Geotechnical Engineering Report

Big Flat Road Review
Missoula County, Montana

May 17, 2017

Terracon Project No. C4165060

Prepared for:

Missoula County Department of Public Works
6089 Training Drive
Missoula, MT 59808

Prepared by:

Terracon Consultants, Inc.
1392 13th Ave SW
Great Falls, Montana

May 17, 2017

Missoula County Department of Public Works
6089 Training Drive
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Attn: Mr. Greg Robertson, P.E., AICP
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Re: Geotechnical Engineering Report
Big Flat Road Review
Missoula County, Montana
Terracon Project No. C4165060

Dear Mr. Robertson:

Terracon Consultants, Inc. (Terracon) has completed the geotechnical engineering services for the above referenced project. This study was performed in general accordance with our proposal number PC4165060 dated December 22, 2016 and subsequent signed agreement dated March 21, 2017. This report presents the findings of our review of historic and recent aerial and ground imagery of the subject road alignment, and provides geotechnical opinions as to the cause, extent, and potential costs associated with stabilization of the impacted segments of Big Flat Road in Missoula County, Montana.

We appreciate the opportunity to be of service to you on this project. If you have any questions concerning this report, or if we may be of further service, please contact us.

Sincerely,
Terracon Consultants, Inc.

MONTANA
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LICENSED PROFESSIONAL ENGINEER

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EXECUTIVE SUMMARY

The subject of this project is a segment of the Big Flat Road located in suburban Missoula County, Montana, with the client being the Missoula County Department of Public Works (the “County”). The study area includes approximately 2.8 miles of hillside roadway, beginning from about 0.4 miles south of the intersection of Big Flat Road and Sherman Gulch Road and then extending north and west along Big Flat Road to the intersection of Big Flat Road at the Deep Creek/South Side road intersection near the old Harpers Bridge crossing. It is our understanding that the current road alignment is, in some locations, the third rendition of Big Flat Road, with the most recent road alignment having been shifted laterally (uphill and to the west/southwest) from a previous road alignment adjacent to the Clark Fork River.

This report summarizes our evaluations related to the cause(s) and linear/lateral extent of the landsliding along the project limits as a function of time, beginning in the early 2000’s and continuing through March 2017. The scope of services for these current studies included the preliminary characterization of the existing landslide issues and the evaluation of several potential repair alternatives for the currently-observed landsliding along the project. The landslide evaluations were performed on the basis of geometry that was either measured in the field (during the limited field work performed for these preliminary studies) or as could be determined from available terrestrial and aerial imagery. However, site-specific geotechnical studies have not yet been performed to characterize the geometry or engineering properties (such as shear-strength characteristics) of the soil and bedrock materials that are involved with any specific landslide. Therefore, the landslide repair alternatives discussed herein should be considered conceptual, and if considered for implementation, should be supported by detailed surveying and landslide-specific geotechnical studies. The potential repair alternatives are based on the project information currently available, as described herein, and on our experience in landslide stability analysis and repair.

Based on our review of the geomorphology of the landslide complex, it appears that the initial landsliding below the (original) river-level alignment was related to lateral migration of the Clark Fork River Channel and associated erosion of the riverbank that supported part of this lower road alignment. Our observations also indicate that, aside from the riverine-related landsliding, the remainder of the landsliding (including that which continues to impact the current alignment) is associated with roadway excavation that left very steep slopes unsupported above or below the road alignments; especially, those slides observed above the lower road and below the current Big Flat Road alignment. In addition, our observations indicate that construction of the road included several segments with inadequate drainage, resulting in erosion or inundation of the slope and subsequent landsliding of the slope below as a result of the aforementioned inundation.

In summary, our review of the current observations indicates that the length of landslide-impacted roadway has increased significantly between 2005 and 2017.

In addition to characterizing the size and failure mechanism(s) for the subject landslides, we also developed conceptual repair alternatives that could support repair and continued use of the road. The potential repair concepts were developed absent landslide-specific geotechnical studies, which will be required as the basis for selecting a particular landslide repair alternative. As such, should repair of a particular landslide segment be considered by the County, to include re-grading of small-scale landslides (using either no reinforcement or geogrid reinforcement), installation of mechanically stabilized earth (MSE) retaining walls, tieback slope repair/walls, or micropile-supported MSE or cantilever retaining walls, the County will need to commission site-specific geotechnical studies as a technical and cost basis to support selected landslide repairs. We should note that, due to the size, associated repair complexity, and the high costs associated with some of the repair scenarios (particularly those associated with Landslide #4, discussed herein), we also considered the "no action" alternative, which would result in permanent closure of the road. While some of the repair alternatives may be suitable for the smaller landslides, repair of the larger landslides may not be economical, based on the number of vehicles utilizing the roadway, and we recommend that Missoula County consider the economic costs of road repair in their decision-making evaluations as to whether the road should be repaired or abandoned.

This summary should be used in conjunction with the entire report for conceptual design purposes. It should be recognized that details were not included or fully developed in this section, and the report must be read in its entirety for a comprehensive understanding of the items contained herein. The section titled **GENERAL COMMENTS** should be read for an understanding of the report limitations.

GEOTECHNICAL ENGINEERING REPORT
BIG FLAT ROAD REVIEW
MISSOULA COUNTY, MONTANA

Terracon Project No. C4165060
May 17, 2017

1.0 INTRODUCTION

A preliminary geotechnical investigation has been performed for part of the Big Flat Road in Missoula County, Montana. The project includes a segment of unpaved roadway south of the Clark Fork River in Missoula County, Montana. The subject road section has exhibited historic instability issues along much of the alignment, with landslides ranging from localized small-scale slumps less than 10 feet in length and height to large-scale slump features over 175 feet high that extend several hundred yards along and adjacent to the north edge of the road. Because of ongoing slide issues, it is our understanding that the County has concerns regarding the long-term viability of the road stability and maintenance of the subject road segment, with concerns that failure of the larger slide areas would require extensive and expensive repair options.

On that basis, the County has requested that Terracon evaluate the potential impacts of landsliding along this section of Big Flat Road, and to provide planning-level cost estimates related to stabilization and/or repair of the re-emergent and ongoing landslide issues along the project. The focus of the geotechnical investigation was therefore to evaluate the extent of landslide development along the subject road alignment, to evaluate the root cause(s) of the landslide development, to evaluate the (apparently) advancing rate of landslide development, to develop potential repair alternatives and the costs associated with those repair alternatives, and then to provide our opinion as to the viability of long-term maintenance of the road.

Our reviews indicate that many of the smaller features pose relatively frequent and ongoing maintenance issues following rainfall or snowmelt events, while the larger stability issues tend to be more infrequent but potentially pose more significant consequences, both from an operational standpoint as well as from an economic (cost of repair) standpoint. Thus, while some of the smaller landslides could (and have been) repaired with county forces, requiring only temporary/partial road closures, repair of a large landslide along the project could initially involve a complete loss of the roadway plus costly repairs requiring months or years. Our review of the current landslide issues indicates that the length of landslide-impacted roadway has increased significantly between 2005 and 2017.

A Regional Project Map is shown on the attached Exhibit A-1 in Appendix A, and a Project Site Plan, that includes the locations of the seven primary landslide zones impacting to roadway, is shown on the attached Exhibit A-2, also in Appendix A. Photographs and discussion of example landslide issues from each of the seven landslide zones are shown on the attached exhibits A-3 through A-22, also attached at the back of Appendix A.

