Channel Migration Zone Delineation

JRP Land Company, Hangman Creek

Spokane, Washington

for
JRP Land LLC

September 27, 2016

GeoEngineers
Earth Science + Technology

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File No. 22016-001-00

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INTRODUCTION

The City of Spokane (City) and Department of Ecology (Ecology) requested that JRP Land, LLC (JRP Land) complete a detailed channel migration zone (CMZ) delineation and evaluation of erosion hazards for a reach of Hangman Creek (also called Latah Creek) around their property prior to approving land use development. Previous analyses for this reach of Hangman Creek have been completed for flood hazard and shoreline management planning purposes but did not included a quantitative CMZ delineation. Ecology and the City requested preparation of a detailed CMZ delineation and assessment that uses Ecology's Channel Migration Assessment web guidance methods for the reach scale, very high level category (http://www.ecy.wa.gov/programs/sea/sma/cma/page11_table4.html).

The JRP Land property is located on the east side of Hangman Creek about 3.3 miles upstream of the stream's confluence with the Spokane River as shown in Figure 1. The property includes Tax Parcels 25361.0006, 25361.0007 and 35312.0002, and comprises approximately 50 acres. The property is situated on a low terrace on the right bank of the alluvial valley and extends part of the way up a steep slope toward High Drive Parkway (Figure 2).

Purpose and Regulatory Framework

The intent of this project is to complete a reach-scale, very high level CMZ assessment of Hangman Creek along the JRP Land property and delineate a 100-year CMZ boundary on the JRP Land property project reach. The 100-year time frame was selected by the City and JRP Land at the beginning of the project. This assessment extended approximately 1.1 miles along Hangman Creek, from near the Qualchan Golf Course downstream to the railroad bridge over the creek at River Mile (RM) 3.4. Specific objectives were to:

1. Estimate migration rates
2. Calculate erosion and geotechnical setbacks
3. Estimate the extent of potential future migration over a 100-year time span

This analysis was performed in response to a request from Ecology and the City for planning purposes related to potential development in the project area. Development near shorelines of the state are governed by the Washington Administrative Code (WAC). Specifically, Flood Hazard Reduction and the Shoreline Master Program pertain to development in or around waterbodies.

WAC 173-26-241(2)(3)(j) states: Residential development, including appurtenant structures and uses, should be sufficiently set back from steep slopes and shorelines vulnerable to erosion so that structural improvements, including bluff walls and other stabilization structures, are not required to protect such structures and uses. (See RCW 90.58.100(6)).

Spokane Municipal Code: Section 17E.060.190.B. - A use, modification, or development within flood hazard (frequently flooded) areas shall not be allowed when it will require flood hazard reduction measures within the channel migration zone or floodway and shall comply with the applicable requirements in chapter 17E.030 SMC, Floodplain Management.

METHODS AND SCOPE

The channel migration zone delineation followed Rapp and Abbe (2003) and Ecology's web guidance to derive erosion hazard and geotechnical setbacks for a 100-year time frame. Based on the record period of available historic data, a 100-year time frame is appropriate. Combined, these setbacks define the 100-year channel migration zone for the project reach.

Desktop Study

GeoEngineers, Inc. (GeoEngineers) gathered available, relevant information necessary to complete the CMZ analysis. This included topographic maps, the most recent LiDAR, the 2011 Washington State Department of Transportation (WSDOT) Conditional Letter of Map Revision (CLOMR) Application for Hangman Creek, and historic aerial photos. LiDAR was flown in February and March of 2015 by the Puget Sound LiDAR Consortium (PSLC) and was downloaded from the PSLC website. A longitudinal profile of the creek (shown in Figure 3) and relative water surface elevation map (RWSE; shown in Figure 4) were developed from the LiDAR. The CLOMR was prepared by WSDOT and provided by the City.

Historical aerial photographs were provided by the City. Aerial coverage ranged from the years 1948 to 2014. Aerials from 1995 and later were provided as georeferenced .sid files, 1979 and earlier aerials were provided as non-georeferenced .tif files. These earlier aerials were georeferenced by a GIS analyst using ESRI's Georeferencing tool and the Spline method. The Spline method allows for enhanced geo-referencing of the river with lesser attention given to areas beyond the floodplain. Table 1 provides a list of photograph years utilized in the analysis. In general, aerial photographs are collected in summer or fall; flight months are listed if known. Photographs used in the analysis are also shown in Appendix A.

TABLE 1: AERIAL PHOTO RECORD

Year	Previously Georeferenced .sid Files	Georeferenced by GeoEngineers; .tif Files
1948 summer		X
1957 December		X
1963 August		X
1979 September		X
1995	X	
2001	X	
2008	X	
2014	X	

Additional data were derived within the GIS environment from the aerial photos for use in the channel migration analysis. Traces of channel boundaries were developed for each photo period in order to record where the channel has been over the historical period of record. Channel centerlines for each photo record were drawn for use in transect measurements for obtaining erosion rates. Meander bend wavelengths were measured. Floodplain transects were generated at equal intervals from which floodplain and channel widths were measured. These data were used in calculations for the CMZ delineation as explained below.

Historical topographic maps also were reviewed to understand the history of site development. Maps reviewed include the 1880 cadastral survey and the 1901 United States Geological Survey (USGS) topographic map (1:125,000 scale).

Field Study

Two geomorphologists and a geotechnical engineer from GeoEngineers visited the site on Thursday April 28th, 2016. The purpose of the field reconnaissance was to observe the geomorphic character of the creek and identify dominant processes. Channel bedforms were mapped and valley side slopes measured. Channel and valley/terrace materials, vegetation, and obstructions to flow were observed and noted.

CMZ Delineation

Subsequent to completion of field work, additional spatial data were derived for use in the CMZ analysis. The methodology for determining the CMZ followed that of Rapp and Abbe 2003 which starts with the delineation of the Historic Migration Zone (HMZ) followed by an avulsion hazard analysis to determine the Avulsion Hazard Zone (AHZ). An Erosion Setback (ES) and a Geotechnical Setback (GS) are then estimated and applied beyond the HMZ and AHZ. The ES and GS together make up the Erosion Hazard Area (EHA) All components together represent the final CMZ boundary.

This task includes developing an erosion coefficient based on the probability of channel occupation within the CMZ and the calculated channel migration rates. Historic, current and future channel migration were evaluated relative to the hydrologic regime of Hangman Creek, including the high flows of record, as well as episodic and chronic erosion.

Historic Channel Migration Zone

The HMZ is the area that has been occupied by the active channel at any time within the historical photo record. The active channel is defined by wetted area and any un-vegetated bars (O'Conner et al. 2003). The channel traces for each photo year developed in the desktop study represent the active channel and included wetted areas, un-vegetated bars and banks, and the intersection of the traces constitutes the HMZ.

Avulsion Hazard Analysis

Avulsion Hazards include areas both inside and outside the HMZ that represent an easy pathway for water to travel and eventually create a new channel at that location based on analysis of topography and water surface elevations. The CLOMR (2011) study was reviewed for base-flood elevations in the creek and on the floodplain. A Relative Water Surface Elevation (RWSE) Map (Figure 4) was generated from the LiDAR to aid in identifying low lying areas or historic channels that would represent avulsion hazards. These locations were located and observed during the field visit to verify preliminary assessments.

Erosion Setback

The ES is defined as the component of the CMZ that accounts for future channel migration beyond the HMZ. The ES was determined by multiplying the time life of the CMZ (T) and an erosion setback coefficient (C_E) that takes into account erosion and migration rates.

$$E_S = T\,C_E$$

The CE consists of an erosion rate of bank material (ER) multiplied by the amount of time the channel is expected to erode at any one location (T_E) divided by the time it takes to for the river to reoccupy the same location in the floodplain (T_R).

$$C_E = E_R\,(T_E/T_R)$$

T_R takes into account both a downstream (T_{r1}) and a lateral (T_{r2}) direction.

$$T_R = (T_{r1} + 2T_{r2})/2$$

Therefore:

$$C_E = E_R\left(\frac{T_E}{(T_{r1} + 2T_{r2})/2}\right)$$

The value for E_R was determined using the transect method of measurement. Floodplain transects were generated every 0.1 mile perpendicular to the 2015 LiDAR channel within the study reach. Centerlines of the creek were generated for each photo record. The distance between centerlines along each transect from successive photo years was measured. Only movement into area previously unoccupied by the creek in earlier photographs was recorded and used in the erosion measurement. O'Connor, et al. (2003) and Legg et al. (in preparation) have presented results indicating that using only measurements of movement into previously unoccupied areas better represents how total channel area changes with time and better defines floodplain occupation, producing more accurate channel migration estimates. An average erosion rate was then calculated for each transect, the values of which were used to calculate an average erosion rate for the entire reach.

T_E was determined by observing the amount of time the creek stayed in one location along each transect over the period of record. The values were averaged to get a single value for the entire reach.

T_{r1} is the downstream component of T_R defined by the time it takes a meander to move downstream one meander wavelength. This requires the rate of migration divided by a distance (meander wavelength).

Downstream migration rates were calculated by measuring downstream translation of bends over the period of record. Four locations were observed with downstream bend migration occurring over time. Average rates for each bend were calculated, the values of which were used to calculate an average downstream migration rate for the reach. Meander wavelength was determined by averaging measured wavelengths from a series of three bends that were present in all photo years.

Tr_2 is the lateral component of T_R defined by the time it takes the creek to meander from one side of the valley to the other. This requires the rate of migration divided by a distance (floodplain/width).

Ten locations were identified with measurable lateral migration of the channel. Distances moved were recorded from one photo record to the next and an average rate at each location over the photo record was calculated. Only movement into areas unoccupied in earlier photographs was recorded (Legg, et al. in prep). Average rates at each location were used to calculate an average lateral migration rate for the reach.

An average floodplain width was determined by averaging the measured floodplain widths at each transect and subtracting an average channel width for the reach. The average channel width was determined by averaging measured active channel widths at each transect for each photo record.

These values applied to equations above provide an extent that defines the ES. The ES is a buffer width that is applied laterally to the HMZ. It is assumed the HMZ encompasses easily erodible materials and the creek could re-occupy those areas at any given time. Therefore the ES buffer begins at the outside of the HMZ boundary where erosion would take place into previously unoccupied areas relative to the available historical record.

Geotechnical Setback

The purpose of the GS is to account for mass wasting as the slope adjacent to the stream at the ES boundary adjusts towards its preferred angle of repose. The GS was determined by assuming a vertical slope at the ES boundary and projecting the preferred angle of repose up landward from the base of the vertical slope at the elevation of the stream bed. Observations in the field provided the information needed to determine the angle of repose and eventual GS setback.

Cross sections were generated in Excel from the LiDAR at each transect and the ES was added to the HMZ at each cross section (transects shown in Figure 5). The GS was derived graphically by drawing a line representing the angle of repose started at the base of the ES projected laterally from the channel surface and the intersection of the line and top of bank; an example GS derivation is shown in Figure 6. The GS was smoothed at transitions between cross sections where visible changes in slope height and configuration occurred. Where the GS intersects State Route (SR) 195, the GS was set at the base of the highway embankment; therefor the GS was not applied to the left bank at some transects.

