3 Task Descriptions

Twelve specific research tasks were identified to guide research directions. However, most of the planned tasks were not implemented because this study was terminated before planned completion. Thus, this Executive Summary addresses only two tasks for which substantial efforts were applied for this study. These are task 3 (performing preliminary reconnaissance) and task 4 (activities associated with Section 106 of the National Historic Preservation Act; hereinafter referred to as Section 106).

Task 3 involved performing preliminary reconnaissance within the larger drainages in the study area to identify stream reaches with the best potential for providing high-quality paleoflood evidence and conducting comprehensive paleoflood investigations. Reconnaissance efforts involved first identifying candidate streams with favorable geologic conditions and sufficient drainage area to justify additional reconnaissance. This was accomplished as an office activity and resulted in preliminary identification of 10 primary candidate streams or drainage basins. A next step involved field reconnaissance of candidate stream reaches, which generally first involved viewing from a vehicle for reaches that were accessible by roads. Additional exploration for some stream reaches was conducted by walking, as many of the candidate reaches are not entirely accessible by roads and more detailed inspection is highly beneficial. A primary goal for field reconnaissance, whether by driving or walking, was to identify locations favorable for deposition and preservation of paleoflood evidence, with the most favorable locations typically being within alcoves in canyon reaches. Ground disturbing activities were categorically avoided during all field reconnaissance to accommodate Section 106 requirements.

Preliminary reconnaissance indicated that conditions in the southern Black Hills appear to be quite favorable for conducting paleoflood investigations. Locations with at least moderate potential for deposition and preservation of paleoflood evidence were found in all 10 of the candidate streams, and locations with good potential were found within 6 of the candidate streams. In general, conditions for hydraulic analyses also were judged to be quite favorable, as many of the reaches with moderate to good potential for paleoflood evidence are well constrained in relatively narrow canyon reaches, which provides good sensitivity for changes in stage, relative to discharge.

Task 4 involved various activities necessary to comply with requirements of Section 106. This task was needed because alcoves and rock shelters that are well suited for deposition and preservation of paleoflood evidence may have been used as shelters or cache locations by indigenous inhabitants and thus may be eligible for consideration as historic properties because of possible archaeological or cultural materials. As such, this study was considered a Federal undertaking and was required to be performed in accordance with Section 106. The Section 106 process involves four primary steps: (1) initiation of the process; (2) identification of potential historic properties; (3) assessment of adverse effects; and (4) resolution of adverse effects. Initiation of the Section 106 process for this study of the southern Black Hills essentially involved (1) initial notification of the State Historic Preservation Office, numerous Native American tribes having cultural and religious ties to the Black Hills, and other appropriate agencies and parties; and (2) a subsequent consultation process involving the aforementioned entities. Consultation is an inherent part of the process that spans all four steps.

At the onset of this study phase for the southern Black Hills, USGS notified the State Historic Preservation Office (SHPO) and began working with SHPO staff to become more familiar with the Section 106 process and begin pursuing necessary activities. The complexity of the Section 106 concerns and issues became progressively more apparent as the consultation process evolved. Task 4 progressed as far as developing a preliminary draft of a Programmatic Agreement to formalize how the Section 106 issues would be addressed. However, progress on this effort halted when it became apparent that the resources needed to address the Section 106 issues would overwhelm the resources available for implementation of the study. Thus, by mutual agreement of SDDOT and USGS, the study was terminated before addressing the remaining tasks originally planned for this study.

1.4 Findings and Conclusions

Because this study had to be terminated before completion, findings were very limited. Thus, this section addresses only findings relative to preliminary reconnaissance (task 3) and to the Section 106 issues (task 4), which were the only two primary tasks that had substantial activities as part of the truncated study.

Ten candidate streams having favorable geologic conditions and sufficient drainage area to potentially justify field paleoflood investigations were identified by conducting preliminary field reconnaissance. In general, field reconnaissance indicated that conditions in the southern Black Hills appear quite favorable for conducting paleoflood investigations. Locations with at least moderate potential for deposition and preservation of paleoflood evidence were found along 10 of the candidate streams, and locations with good potential were found along 6 of the candidate streams. Sediment deposits from 2007 flooding (Driscoll and others, 2010) were found in locations along Battle Creek and Grace Coolidge Creek, which indicates reasonable potential for existence of sediments from paleofloods, and locations with likely sediment deposits from paleofloods were found in several additional candidate stream reaches. In general, conditions for hydraulic analyses were judged to be quite favorable, with most of the reaches having moderate to good potential for paleoflood evidence being well constrained in relatively narrow canyon reaches, which provides good sensitivity for changes in stage, relative to discharge.

The complexity of the Section 106 concerns and issues became progressively more apparent as the consultation process evolved. It eventually became apparent that the resources needed to address the Section 106 issues would overwhelm the resources available for implementation of the study. Thus, by mutual agreement of SDDOT and USGS, the study was terminated before addressing the remaining tasks originally planned for this study.

1.5 Considerations Regarding Potential Future Paleoflood Studies

This section addresses considerations regarding potential future re-implementation of paleoflood studies for the southern Black Hills. These considerations are addressed relative to preliminary reconnaissance (Task 3) and Section 106 activities (Task 4), which were the only two primary tasks that had substantial activities as part of the truncated study.

1.5.1 Considerations Relative to Availability of Paleoflood Evidence

Preliminary reconnaissance indicated a relatively high likelihood of finding sufficient paleoflood evidence of sufficient quality to obtain high-quality chronologies of paleofloods for many stream reaches in the southern Black Hills.

Preliminary field reconnaissance was conducted for 10 candidate streams judged to have favorable geologic conditions and sufficient drainage area to potentially justify field paleoflood investigations. Field reconnaissance indicated conditions that generally appeared quite favorable for conducting paleoflood investigations. Locations with at least moderate potential for deposition and preservation of flood slack-water deposits (SWDs) were found along all 10 of the candidate streams, and good potential was found along 6 of the candidate streams. SWDs from 2007 flooding were found in locations along Battle Creek and Grace Coolidge Creek, which indicates reasonable potential for existence of SWDs from paleofloods, and locations with likely SWDs from paleofloods were found in several additional candidate stream reaches. In general, conditions for hydraulic analyses were judged to be quite favorable, with many of the reaches with moderate to good potential for SWDs being well constrained in relatively narrow canyon reaches, which provides good sensitivity for changes in stage, relative to discharge.

1.5.2 Considerations Relative to Section 106 Issues

In the event of potential re-implementation of this study, substantial financial resources would be needed to address the complex Section 106 issues; however, with sufficient financial resources, the Section 106 issues should not be insurmountable.

In the event of consideration of future re-implementation, various things might be done to help expedite addressing the Section 106 issues. One approach that might help substantially could be a partnership with another Federal agency that has substantial experience with the Section 106 process. USGS has very little experience with this process, and this is a particularly complicated project that requires substantial expertise. The Bureau of Land Management, National Park Service, and U.S. Forest Service could potentially be candidates as future partners, as all have Federal land holdings within the Black Hills area with potential for application of paleoflood surveys. In addition, substantial financial resources need to be available in order to adequately fund this aspect. Another approach that might help could be securing assistance from a consultant that could help with both the Section 106 process and the required archaeological component. Another approach that might help could be partnering with a tribal college with an archaeological program, which could help make this study become part of a learning exercise. Further partnering with a tribal college with an earth science/hydrology program also could be advantageous.

2.0 PROBLEM DESCRIPTION AND BACKGROUND SUMMARY

2.1 Problem Description

Flood-frequency analyses for the Black Hills area have especially large uncertainties and are especially important for planning purposes because of a history of extremely large and damaging flood events, such as the extreme floods of June 9–10, 1972 (Schwarz and others, 1975), in which at least 238 lives were lost (Carter and others, 2002). Development of meaningful flood-frequency analyses for especially large (low-probability) floods is particularly challenging because of large outliers in the relatively short-term peak-flow records available for many area streamgages (Sando and others, 2008). The largest flood peaks for many streamgages are an order of magnitude (or more) larger than the next largest observed peaks. The potential for extreme property damage and loss of life from exceptional flood events poses risks that go substantially beyond those associated with highway infrastructure. Thus, issues associated with improved flood-frequency characterization have widespread relevance.

Geology, topography, and climatology are additional complicating factors for flood-frequency characterization for the Black Hills area. Sando and others (2008) identified the "limestone plateau" area (Figure 1, east of the South Dakota/Wyoming border) as having distinctively "suppressed" peak-flow characteristics, with annual peak flows for streamgages that are consistently much smaller than for other parts of the Black Hills area. High infiltration capacities of the predominant geologic outcrops (Madison Limestone and Minnelusa Formation) and generally low topographic relief were cited as primary causes of the suppressed peak-flow characteristics that are apparent from the limited peak-flow records available for this area. Sando and others (2008) noted that the suppressed characteristics are well defined for peak flows with small recurrence intervals (that is, 2-year through about 25- or 50-year return periods, which have annual exceedance probabilities of 50, 4, and 2 percent, respectively), but uncertainty is especially large for low-probability floods with larger recurrence intervals.

The potential influence of topography on precipitation patterns may be one of the most substantial factors regarding characterization of low-probability floods for the Black Hills area. Driscoll and others (2010) described climatological factors that enhance the probability of exceptional rainstorms along the eastern flanks of the Black Hills, relative to the highest terrains. These investigators identified (1) a propensity for heavy precipitation to occur east of the major axis of the Black Hills, from the northern hills (near Spearfish) toward the southeast through the eastern foothills near Hermosa, and (2) a proclivity for short-duration but intense convective precipitation events. The largest gradients in topography lie along the foothills, as opposed to over the higher altitudes, and this helps favor heavy precipitation in the lower altitudes. Quantifying the effects of the aforementioned influences relative to low-probability flood events could require collection of many hundreds of station-years of systematic peak-flow records throughout the Black Hills area. A more efficient and immediate approach would be determination of previous histories of large floods for selected stream reaches through paleoflood investigations.

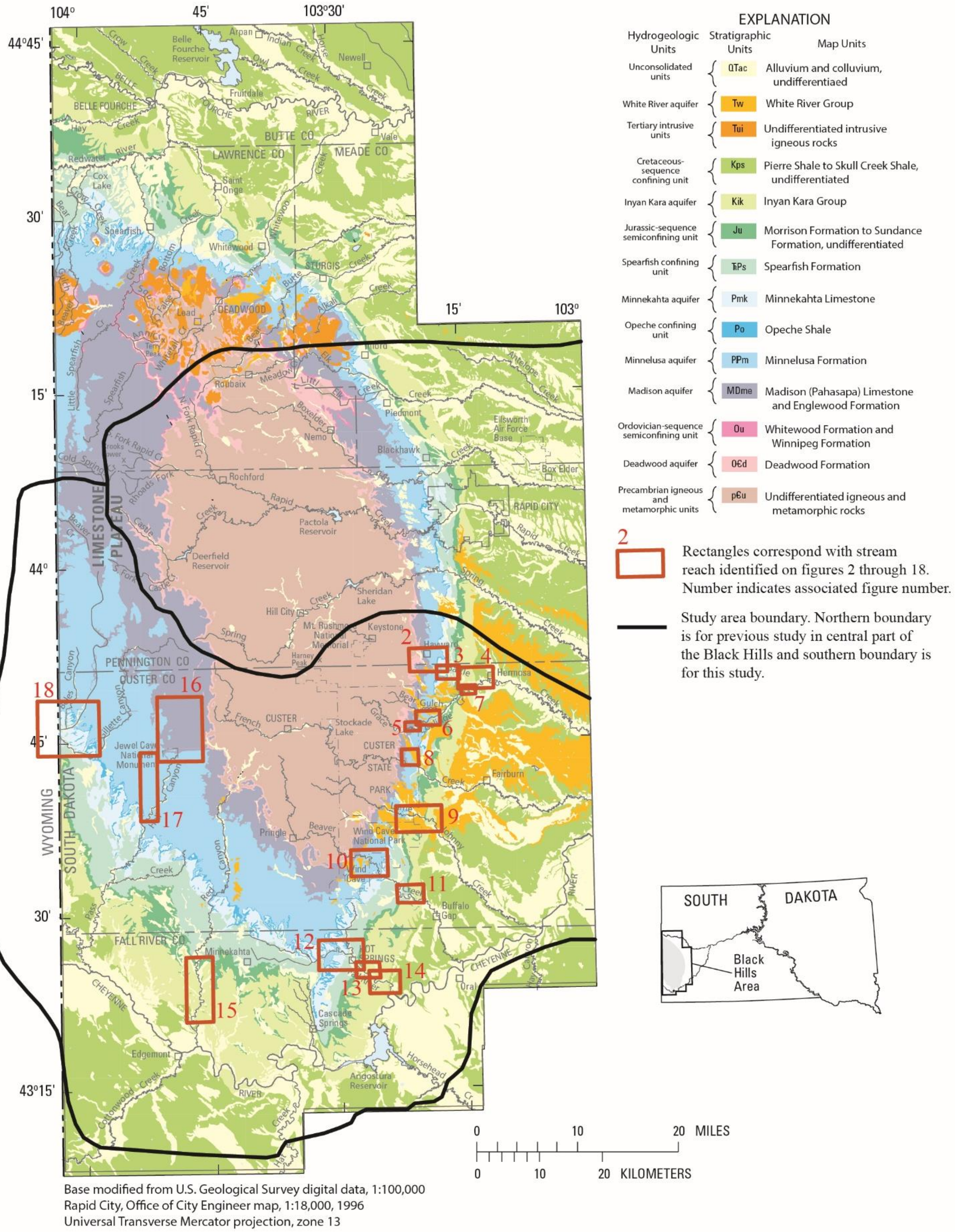

Figure 1: **Distribution of hydrogeologic units in the Black Hills area (modified from Strobel and others, 1999). The study areas for this study and a previous study in the central Black Hills also are shown.**

2.2 Background Summary

Paleoflood hydrology is the study of previously unmeasured floods (paleofloods), whether relatively recent or ancient, and has been used in various settings to investigate the magnitudes and timing (approximate dates) of large and infrequent floods. A reconnaissance-level paleoflood study for the Black Hills area was initiated in March 2006, as a cooperative effort between SDDOT and USGS. That study was performed in response to Research Project Statement SD2005-12, with an objective of assessing the applicability of paleoflood hydrology techniques for obtaining detailed evidence regarding the magnitude and frequency of especially large floods in the Black Hills area. Results were reported in Completion Report No. SD2005-12 (O'Connor and Driscoll, 2007). The primary conclusion from that reconnaissance-level study was that evidence well suited for paleoflood investigations could be found in many locations throughout the Black Hills area.