2.0 PROJECT INFORMATION

2.1 Project Alignment and Description

The study area includes approximately 2.8 miles of hillside roadway, beginning from about 0.4 miles south of the intersection of Big Flat Road and Sherman Gulch Road and then extending north and west along Big Flat Road to the intersection of Big Flat Road at the Deep Creek/South Side road intersection near the old Harpers Bridge crossing. It is our understanding that the current road alignment is, in some locations, the third rendition of Big Flat Road, with the road alignment having been previously shifted laterally (uphill and to the west/southwest) from the initial road alignment directly adjacent to the Clark Fork River, then uphill to a mid-slope location, and then further uphill to the current alignment (see the attached Exhibits A-2, A-13, and A-15).

The existing roadway varies in width from over 40 feet to less than 20 feet in the more narrow segments northwest of the intersection of Big Flat Road and Sherman Gulch Road. The uphill cut slopes vary from less than 5 degrees in some locations to 30 degrees and steeper at many locations, especially within Landslide Zone #4 (see discussion below). The downhill fill and natural slopes vary from less than 15 degrees to near vertical where past and ongoing landsliding has/is occurring. Grading across the width of the roadway varies, from an inboard slope to an outboard slope in several locations. And, although there are culverts at some of the inboard-sloping locations, maintenance and usefulness of the poorly-drained road segments is hampered by seasonal filling of the culverts with soils eroded from the roadway cut slopes that creates flooded zones (and which contributes to landsliding) during and following precipitation and snow melt events.

3.0 SUBSURFACE CONDITIONS

3.1 Site Geology

The geology of the site is characterized by an extensive erosional landslide complex that consists of slightly to moderately cemented sand and gravel alluvial terrace with a clay matrix interbedded with varved to thicker-bedded lean to fat glacial lacustrine silt and clay soils. These soils, collectively mapped as Alluvium on both U.S.Geological Survey and Montana Bureau of Mines and Geology mapping products, are the product of glacial outwash and development of glacial lakebed during quiescent times associated with the Glacial Lake Missoula ice damming and floodburst episodes of the Bull Lake and Pinedale glacial episodes. These soils are mantled upon Cambrian (early Paleozoic) bedrock that includes dolomite of the Hasmark Formation. The dolomite outcrops at several locations along the project, most prominently near the intersection of Big Flat Road and Sherman Gulch Road. In outcrop, the bedrock bedding dips into the hillside, but the outcrop is near vertically jointed primarily along a northwest-southeast orientation as well as a secondary southwest-northeast orientation. The resulting rock face projection is nearly vertical at some locations, giving little support for the overlying alluvial and lakebed sediments that are superimposed on the bedrock.

4.0 GEOTECHNICAL ANALYSIS AND RECOMMENDATIONS

4.1 Evaluation of Historic and Recent Landslide Development

Our field work included two site visits; one in 2005 and one in 2016, 11 years apart. During intervening years, photographs of landslide issues were obtained by the County for their documentation of landslide and maintenance issues associated with this road.

As a part of these studies, seven primary landslide zones were identified along the subject alignment, ranging in length along the roadway from less than 20 feet (Areas #5, #6, and in some cases, #7) to composite landslide zones more than 1,200 feet in length and ranging from 20 to 175 feet in height (Area #4).

Based on our review of the geomorphology of the landslide complex, it appears that sliding in the project area began many years prior to construction of the current roadway alignment, as the Clark Fork River channel began lateral migration to the west-southwest, in some cases eroding the riverbank and part of the original Big Flat Road alignment that was reportedly situated adjacent to the river. It also appears that, as the original alignment of Big Flat Road was eroded by the river, a second alignment further up the slope was developed by cutting into the steep side hill slope and casting the excavated material to the downhill side of the road. This second alignment followed the current alignment uphill to a location approximately halfway between Landslide Zones 3 and 4, near an existing residence (see Exhibit A-2), where the second alignment followed an approximately horizontal vertical alignment for approximately 200 feet before slowly descending back down to near river elevation, following the base of the hillside to near the project end at Deep Creek road and the former Harpers Bridge crossing. Excavation for this second Big Flat Road alignment cut into the toe of the steep alluvial slope, resulting in a loss of buttressing for the stability of the slope, eventually resulting in extensive landsliding uphill of the alignment that likely required frequent maintenance, and which eventually over-ran this second road alignment, requiring re-alignment of Big Flat Road to the third (and current) location.

The third Big Flat Road alignment follows the same approximate alignment as the second alignment, from the flats southeast of the intersection with Sherman Flats Road up to an area now occupied by a residential structure (Exhibit A-2). At this location, the third alignment departs the second alignment by shifting left and uphill of but approximately parallel to the second alignment. The third alignment was constructed as a cut-and-fill section through a slightly to moderately cemented sand and gravel alluvial terrace that is interbedded with glacial lacustrine silt and clay soils. Grading for the third Big Flat Road alignment also appears to have been poorly planned (if, in fact, any planning or engineering went into development of the road at all), with essentially no slope treatment of the uphill (cut) side of the new alignment, and with apparently all of the material excavated from the road cut cast directly outboard and downhill of the alignment onto the previous slide surface (see Exhibits A-8 through A-15), with little or no benefit of compaction or even removal of topsoil and vegetation prior to fill placement. The current alignment also includes several zones that allow collection and ponding of runoff on the uphill side of the road prism, causing the road prism to become seasonally inundated.

4.2 Evaluation of Landslide Mechanisms

Our evaluation of the second Big Flat Road alignment indicates that most of the landsliding associated with that roadway (above the second Big Flat Road alignment and downhill of the third and current Big Flat Road alignment) can best be characterized as a series of overlapping infinite slope failures, where the failure surface is usually shallow (in general, less than 5 feet in depth perpendicular to the slope face) and where the slide movement is approximately parallel to the slope face. In several cases, however, individual landslide masses form an arcuate or wedge-shaped slide shape at the uphill end (the scarp) of the new landslide. In the case of the Second Big Flat Road alignment, our review indicates that the toe of the uphill slope was cut off as part of that alignment construction, destabilizing the slope above the road and allowing for the formation of infinite-slope-type landslides (see the attached Exhibit A-4).

4.3 Evaluation of Potential Landslide Repairs

As a part of our landslide characterization efforts, we undertook an evaluation of potential landslide repair alternatives and cost estimates for those alternatives, such as may be applicable to the landslide issues observed along the Big Flat Road project alignment. Our evaluations insofar as applicability and geometric constraints for each of the repair alternatives are discussed in the paragraphs below. It is important to remember that final design and actual project cost estimates must be based on site-specific surveying and site-specific geotechnical studies related to each site and the repair alternatives selected for consideration. As such, potential planning-level costs discussed in this report should be considered as conceptual only, as subsurface conditions at a particular landslide location would affect the actual project costs compared to those discussed herein.

A table at the end of this section summarizes the potential landslide repair methodologies and their associated costs for a “typical” landslide repair 25 feet or less in height. It should be noted that these costs were derived from our past experience with retaining wall construction costs obtained from the Montana Department of Transportation (MDT), the Washington State Department of Transportation (WSDOT), and the Western Federal Lands Division of the Federal Highway Administration (WFL FHWA). **The costs shown in this table do not reflect the costs associated with installation of a drainage system applicable to the selected repair. Nor do the tabulated repair costs include the costs for new road base or installation of any asphalt**

or concrete surfacing. Importantly, too, the tabulated repair costs do not include the costs associated with engineering of the final repair alternative.