Channel Migration Zone

The final CMZ is represented by the sum of the HMZ, the GS boundary plus the ES boundary. The CMZ boundary is drawn first without regard for infrastructure. Once drawn, any areas within the CMZ that are landward of, and including, structures or infrastructure that will be maintained in perpetuity for the life of the CMZ, thereby preventing the creek from migrating there, is considered a Disconnected Migration Area (DMA).

PHYSICAL SETTING

Topography and Geomorphic Setting

Hangman Creek watershed encompasses approximately 689 square miles in Washington and Idaho (USGS gauge 12424000). The headwaters lie in the St. Joe National Forest in Idaho with a maximum elevation at approximately 5,000 feet. Hangman Creek flows generally northwest and transitions from its mountainous headwaters to an upland plateau and then enters a bedrock canyon section before discharging into a broad alluvial valley where it finally joins the Spokane River in Spokane, Washington at an elevation of around 1,720 feet. Flow in Hangman Creek is unregulated. The project site is situated on the low end of the creek near its confluence with the Spokane River (see Figure 1).

The section of the creek where the project site is situated is generally a low energy, low profile reach with a gentle stream gradient but highly erodible banks and valley walls composed of soft, glaciolacustrine sediments and granular Missoula Flood outburst deposits.

Site Development History

The project reach has seen consistent urbanization over the historic record. In the 1901 USGS topographic map, the City of Spokane was developed within 1 mile north of the subject site. The house on the site was constructed about 1904 and neither flooding nor bank erosion have impacted the residence or farm buildings (Buchanan 2011). The railroad was constructed between 1880 and 1901 because it is not present on the 1880 cadastral survey. Roads were present west of the current highway in the general configuration of the Cheney Spokane Road and West Qualchan Drive on the 1901 topographic map. The four-lane roadway of Highway 195 was constructed as part of the Inland Empire Highway in 1939 but began as early as 1898 as a county gravel road (https://en.wikipedia.org/wiki/U.S._Route_195). The SR 195 interchange with the Cheney Spokane Road was reconstructed beginning in 2013. A mobile home community that was situated on the left bank opposite the subject site was removed for the highway interchange construction. Construction was completed by 2015. A CLOMR was submitted by WSDOT to Federal Emergency Management Agency (FEMA) for the interchange construction. Modeling indicates that the 100-year flood elevations increase up to 0.5 foot upstream of the subject site. Streambank restoration including rip rap bank toe-protection and upper bank vegetation planting was completed for the interchange project.

Climate, Groundwater and Hydrology

The climate in this region varies from a mild arid environment in the summer and a cold coastal climate in the winter (SCCD 2000). The higher elevations in the headwaters receive about 40 inches of precipitation per year, some in the form of snow, while the lower watershed receives approximately 16 inches per year (Buchanan and Brown 2003).

Several aquifers exist under or near the Hangman Creek watershed. The Hangman Valley aquifer is the most significant to the project area as it is connected to the stage of low flow in Hangman Creek (Buchanan and Brown 2003).

Although Buchanan and Brown (2003) suggest a gaining reach for the lower portion of Hangman Creek, base flow is typically minimal in summer with flow as little as 0.74 cubic feet per second (cfs) (SCCD 2000). Mean Monthly flows range from a minimum of 1.01 cfs in September to a Maximum of 2,097 cfs in January (SCCD 2005).

Stream flow and flood frequency in Hangman Creek were evaluated using data from USGS gauge 12424000. The gauge is located at RM 0.8 approximately 2.5 miles downstream of the project site at elevation 1,717 feet NGVD 1929. Daily discharge data has been collected at the site since 1948 and was used to develop a flood frequency curve for the creek. Flood magnitudes for recurrence intervals corresponding to the 2-, 10-, 25-, 50- and 100-year flood flows are summarized in Table 2 along with high flow events recorded for the creek. The two highest flows from winter 2016 also are included in Table 2. Flows are listed by magnitude in descending order.

TABLE 2. CALCULATED RECURRENCE FLOWS AND RECORDED PEAK ANNUAL FLOWS FOR HANGMAN CREEK (USGS GAUGE 12424000)

Flow	Source	Discharge (cfs)
100 year recurrence interval	Calculated	21,863
January 1, 1997	High flow event	21,200
February 3, 1963	High flow event	20,600
50 year recurrence interval	Calculated	19,363
January 15, 1974	High flow event	17,700
25 year recurrence interval	Calculated	16,759
January 24, 1959	High flow event	16,200
February 8, 1996	High flow event	15,200
December 23, 1964	High flow event	14,500
10 year recurrence interval	Calculated	13,133
March 10, 1989	High flow event	12,700
May 24, 1948	High flow event	11,900
January 21, 1972	High flow event	11,600
January 13, 1973	High flow event	11,500
December 22, 1955	High flow event	11,300
January 4, 1984	High flow event	10,700
February 13, 1979	High flow event	10,400
December 28, 1998	High flow event	9,580
2 year recurrence interval	Calculated	5,901
January 30, 2016	Recent event	1,820
March 23, 2016	Recent event	3,220

The January 1997 flood event was the highest flow event on record for Hangman Creek and was preceded by another very high flow event in February 1996. The high flow events that occurred in winter and spring 2016 did not approach the magnitude of a 2-year recurrence interval flow.

Geology and Soils

The Hangman Creek watershed lies at the eastern edge of the Columbia Plateau. Underlying Tertiary-age bedrock in the watershed consists of lava flows from the Columbia River Basalt Group and Latah Formation sedimentary rocks (DGER 2004; Hamilton et al. 2001). These include the Grande Ronde Basalt and the Wanapum Basalt, Priest Rapids Member (DNR 1:100,000 digital Geologic Map). Interlayered with the Grand Ronde flows is a sequence of clay, silt and sand of the Latah Formation that eroded from the surrounding hillslopes and deposited in a lake environment (DGER 2004; Hamilton, et al. 2001).

During the Pleistocene the area that is now the lower portion of the Hangman Creek Valley was filled with alternating glacial lake deposits from the ice-dammed glacial Lake Columbia and outburst flood deposits from Glacial Lake Missoula. The lake deposits consist of silt and clay deposited in a low energy environment at the bottom of the lake. The glacial flood deposits consist predominantly of sand and gravel that accumulated as flood debris entered the lake. These deposits together form a distinct geologic unit (Qglf: DGER 2004) and comprise the valley walls in lower Hangman Creek (see Figure 2).

Soils in the lower Hangman Creek Valley consist of loamy sand through much of the floodplain or valley floor areas and very gravelly loamy coarse sand in the adjacent valley walls to the east (NRCS Web Soil Survey). Both of these soils are highly erodible.

PREVIOUS STUDIES

Previous studies reviewed for this project that included pertinent information are summarized below, from oldest to youngest.

Hangman (Latah) Creek Comprehensive Flood Hazard Management Plan. Spokane County Conservation District, 2000. This plan summarized flood hazards and damage in the lower 25 miles of Hangman Creek and recommended flood hazard management strategies, programs and plans for the area. The report was prepared in part in response to large rain-on-snow flood events in 1996 and 1997 that damaged areas upstream and downstream of the project site. The Plan included a fluvial geomorphic and channel stability assessment of approximately the lower 25 miles of the Creek. The assessment included review of historical aerial photographs, development of historic channel traces from the photos and outline the meander belt (by Agua Tierra Environmental Consulting). This report did not delineate a channel migration zone consistent with methods outlined in Rapp and Abbe (2003).

Lower Latah Creek Buffer Assessment. Department of Ecology, Shorelands and Environmental Assistance, February 10, 2009. This report completed by Patricia Olson presents the results of a technical evaluation requested by the City to identify parcels along lower Latah (Hangman) Creek that may be impacted by the 200-foot ordinary high water mark regulatory buffer (OHWM) as compared to floodplain, channel migration, and FEMA floodplain mapping. The memo also included a CMZ analysis for the subject property using GIS tools and an analysis of 1958, 1995 and 2007 aerial photographs as well as LiDAR and a field reconnaissance. An OHWM from a biological assessment completed on the subject property by Towey in 2008 was used to determine buffers. Channel migration rates were determined following Rapp and Abbe 2003 by dividing the maximum migration rate measured for the reach by the time in years between aerial photos. A buffer applied using GIS tools developed by Ecology created 25-, 50- and 100-year CMZ boundaries. Relic channels were identified in the floodplain terrace on the subject property at elevations 14 and 18 feet above the active channel.

Memorandum to Doug Pineo/ERO SEA Senior Shoreline Planner, Addendum to Assessment of CMZ on Pilcher Property. Olson, Patricia L., May 17, 2010. This memo includes additional information from a site reconnaissance and updates the 2009 CMZ analysis. A potential avulsion pathway location is updated and erosion at the rip rap revetment on the subject property near the house is suggested to indicate piping.

Technical Memorandum, CMZ Evaluation and Delineation at Latah Creek Property. From John P. Buchanan, June 26, 2011. This memorandum outlines a channel migration zone analysis for the subject property in accordance with WAC 173-26-010 (7). It includes review of the Flood Hazard Management Plan analysis, historical aerial photograph record analysis from 1950 to 2009, field reconnaissance and geomorphic observations. The analysis reviewed meander bend movement measured by Olson in her 2009 memo and concludes that a trend of decreasing migration reduces the risk to the subject property. The memo does not include a review of LiDAR data, does not provide a map with a CMZ delineation, and refers to the historic migration zone as the CMZ. The narrative conclusions state that a 30-foot erosion hazard zone extending landward from the top of the right bank on the subject property defines the landward edge of the CMZ. Further CMZ delineation is qualitative and focuses on likely and probable scenarios without quantitative support.

Memorandum to Sara Hunt/ERO SEA Program Manager, Comments on latest Pilcher documents. From Patricia Olson, March 7, 2011. This memo provides Ecology's comments on a draft version of the June 26, 2011, Technical Memorandum, above. Olson indicates that the Buchanan CMZ does not measure erosion rates and does not include a geotechnical evaluation of the "proposed bank stabilization." This memo focuses on the rip rap revetment on the south end of the subject property and whether it constitutes a barrier to channel migration.

Results of a Preliminary Geotechnical Site Characterization Study, Latah Creek Preliminary Plate, 3515 S. Inland Empire Way, Spokane, Washington. Cummings Geotechnology, Inc., February 22, 2010. Six test pits were excavated and soil samples collected and analyzed to evaluate subsurface conditions for possible future residential development on the subject property. Subsurface soils consist of layered sand, silty sand, and sandy gravel, consistent with alluvial deposits. The report concludes that excavation into or placing fill on the steep slopes at the east end of the site is not recommended.

RESULTS

Desktop Evaluation

The desktop evaluation consisted of historical review of the project area and areas both upstream and downstream, definition of the study reach boundaries, aerial photograph and LiDAR analyses including creating historic channel traces in GIS, evaluating gradient, relative water surface elevation and cross section information from LiDAR topography and targeting areas of interest for field evaluation.