Following completion of the reconnaissance-level study (O'Connor and Driscoll, 2007), an implementation-level paleoflood study for the central part of the Black Hills (Figure 1) was initiated in 2008 in response to SDDOT Research Project Statement SD2008-01. Subsequent to completion of that second study (Driscoll and others, 2011; Harden and others, 2011), the SDDOT Research Review Board authorized initiation of this third study phase, as described in Research Project Statement SD2010-04 and with a proposed study area consisting of the southern part of the Black Hills (Figure 1). This study was implemented, but was subsequently terminated before planned completion because of issues described later in this report under task 4 (section 4.4). Thus, this completion report describes only those tasks that could be addressed within the abbreviated scope of the truncated study. Additional background information is provided within the remainder of this section in order to provide context for task 3 (section 4.3 that follows), which was largely completed prior to termination.

An overview of approaches for paleoflood investigations was provided in the completion report for the reconnaissance-level study (O'Connor and Driscoll, 2007). Details regarding the implementation-level study for the central part of the Black Hills are provided within the completion reports (Driscoll and others, 2011; Harden and others, 2011). A full-scale paleoflood study for a given river or stream typically might consist of (1) searching for historical accounts of floods that pre-date observed peak-flow records; (2) extensive reconnaissance to identify and evaluate the existence of various forms of paleoflood evidence suitable for investigation; (3) selecting discrete stream reaches deemed most suitable for detailed examination of paleoflood evidence and hydraulic analysis of paleoflood discharges; (4) detailed examination and investigation of paleoflood evidence at an appropriate number of discrete locations (multiple locations within a reach can be highly beneficial); (5) age dating of paleoflood evidence using various appropriate methods; (6) detailed topographic surveys of channel geometry in appropriate reaches; (7) rigorous hydraulic analyses to estimate discharges associated with paleoflood evidence; (8) interpretation of a paleoflood chronology (estimates of discharges and associated dates) for the reach from correlations among multiple sites, when applicable; (9) development of a flood-frequency analysis by incorporating the paleoflood chronology (peak-flow magnitudes and dates) with existing historical and observed peak-flow records (if available); and (10) documentation of methods and results in a published report.

Large floods can leave various forms of evidence that can be used to infer maximum flood stage. Some flood evidence can be preserved for hundreds, or even thousands of years, and various methods can be applicable for dating of flood evidence. Detailed site investigations performed to date in the two previous paleoflood studies in the Black Hills area have primarily involved stratigraphic analysis of sequential deposits of flood sediments, along with radiocarbon dating of entrained organic materials. These investigations have demonstrated the regional applicability of an approach that has been used worldwide in suitable environments to assess the frequency of low-probability floods. Flood SWDs are composed of sand and silt deposited from the suspended load of individual floods. The SWDs form and can be preserved along margins of canyon bottoms, typically in zones of flow separation (Kochel and Baker, 1982, 1988). For the Black Hills area, this most typically occurs in canyon reaches in small areas that are sheltered by cliffs or rock overhangs (generically referred to as alcoves within this report). Where SWDs are protected from erosion or extensive disturbance by plants and animals, successive floods may leave a sequence of deposits forming a stratigraphic record of large flow events encompassing many hundreds or thousands of years (O'Connor and others, 1994; Hosman and others, 2003). Individual flood deposits typically are separated by rockfall, organic duff, or local tributary sediment (which commonly has distinctly different grain size and mineral composition), thus allowing for determination of the number of floods that left deposits at a particular site. Organic detritus, including charcoal, driftwood, and blown-in leaf fall within and between individual flood deposits, can be dated using radiocarbon techniques, allowing for determination of the approximate timing of individual floods and the length of record represented by a sequence of flood deposits. The elevation of an individual flood deposit indicates a minimum value for the elevation or stage attained by the flow. By combining stratigraphic and geochronologic records of multiple depositional sites with hydraulic flow modeling techniques to obtain corresponding discharge estimates, robust flood-frequency analyses are possible that vastly improve recurrence interval estimates for large, low-probability floods (O'Connor and others, 1994; Hosman and others, 2003). This approach is considered as one of the most effective paleohydrologic methods for improving frequency estimates of low-probability, high-magnitude floods (Stedinger and Baker, 1987).

Numerous specific sites with various forms of paleoflood evidence were located and documented during the initial reconnaissance-level study (O'Connor and Driscoll, 2007). A key finding of that study was that local conditions in the Black Hills are ideal for formation, preservation, and analysis of flood SWDs. The Paleozoic rocks (primarily Minnekahta Limestone through Deadwood Formation) ringing the periphery of the Black Hills (Figure 1) form resistant-walled canyons bounding the larger creeks that drain radially from the central hills. In particular, the uplift history of the carbonate rock units resulted in extensive dissolution and lateral erosion, forming caves, alcoves, and ledgy overhangs that shelter SWDs from erosion. The Precambrian metamorphic rocks and Tertiary intrusive rocks of the central Black Hills (Figure 1) provide abundant sand carried in suspension by large floods, with mineral compositions distinct from those of slopewash and fluvial sediment derived from local drainages and hill slopes. The generally arid conditions within many rock shelters aid in preservation of stratigraphic boundaries and detrital organic materials necessary for reconstructing flood chronologies.

Results of the recent implementation-level paleoflood study (Driscoll and others, 2011; Harden and others, 2011) for the central part of the Black Hills (Figure 1) confirmed the suppositions from the earlier reconnaissance-level study (O'Connor and Driscoll, 2007) that (1) evidence well suited for paleoflood investigations could be found in many locations throughout the study area, and (2) flood-frequency analyses could be substantially improved through incorporation of paleoflood data. The knowledge that similar success might occur in conducting paleoflood investigations in other parts of the Black Hills led to development of this third study phase.

3.0 RESEARCH OBJECTIVES

This study involved two primary objectives, as described herein.

3.1 Develop Flood Chronologies and Associated Peak-Flow Frequency Analyses

Develop long-term flood chronologies and associated peak-flow frequency analyses for selected stream reaches in the southern Black Hills, based on application of paleoflood hydrology approaches demonstrated within previous SDDOT Research Projects SD2005-12 and SD2008-01.

The intended approach for addressing Objective 1 was through application of paleoflood survey techniques similar to those that were used in the two aforementioned SDDOT research projects. A brief listing of general steps involved in a typical full-scale paleoflood study was provided in section 2.2 (Background Summary). The planned scope of this effort was to complete all steps necessary to achieve full-scale implementation for selected stream reaches, including documentation of analytical procedures and results in published reports. The planned study area is within the outlined area in the southern Black Hills (Figure 1) and includes drainage basins south and southwest of those considered in the previous study of the central Black Hills. It was anticipated that paleoflood surveys would be conducted primarily in the vicinity of canyons entrenched within and near the Madison Limestone and Minnelusa Formation along the southeastern and southwestern flanks of the Black Hills.

3.2 Develop Flood-Frequency Information for "High-Elevation" Stream Reaches

Develop flood-frequency information regarding "high-elevation" stream reaches within the southern Black Hills to help address questions regarding differential potential for generation of exceptionally strong rain-producing thunderstorms across elevation gradients in the area.

The higher elevations of the Black Hills, especially within the Limestone Plateau area along the west-central Black Hills (Figure 1), are perceived to have substantially different (smaller) peak-flow potential than the surrounding lower-elevation areas (Driscoll and others, 2012). Steeper topography in the lower-elevation areas is hypothesized as one primary factor. Another hypothesized factor is reduced potential for exceptionally strong rain-producing thunderstorms in the higher elevations. Geologic conditions in the higher elevations generally are less favorable for formation and preservation of flood SWDs than in lower elevations; however, to the extent possible, there is a desire to better characterize the perceived differences in peak-flow potential.

4.0 TASK DESCRIPTIONS

Research Project Statement SD2010-04 identified 12 specific research tasks that are listed within this section, along with general descriptions of planned approaches and activities for accomplishment of the stated tasks. This study was terminated before the planned completion because of issues described later in this report under task 4 (section 4.4). Thus, this completion report addresses only the first four tasks and task 11, which consists of this completion report.

4.1 Review of Historical Flood Accounts

Continue (from the two previous related studies) to research the availability of historical flood accounts pre-dating systematic peak-flow records for the study area. Although numerous historical flood accounts have been compiled through previous studies, additional information probably still exists and could have utility.

Extensive searches for historical flood information were conducted as part of the two previous paleoflood studies, and a comprehensive history of Black Hills floods was provided by Driscoll and others (2010). This comprehensive flood history was the basis for a web-based chronology of Black Hills area storm and flood events (http://sd.water.usgs.gov/projects/FloodHistory/floodhistory.html). Because the flood chronology that had already been assembled was very comprehensive, very little activity was anticipated for this task. Additional minor historical flood information was found during the limited course of the study. This information was filed for future use and the existing web site for historical flood information was updated, when appropriate.

4.2 Project Scope Review

Meet with the project's technical panel to review the project scope and work plan, and to establish preliminary priorities for selecting initial stream reaches for conducting comprehensive paleoflood investigations.

A kick-off meeting of the Project Technical Panel was held, as planned. The project scope and work plan were discussed along with general priorities for selection of streams to be considered for future site investigations. A general consensus was reached that Battle Creek and French Creek probably would be two of the priority streams because (1) population bases are larger than for most of the other candidate streams; (2) Battle Creek had exceptional flooding during 1972 and 2007; and (3) site investigations had been conducted at several sites along French Creek during an initial reconnaissance-level study phase (O'Connor and Driscoll, 2007). The Fall River also was identified as a priority stream because of potential collaboration from U.S. Army Corps of Engineers relative to two flood control reservoirs in the basin. In addition, stream reaches with potential for providing insights regarding the second objective of addressing peak-flow potential for high-elevation areas were considered to have an inherent priority.

4.3 Preliminary Reconnaissance

Perform preliminary reconnaissance within the larger drainages in the study area to identify stream reaches with the best potential for providing high-quality paleoflood evidence and conducting comprehensive paleoflood investigations. The study area would essentially include all of the Black Hills of South Dakota south and southwest of the study area for Project SD2008-01.

Preliminary plans called for performing preliminary reconnaissance within the larger drainage basins within the southern Black Hills and prioritizing candidate locations for future field investigations of paleoflood evidence. Identification of candidate stream reaches was a necessary prelude relative to accommodating requirements of Section 106 of the National Historic Preservation Act, as prior knowledge of potential locations for field investigations was necessary for the associated consultation activities, as described in more detail in section 4.4 that follows.

In general, reconnaissance efforts involved first identifying streams with favorable geologic conditions and sufficient drainage area to justify additional reconnaissance. This was accomplished as an office activity and resulted in preliminary identification of 10 primary candidate streams or drainage basins. The 10 candidate streams, in counter-clockwise order around the flanks of the southern Black Hills are Battle Creek, Grace Coolidge Creek, French Creek, Lame Johnny Creek, Beaver Creek, Fall River, Red Canyon, Hell Canyon, Gillette Canyon, and Boles Canyon (Figure 1). A next step involved field reconnaissance of candidate stream reaches, which generally first involved viewing from a vehicle for reaches that were accessible by roads. Additional exploration for some stream reaches was conducted by walking, as many of the candidate reaches are not entirely accessible by roads and more detailed inspection is highly beneficial. A primary goal for field reconnaissance, whether by driving or walking, was to identify locations favorable for deposition and preservation of flood SWDs, with the most favorable locations most typically being within alcoves in canyon reaches flanked by bedrock outcrops, as described earlier in section 2.2. Ground disturbing activities were categorically avoided during all field reconnaissance to accommodate Section 106 requirements.