4.3.1 Side Hill Grading

Side Hill Grading is generally the least-cost landslide repair alternative, and such repairs can often be accomplished by County construction forces. Side Hill grading is accomplished by excavating the landslide zone to an elevation below the lowest reach of the landslide, and then (where feasible) replacing and compacting the excavated material into the excavated zone in lifts usually a foot or less in maximum thickness, with the resulting slope no steeper than the pre-slide slope surface. If the slope geometry has sufficient space the repaired slope will be no steeper than the pre-landslide slope surface. Very limited landslide control can also be affected using short-term slope retention methods, such as short gabion walls or jersey barriers to collect small landslide lobes or erosional debris that forms uphill of a given roadway.

One of the important constraints of this repair method is that the site must have sufficient horizontal space in which to make the excavation and then form the compacted slope. For this project, Landslide Zones #1 and #2, and possibly #3 appear to have the potential that Side hill Grading could be a viable repair alternative. However, for areas like Landslide Zone #4, this repair alternative is likely not feasible, due to the often limited downhill space and the fact that the upward-progressing landslides below the road are often at or within the landslide volume.

4.3.2 Reinforced Soil Slope

Construction of a Reinforced Soil Slope (RSS) is, in concept, similar to conventional Side Hill Grading, with the exception that (assuming the concept is sound geotechnically), the finished slope can be steepened from a simple Side Hill Grading slope by the inclusion of a synthetic geogrid within the compacted soil lifts that replace the excavated landslide volume.

In some cases, depending upon the quality of the fill materials used in the slope replacement, an RSS slope repair can be made steeper than 1H:1V. Such a repair requires sufficient bearing capacity in the zone below the landslide repair and sufficient room at the top of the repair for equipment and material movement. RSS slope repairs need to be designed by a geotechnical engineer specialist with experience in design and construction of such structures.

4.3.3 Mechanically Stabilized Earth (MSE) Retaining Wall

While MSE retaining walls are often employed as grade control structures, they can also be employed as a stabilized mass to repair a landslide. Typical MSE wall construction includes a facing unit of some type (modular concrete blocks, gabions, or welded wire facing units) are attached to high-strength geogrid that extends into the backfill in a manner similar to that of an RSS repair, except that the MSE wall has a near-vertical face when completed. Where any welded wire or other metallic reinforcement or facing units are employed, non-corrosive soils must be used in the retained zone so that the pullout resistance of the reinforcement or facing unit is not lost to corrosion of the metallic elements. Like an RSS slope repair, the zone immediately beneath the MSE wall needs sufficient bearing capacity to support the mass of the MSE wall. The primary constraint of MSE wall deployment is that like RSS slope repairs, design of MSE retaining walls, especially those used to replace a landslide zone, must be designed by a geotechnical engineering specialist with experience in the design and construction of such systems.

4.3.4 Crib/Bin Walls

Crib or bin walls can be used to repair landslide zones in a manner the same as an MSE wall, with the general exception being that non-corrosive soils are typically required in the retained volume. Crib or bin walls have the same bearing capacity constraints as RSS slopes and MSE retaining walls.

4.3.5 Tieback/Shotcrete/Specialty Wire Faced Slopes

Wall repairs of this type are relatively new in the U.S. market, having only been in widespread use in the last 20 years or so. Using this method, a series of high-strength tendons is drilled into the hillside (to depths on the order of 20 or 30 feet beyond the landslide zone), with the slope then faced with welded wire and shotcrete, gabions, or proprietary high-strength woven wire (cable) products. Geometrically, this system is usually installed such that the reinforced slope face is at least 10 feet away from the edge of the road to allow for traffic departure or the installation of traffic control barriers. Systems such as these require specialty geotechnical design by consultants with specific experience in the design and construction of such systems, and the costs associated with such systems are typically eight to ten times the cost of a conventional Side hill Grading repair alternative. The utility of these systems (and the micropile supported wall system discussed below) is that these systems can be employed in a situation with very limited side hill geometry and above a steep downhill slope, such as is encountered along much of Landslide Zone #4.

4.3.6 Micropile-Supported Retaining Wall

In instances where there is essentially no competent ground outside of the planned wall face, but where cemented gravel and/or bedrock may be encountered beneath the proposed wall section, micropiles can be used to support either a cantilever concrete retaining wall or an MSE retaining wall. The costs for such a system usually represent the upper end of feasible construction for terrains such as are encountered along Big Flat Road, but depending on the geotechnical conditions and geology present at the site, such systems may be the only geotechnically feasible repair alternative to landslide repair above a very steep or near-vertical slope. Based on the high costs associated with the design and construction of such a slope repair system, the owner generally must be able to economically justify the project costs in terms of actual vehicle use of the roadway. Terracon has previously designed such walls to repair damaged sections of the Going-To-The-Sun Highway in Glacier National Park and other high-profile highway projects across the U.S. In our opinion, while possibly feasible geotechnically for the Big Flat Road project, the costs associated with this repair alternative are probably not economically tenable for a such as Big Flat Road, but should rather be considered as the upper end of potential repair costs for the most geometrically challenging of the landslide zones along the project alignment.

4.3.7 Potential Repair Alternative Costs

The table below presents our current estimate for landslide repair costs based on a repair no taller than 25 feet and a minimum of 50 feet in length (to accommodate equipment operation). The costs below assume that geotechnical engineering and analysis supports the design and construction constraints of the alternatives as discussed in the paragraphs above.

SLIDE REPAIR TYPE	COST, IN DOLLARS, PER SQUARE FOOT OF VERTICAL FACE PROJECTION
Side hill Grading	**$20.00**
Reinforced Soil Slope (RSS)	**$30.00**
MSE Wall	**$40.00**
Crib/Bin Wall	**$55.00**
Tieback/Shotcrete/Specialty Wire Wall	**$200.00**
Micropile-Supported Retaining Wall	**$250.00+**

One potential cost we did not evaluate was complete realignment of the current road prism to a location at least 20 feet left toward the hill. Such a repair alternative would represent a major cost undertaking, and would require adequate design of uphill slope retention, but would likely reduce the potential for downhill landslide failure of the road prism for a period on the order of 50 years, based on the currently-observed rate of landsliding.

4.4 Discussion of Individual Landslide Issues

4.4.1 Landslide Zone #1

Landslide Zone #1, shown on the attached Exhibits A-3 and A-4, is located on the downhill side of Big Flat Road, about 1,500 feet southeast of the intersection of Big Flat Road and Sherman Creek Road. The overall slide area is about 75 feet in length and 25 feet in height, was first observed in 2006, and movement continues into 2017.

Repair of Landslide Zone #1 could be accomplished using either side hill grading or RSS techniques. Based on the assumption that the least-cost (Side Hill Grading) approach could be employed, repair of this landslide segment would cost, at a minimum, $37,500.00. This cost assumes that the landslide area has not increased since the site was observed earlier this year, and that the Side Hill Grading approach was deemed acceptable based on a site-specific geotechnical study. Even using the Side Hill Grading approach, it is likely that at least half of the roadway width would have to be closed to accommodate the excavation required to support the subject construction.

4.4.2 Landslide Zone #2

Landslide Zone #2 is located on the downhill side of Big Flat Road, adjacent to the intersection of Big Flat Road and Sherman Creek Road. The overall slide area is about 80 feet in length and about 35 feet in height. This landslide was first observed in 2006, and movement continues into 2017.