Project Reach

Differences in channel planform, slope and bed-form characteristics are used to identify channel processes that control channel migration. Bridges, culverts and other man-made impediments to flow often alter a stream's behavior, therefore, these structures may mark transitions between reaches. The project reach begins at RM 4.5 where a large amplitude meander was truncated by SR 195 in the 1930s and extends 1.1 miles to RM 3.4, marked by the railroad bridge crosses the creek (see Figure 2 and Figure 4). The reach is defined by its low sinuosity, open, low-amplitude, high wavelength meander bends, confinement by the highway, two bridges, and the valley wall, and riffle-glide bedforms. The reach has a gradient of 0.3 percent and is within a segment of the stream with gradients ranging from 0.3 to 0.6 percent.

The planform of the creek upstream and downstream of the project reach also is more sinuous than the project reach, with a wider floodplain and pool-riffle and glide-riffle bedforms. The project reach has been cut-off from a large portion of its floodplain by the fill prism and roadbed of SR 195 and the stream is now confined between the highway and the east valley wall for a majority of its length.

A longitudinal profile from the confluence with the Spokane River (RM 0) up to RM 9 was generated based on the 2015 LiDAR and channel gradients were calculated (Figure 3). Upstream of RM 6.7 and downstream of RM 0.6, the creek gradient is an order of magnitude lower than in the project reach, indicating that the project reach is in a relatively steep section of the creek. The large, high amplitude meander bends through the golf course reach upstream of the project reach are balanced by a short, steep drop through a boulder riffle.

The RWSE map (Figure 4) illustrates portions of the channel that have been cut-off by the installation of SR 195, resulting in the confining of the project reach for most of the length between the highway and the east valley wall. The project reach was shortened during construction by approximately 0.65 miles, reducing sinuosity from approximately 1.7 to approximately 1.1 and steepening the stream gradient. As a result, the stream has been incising in the project reach since highway construction in the 1930s.

Historical Map and Aerial Photograph Analysis

Analysis of aerial photos provided snapshots in time of the creek planform and processes in the project occurring in the reach. Review of historical topographic maps provided additional insight to the development history of the area. Channel traces are shown in Figure 5.

Based on the 1901 USGS topographic map (1:125,000 scale), Hangman Creek was situated closer to the central portion of the valley prior to construction of SR 195. The large amplitude, tight meander bend is not shown on the 1901 map but the railroad is in place, though the location of the railroad is not aligned with that shown on the 1950 USGS map. This suggests that the 1901 map accuracy is in question. By 1950 (and the 1948 aerial photograph), SR 195 is in place and has truncated both the large upstream meander bend and another large bend immediately downstream of the railroad bridge, and the creek is disconnected from much of the left floodplain and close to the right valley wall over most of the reach.

We observed small movements of the creek over the aerial photograph record. The formation of seasonally vegetated stable, medial bars with small channels around and between bars is common in the record. Three small avulsions within the active channel were observed through the record. Based on our observations, the avulsions are the result of shifting sediment transport and storage in the reach. Avulsion does not appear to be a dominant channel process in this reach of Hangman Creek.

The greatest total distance of migration measured on the 10 project reach transects was 331 lineal feet between the 1963 and 1979 photo years (average 20.1 feet per year). Five high flow events occurred during this 16 year interval (see Table 2), although the February 1963 event of 20,600 cfs, the second highest flood of record, occurred before the 1963 aerial photography was taken.

The period with movement along most of the 10 project transects was 1948 to 1956 with a total of 285 lineal feet measured (average 35.6 feet per year). During this 8-year period, two high flow events occurred: 1955 (11,300 cfs) and May 1948 (11,900 cfs) which may have occurred before the aerial photograph was taken.

Between February 1996 and December 1998, three high flow events occurred including the January 1, 1997 flood of record at 21,200 cfs. Channel migration associated with these three events was minor in the project reach. Upstream of the subject site, the channel moved into the right bank and a minor avulsion took place, observed near RM 4.1. A large amount of sediment appears to have been deposited on the left bank by accretion to a left lateral bar, forcing the channel to the right. Right bank erosion added more sediment to the channel and two medial bars formed in the channel and still are present today. Erosion also occurred on the right bank immediately upstream of the house located on the subject property. Vegetation has become re-established on the lower portion of this bank and large concrete debris revetment is present at the toe of the bank. The right bank of the subject site forms a terrace elevated about 16 to 20 feet above the active channel. Although the banks are composed of similar non-cohesive, highly erodible sediments as upstream, this section of the channel has not experienced significant migration over the historic record (see Figure 5 and Appendix A).

Sediment Transport

Typically, stream reaches near the mouth of a stream begin to flatten as the confluence is approached and the main sediment regime is depositional. Because of the steeper gradient in the project reach caused by the meander bend truncation and channel shortening, the project reach currently behaves primarily as a transfer reach in which sediment that comes in from upstream is transferred through to the downstream reach. Some sediment is deposited in the reach on the floodplain areas or in the channel, often forming islands that are subsequently colonized by reed canary grass that holds the sediment in storage.

The USGS measured suspended sediment discharge at gauge 12424000 for three years from 1999 to 2001. Sediment discharge directly correlates with water discharge for the three years of sediment data, as shown in Table 3.

TABLE 3. SUSPENDED SEDIMENT DISCHARGE MEASURED AT GAUGE 12424000, HANGMAN CREEK, AND ASSOCIATED MEAN ANNUAL DISCHARGE.

Water Year	Mean Water Discharge (cfs)	Sediment Discharge (tons per day)
1999	314.6	514.2
2000	272.8	227
2001	83.7	9.39

Sediment transport through the project reach is indicated by observations of changing sediment bars throughout the aerial photograph history.

Field Geomorphic Evaluation

Field observations were made almost exclusively from the channel right bank because access to the left bank is limited by the highway and permission was not obtained from WSDOT to access their property. Geomorphic characteristics from the field evaluation are shown in Figure 7. The current channel is a single thread meandering channel with several flow-parallel elongated medial bars or islands seasonally vegetated with reed canary grass. The channel bed is a glide-riffle with mainly sand in glides and cobble-gravel in riffles. Riffles are generated by medial gravel bars that have built up in the channel that are lined with reed canary grass and act to back up water creating a glide upstream and riffle downstream. Channel roughness is relatively high in the riffles formed by cobbles and boulders with reed canary grass vegetating the banks and medial bars. Glide roughness is relatively low though lag deposits of cobbles and boulders are local roughness elements that can deflect flow and create turbulence. Banks are vegetated dominantly by willows and reed canary grass.

The upstream end of the project reach is the end of a sharp meander bend with a steep riffle and high valley walls on the right bank and a wide left floodplain with significant sediment storage in the form of bars and overbank deposits. Marshall Creek flows into the large meander that was cut-off from the river left and now flows through a box culvert under the highway to enter Hangman Creek near the upstream end of the reach.

Valley walls consist of interlayered sands, silts and gravels with cobbles and gravel-cobble layers. As material is deposited in the channel from the side slopes, Fine-grained material is washed away by routine suspended sediment transport, leaving a cobble bed below the sand in the channel. Although the stream has incised in the past, the cobbles now armor the channel, increasing channel roughness and inhibiting further channel incision. The valley walls immediately adjacent to the creek decrease in height from the start of the reach downstream to the subject site.

Recent slope erosion was observed near the top of the slope near RM 4.2. A large diameter stormwater culvert is perched about 20 feet above the channel, extends approximately 5 feet out from the slope and discharges directly onto the lower slope. Aerial photographs show approximately 15 feet of erosion of the top of the slope since 2001. Cobbles accumulated at the base of the slope are left behind while finer material is swept away during higher flows.

Riprap revetments protect a majority of the lower left bank and the outside of two right side meander bends, as shown in Figure 7. Several are associated with current or past highway and railroad fill prisms, and bridges. Concrete aprons were placed around bridge piers at the former Avista Bridge and remain in the channel on the downstream side of the current bridge. Large boulders and blocks of concrete debris are situated at the toe of the right bank for a length of about 550 feet from about RM 3.85 downstream to the Avista Bridge. Close to the bridge, additional rip rap is built up to the top of the slope and is overlain with soil vegetation has become established. Several holes with loose soil near the surface were observed in the bank at the top of the rip rap revetment near the residence on the subject property. Based on our observations, these holes are animal burrows and not the result of piping as suggested by previous observations (Olson 2011). In our opinion, the revetment is stable. At the downstream end of the project reach on the right bank, a substantial rip rap revetment is built up around the railroad bridge fill prism. This revetment extends more than 100 feet upstream into the current floodplain and appear to have been placed as bank protection at the previous channel location observed through the 1979 aerial photographs.

Channel Migration Zone Delineation

Avulsion Hazard Analysis

Based on interpretation of the RWSE and field observations, there were no avulsion hazards present outside the HMZ in the project reach. Several historic channels were visible within the RWSE map but elevations were considered too high to be an avulsion hazard under current conditions. Thick vegetation was observed at the lower end of the channels which would slow water considerably, impeding potential erosion and head cutting.

Erosion Setback

The ES was calculated for a 100-year life of the CMZ. Using equations listed in the Methods section, a value of 87 feet was estimated for the ES and illustrated in Figure 8. Values from the analyses used in the equations above and solutions to the equations are listed in Table 4.

TABLE 4: EQUATION VALUES AND SOLUTIONS

Element	Value
Tr1 (years)	110
Average Downstream Migration Rate (feet per year [ft/y])	17.0
Average Meander Wavelength (feet [ft])	1872
Tr2 (years)	41
Average Lateral Migration Rate (ft/y)	7.4
Average Floodplain Width (ft)	364
Average Channel Width (ft)	59
TR (years)	96.2
TE (years)	38
ER (ft/y)	2.2
CE (ft/y)	0.87
T (years)	100
ES (ft)	87

Geotechnical Setback

The angle of repose for the side slopes in the project reach, based on current stable slopes and material properties, ranges between 30 and 34 degrees. The median, thirty-two degrees, was used to estimate the width of the GS. GS widths at each transect are presented in Table 5 and illustrated in Figure 8.

TABLE 5: GEOTECHNICAL SETBACK DISTANCES

Transect	Left Bank (feet)	Right Bank (feet)
1	14	27
2	38	20
3	-	21
4	-	36
5	23	51
6	-	52
7	38	94
8	-	48
9	14	124
10	-	142
11	-	116

Channel Migration Zone

The area that includes the HMZ plus the ES and the GS (if any), delineates the CMZ. Part of the CMZ includes disconnected migration areas (DMAs), areas that extend into SR 195, the railroad bridge and the Avista bridge within the project reach (Figure 8). Final CMZ widths beyond the HMZ are presented in Table 6.