Stream reaches where field reconnaissance was conducted are shown in Figure 1, and brief descriptions of the general potential for finding paleoflood evidence favorable for high-quality field investigations are provided within the remainder of this section. For each stream reach shown in figure 1, a corresponding figure is provided along with the ensuing brief descriptions. The figures were generated by capturing imagery using basic tools available through Google Earth (Map data ©2016 Google). The images are shown in oblique views to provide a visual perspective on the topography. Each figure shows one or more colored lines that denote the approximate location of the stream channel in the reach where reconnaissance occurred, the primary method or methods for viewing (whether primarily by driving, walking, or both), and a generalized assessment of the potential (minimal, limited, moderate, or good potential) for finding high-quality flood SWDs or other paleoflood evidence suitable for field investigations. It was not possible to set firm criteria for the generalized assessments. Minimal potential indicates conditions that are generally unfavorable for sheltering and preservation of SWDs. Limited potential indicates a general sparsity of well-sheltered alcoves along canyon walls perceived to be within reasonable elevation ranges of flood stages that might be anticipated for any given drainage. Moderate and good potential indicate progressively greater abundance of well-sheltered alcoves, relative to the general sparsity associated with limited potential. Narrower canyons generally lend to better perceived potential because of greater sensitivity of flood stage, relative to discharge. Specific locations of alcoves or associated SWDs are not shown on figures because of sensitivity regarding considerations relative to Section 106 issues.

The brief descriptions also include references to bedrock outcrops within the reach that correspond with the stratigraphic units from figure 1. Mapped alluvial deposits that exist within some stream reaches are not mentioned.

Three reaches along Battle Creek (Figures 2, 3, and 4 in Appendix A) were explored as part of the reconnaissance efforts. The upstream reach (Figure 2) includes two sub-reaches, both of which were explored by walking. The upstream of these two sub-reaches is within outcrops of Precambrian rocks

(Figure 1), where potential for alcoves sheltering SWDs generally tends to be somewhat limited. However, good potential was found within this short sub-reach. The downstream of these two sub-reaches is primarily within outcrops of the Madison Limestone and Minnelusa Formation, where potential for alcoves typically can be very good. Many alcoves with moderate to good potential for sheltering SWDs were found in this reach. The intermediate reach of Battle Creek (Figure 3) is primarily within outcrops of the Minnelusa Formation and Minnekahta Limestone. Because of numerous landowners throughout this reach, exploration was done only by driving; however, moderate potential likely exists within this reach, based on viewing of the topography and geology. The downstream reach (Figure 4) is primarily within outcrops of the Inyan Kara Group and was explored by a combination of driving and walking. One alcove reach was found that contained surficial SWDs from the large flood of August 17, 2007 (Driscoll and others, 2010), which indicates good potential for SWDs from previous large floods.

Three reaches along Grace Coolidge Creek (Figures 5, 6, and 7 in Appendix A) were explored. The upstream reach (Figure 5) includes two sub-reaches, and both were explored entirely by walking. Only limited potential was found within the upstream sub-reach, which is primarily within outcrops of the Deadwood Formation and Madison Limestone. Good potential was found within the downstream sub-reach, which is primarily within outcrops of the Madison Limestone. The intermediate reach of Grace Coolidge Creek (Figure 6) is primarily within outcrops of the Minnelusa Formation and Minnekahta Limestone. Because most of this reach was quite visible from the road, exploration was done only by driving; however, moderate potential exists within this reach, based on viewing of the topography and geology. The downstream reach (Figure 7) is primarily within outcrops of the Inyan Kara Group and was explored by driving and walking. One alcove reach was found that contained surficial SWDs from the large flood of August 17, 2007 (Driscoll and others, 2010), which indicates good potential for SWDs from previous large floods.

One reach along French Creek (Figure 8 in Appendix A) was explored entirely by walking. This reach is located upstream from the reach where field investigations were made as part of the reconnaissance-level study reported by O'Connor and Driscoll (2007). This reach transitions from outcrops of Precambrian rocks in the upstream extent to outcrops of the Madison Limestone at the downstream extent. Surficial SWDs were visible in one alcove reach and several additional alcoves with moderate to good potential were found.

Two reaches along Lame Johnny Creek (Figure 9 in Appendix A) were explored. The upstream reach is primarily within outcrops of the Minnelusa Formation and was explored by a combination of driving and walking, with moderate potential identified in this reach. Another reach farther downstream was not explored; however, this reach could have moderate potential, based on topography and geology (primarily within outcrops of the Inyan Kara Group).

Two reaches along Beaver Creek (Figures 10 and 11 in Appendix A) were explored. The upstream reach (Figure 10) has two sub-reaches. The upstream sub-reach is within outcrops of the Madison Limestone, and several alcoves with good potential for sheltering SWDs were found by walking. The downstream sub-reach extends for several miles through several geologic units (Figure 1) and was not explored because good potential was found within the upstream sub-reach. However, this reach likely would have moderate potential, based on topography and geology. The downstream reach of Beaver Creek (Figure 11) was explored by driving and walking; moderate potential likely exists within this reach, based on viewing of the topography and geology, which includes several stratigraphic units (Figure 1).

Three reaches along the Fall River (Figures 12, 13, and 14 in Appendix A) were explored. The upstream reach (Figure 12) has three sub-reaches within outcrops of the Minnelusa, Minnekahta, and Spearfish Formations. The sub-reach farthest upstream was explored by driving and walking, with moderate potential identified in this reach. The intermediate sub-reach was explored by walking, and good potential is indicated by at least one location where likely SWDs were identified. The sub-reach farthest downstream has minimal potential, based on viewing from several vantage points. The intermediate reach of the Fall River (Figure 13) was explored primarily by driving. It has moderate potential based on topography and geology, which includes several stratigraphic units (Figure 1).

The third reach (farthest downstream) along the Fall River was divided into six sub-reaches (Figure 14). The five sub-reaches farthest upstream are primarily within outcrops of the Inyan Kara Group and were explored by a combination of walking and driving. The topography and geology in all five sub-reaches are reasonably favorable for alcoves, with potential rated moderate to good. However, surficial evidence of SWDs was not apparent in any of the sub-reaches. The sub-reach farthest downstream is primarily within an outcrop of the undifferentiated Pierre Shale to Skull Creek Shale and has minimal potential, based on geology and viewing from several vantage points.

One reach along Red Canyon (Figure 15 in Appendix A) was explored by driving and walking. Moderate potential was identified in this reach, which is primarily within outcrops of the Inyan Kara Group.

Two reaches along Hell Canyon (Figures 16 and 17 in Appendix A) were explored. The upstream reach (Figure 16) is primarily within outcrops of the Madison Limestone and has three sub-reaches. Moderate potential was found by driving and walking within the upstream sub-reach. Good potential was found by walking within the intermediate and downstream sub-reaches, which are separated by U.S. Highway 16 (runs east/west in the southern part of the study reach). The second reach (Figure 17) is located several miles farther downstream and is within outcrops of the Minnelusa Formation. Good potential was found by walking within this reach.

Two reaches along Boles Canyon and Gillette Canyon are shown on figure 18 in Appendix A. Both reaches were explored only by driving, and both have moderate potential based on topography and geology (both are within outcrops of the Minnekahta Limestone).

In summary, conditions in the southern Black Hills appear quite favorable for conducting paleoflood investigations. Locations with at least moderate potential for deposition and preservation of SWDs were found along all 10 of the candidate streams, and good potential was found along 6 of the candidate streams. SWDs from 2007 flooding were found in locations along Battle Creek and Grace Coolidge Creek, which indicates reasonable potential for existence of SWDs from paleofloods. Locations with likely SWDs from paleofloods were found in several additional candidate stream reaches. In general, conditions for hydraulic analyses were judged to be quite favorable, as many of the reaches with moderate to good potential for SWDs are well constrained in relatively narrow canyon reaches, which provides good sensitivity for changes in stage, relative to discharge.

4.4 Section 106 of the National Historic Preservation Act

Engage in various activities necessary to comply with requirements of Section 106 of the National Historic Preservation Act.

This task was needed because alcoves and rock shelters that are well suited for deposition and preservation of SWDs may have been used as shelters or cache locations by indigenous inhabitants and thus may be eligible for consideration as historic properties because of possible archaeological or cultural materials. As such, this study was considered a Federal undertaking and was required to be performed in accordance with Section 106. The Section 106 process involves four primary steps: (1) initiation of the process; (2) identification of potential historic properties; (3) assessment of adverse effects; and (4) resolution of adverse effects. An initial work plan for this study had been submitted on October 27, 2010; however, a revised work plan with substantially expanded planning for this task was finalized on September 9, 2011. This expansion was needed because as activities progressed it became apparent that the magnitude of this task would be much larger than originally anticipated.

Initiation of the Section 106 process for this study of the southern Black Hills (step 1 in the previous paragraph) essentially involved (1) initial notification of the SHPO, numerous Native American tribes having cultural and religious ties to the Black Hills, and other appropriate agencies and parties; and (2) a subsequent consultation process involving the aforementioned entities. Consultation is an inherent part of the process that spans all four steps. The Federal Highway Administration also had an inherent role in this process because of their involvement with the SDDOT Research Program. However, USGS assumed the role of the lead Federal agency because of its much larger role as the primary agency for implementation of this study.

At the onset of this study phase for the southern Black Hills, USGS notified the SHPO and began working with SHPO staff to become more familiar with the Section 106 process and begin pursuing necessary activities. An early activity involved development of a "Project Description Statement" that provided an overview of the study purpose, previous study efforts, methods to be used, and general locations of stream reaches anticipated for exploration and field investigations during this study. The consultation process was then initiated by circulating the Project Description Statement to numerous tribes, various appropriate agencies, and various other parties with potential interest.

The complexity of the Section 106 concerns and issues became progressively more apparent as the consultation process evolved. Many logistical challenges began to emerge regarding identification of potential sites for detailed site investigations and the ensuing process of conducting the site investigations. The consultation process indicated a strong desire for extensive tribal monitoring for all site investigations beyond the most cursory reconnaissance-level activities such as those described under task 4.3. A likely stepwise progression for tribal monitoring following the cursory reconnaissance may have included (1) field trips to provide opportunities for tribal inspection of all potential sites, (2) monitoring while conducting preliminary test excavations as part of more rigorous reconnaissance to identify sites with the best potential for suitable deposits of paleoflood evidence, and (3) monitoring throughout the detailed site investigations. Another logistical challenge was an identified need for rigorous archaeological monitoring while performing both test excavations and detailed site investigations, with a need for full-scale archaeological investigations to be conducted at sites deemed to have a sufficient level of richness relative to existence, or potential existence, of archaeological material. Task 4 progressed as far as developing a preliminary draft of a Programmatic Agreement to formalize how the Section 106 issues would be addressed. However, progress on this effort halted when it became apparent that the resources needed to address the Section 106 issues would overwhelm the resources available for implementation of the study. Thus, by mutual agreement of SDDOT and USGS, the study was terminated before addressing the remaining tasks originally planned for this study.

4.5 Field Investigations of Paleoflood Evidence

Along selected stream reaches in the southern Black Hills, conduct comprehensive investigations of available paleoflood evidence consistent with methodologies and principles established in previous Black Hills studies.

Task not addressed because of project termination.

4.6 Hydraulic Analyses for Estimation of Discharge

Perform surveys of channel geometry and employ appropriate methods of hydraulic analysis for estimation of discharge associated with paleoflood evidence. Coordinate with SDDOT or other agencies as appropriate, for obtaining detailed topographic surveys (such as high-resolution aerial photography or LiDAR) for development of hydraulic models, where needed, or as appropriate.

Task not addressed because of project termination.

4.7 Conduct Annual Field Visits with the Project Technical Panel

Conduct field visits of representative paleoflood survey sites with the Project Technical Panel on an annual basis.

Task not addressed because of project termination.

4.8 Submit Interim Progress report

Submit an interim report to the Project Technical Panel that reviews work progress, assesses project accomplishments to date, and provides a general status on work progress after the first full summer of detailed site investigations.

Task not addressed because of project termination.

4.9 Complete Remaining Paleoflood Investigations and Hydraulic Analyses

Complete remaining paleoflood investigations and hydraulic analyses during ensuing work phases.

Task not completed because of project termination.

4.10 Submit Preliminary Results for Technical Panel Review

Develop and submit for Technical Panel review, as preliminary products of the study efforts, resulting flood chronologies and associated peak-flow frequency analyses derived using appropriate statistical applications.

Task not addressed because of project termination.

4.11 Final Report

Upon review of the updated datasets and flood frequency curves by the Technical Panel, prepare a final report and executive summary of the research methodology, data derivations, findings, conclusions, and recommendations.

This document represents the final report for this study.