Our review indicates that, although landslide Zone #2 could possibly be repaired using only the Side Hill Grading approach, it is likely that either the RSS or MSE wall approach would have to be employed to accommodate the height of this landslide. In addition, like the repair work at Landslide Zone #1, it is likely that at least half of the roadway width would have to be closed to accommodate the construction here. Costs associated with repair of this landslide could range from $56,000.00 to $112,000.00, assuming that the area of this landslide has not increased since our observations of earlier this year.

4.4.3 Landslide Zone #3

Landslide Zone #3 is located on the downhill side of Big Flat Road, about 1,500 feet northwest of the intersection of Big Flat Road and Sherman Creek Road, as shown on the attached Exhibit A-7. This landslide is about 115 feet in length and about 50 feet in height. According to reports from the County, Landslide #3 was first observed in 2017. Like many of the other landslides along this reach, the scarp that remains along the road following the initial slide movement is nearly vertical; and although the scarp may remain inactive for several years, a steep scarp such as this one will be in a state of imminent slope failure more so than the original slope, potentially precipitating landslide growth that would extend further across the road in the next slide episode.

This landslide is relatively large but is relatively shallow, with a total active height on the order of 50 feet but with a depth of only about 5 to 10 feet parallel to the slope surface. This landslide extends from the roadway almost down to the Clark Fork River. Such failure height limits repair alternatives, since the existing slope grade is at or near the angle of repose, meaning that the current slope angle is only marginally stable as-is. On that basis, the Side hill Grading approach may not suitable for repair of this landslide because the repairs would have to extend to or near the Clark Fork River, potentially triggering a lengthy and costly permitting process. On that basis, a reinforced approach (such as an RSS slope or and MSE or Crib/Bin wall approach that terminates at least 20 above river elevation would likely have to be adopted, based on the outcome of a site-specific geotechnical study. Repair costs for this landslide segment could range from a minimum of about $103,500.00 to $189,750.00, or possibly more, depending on the outcome of the site-specific geotechnical study. We should note here that repair of this road segment would likely require full-width road closure to accommodate the excavation necessary to accomplish the necessary construction of this landslide segment.

4.4.4 Landslide Zone #4

Landslide Zone #4 is the longest area of active or recent landsliding along the project, and includes a total length of about 2,000 feet, with a maximum slide zone height (inclusive of runout) of about 175 feet (see the attached Exhibits A-8 through A-15). A review of historical aerial imagery indicates that landsliding along this road segment has been an issue since at least the year 2000, and likely since the existing road alignment was originally developed. The at-risk area of Landslide Zone #4 (defined herein as that area below which landsliding has progressed uphill and which leaves a vertical scarp within 25 feet of the roadway, or where groups of trees and turf are currently observed to be rotating downhill, such as is observed on Exhibits A-8 through A-15) has a combined length of about 500 feet, with observed individual slide heights ranging from about 20 to 175 feet below the roadway.

Because of the steep downhill slope geometry of the slide zones that make up Landslide Zone #4, it is our opinion that simple grading of the side hill slopes or even using an RSS approach will probably not represent feasible repair approaches for these landslide segments; there simply is not enough area in which to re-develop a stable slope without either cutting into the hillside uphill of the road or re-constructing the slope downhill of the road down to the previous road alignment near the Clark Fork River. (In the first case, such construction would probably require complete road closure to accommodate the required excavation, and in the second case, the cost of the stabilizing the entire slope height greater than 100 feet would be prohibitively expensive.) And, although the road surface through much of this zone currently appears stable (likely due to the partial cementation of the underlying alluvial soils), there are areas we observed where the next round of slope failure, when it occurs, will probably include most of the current road width (see for example, the attached Exhibits A-9 through A-12).

The costs to repair this segment of roadway could be substantial, and without a detailed subsurface investigation, defining and designing feasible repair alternatives and the limits of such repairs along Landslide #4 would be extremely difficult. Based on our site visits and photo reconnaissance, we have, however, developed conceptual costs for a 100-foot-length of the road where the potential construction elevations would be at least 40 feet. Because of the site geometry (as discussed above), neither simple slope grading nor development of an RSS system are, in our opinion, feasible for this area. If subsurface conditions include a sufficient width and depth of cemented alluvial soils, then development of an MSE alternative is possible; but, lacking sufficient width upon which to establish the foundation of an MSE wall system, repairs could conceivably require some combination of tiebacks and vertical slope stabilization to stabilize the marginally stable slopes currently observed along the entirety of Landslide Zone #4. On the basis of the above discussions, and using a model slope height of at least 40 feet and an example road length of 100 feet, repair costs for this example section could range from $160,000 for an MSE wall alternative to $800,000 for a tied-back stabilization approach. It is important to note, however, that the length of roadway requiring stabilization could be well in excess of the 100-foot example length discussed here, with the actual repair costs being some multiple of the above estimates. In any case, construction of any of the alternatives would likely require closure of the entire road to accommodate excavation during construction.

4.4.5 Landslide Zone #5

Landslide Zone #5 comprises a relatively limited failure zone, with measurements form early 2017 indicating a failure zone about 30 feet in length and 40 feet in height (see the attached Exhibits A-16 and A-17). One of the major issues with this landslide is that it is located within an area that exhibits slope instability, with some ground cracking and tilting vegetation (in response to downhill slope movement) evident on both ends of the current slide mass.

At this time, repair of this landslide could conceivably be performed using an RSS slope solution. However, our observations also indicate that upward-migration of the landslide below the road (the landslide generated by uphill excavation of the original road alignment near river level) is ongoing, at the rate of several feet per year, so an RSS slope solution could potentially last only 5 to 10 years, depending on the amount of precipitation over that time frame.

If further geotechnical study indicates that an RSS slope solution is feasible, the minimum costs associated with such construction (assuming that the adjacent marginally stable slope sections do not become unstable and require repair) could be as little as $36,000.00, but the costs could be considerably higher depending on the subsurface geometry at the site. It is likely, too, that construction of this repair would require closure of this road segment to accommodate site excavation.

4.4.6 Landslide Zone #6

Landslide Zone #6 exhibits limited lengths of landsliding along the roadway, but the zone below is very steep (nearing vertical at some locations; see the attached Exhibits A-18 and A-19), with the landsliding that originated from the original alignment below having advanced uphill and now into the existing alignment. Even outside of the current landslide zone, large-diameter trees are observed leaning precariously downhill, indicating that the length of roadway involved in sliding and requiring repair will extend beyond the current slide zone.

Because of the geometry of the current landslides involved in Landslide Zone #6 (including the near-vertical to vertical slopes immediately next to the road), repairs here will likely require a tieback repair system unless the results of a geotechnical study indicate a sufficient extent of cemented alluvium in the slide areas. Absent sufficient alluvium, we anticipate that, for an example slide zone 100 feet long and 40 feet in height, repair costs for Landslide Zone #6 could be on the order of $500,000 to $800,000.

4.4.7 Landslide Zone #7

Much of the sliding along Landslide Zone #7 is uphill of the road alignment, as shown on the attached Exhibits A-20 and A-22, although sliding below the road is also observed at several locations below the road. The landsliding above the road is, at this point, associated with erosion of the hillside (in the same manner as the slope erosion and failure above the former Big Flat Road alignment below the Landslide #4, #5, and #6 locations), while the landsliding below the road is both man/vehicle induced erosion (Exhibit A-21) and associated small-scale sliding.