TABLE 6: FINAL CMZ DISTANCES FROM THE HMZ

Transect	Left Bank (feet)	Right Bank (feet)
1	101	114
2	125	107
3	87	108
4	87	123
5	110	138
6	87	139
7	125	181
8	87	135
9	101	211
10	87	229
11	87	203

DISCUSSION

Channel Migration in the Project Reach

The project reach of Hangman Creek originally was a low-gradient, high sinuosity meandering stream with pool-riffle-glide bedforms. Highly erodible banks and valley walls comprised of non-cohesive Missoula Flood deposit sediments contributed wash load and suspended load sediment that were readily transported downstream while coarser cobbles and boulders remained as lag deposits on the channel floor and base of the banks. Channel migration generally occurred through meander bend growth with infrequent chute and neck avulsions that likely were induced by shifting sediment loads transported downstream from bank erosion upstream. The channel avulsion seen in the 2001 aerial (presumed to have been caused by the 1997 flood) in the project reach was a small shift of the active channel to the right at RM 4.1. Based on field and aerial photograph observations, it appears the avulsion was caused by bar accretion on the left bank and sediment buildup on the left floodplain. The source of the sediment appears to have been from bars and banks immediately upstream and additional sediment from right bank erosion. Coarse material remains in the channel at the site of the avulsion in medial bars while the bulk of the sediment has been transported downstream and out of the reach.

Significant modifications to the floodplain and active channel corridor have strongly impacted channel migration processes. The impact of meander-bend cutoff by the construction of SR 195 in the 1930s both upstream and downstream of the project reach has shortened the channel and steepened the profile, transforming the reach from a deposition-dominated (response) reach to a transport-dominated reach. Another small reduction was made to the active channel corridor associated with the 2013 completion of the new Cheney Spokane Road interchange. In addition, rip rap revetments placed to armor the highway road prism (both current and historic locations), Avista Bridge, and the railroad bridge impede channel migration and create hard banks that redirect hydraulic forces back to the middle of the channel or to the opposite bank. The reach likely is still adjusting to the disturbances of highway and revetment construction; however, the channel response appears to be slowing down. More channel movement was measured in the first 30-40 years after highway construction (1948 – 1979) than the latter 35 years, (1979 – 2014; Figures 9 and 10), despite three successive years of high flow events in the late 1990s.

Channel Migration at the Subject Site

Two areas of potential channel migration were identified on the right bank at the project site, both associated with the outside of meander bends: at RM 3.85 near the existing residence and at the downstream end of the reach, and at RM 3.5 at the bend approaching the railroad bridge. Potential causes of migration at these locations include sediment aggradation in the channel that would result in bar accretion and bend migration or avulsion, and bank erosion from hydraulic forces impinging on the outside of the meander bend. Over the historic record, the downstream bend shows evidence of aggradation and bend migration while the upstream bend shows evidence of bank erosion. The flood of record occurred in 1997 at a flow of 21,200 cfs. Only minor bank erosion and no channel migration was observed along the subject property in the aerial photograph record. A likely cause of the low bank erosion is the presence of revetments along meander bend cut banks on the subject property (see Figure 7). Although regulations do not recognize a revetment as a barrier to channel migration, the right bank revetment near the house on the subject property appears to be inhibiting bank erosion and slowing migration. Upstream of the revetment, large rocks and debris situated at the toe of the slope add roughness to the channel and provide protection against toe erosion. For reference, the FEMA 100-year floodway is shown in Figures 8, 9 and 10.

CONCLUSIONS

The channel migration zone delineated using the methods and data presented in this report and shown in Figures 9 and 10 represents the area where the channel is most likely to migrate within a 100-year time frame under similar conditions observed in the past 68-year historical record. Although the channel has highly erodible banks and can see significant flood flows, in our judgement the straightening and steepening of the channel caused primarily by the highway roadbed limits channel migration. While the project reach has characteristics that typically indicate significant channel migration potential, including high amplitude, tight meander bends and floodplain terraces composed of alluvial sediments in a wide, low-gradient valley, migration measurements based on the historic aerial photograph record show lower than expected migration rates. In our opinion, the flow regime responsible for creating the stream and floodplain configuration that was in place prior to highway development was characterized by much higher water and sediment discharge that immediately followed glacial retreat at the end of the last ice age. The current flow regime is characterized by very low summer flows and infrequent, large flood pulses in an altered geomorphic setting with a reduced floodplain. While these flood pulses are capable of causing significant bank erosion, landsliding and sediment transport, the lack of sediment trapping structures such as large woody debris reduces the occurrence of bank erosion, meander bend growth, avulsions and channel migration.

LIMITATIONS

We have prepared this report for JRP Land LLC and their authorized agents and regulatory agencies for lower Hangman Creek Channel Migration Zone Analysis.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the field of geomorphology and hydrology/hydraulics in this area at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

Any electronic form, facsimile or hard copy of the original document (email, text, table and/or figure), if provided, and any attachments should be considered a copy of the original document. The original document is stored by GeoEngineers, Inc. and will serve as the official document of record.

Please refer to the appendix titled "Report Limitations and Guidelines for Use" for additional information pertaining to the use of this report.

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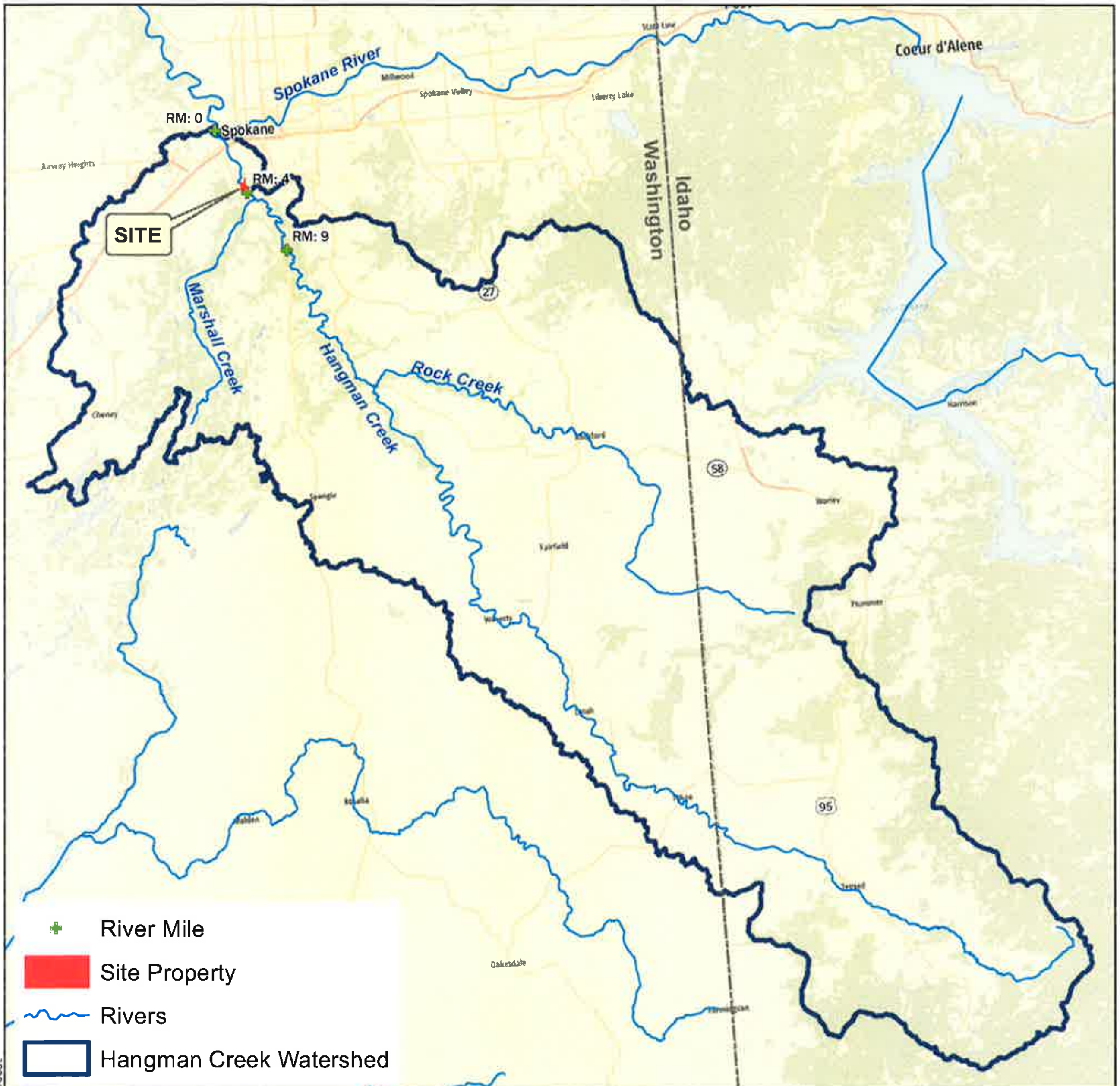
FIGURES

GeoEngineers



N
W E
S

10 0 10
Miles

Vicinity Map

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

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Figure 1

Notes:
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Data Source: Mapbox Open Street Map, 2016

Projection: NAD 1983 UTM Zone 10N

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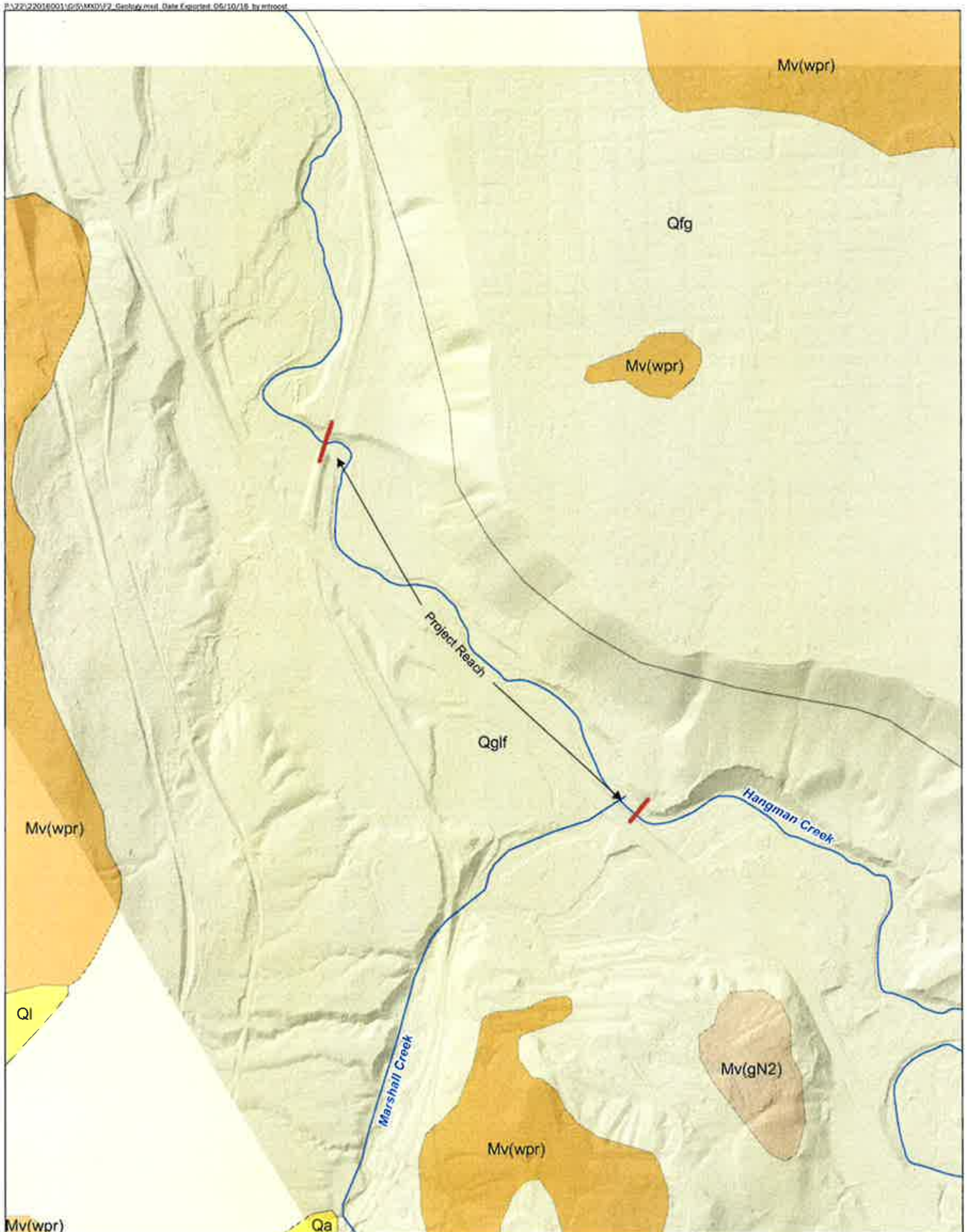