4.12 Executive Presentation

Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

The executive presentation was deferred at the mutual agreement of SDDOT and USGS because of project termination.

5.0 FINDINGS AND CONCLUSIONS

Because this study was terminated before completion, findings were minimal. Thus, this section addresses only findings relative to preliminary reconnaissance and the Section 106 issues, which were the only two primary tasks that had substantial activities as part of the truncated study.

5.1 Findings from Preliminary Reconnaissance

Ten candidate streams having favorable geologic conditions and sufficient drainage area to potentially justify field paleoflood investigations were identified for conducting preliminary field reconnaissance. In general, field reconnaissance indicated that conditions in the southern Black Hills appear quite favorable for conducting paleoflood investigations. Locations with at least moderate potential for deposition and preservation of SWDs were found along all 10 of the candidate streams, and good potential was found along 6 of the candidate streams. SWDs from 2007 flooding were found in locations along Battle Creek and Grace Coolidge Creek, which indicates reasonable potential for existence of SWDs from paleofloods, and locations with likely SWDs from paleofloods were found along several additional candidate streams. In general, conditions for hydraulic analyses were judged to be quite favorable, with most of the reaches with moderate to good potential for SWDs being well constrained in relatively narrow canyon reaches, which provides good sensitivity for changes in stage, relative to discharge.

5.2 Findings Relative to Section 106 Issues

The complexity of the Section 106 concerns and issues became progressively more apparent as the consultation process evolved. It eventually became apparent that the resources needed to address the Section 106 issues would overwhelm the resources available for implementation of the study. Thus, by mutual agreement of SDDOT and USGS, the study was terminated before addressing the remaining tasks originally planned for this study.

6.0 CONSIDERATIONS REGARDING POTENTIAL FUTURE PALEOFLOOD STUDIES

This section addresses considerations regarding potential future re-implementation of paleoflood studies for the southern Black Hills. These considerations are addressed relative to preliminary reconnaissance (Task 3) and Section 106 activities (Task 4), which were the only two primary tasks that had substantial activities as part of the truncated study.

6.1 Considerations Relative to Availability of Paleoflood Evidence

Preliminary reconnaissance indicated a relatively high likelihood of finding sufficient paleoflood evidence of sufficient quality to obtain high-quality chronologies of past paleofloods for many stream reaches in the southern Black Hills.

Preliminary field reconnaissance was conducted along 10 candidate streams in the southern Black Hills judged to have favorable geologic conditions and sufficient drainage area to potentially justify field paleoflood investigations. Field reconnaissance indicated conditions that generally appeared quite favorable for conducting paleoflood investigations. Locations with at least moderate potential for deposition and preservation of SWDs were found along all 10 of the candidate streams, and good potential was found along 6 of the candidate streams. SWDs from 2007 flooding were found in locations along Battle Creek and Grace Coolidge Creek, which indicates reasonable potential for existence of SWDs from paleofloods, and locations with likely SWDs from paleofloods were found along several additional candidate streams. In general, conditions for hydraulic analyses were judged to be quite favorable, as many of the reaches with moderate to good potential for SWDs are well constrained in relatively narrow canyon reaches, which provides good sensitivity for changes in stage, relative to discharge.

6.2 Considerations Relative to Section 106 Issues

In the event of potential re-implementation of this study, substantial financial resources would be needed to address the complex Section 106 issues; however, with sufficient financial resources, the Section 106 issues should not be insurmountable.

In the event of consideration of future re-implementation, several approaches might help expedite addressing the Section 106 issues. One approach that might help substantially could be a partnership with another Federal agency that has substantial experience with the Section 106 process. USGS has very little experience with this process, and this was a particularly complicated project that requires substantial expertise. The Bureau of Land Management, National Park Service, and U.S. Forest Service could potentially be candidates as future partners, as all have Federal land holdings within the Black Hills area with potential for application of paleoflood surveys. In addition, substantial financial resources need to be available in order to adequately fund this aspect. Another approach that might help could be securing assistance from a consultant that could help with both the Section 106 process and the required archaeological component. Another approach that might help could be partnering with a tribal college with an archaeological program, which could help make this study become part of a learning exercise. Further partnering with a tribal college with an earth science/hydrology program also could be advantageous.

7.0 RESEARCH BENEFITS

Because this study was terminated before completion, anticipated benefits from improved peak-flow frequency analyses were not realized. Benefits were essentially limited to the finding that conditions in the southern Black Hills appear to be quite favorable for conducting paleoflood investigations.

8.0 REFERENCES

Benito, G., and O'Connor, J.E., 2013, Quantitative paleoflood hydrology, *in* John F. Shroder, ed., Treatise on geomorphology. San Diego: Academic Press, vol. 9, pp. 459-474, accessed July 17, 2017, at http://www.elsevier.com/locate/permissionusematerial.

Carter, J.M., Teller, R.W., and Williamson, J.E., 2002, The 1972 Black Hills-Rapid City flood revisited: U.S. Geological Survey Fact Sheet FS-037-02, 6 p., accessed March 8, 2017, at https://pubs.usgs.gov/fs/fs-037-02/.

Driscoll, D.G., Bunkers, M.J., Carter, J.M., Stamm, J.F., and Williamson, J.E., 2010, Thunderstorms and flooding of August 17, 2007, with a context provided by a history of other large storm and flood events in the Black Hills area of South Dakota: U.S. Geological Survey Scientific Investigations Report 2010-5187, 139 p., accessed March 8, 2017, at https://pubs.usgs.gov/sir/2010/5187/.

Driscoll, D.G., O'Connor, J.E., and Harden, T.M., 2011, Application of paleoflood survey techniques in the Black Hills area of South Dakota: Completion report SD2008-01 submitted to South Dakota Department of Transportation, Office of Research, 88 p., accessed June 15, 2017, at http://www.sddot.com/business/research/projects/docs/SD2008-01-F_Final_Report_07-16-12.pdf.

Driscoll, D.G., Huft, D.L., and O'Connor, J.E., 2012, Extreme floods in the Black Hills area: New insights from recent research: Pierre, S. Dak., South Dakota Department of Transportation, 4 p., accessed March 8, 2017, at http://www.sddot.com/business/research/projects/docs/SD2008-01_Fact_Sheet_06-11-12.pdf.

Harden, T.M., O'Connor, J.E., and Driscoll, D.G., 2011, Flood frequency analyses derived from paleoflood chronologies for selected streams in the Black Hills area of South Dakota: U.S. Geological Survey Scientific Investigations Report 2011–5131, 136 p., accessed June 15, 2017, at https://pubs.usgs.gov/sir/2011/5131/.

Hosman, K.J., Ely, L.L., and O'Connor, J.E., 2003, Holocene paleoflood hydrology of the lower Deschutes River, Oregon, in O'Connor, J.E., and Grant, G.E., eds., A peculiar river—Geology, geomorphology, and hydrology of the Deschutes River, Oregon: American Geophysical Union Water Science and Application Series No. 7, pp. 121–146.

Kochel, R.C., and Baker V.R., 1982, Paleoflood hydrology: Science, vol. 215, pp. 353–361.

Kochel, R.C., and Baker, V.R., 1988, Paleoflood analysis using slackwater deposits, *in* Baker, V.R., Kochel, R.C., and Patton, P.C., eds., Flood geomorphology: New York, John Wiley and Sons, pp. 357–376.

O'Connor, J.E, Ely, L.L., Wohl, E.E., Stevens, L.D., Melis, T.S., Kale, V.S., and Baker, V.R., 1994, A 4000-year record of extreme floods on the Colorado River in the Grand Canyon: Journal of Geology, vol. 102, pp. 1–9.

O'Connor, J.E., and Driscoll, D.G., 2007, Applicability of paleoflood surveys to the Black Hills of Western South Dakota: Completion report SD2005-12 submitted to South Dakota Department of Transportation, Office of Research, 59 p., accessed March 8, 2017, at http://www.sddot.com/business/research/projects/docs/SD2005-12_Final_Report.pdf.

O’Connor, J.E., Atwater, B.F., Cohn, T.A., Cronin, T.M., Keith, M.K., Smith, C.G., and Mason, R.R., 2014, Assessing inundation hazards to nuclear powerplant sites using geologically extended histories of riverine floods, tsunamis, and storm surges: U.S. Geological Survey Scientific Investigations Report 2014–5207, 66 p., accessed July 17, 2017, at http://dx.doi.org/10.3133/sir20145207.

Sando, S.K., Driscoll, D.G., and Parrett, Charles, 2008, Peak-flow frequency estimates based on data through water year 2001 for selected streamflow-gaging stations in South Dakota: U.S. Geological Survey Scientific Investigations Report 2008-5104, 367 p., online only, accessed March 8, 2017, at https://pubs.usgs.gov/sir/2008/5104/.

Schwarz, F.K., Hughes, L.A., Hansen, E.M., Petersen, M.S., and Kelly, D.B., 1975, The Black Hills—Rapid City flood of June 9-10, 1972: A description of the storm and flood: U.S. Geological Survey Water Supply Paper 877, 47 p., accessed March 8, 2017, at https://pubs.er.usgs.gov/publication/pp877 .

Stedinger, J. R., and Baker, V.R., 1987, Surface water hydrology—Historical and paleoflood information: Reviews in Geophysics, vol. 25, pp. 119–124.

Strobel, M.L., Jarrell, G.J., Sawyer, J.F., Schleicher, J.R., and Fahrenbach, M.D., 1999, Distribution of hydrogeologic units in the Black Hills area, South Dakota: U.S. Geological Survey Hydrologic Investigations Atlas HA-743, 3 sheets., accessed March 17, 2017, at https://pubs.usgs.gov/ha/ha743/.

Appendix A: FIGURES SHOWING STREAM REACHES WHERE RECONNAISSANCE WAS CONDUCTED

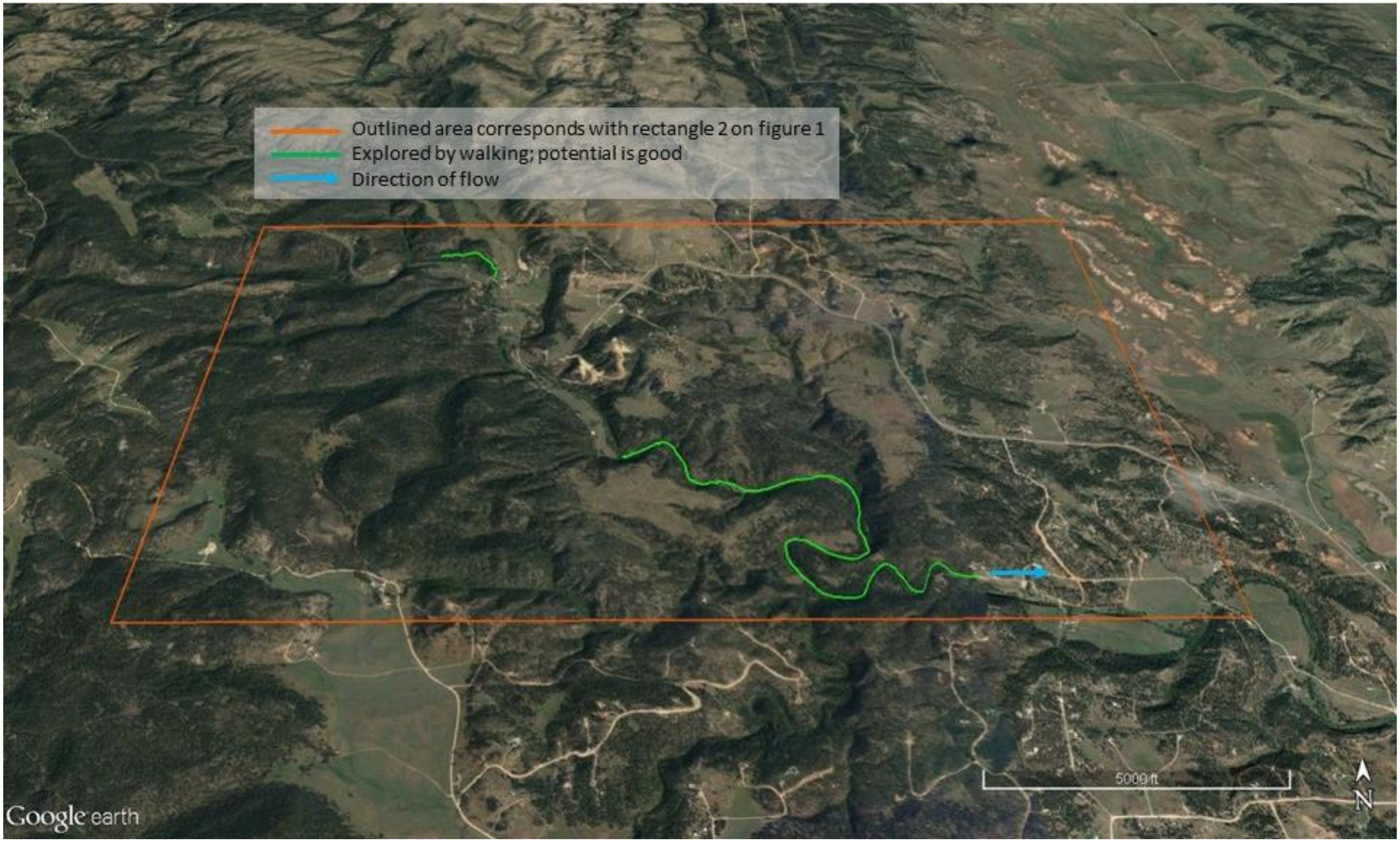

Figure 2: Oblique view of upstream reach of Battle Creek (Map data ©2016 Google)