The erosion above the road in the area of Landslide Zone #7 has resulted in overhanging turf and slope zones that, to some degree, resist landsliding (see, for example, the left arrow on Exhibit A-22), with the slope continuing to erode beneath the resistant turf zone until the crest of the eroded slope over-steepens. Eventually, the shear strength at the base of the resistant turf and eroded slope block falls below the driving force of the block, and landsliding is initiated.

The sliding and erosion along Landslide Zone #7 are generally smaller-scale erosion and sliding resulting from the toe of the original slope being removed by the road cut without any stabilization efforts associated with the original construction, here or downhill of Landslide Zones #4 through #6. Erosion uphill of the road can be slowed by installing a permanent buttress system (such as two vertical/two horizontal course geometry of rock-filled gabions) behind which the eroding slope material could build up over time, effectively flattening the slope and reducing the tendency to slide. It may also be possible to afford slope protection by hydroseeding the steep slope, but a specific evaluation of hydroseed effectiveness would have to be undertaken to evaluate the efficacy of such a system. In general, it is difficult to establish vegetation on slopes much greater than 3H:1V. The same can be said for the zone below the road. The landsliding at this point is rather small-scale, and could be slowed by the installation of erosion control measures to reduce the wholesale sheet erosion that has resulted in the buildup and over-steepening of the slope directly below the road (see for example, the buildup of sediment eroded from uphill now being deposited directly downhill of the road around tree trunks on Exhibit A-21). In addition, erosion could be further mitigated by installing barrier systems (such as jersey barriers) across the trails that have been developed by off-road vehicle use. Such use, while providing some degree of recreational benefit, is simply augmenting (and in several cases, exceeding) the natural rate of erosion and slope damage that is occurring along this segment of the road alignment.

The cost of erosion control and smaller-scale landslide stabilization measures, as described above, is relatively small compared to the landslide repair costs associated with the previously-discussed landslide zones. It is our opinion that most of the erosion-control and small-scale landslide measures could be installed for less than $30,000 along this alignment.

4.5 Conclusions and Recommendations

The overall results of our observations and analyses indicate that, despite the extreme geometry imposed by some of the landslide zones along the alignment, all of the landslide issues discussed herein are repairable, from a geotechnical standpoint. We do, however, also note that the potential repair costs associated with the project (on the order of 2 to greater than 5 million dollars, depending on the extent of repairs along Landslide Zones #4 and #6) likely exceed the budget that the County has available for maintenance and repair of Big Flat Road. In addition, while we understand that this segment of Big Flat Road provides a convenient access route to parts of the county, we also observed very limited traffic volumes during our site visits. On that basis alone, we recommend that the County carefully consider the cost/benefit ratio of undertaking such repairs. Another consideration in that regard is the fact that, with time, more landsliding (than is currently observed) will develop, increasing the long-term repair costs above those discussed herein.

Of more importance, though, are our observations of potentially extreme safety issues associated with this segment of Big Flat Road. There are numerous road segments (in Landslide Zone #4 alone) where if a car (for whatever reason) leaves the road on the downhill side, there is the likelihood of a traffic death associated with the car sliding or falling down the steep slopes and then vertically dropping off the edge of the cliff at the bottom terminus of those steep slopes (see for example, Exhibits A-6, A-11, A-12, A-17, and A-19). Simply placing jersey barriers along the downhill side of the road at these locations, while providing some degree of accident re-direction, would reduce the available traffic width and would make snow removal more difficult.

In closure, we recommend that the County consider all of the issues discussed herein, including the cost/benefit ratio of performing the repairs, the limited traffic volume using the road, and the safety issues associated with the current alignment, in deciding a course to follow in regard to the future of Big Flat Road.

5.0 GENERAL COMMENTS

The analysis and recommendations presented in this report are based upon the data and observations obtained from the our site visits, photographs provided by the County, and our evaluation of proprietary and public aerial imagery (via Google Earth Pro and the U.S. Geological Survey EROS website). No subsurface explorations or detailed landslide analyses have been performed for these studies; as such, this report does not reflect actual subsurface conditions along the project alignment. Selection or design of any particular landslide repair alternative shoud be based upon a site-specific geotechnical study specifically scoped to evaluate the landslide issues along a subject road segment. The reader is cautioned that variations in subsurface conditions may vary significantly between those observed in outcrop adjacent ot the roadway and those located within and beneath the road prism at any given area, and the nature and extent of such variations may not become evident until during or after construction.

The scope of services for this project does not include either specifically or by implication any environmental or biological (e.g., mold, fungi, bacteria) assessment of the site or identification or prevention of pollutants, hazardous materials or conditions. If the owner is concerned about the potential for such contamination or pollution, other studies should be undertaken.

This report has been prepared for the exclusive use of our client for specific application to the project discussed and has been prepared in accordance with generally accepted geotechnical engineering practices. No warranties, either express or implied, are intended or made. Site safety, excavation support, and dewatering requirements are the responsibility of others. In the event that changes in the nature, design, or location of the project as outlined in this report are planned, the conclusions and recommendations contained in this report shall not be considered valid unless Terracon reviews the changes and either verifies or modifies the conclusions of this report in writing.

APPENDIX A – EXHIBITS A-1 THROUGH A-22

Project Manager: BJW	Project No. C4175015
Drawn by: BJW	Scale: N.T.S.
Checked by: MDH	File Name:
Approved by: MDH	Date: 4/7/2017