Legend

- Reach Bounds
- Qa, Ql: Quaternary alluvium, dune sand, loess, and artificial fill
- Qfg, Qglf: Pleistocene continental glacial, glaciolacustrine, and outburst flood deposits, Fraser-age
- Mv(wpr): Miocene Columbia River Basalt Group, Wanapum Basalt
- Mv(gN2): Miocene Columbia River Basalt Group, Grande Ronde Basalt

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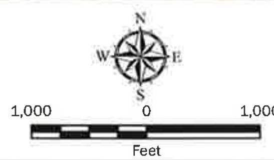
Data Source: DNR 1:100,000 digital Geologic Map

Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

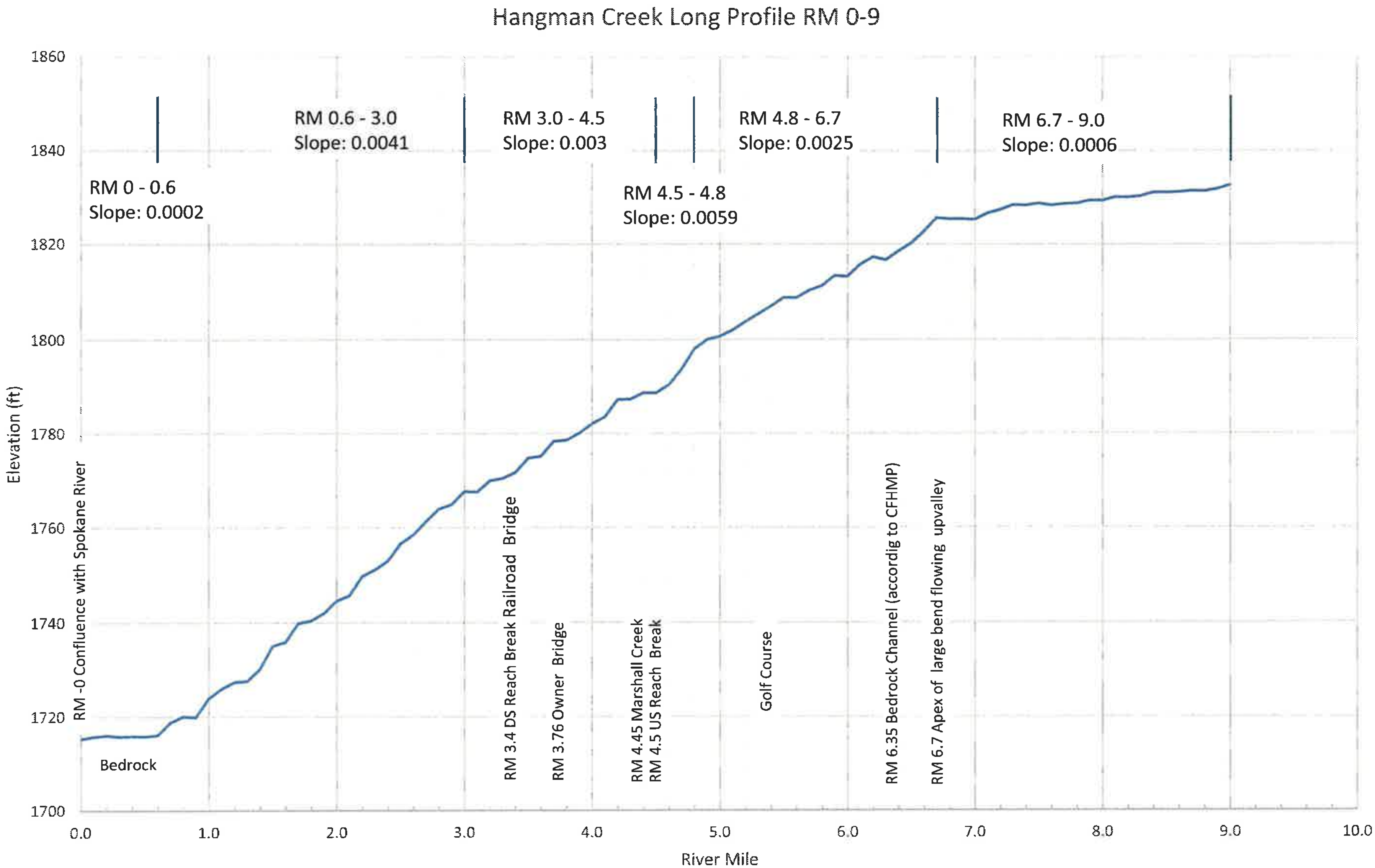


Geology And Reach Boundaries

Channel Migration Zone Analysis
Hangman Creek - Spokane, WA

GEOENGINEERS

Figure 2



Based on 2015 LiDAR. Points sampled every tenth of a mile.

Longitudinal Profile –Hangman Creek	Channel Migration Zone Analysis Hangman Creek - Spokane, Washington	GeoEngineers	Figure 3

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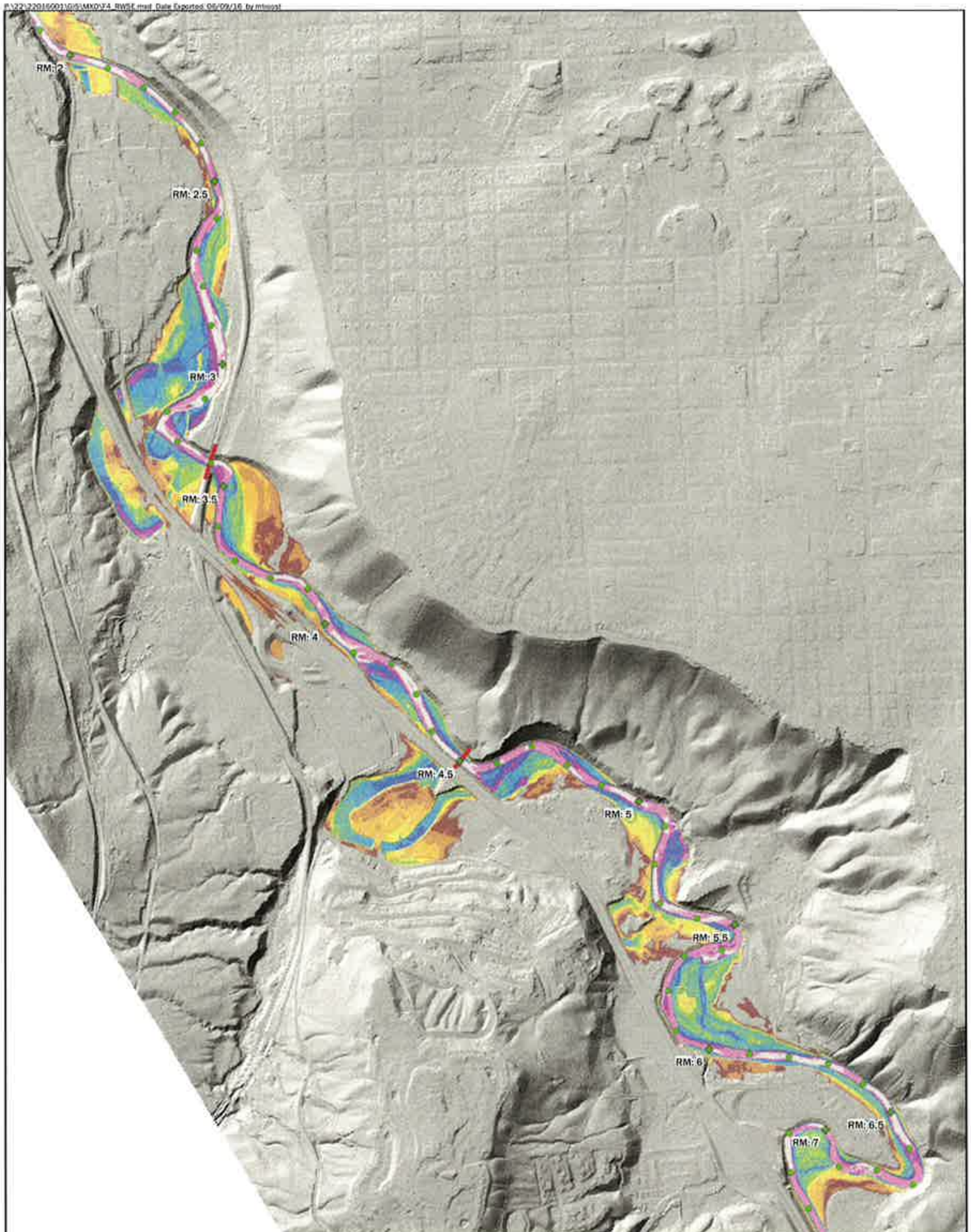

Legend

River Mile Label

- Tenth
- Whole
- Reach Bounds

Relative Water Surface Elevation (Feet)

-2.5 - 0, 0.01 - 2, 2.1 - 4, 4.1 - 6, 6.1 - 8, 8.1 - 10, 11 - 12, 13 - 14, 15 - 16, 17 - 18, 19 - 20

N W E S

1,250 0 1,250

Feet

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Data Source: LiDAR (2015) - Puget Sound LiDAR Consortium

Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

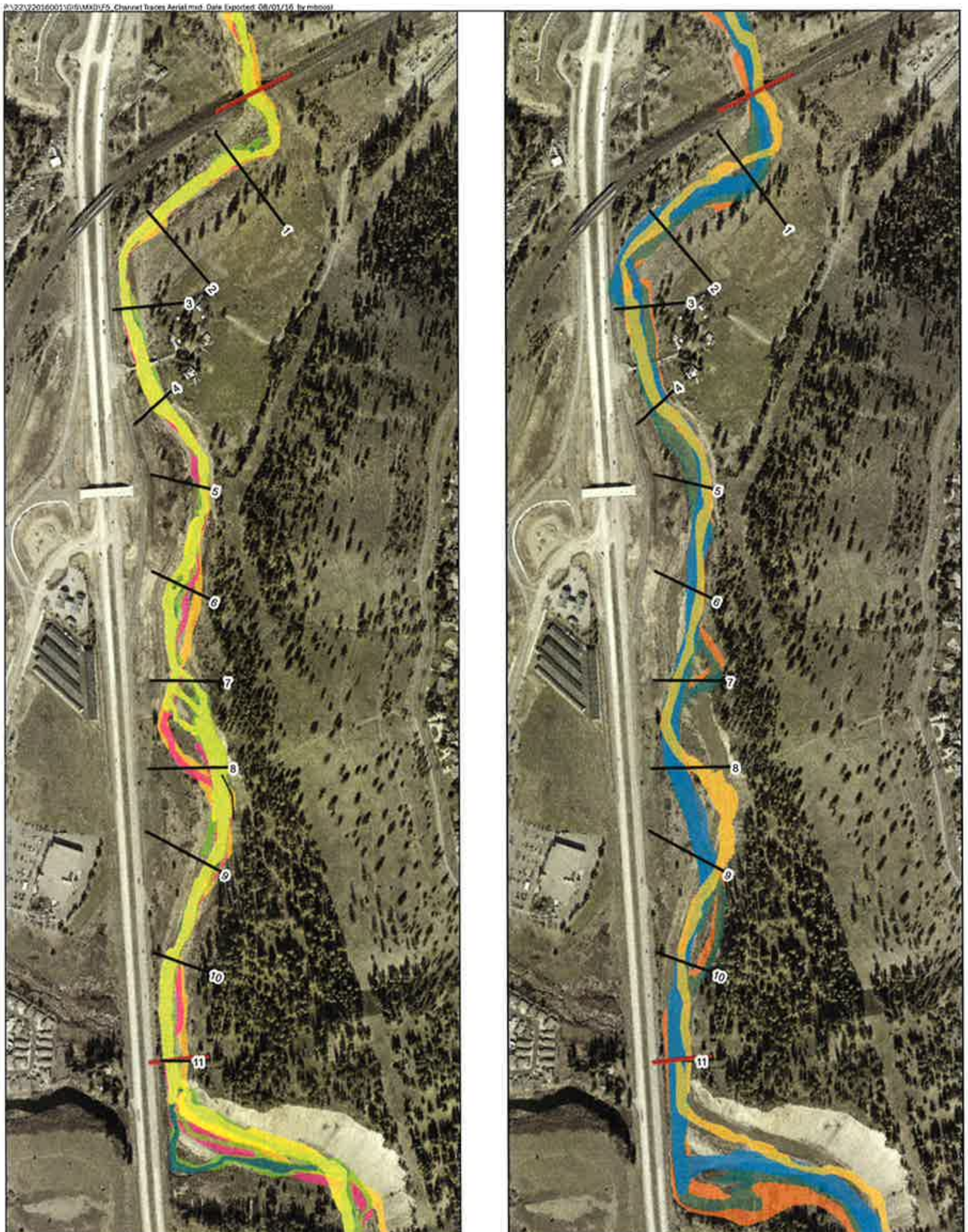
Relative Water Surface Elevation

Channel Migration Zone Analysis
Hangman Creek - Spokane, WA

GEOENGINEERS

Figure 4

P:\22\22016001\GIS\MXD\F5_Channel Traces Aerial.mxd Date Exported: 08/01/16 by mbooz



Legend

2014	1979
2008	1963
2001	1957
1995	1948

Transects for Measuring Migration

500 0 500

Feet

Notes:

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Data Source: Aerial - 2014 City of Spokane

Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

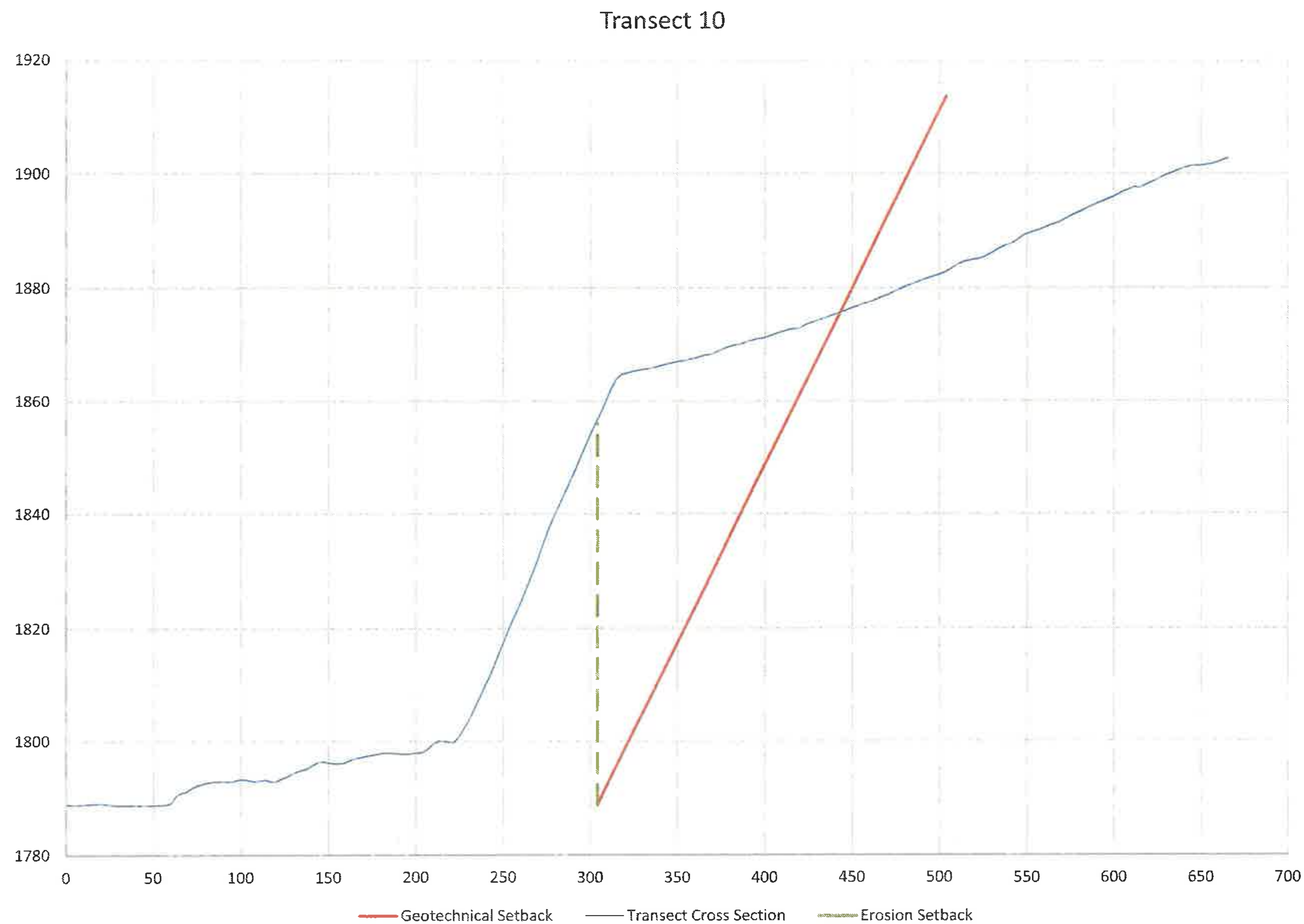
Channel Traces 1948 - 2014

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure 5

P:\22\22016001\00\Geomorph\Profile.pptx



Geotechnical Setback	**Channel Migration Zone Analysis** **Hangman Creek - Spokane, Washington**	GeoEngineers	**Figure 6**

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Legend

River Mile

- Tenth
- Whole

Rip Rap

Culverts

Areas of Deposition

Bedform Transitions

- Glide
- Riffle

New Plantings

Parcel, JRP Land

N W E S

400 0 400

Feet

Notes:

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Data Source: LiDAR - 2015 PSLC

Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

Geomorphic Observations

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure 7

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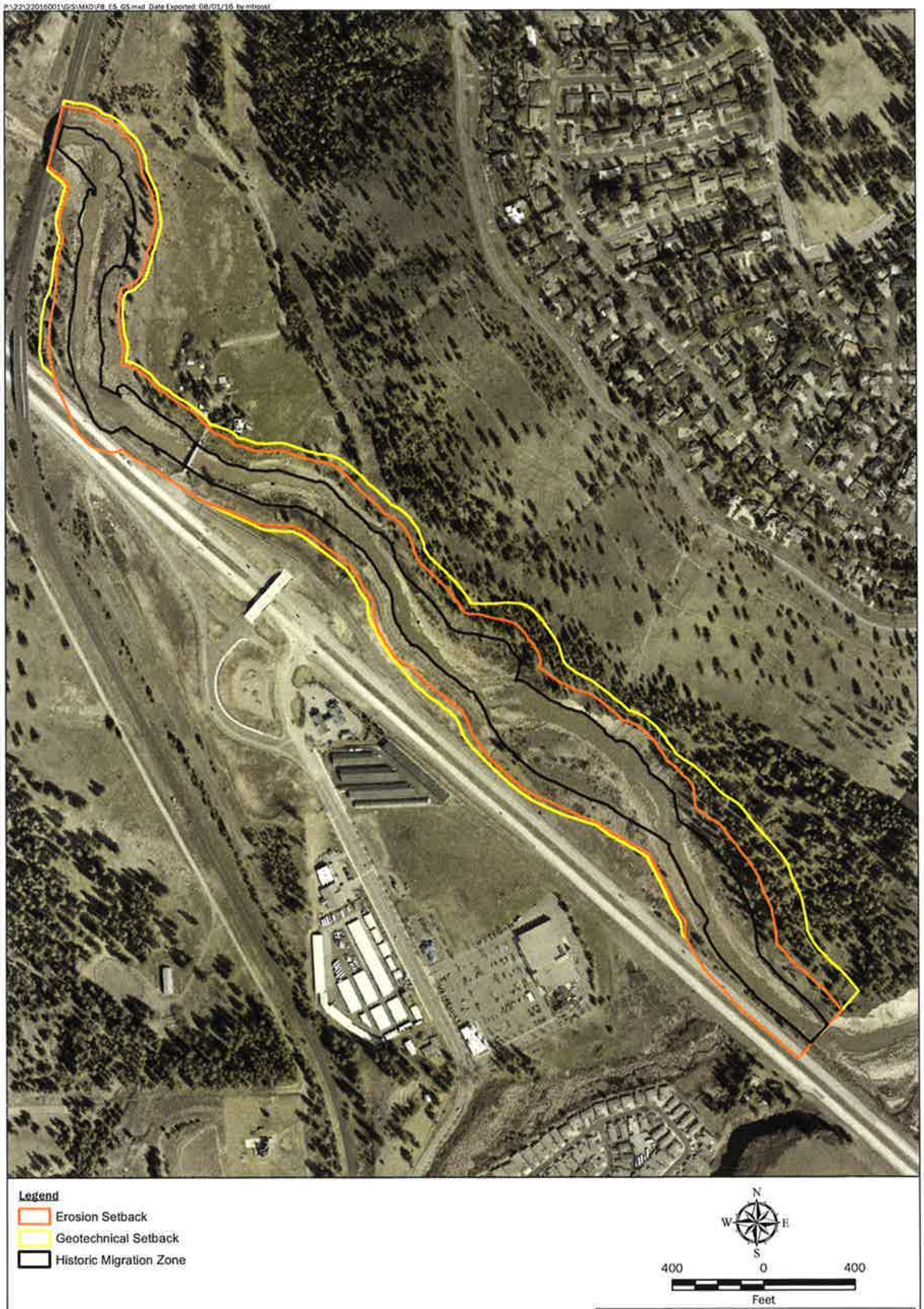