Figure 3: Oblique view of intermediate reach of Battle Creek (Map data ©2016 Google)

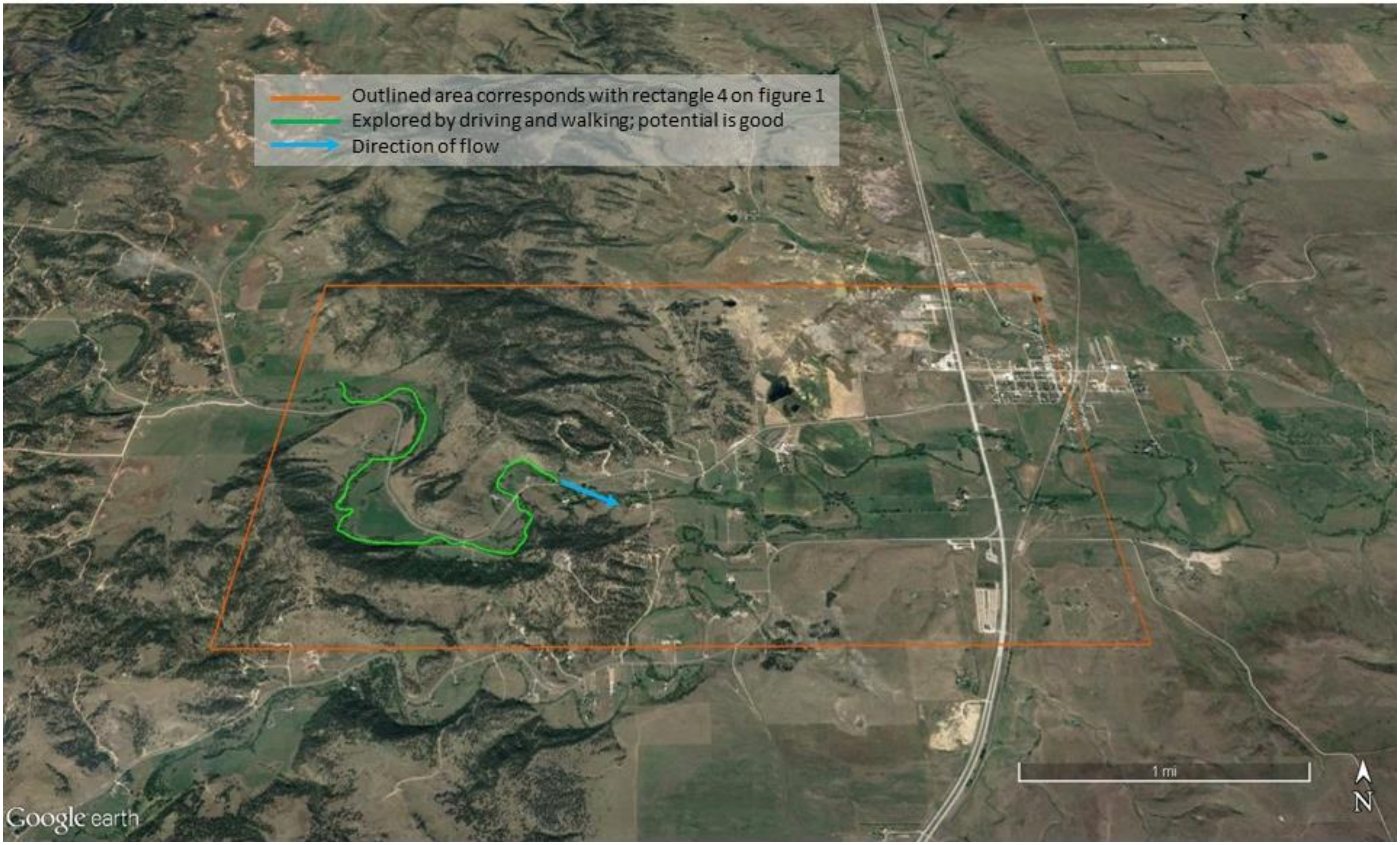

Figure 4: Oblique view of downstream reach of Battle Creek (Map data ©2016 Google)

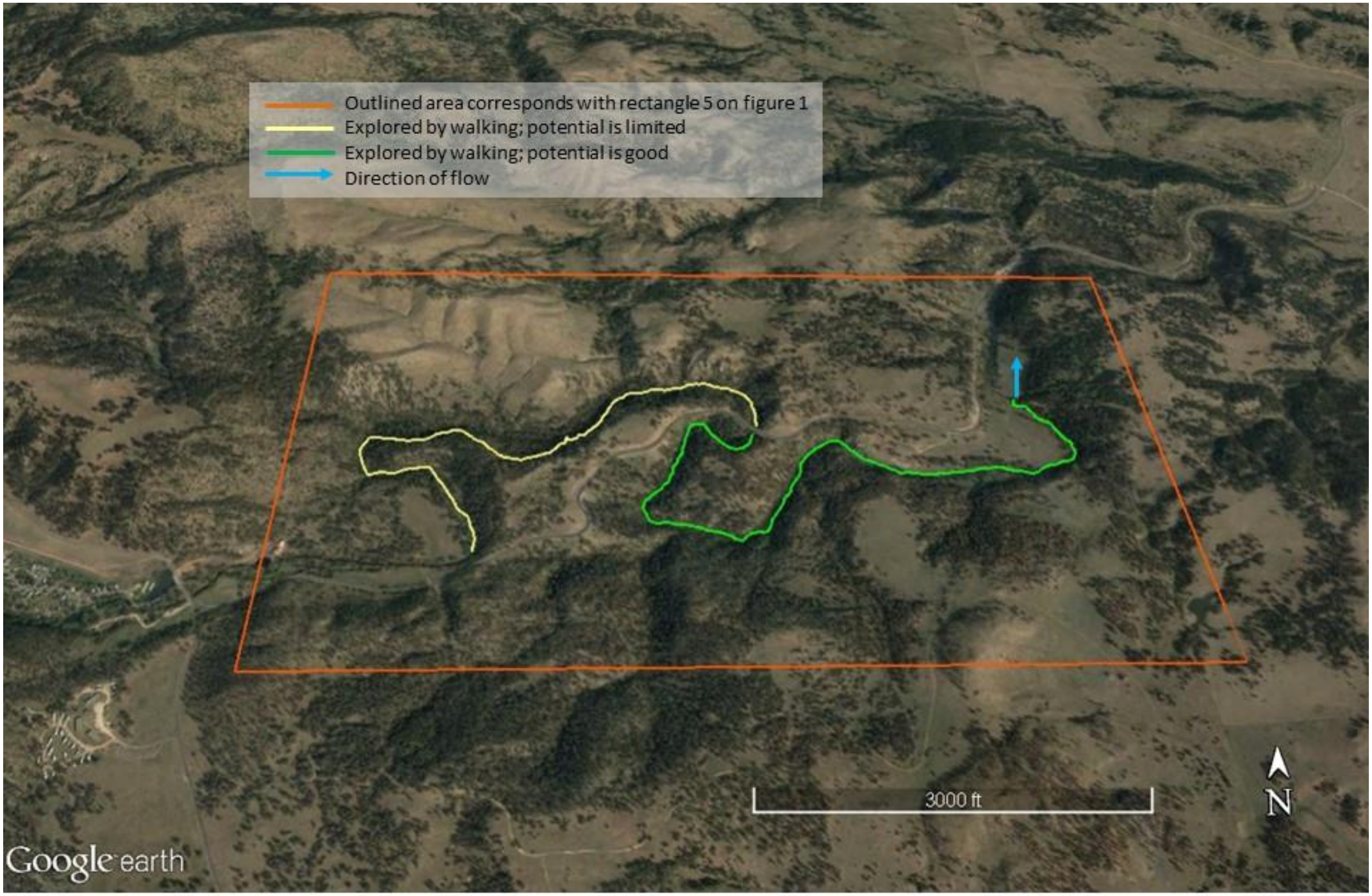

Figure 5: Oblique view of upstream reach of Grace Coolidge Creek (Map data ©2016 Google)

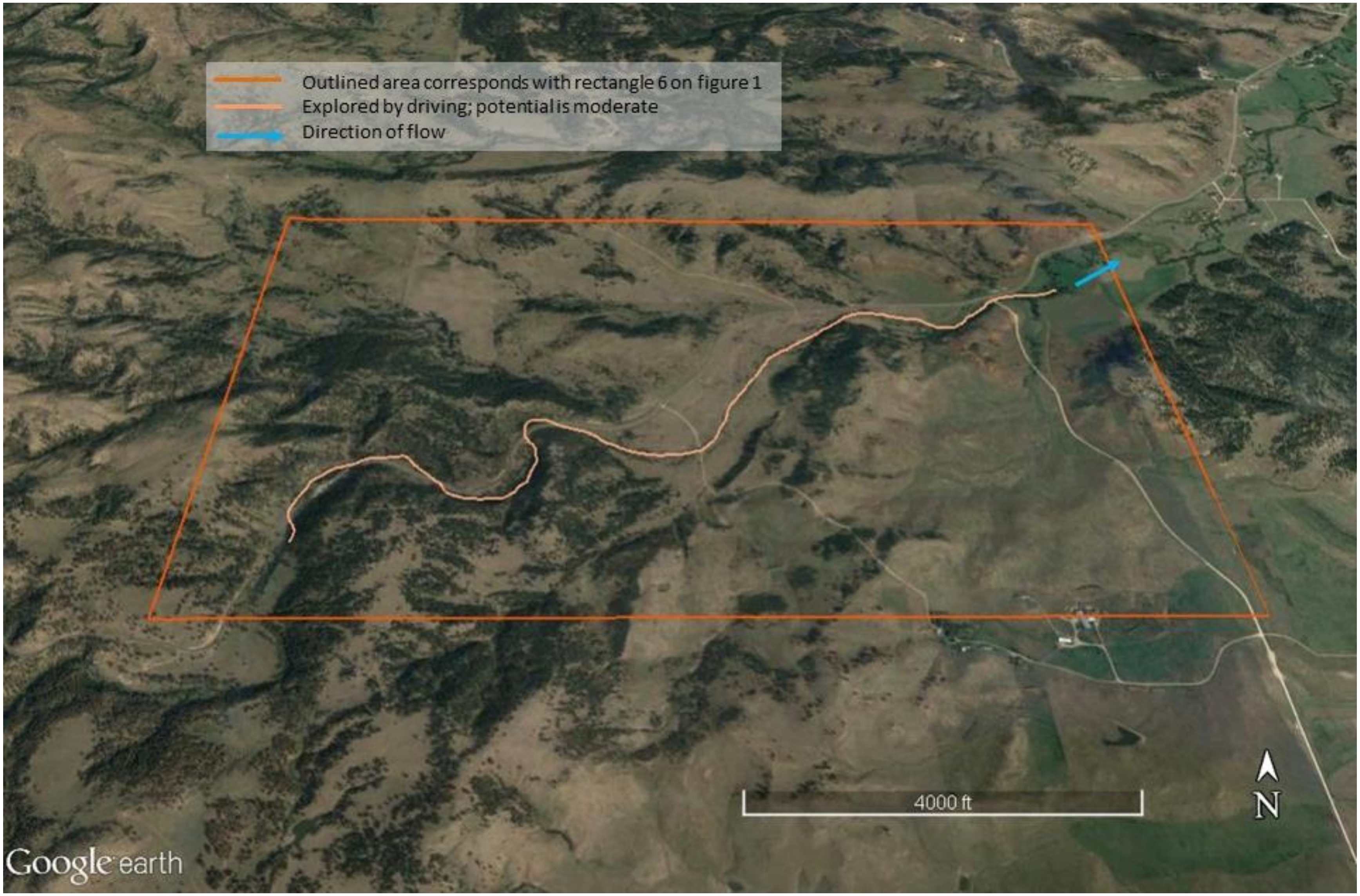

Figure 6: Oblique view of intermediate reach of Grace Coolidge Creek (Map data ©2016 Google)