Terracon
Consulting Engineers & Scientists

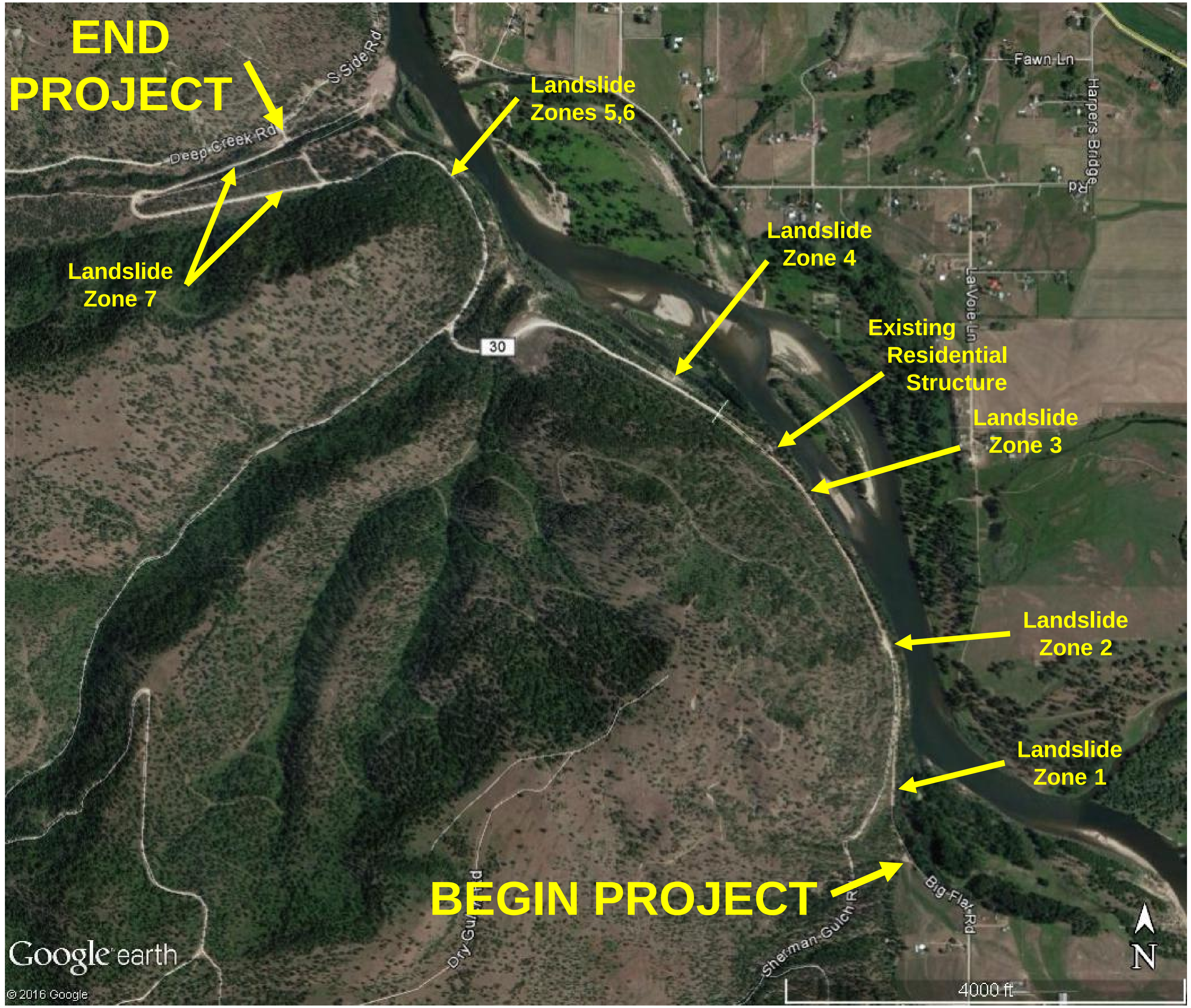
1392 13th Ave SW Great Falls, Montana 59404
PH. (406) 453-5400 FAX. (406) 761-6655

REGIONAL PROJECT LOCATION MAP

BIG FLAT ROAD REVIEW
MISSOULA COUNTY, MONTANA

Exhibit

A-1



N

Scale: AS SHOWN
on 11x17 Sheet

0 500 1000 2000
FEET

DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

Project Manager: BJW	Project No. C4175015	Terracon Consulting Engineers & Scientists	PROJECT SITE PLAN
Drawn by: BJW	Scale: N.T.S.	1392 13th Avenue SW Great Falls, Montana 59404	BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA
Checked by: BJW	File Name:	PHONE: (406) 453-5400 FAX. (406) 761-6655	Exhibit
Approved by: MDH	Date: 4/10/2017		A-2

April 7, 2006 Photo of Landslide Zone #1. The upper edge of the scarp extends approximately 8 feet into the road from the crest of the slope. At this time, the scarp extends about 45 feet along the slope crest. This slide was repaired but would continue to periodically fail, including a March 2017 failure (see Exhibit A-4)

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 1, APRIL 2006	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-3
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

March 13, 2017 landslide failure at Zone 1, Big Flat Road. Despite previous repairs, the downslope area at and adjacent to Zone 1 failed again in March 2017. The cleared area in the foreground (absent of trees) is the re-graded surface of previous landslides and repairs. The tilted trees shown in the near background are part of the current landslide mass, but many "stable" areas along Big Flat Road exhibit similar tilting trees as the slope creeps but prior to full-scale landsliding.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists 1392 13th Ave SW Great Falls, Montana 59404 PH. (406) 453-5400 FAX. (406) 761-6655	LANDSLIDE FEATURE AT ZONE 1, MARCH 2017 BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA
Drawn by: BJW	Scale: N.T.S.		Exhibit A-4
Checked by: GWR	File Name:		
Approved by: GWR	Date: 4/24/2017		

Shown here is the downhill extent of a landslide that extends about 80 feet along the outside (downhill) edge of Big Flat Road, just to the right of the intersection with Sherman Gulch Road (see exhibit A-2). The slide here is about 35 feet tall, and is primarily an infinite slope failure, although there is an arcuate component to the slide base near the top of the landslide. Note, too, the tilting trees downhill and outside of the current slide mass.

Project Manager: BJW	Project No. C4165060
Drawn by: BJW	Scale: N.T.S.
Checked by: GWR	File Name:
Approved by: GWR	Date: 4/24/2017

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LANDSLIDE FEATURE AT ZONE 2, APRIL 2006

BIG FLAT ROAD REVIEW
MISSOULA COUNTY, MONTANA

Exhibit
A-5

Photo of the Zone 2 Big Flat Road Landslide on March 13, 2017. The 2017 landslide crest is delineated by the yellow arrows, and an older scarp, not well developed but in the roadway, is shown by the red arrows. The 2017 slide did not develop to the extent of earlier slide episodes, but did undergo movement nonetheless.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 2, MARCH 2017	Exhibit
Drawn by: BJW	Scale: N.T.S.	1392 13th Ave SW Great Falls, Montana 59404	BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-6
Checked by: GWR	File Name:	PH. (406) 453-5400 FAX. (406) 761-6655		
Approved by: GWR	Date: 4/24/2017			

This photograph shows a slide that first exhibited movement in 2017. Designated as Landslide Zone #3, this slide is a relatively shallow infinite slope ("skin slide") that, while less than about 5 to 10 feet in thickness normal to the slope, extends more than 110 feet along the road, and extends almost down to the Clark Fork River at the left of this scene, a height of about 50 feet. Like many of the other landslides along this reach, the scarp that remains along the road is nearly vertical. Although the scarp may remain so for several years, a steep scarp such as this one (and the scarp downhill of most of Landslide Zone #4) has a much lower factor of safety against additional slope failure than the original steep slope face that just failed here.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 3, MARCH 2017	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-7
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