Erosion Setback and Geotechnical Setback

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure 8

Notes:
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Data Source: LiDAR - 2015 PSLC
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

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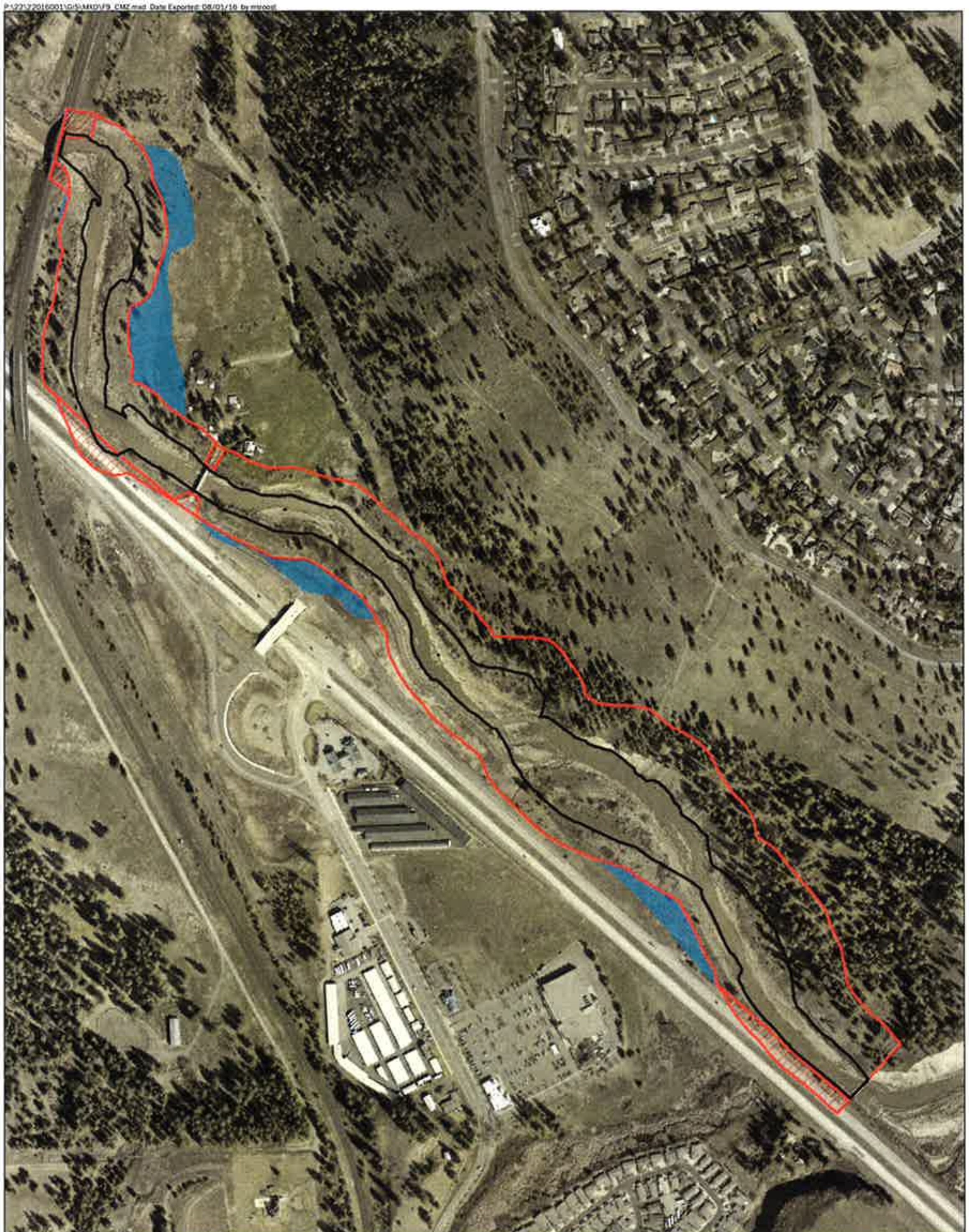

Legend

Historic Migration Zone

CMZ 2015

CMZ

DMA

FEMA 1% Annual Chance Flood Hazard Beyond the CMZ

N W E S

400 0 400

Feet

Notes:
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Data Source: Aerial - 2014 City of Spokane; FEMA 1% Annual Chance Flood Hazard (http://hazards.fema.gov/gis/nfhl/rest/services)
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

Channel Migration Zone

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure 9

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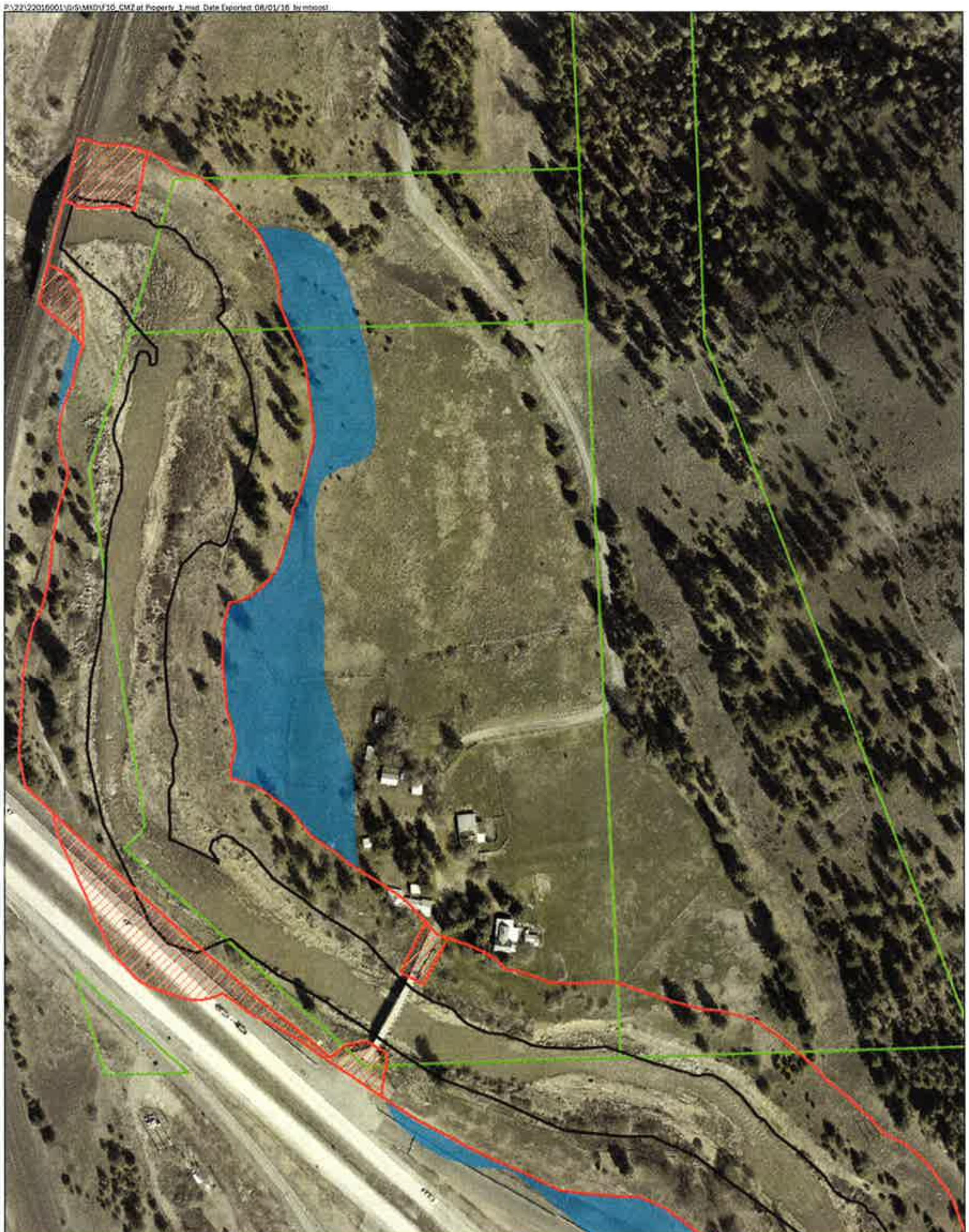

Legend

- Parcel, JRP Land
- Historic Channel Migration Zone

CMZ_2015

- CMZ
- DMA
- FEMA 1% Annual Chance Flood Hazard Beyond the CMZ

N, W, E, S

200 0 200

Feet

Channel Migration Zone at JRP Property

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure 10

Notes:

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Data Source: Aerial - 2014 City of Spokane; FEMA 1% Annual Chance Flood Hazard (http://hazards.fema.gov/gis/nfhl/rest/services)
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