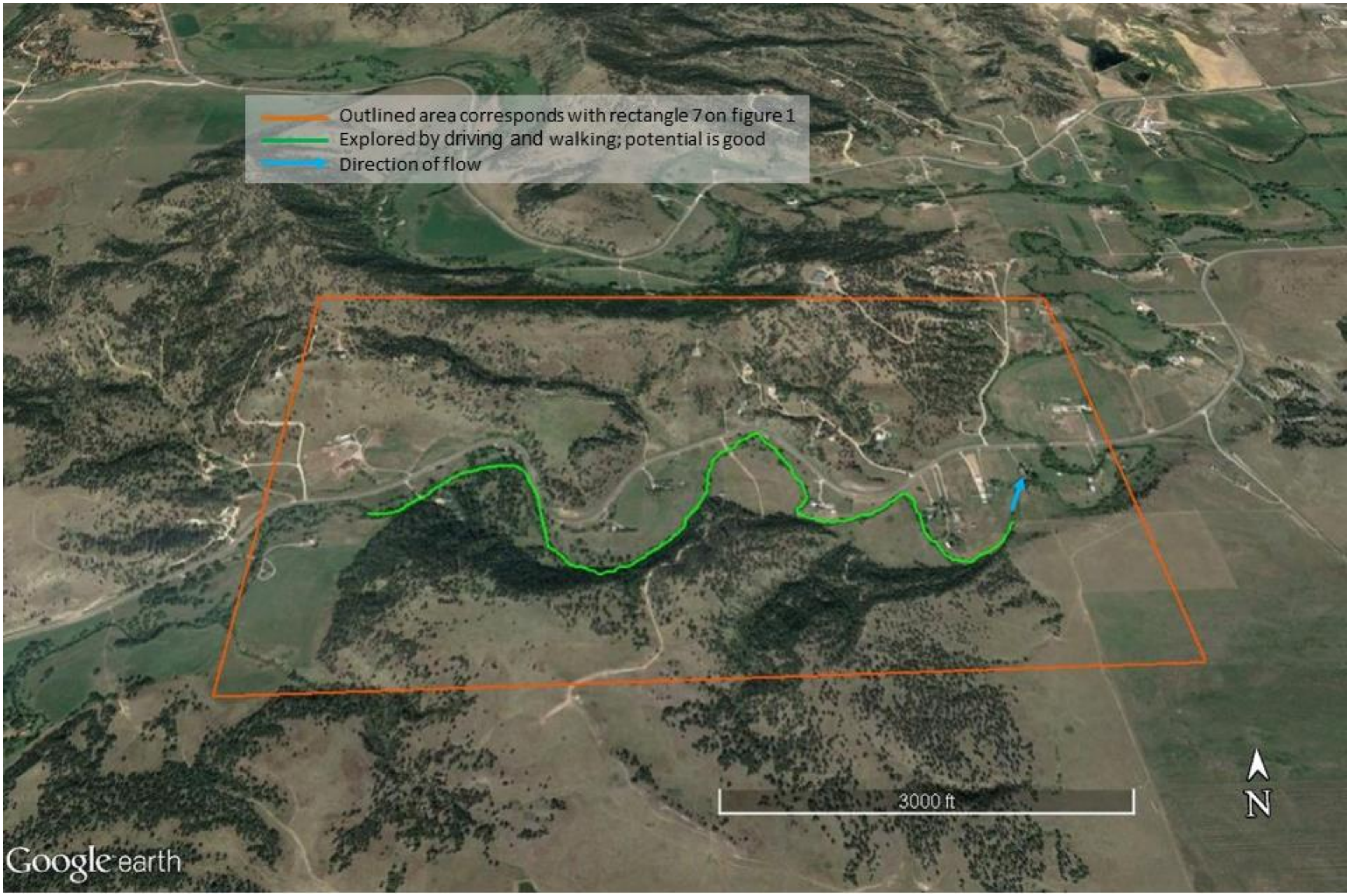

Figure 7: Oblique view of downstream reach of Grace Coolidge Creek (Map data ©2016 Google)

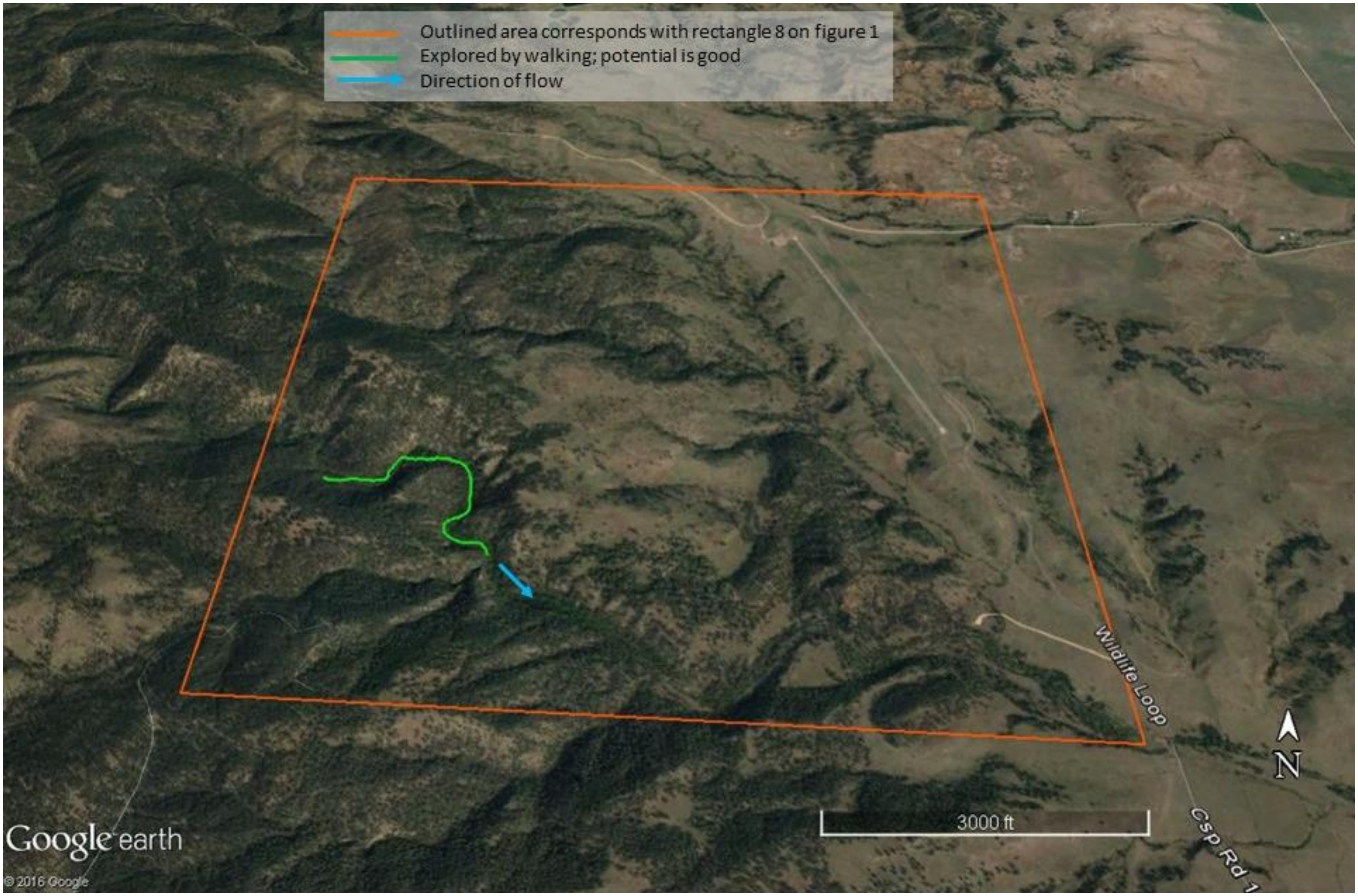

Figure 8: Oblique view of stream reach for French Creek (Map data ©2016 Google)

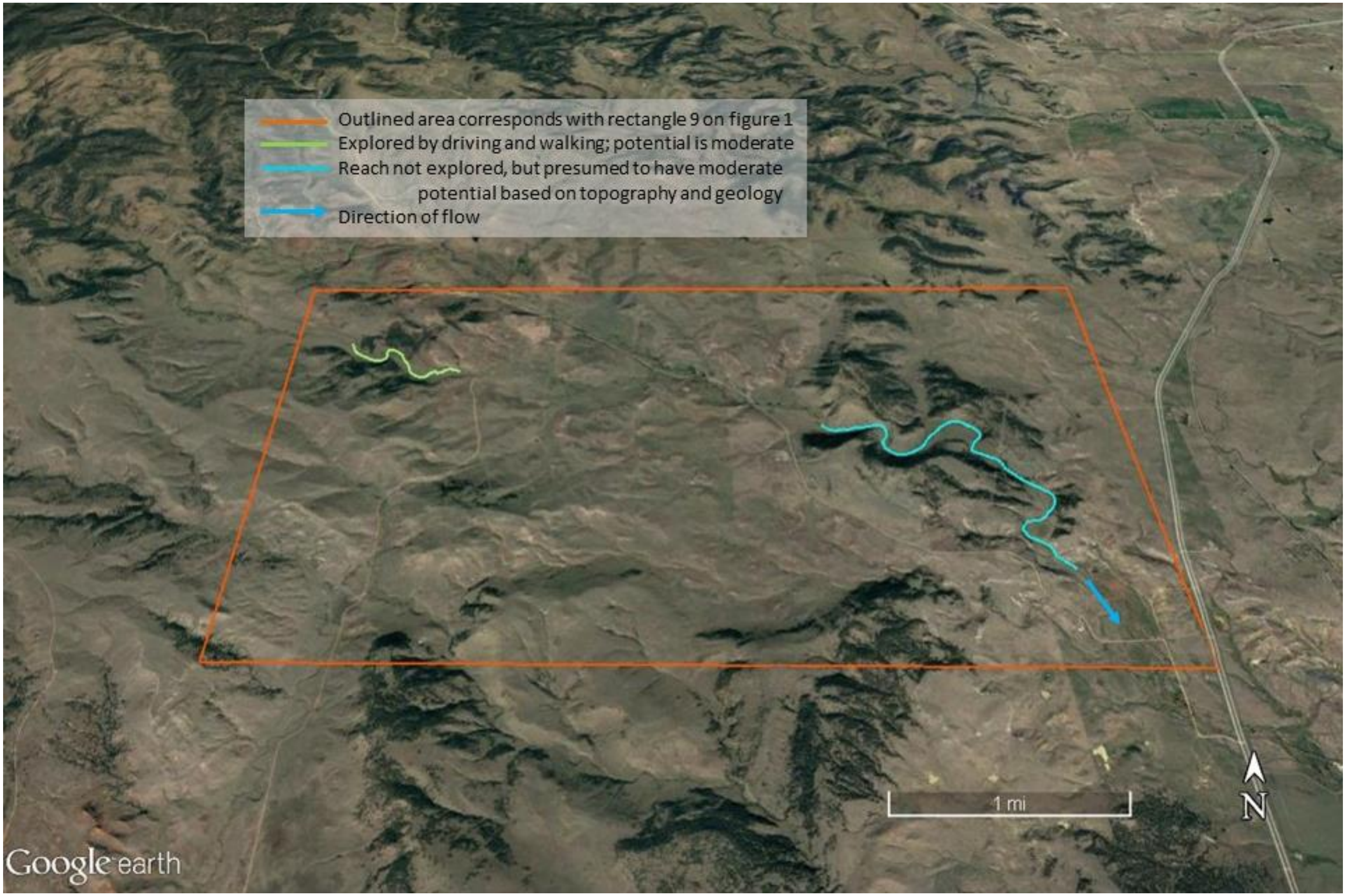

Figure 9: Oblique view of stream reaches for Lame Johnny Creek (Map data ©2016 Google)