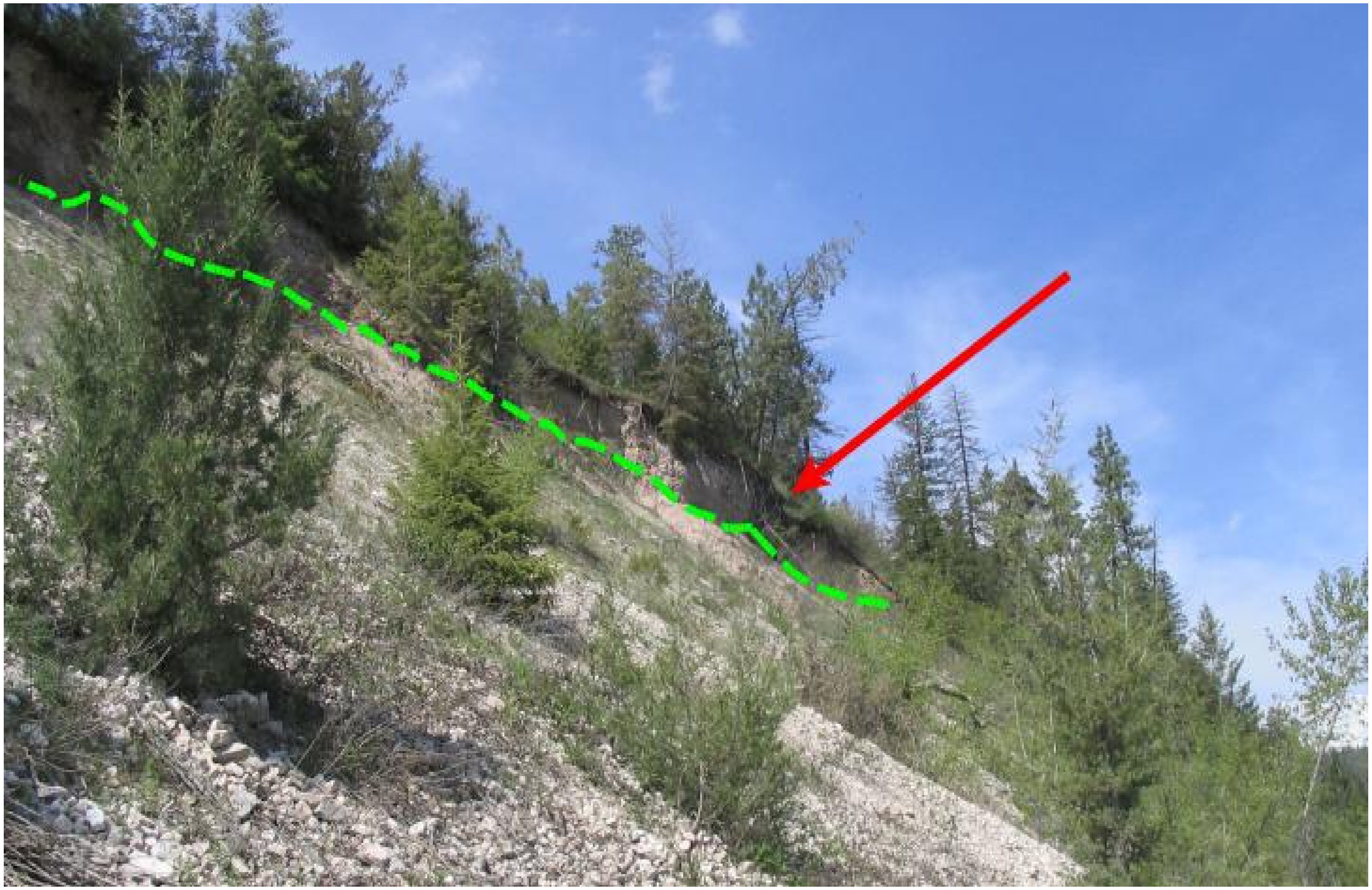

Image of Landsliding at Zone 4 location (Exhibit A-2). This photo was taken May 13, 2005, and exhibits a view of Big Flat Road from the old road alignment downhill of the current Big Flat Road alignment. The dashed green line separates a layer of moderately cemented gravel (above the dashed green line) from a layer of interbedded glacial lacustrine silt/clay below the dashed green line. As the glacial lacustrine soils erode on the face of the slope, the upper gravel layer is undermined and then fails along a near vertical face. At this location, the Big Flat Road alignment is less than 15 feet back from the crest of the hill (shown by the red arrow).

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #1 AT ZONE 4, MAY, 2005	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-8
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Enlargement of photo from Exhibit A-8. The foreground is landslide debris from the uphill propagation of landsliding from the old road alignment below, from which this photo was taken. Note that the vertical face at the crest of the old landslide is less than 15 feet away from the edge of the current Big Flat Road alignment. Note also the downhill-tilting trees atop the remnant soil block above the cliff face.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #2 AT ZONE 4, MAY, 2005	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-9
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Image of Landsliding at Zone 4 location (Exhibit A-2). This photo was taken May 13, 2005, and shows a view of the same landslide zone shown on the previous Exhibit A-8, except that this photo is taken from uphill of the slide zone looking down from the edge of the road. Note that the crest of the landslide is about 15 feet from the edge of the road.

Project Manager: BJW	Project No. C4175060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #3 AT ZONE 4, MAY 2005	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	**A-10**
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

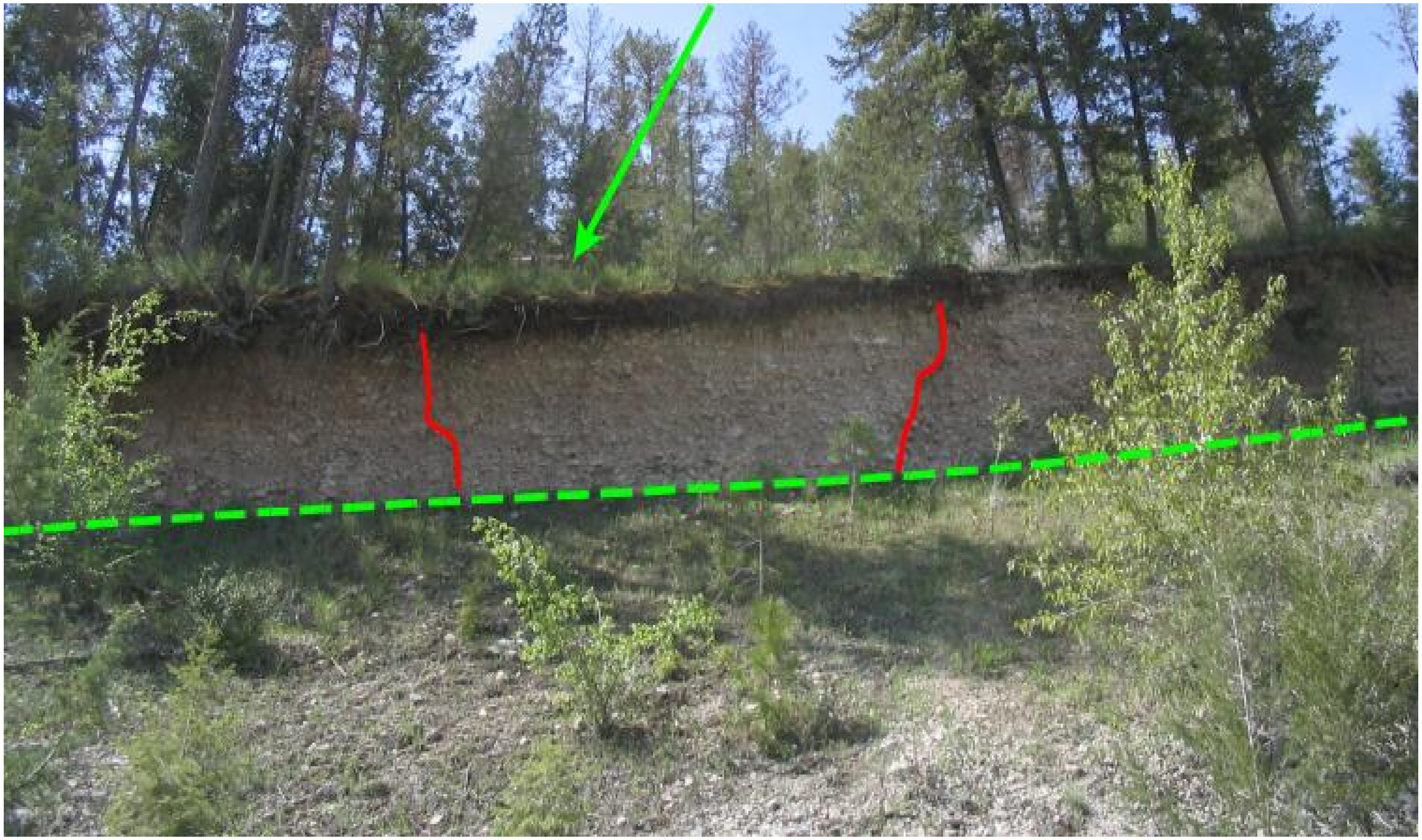

Image of Landsliding at Zone 4 location (Exhibit A-2). This photo was taken May 13, 2005, and shows a view near the southeast end of the slide area from the old road alignment below. Like Exhibit A-8, the cemented gravel layer is shown above the dashed line and glacial lacustrine clay is shown below the dashed line. Also shown is an overhanging layer of organic detritus beneath which part of the gravel layer has already failed. At this location, the outside edge of the road is less than 10 feet from the crest of the slide, and the cab of a log hauling truck (noted by the green arrow, heading downhill) is observed directly above the slope crest from the aspect of this photo. Also observed are two cracks in the gravel layer (denoted by the red traces). At this location, the cracks in the gravel layer indicate a section of gravel where sloughing failure is imminent.