APPENDICES

GeoEngineers

APPENDIX A
Aerial Photographs

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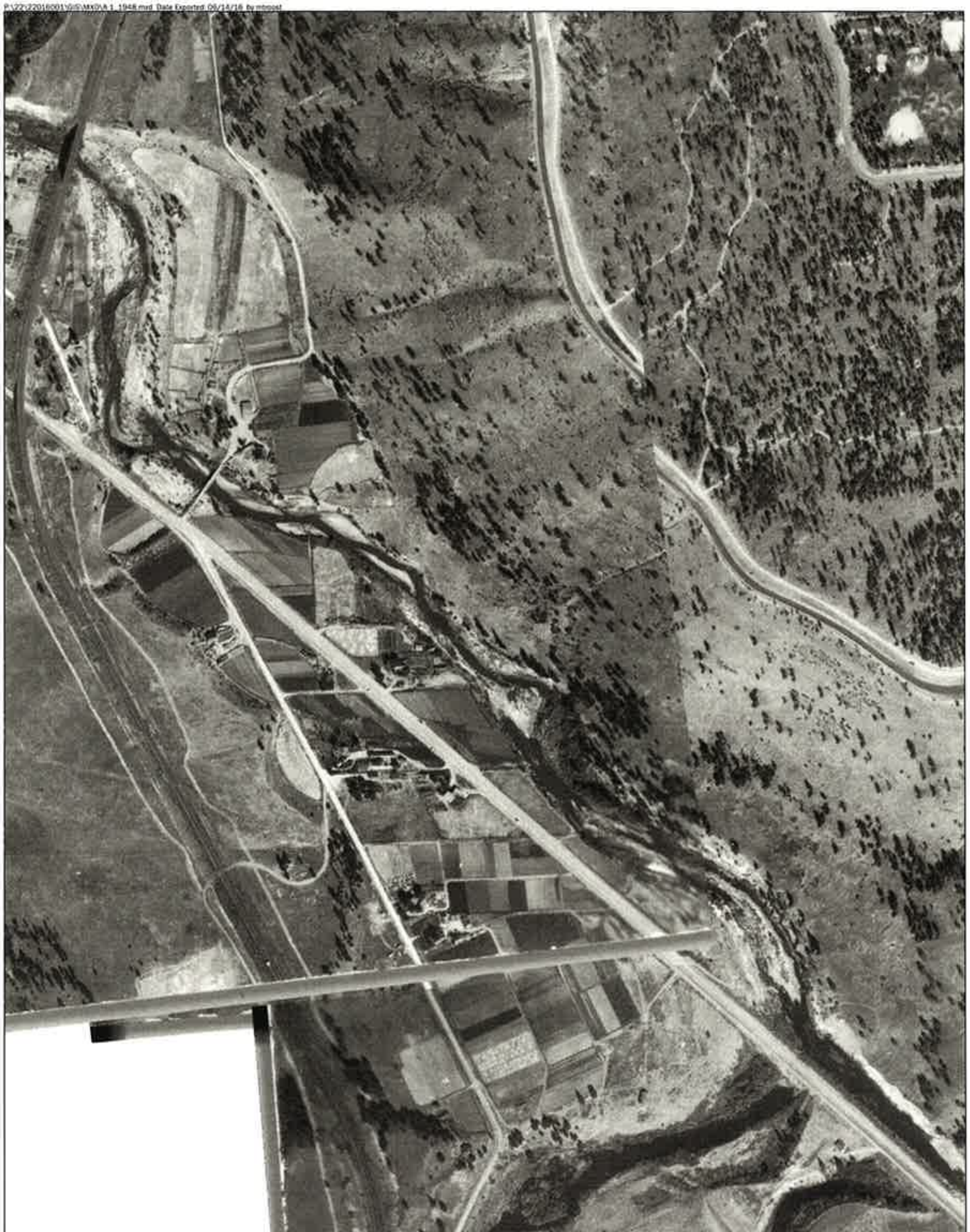

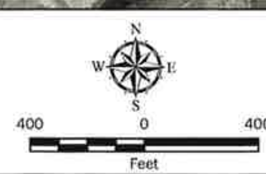

Aerial - 1948

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

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Figure A-1

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Data Source: Aerial - 1948, City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

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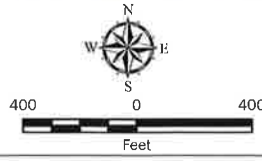

Aerial - 1957

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure A-2

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Data Source: Aerial - 1957, City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

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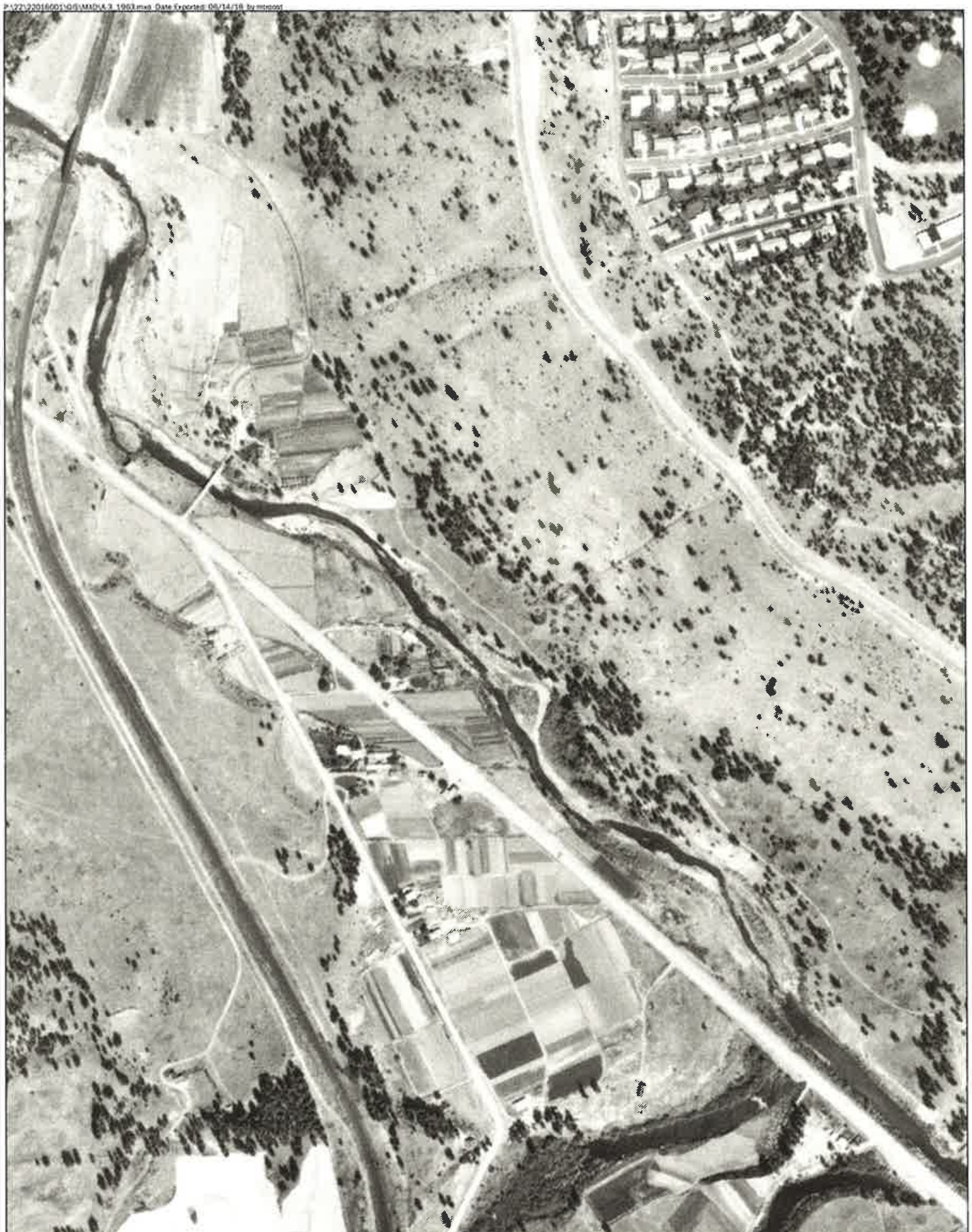

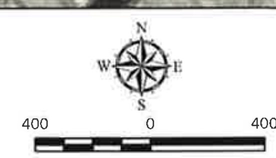

Aerial - 1963

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure A-3

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Data Source: Aerial - 1963, City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

Aerial - 1979

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

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Figure A-4

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Data Source: Aerial - 1979, City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

P:\22\22016001\GIS\MXD\A 5_1995.mxd Date Exported: 06/14/16 by mmost

N
W E
S

400 0 400
Feet

Aerial - 1995

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure A-5

Notes:
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Data Source: Aerial - 1995, DNR via City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

N
W E
S
400 0 400
Feet

Aerial - 2001

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

GEOENGINEERS

Figure A-6

Notes:
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Data Source: Aerial - 2001, City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

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Aerial - 2008

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

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Figure A-7

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Data Source: Aerial - 2008, City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

P:\22\22016001\GIS\MXD\A 8_2014.mxd Date Exported: 06/14/16 by mtoost

Aerial - 2014

Channel Migration Zone Analysis
Hangman Creek - Spokane, Washington

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Figure A-8

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Data Source: Aerial - 2014, City of Spokane
Projection: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet

APPENDIX B
Report Limitations and Guidelines for Use

APPENDIX B
REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

Geotechnical Services Are Performed for Specific Purposes, Persons and Projects

This report has been prepared for the exclusive use of JRP Land LLC and their authorized agents. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. For example, a geotechnical or geologic study conducted for a civil engineer or architect may not fulfill the needs of a construction contractor or even another civil engineer or architect that are involved in the same project. Because each geotechnical or geologic study is unique, each geotechnical engineering or geologic report is unique, prepared solely for the specific client and project site. Our report is prepared for the exclusive use of our Client. No other party may rely on the product of our services unless we agree in advance to such reliance in writing. This is to provide our firm with reasonable protection against open-ended liability claims by third parties with whom there would otherwise be no contractual limits to their actions. Within the limitations of scope, schedule and budget, our services have been executed in accordance with our Agreement with the Client and generally accepted geotechnical practices in this area at the time this report was prepared. This report should not be applied for any purpose or project except the one originally contemplated.

A Geotechnical Engineering or Geologic Report is Based on a Unique Set of Project-Specific Factors

This report has been prepared for a portion of the South Fork Stillaguamish River. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, do not rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored.

Subsurface Conditions Can Change

This geotechnical or geologic report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by manmade events such as construction on or adjacent to the site, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying a report to determine if it remains applicable.

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[1] Developed based on material provided by ASFE, Professional Firms Practicing in the Geosciences; www.asfe.mg.

Most Geotechnical and Geologic Findings are Professional Opinions

Our interpretations of subsurface conditions are based on field observations from widely spaced sampling locations at the site. Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field data and then applied our professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

A Geotechnical Engineering or Geologic Report Could Be Subject to Misinterpretation

Misinterpretation of this report by others can result in costly problems. You could lower that risk by having GeoEngineers confer with appropriate members of the design team after submitting the report. Also retain GeoEngineers to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering or geologic report. Reduce that risk by having GeoEngineers participate in pre-bid and preconstruction conferences, and by providing construction observation.

Read These Provisions Closely

Some clients, design professionals and contractors may not recognize that the geoscience practices (geotechnical engineering or geology) are far less exact than other engineering and natural science disciplines. This lack of understanding can create unrealistic expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory "limitations" provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you are unclear how these "Report Limitations and Guidelines for Use" apply to your project or site.

Geotechnical, Geologic and Environmental Reports Should Not Be Interchanged

The equipment, techniques and personnel Used to perform an environmental study differ significantly from those used to perform a geotechnical or geologic study and vice versa. For that reason, a geotechnical engineering or geologic report does not usually relate any environmental findings, conclusions or recommendations; e.g., about the likelihood of encountering Underground storage tanks or regulated contaminants. Similarly, environmental reports are not used to address geotechnical or geologic concerns regarding a specific project.

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Please let us know by visiting **www.geoengineers.com/feedback**.

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