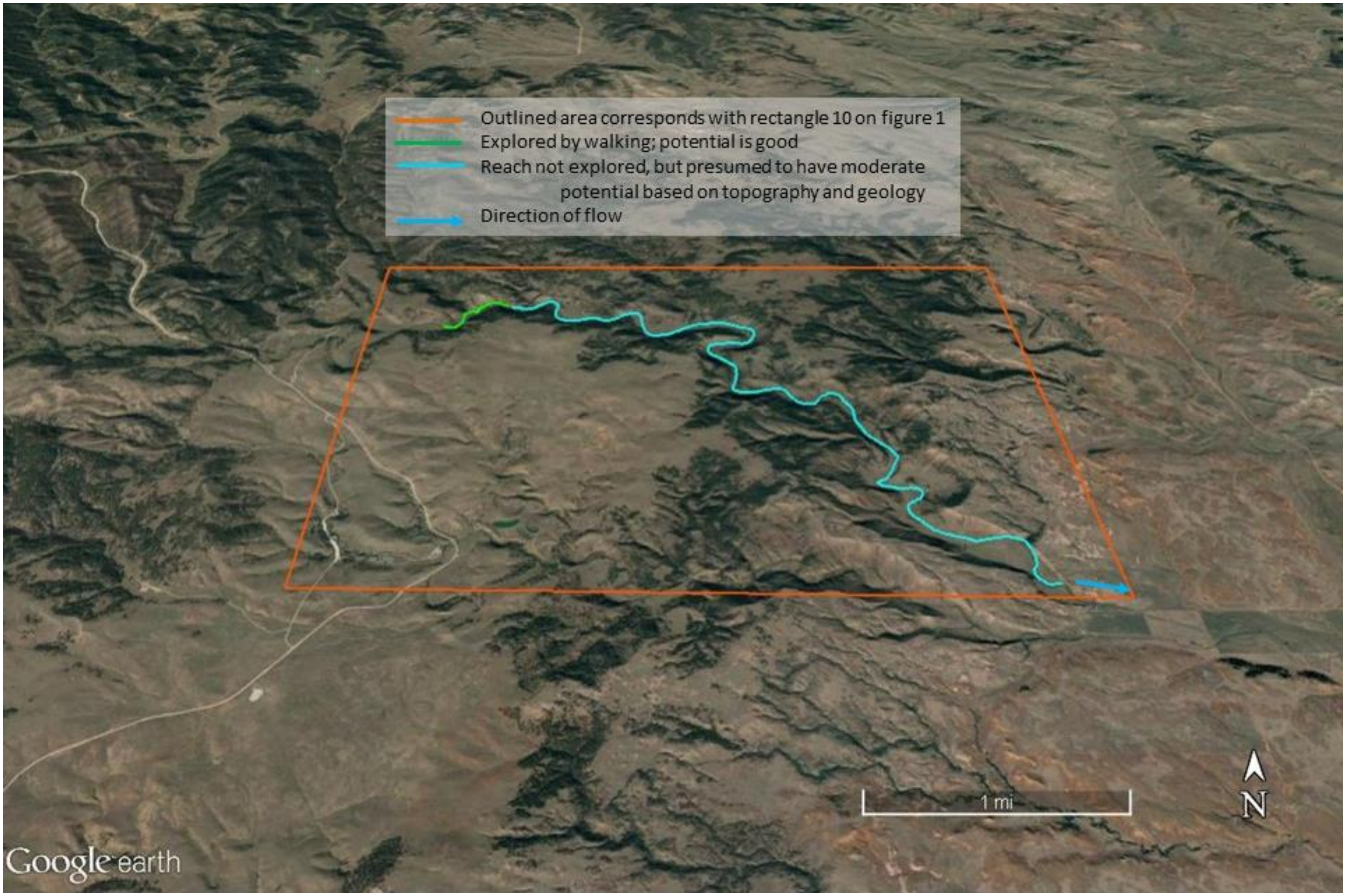

Figure 10: Oblique view of upstream reach of Beaver Creek (Map data ©2016 Google)

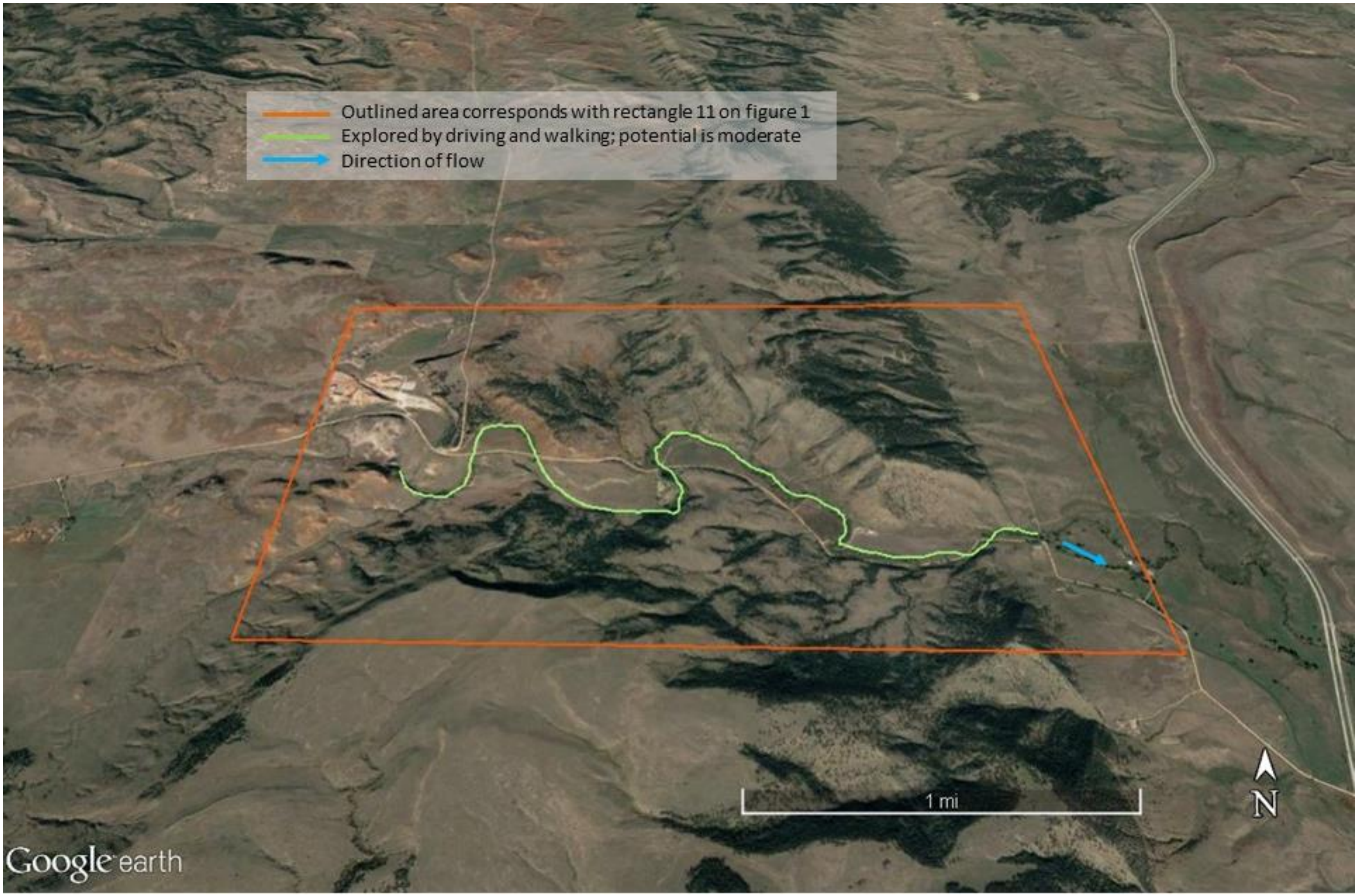

Figure 11: Oblique view of downstream reach of Beaver Creek (Map data ©2016 Google)

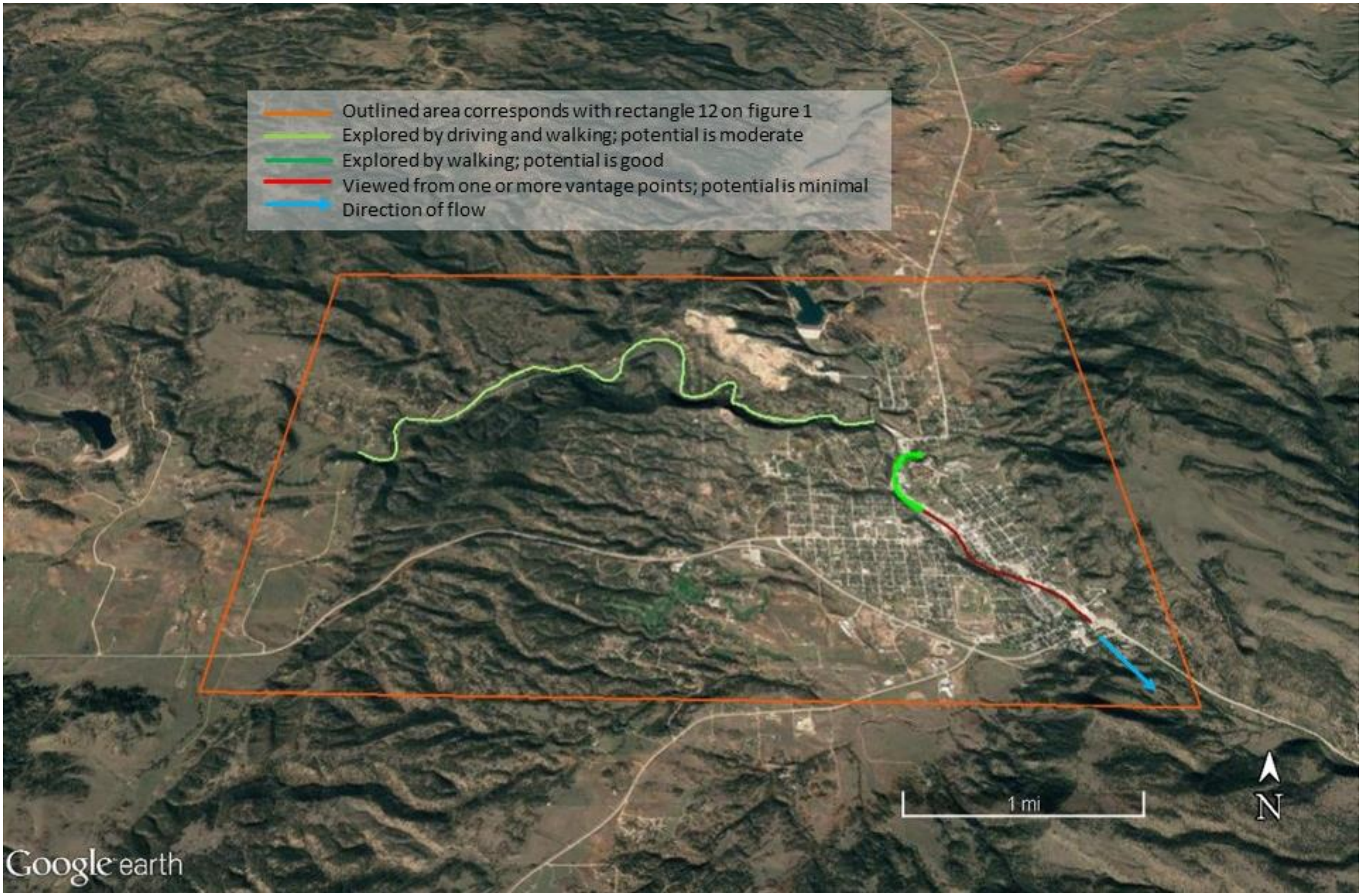

Figure 12: Oblique view of upstream reach of Fall River (Map data ©2016 Google)

Figure 13: Oblique view of intermediate reach of Fall River (Map data ©2016 Google)

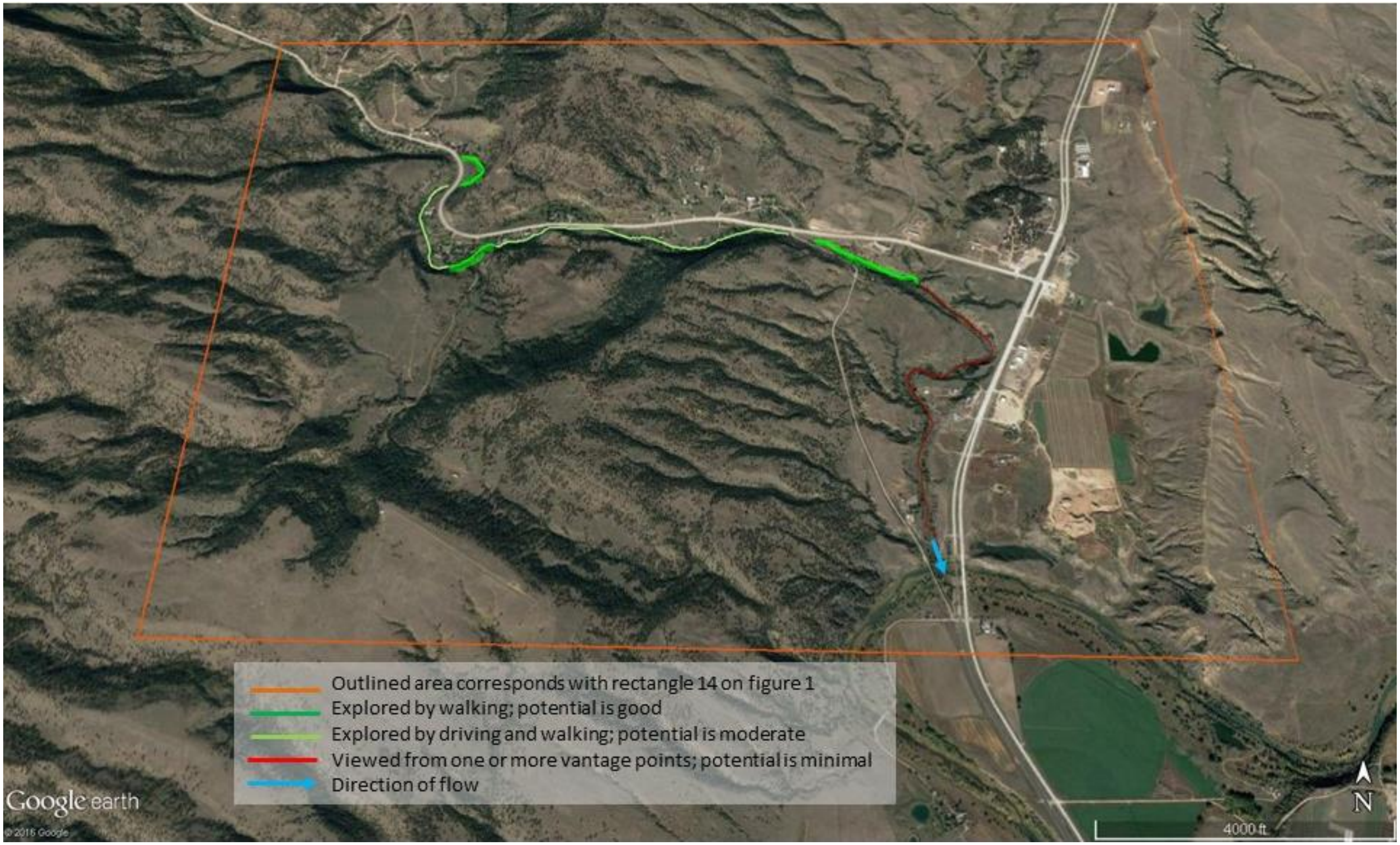

Figure 14: Oblique view of downstream reach of Fall River (Map data ©2016 Google)