Project Manager: BJW	Project No. C4175060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #4 AT ZONE 4, MAY 2005	Exhibit
Drawn by: BJW	Scale: N.T.S.	1392 13th Ave SW Great Falls, Montana 59404	BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-11
Checked by: GWR	File Name:	PH. (406) 453-5400 FAX. (406) 761-6655		
Approved by: GWR	Date: 4/24/2017			

This photograph shows a landslide within Zone #4, just to the northwest of the series of images shown on the previous Exhibits A-8, A-9, and A-10. This landslide is relatively small compared to the overall size of the Zone #4 landslide, but is another example of the start of a larger landslide that could remove the entire width of roadway from service, and which would require extensive and expensive repair to stabilize the road and allow traffic back on the alignment.

Project Manager: BJW	Project No. C4175060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 4, JANUARY 2015	Exhibit
Drawn by: BJW	Scale: N.T.S.	1392 13th Ave SW Great Falls, Montana 59404	BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-12
Checked by: GWR	File Name:	PH. (406) 453-5400 FAX. (406) 761-6655		
Approved by: GWR	Date: 4/24/2017			

Oblique view of the southeast segment of the #4 Landslide Zone. The current Big Flat Road alignment is seen as the gray line at the middle of the scene, and the red line follows a former Big Flat Road alignment. The lower alignment (the red line) was constructed by cutting into the toe of the slope without any effort at slope stabilization. Over time, the cut slope above the red line progressively failed uphill, with the landslide debris covering the lower alignment and causing the road alignment to be shifted uphill to its current location. The current landslide issue is that the landslides initiated by the old road construction are now impacting the current alignment, having caused certain areas (like the pink-hachured zone above) to cause landsliding over the entire slope above the old road and below the new road.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #5 AT ZONE 4	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-13
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Close-up of hachured scene from exhibit A-12. From the former road alignment shown as the dashed yellow line, note how the landsliding has progressed up the slope to the point that the up-slope landsliding has almost (or in some cases, has) encroached into the current Big Flat Road prism. Once the landsliding from below has progressed up the slope, the landslide from below has removed part of the support for the current roadway, and landslides such as those seen on the previous Exhibits A-3 through A-11 (and many of the following Exhibits) will result.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #6 AT ZONE 4	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	**A-14**
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Another view of the Zone 4 Landslides further northwest from the Zone 3/Zone 4 interface. This scene shows 2 landslide areas (denoted by the yellow arrows) where sliding was initiated at the road cut along the old road alignment below and then progressed uphill toward Big Flat Road. The depression at the middle of the scene (denoted by the red arrow) is primarily erosional from the Dry Gulch drainage uphill to the southwest.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #7 ALONG ZONE 4
Drawn by: BJW	Scale: N.T.S.	1392 13th Ave SW Great Falls, Montana 59404	BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA
Checked by: GWR	File Name:	PH. (406) 453-5400 FAX. (406) 761-6655	Exhibit A-15
Approved by: GWR	Date: 4/24/2017		

Landslide at Zone 5, March 10, 2014. This slide is located at the outside edge of the road. Note the relatively young trees that are tilting downhill in the immediate background of this scene, indicative of slope creep beyond the landslide limits.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 5 MARCH 2014	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	**A-16**
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Photo of Landslide Zone #5, March 15, 2017. The landslide has occupied essentially the same failure location as before.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 5 MARCH 2017	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-17
Checked by: GR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

This photo, taken March 10, 2014, shows both an erosional event (due to poor roadway drainage) as well as small-scale landsliding at Landslide Zone #6. Note the tilted trees in the background that are exhibiting various degrees of slope creep.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 6, MARCH 2014	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-18
Checked by: GR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Photograph of renewed landsliding at Zone 6 in March of 2016. Note the over-steepened slope within the landslide as well as the large-diameter Trees tilting downhill just beyond the current landslide zone.

Repair and stabilization of slopes such as this is difficult due to the limited width of the road (within which to conduct excavation) as well as the steepness of the landslide scarp and slope below the outside edge of the road. From a practical standpoint, the entire width of the road would likely have to be employed (and the existing uphill cut slope extended further into the hillside) to accommodate excavation and construction to stabilize this slope.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 6, MARCH 2016	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-19
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Photograph of landsliding and slope erosion along Landslide Zone #7. The yellow arrows above the road indicate uphill-propagating landsliding, the same as the large-scale landsliding observed in Landslide Zone #4 below the current Big Flat Road. The red arrow indicates the small-scale landsliding that is observed along much of this reach of Big Flat Road.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #1 AT ZONE 7, APRIL 2006	Exhibit
Drawn by: BJW	Scale: N.T.S.	1392 13th Ave SW Great Falls, Montana 59404	BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-20
Checked by: GWR	File Name:	PH. (406) 453-5400 FAX. (406) 761-6655		
Approved by: GRW	Date: 4/24/2017			

View downhill at small-scale landslide/slope erosion feature along Landslide Zone #7. This photo shows erosion and sliding of fill and (uphill) slide debris that has been cast downhill of the roadway, partially burying trees in locations such as this. The downhill slope surface in this area is only sparsely vegetated, allowing for erosion and small-scale sliding of the slope during spring runoff.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE #2 AT ZONE 7 APRIL 2006	Exhibit
Drawn by: BJW	Scale: N.T.S.		BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-21
Checked by: GWR	File Name:	1392 13th Ave SW Great Falls, Montana 59404		
Approved by: GWR	Date: 4/24/2017	PH. (406) 453-5400 FAX. (406) 761-6655		

Photograph of headward slope erosion and erosional debris on Big Flat Road, Landslide Zone 7 (see yellow arrows). At this location, slope erosion progresses uphill until a sufficient overhang develops, at which time either the overhang falls off or a block of the uphill slope fails and slides downhill. Currently, such erosion primarily generally poses only a maintenance issue, but eventually, larger-scale erosion and landsliding of this slope will pose a danger to the roadway.

Project Manager: BJW	Project No. C4165060	Terracon Consulting Engineers & Scientists	LANDSLIDE FEATURE AT ZONE 7 MARCH 2017	Exhibit
Drawn by: BJW	Scale: N.T.S.	1392 13th Ave SW Great Falls, Montana 59404	BIG FLAT ROAD REVIEW MISSOULA COUNTY, MONTANA	A-22
Checked by: GR	File Name:	PH. (406) 453-5400 FAX. (406) 761-6655		
Approved by: GR	Date: 4/24/2017			