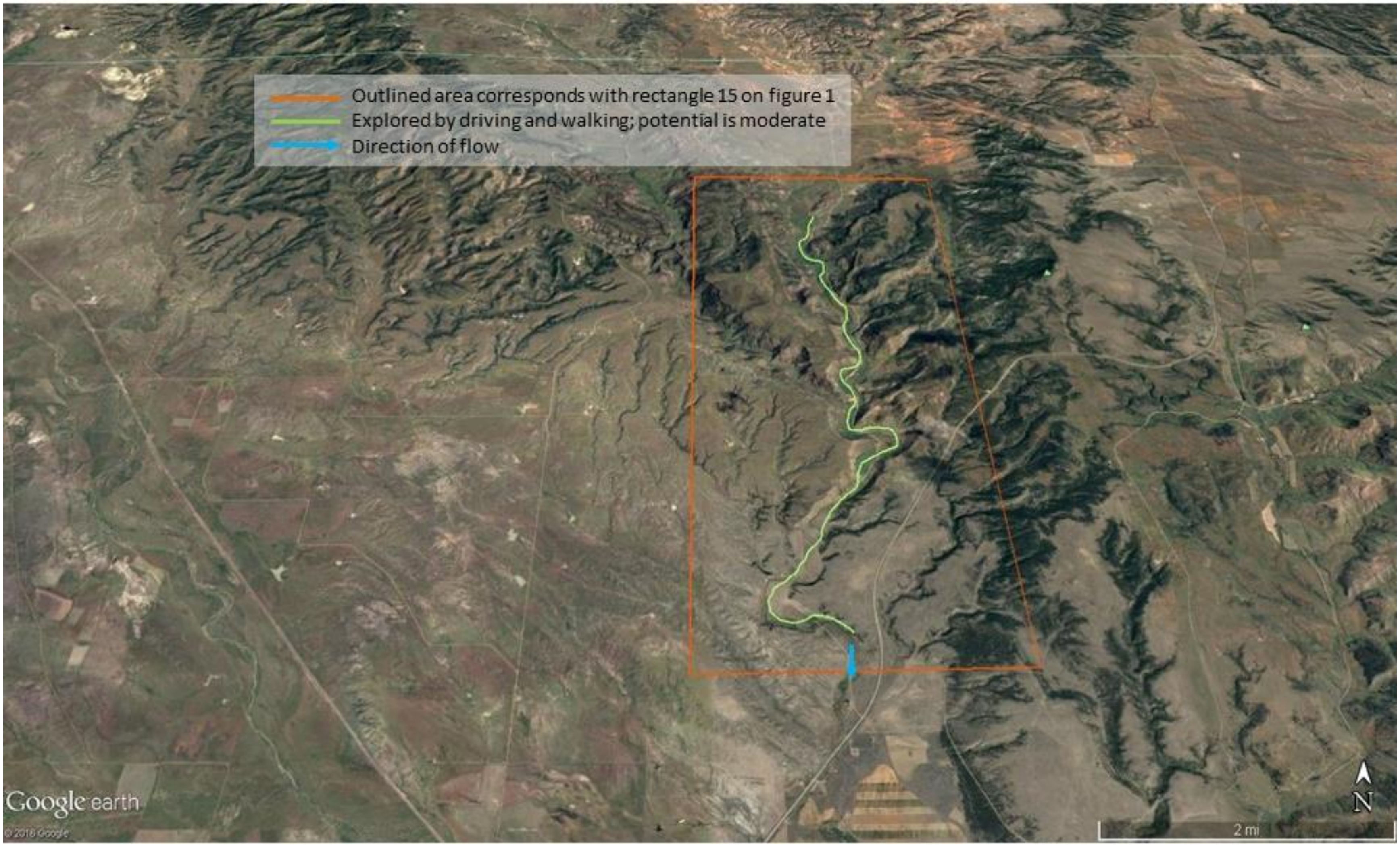

Figure 15: Oblique view of stream reach for Red Canyon (Map data ©2016 Google)

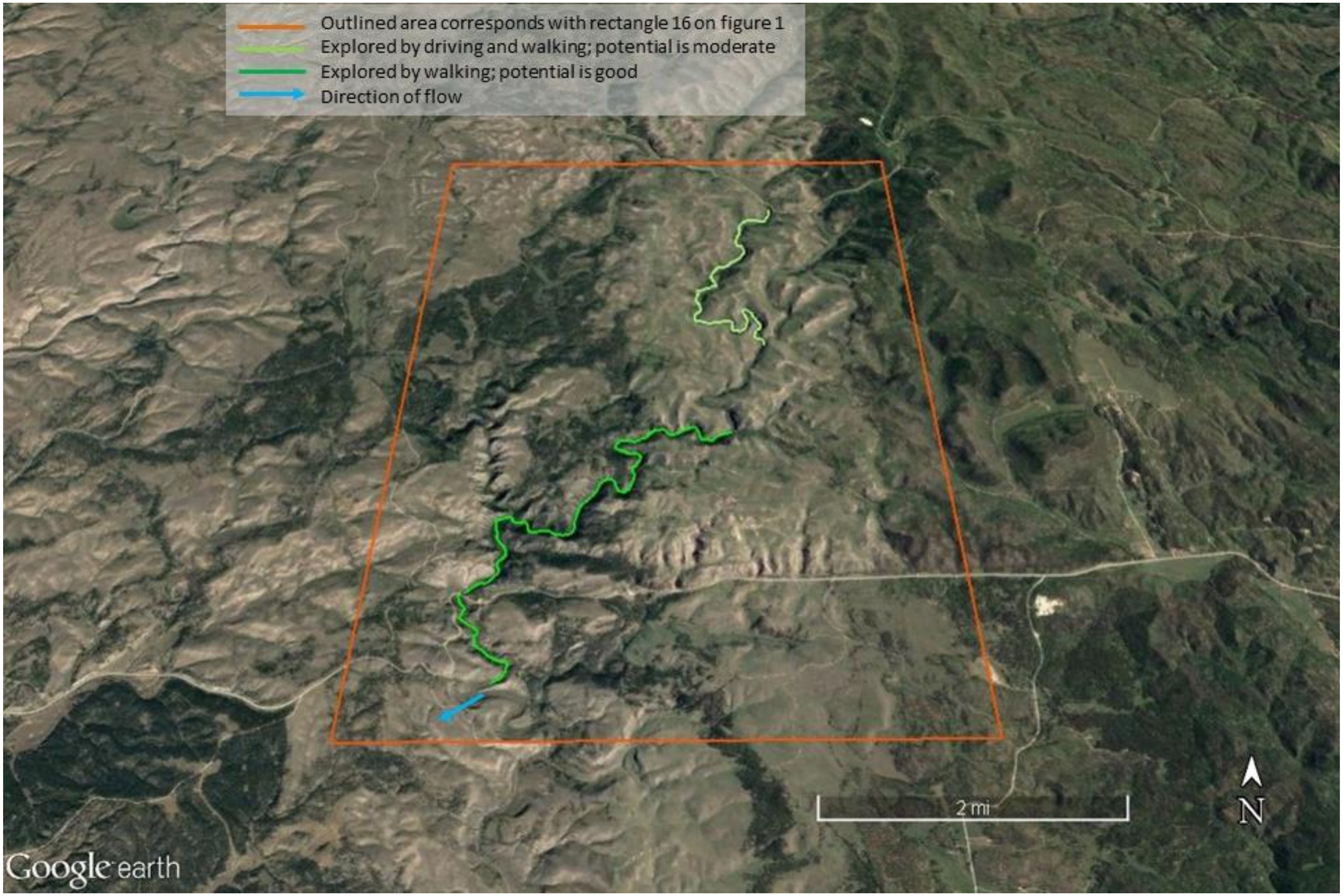

Figure 16: Oblique view of upstream reach of Hell Canyon (Map data ©2016 Google)

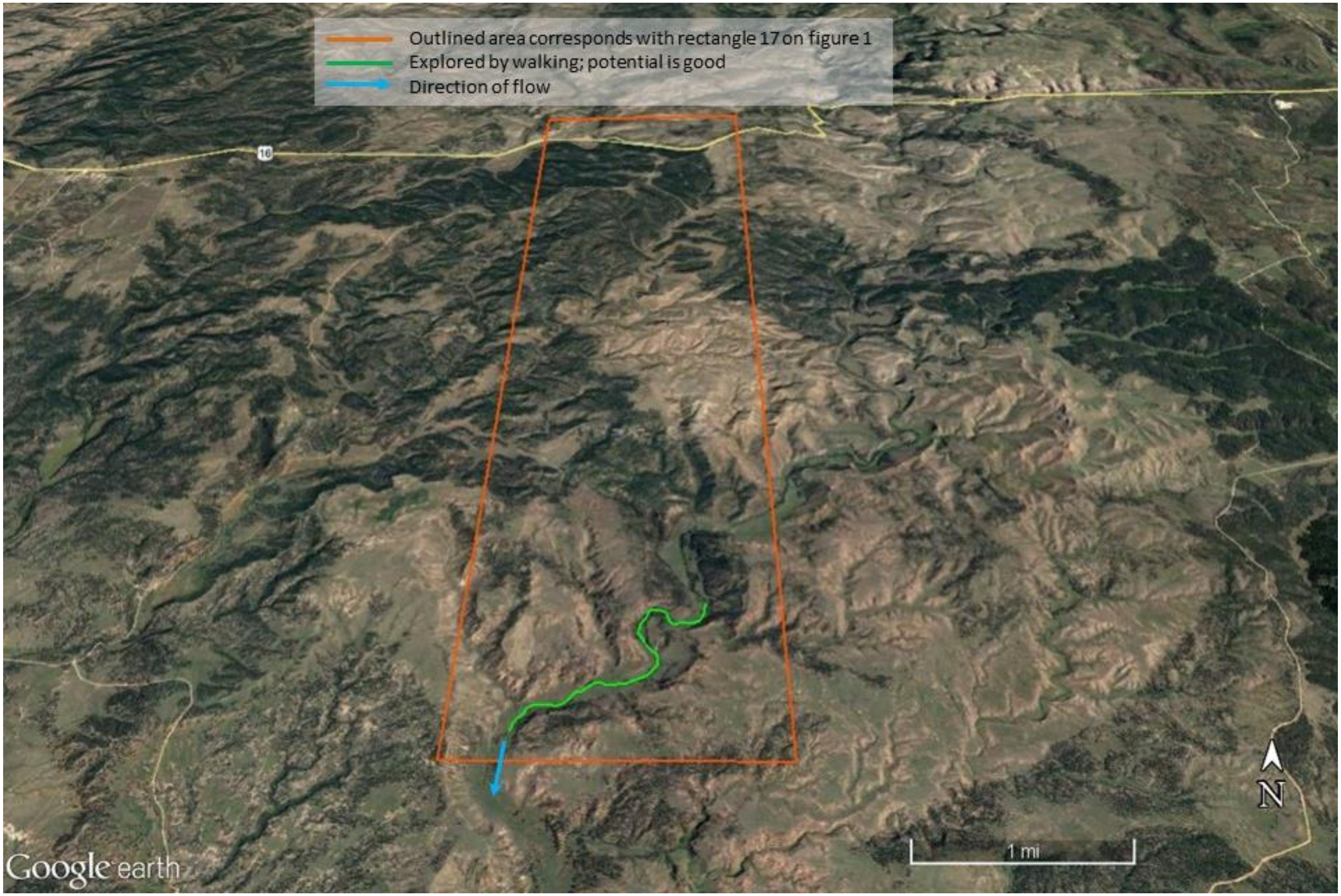

Figure 17: Oblique view of downstream reach of Hell Canyon (Map data ©2016 Google)

Figure 18: Oblique view of stream reaches for Boles Canyon and Gillette Canyon (Map data ©2016 Google)