Intake Diversion Dam Modification

Lower Yellowstone Project, Montana

Bypass Channel 60% Design –
August 2014
Hydraulics Appendix

U.S. Army Corps of Engineers
Omaha District
Hydrologic Engineering Branch
DRAFT August 2014

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1. INTRODUCTION

This document describes the hydraulic analyses conducted since the 30% Design Documentation Report (DDR) for the Lower Yellowstone Intake (Intake) bypass channel was completed in December 2012. The document focuses on efforts that have led to significant bypass channel revisions. Reference 1 (Bypass Channel 30% DDR – December 2012) describes previous analyses in detail. The intent of this document is to build upon the 30% DDR, mainly by describing the changes made since completion of the 30% design.

2. GUIDANCE

The U.S. Fish and Wildlife Service (Service) has defined performance objectives and subsequent design criteria specifically for the bypass channel at Intake. Attachment 1 is the official transmittal of this information. In addition to the performance objectives and design criteria, Attachment 1 describes the request for development of a monitoring and measurement plan.

2.1 Performance Objectives

The Bypass Channel Hydraulic and Physical Performance Objectives (see Attachment 1) were provided to the U.S. Army Corps of Engineers (USACE) in March of 2014. The performance objectives provide a narrative describing the general goals of the bypass channel and give background information pertaining to the subsequent design criteria.

2.2 Design Criteria

The design criteria provided in Attachment 1 follow directly from the performance objectives. Table 1 summarizes the design criteria taken directly from Attachment 1.

Table 1 U.S. Fish and Wildlife Service Design Criteria

Discharge at Sidney, Montana USGS Gage:	7,000-14,999 ft^3/s	15,000-63,000 ft^3/s
Bypass Channel Flow Split	≥12%	13% to ≥ 15%
Bypass Channel cross-sectional velocities (measured as mean column velocity	2.0 - 6.0 ft/s	2.4 - 6.0 ft/s
Bypass Channel Depth (minimum cross-sectional depth for 30 contiguous feet at measured cross-section	≥ 4.0 ft	≥ 6.0 ft
Bypass Channel Fish Entrance (measured as mean column velocity at HEC-RAS station 136)	2.0 - 6.0 ft/s	2.4-6.0 ft/s
Bypass Channel Fish Exit (measured as mean column velocity)	≤ 6.0 ft/s	≤ 6.0 ft/s

2.3 Monitoring and Measurement Plan

In Attachment 1, the Service acknowledges the inherent variability of conditions on the river and the difficulty in the prediction thereof. Additionally, uncertainties associated with the hydraulic modeling upon which the project design is based as well as the monitoring and measurement needed to verify that the constructed bypass channel meets the hydraulic and physical conditions stated in the design criteria are acknowledged. Therefore, the Service requested that USACE, the Service, and Reclamation develop a monitoring and measurement plan that will be used to verify that the completed project meets the hydraulic and physical conditions. The request for the monitoring and measurement plan suggests that the plan should account for the inherent variability of conditions on the river.

3. DESIGN CHANGES – 30% TO MAY 60% TO AUGUST 60%

Based on comments received during the 30% design reviews (Agency Technical Review and interagency reviews), as well as additional hydraulic analyses, changes have been made to the bypass channel configuration and the proposed weir during progression from 30% design to 60% design. An interim progress update was provided to the joint lead agency (US Department of Interior – Bureau of Reclamation (Reclamation)) as well as the Biological Review Team (BRT) in May 2014 to solicit comments. Since the May interim progress update, calibration data was obtained resulting in changes to the proposed bypass. However, tables and figures may refer to information from the May 2014 update for reference and comparison.

Figure 1 shows a general overview of the project while Table 2 compares various parameters of the 30% design to the May 2014 60% design and the currently proposed 60% design (August 2014). The 60% design channel includes changes to the cross section shape (see Figure 2), cross section variation (see Figure 3), upstream and downstream inverts, channel slope, entrance and exit angles, channel length, and channel alignment (see Figure 4).

The proposed weir concept has been changed from a gravity structure to a deep foundation (see Structural Appendix). The deep foundation allows for a narrower crest which is preferable for fish passage. Additionally, cursory evaluation of crest notches has been completed to evaluate various notch width and depth configurations in conjunction with raising the remainder of the weir to maintain diversion head (see Attachment 1).

Attachment 2 describes the evaluation of existing natural side channels as well as the development of natural channel variations and alignment. Much of the natural channel design is based on "*Channel Restoration Design for Meandering Rivers*" (USACE, ERDC/CHL CR-01-1, 2001).

Attachment 3 describes a calibration effort conducted since the May 2014 update that resulted in changes to the bypass channel configuration.

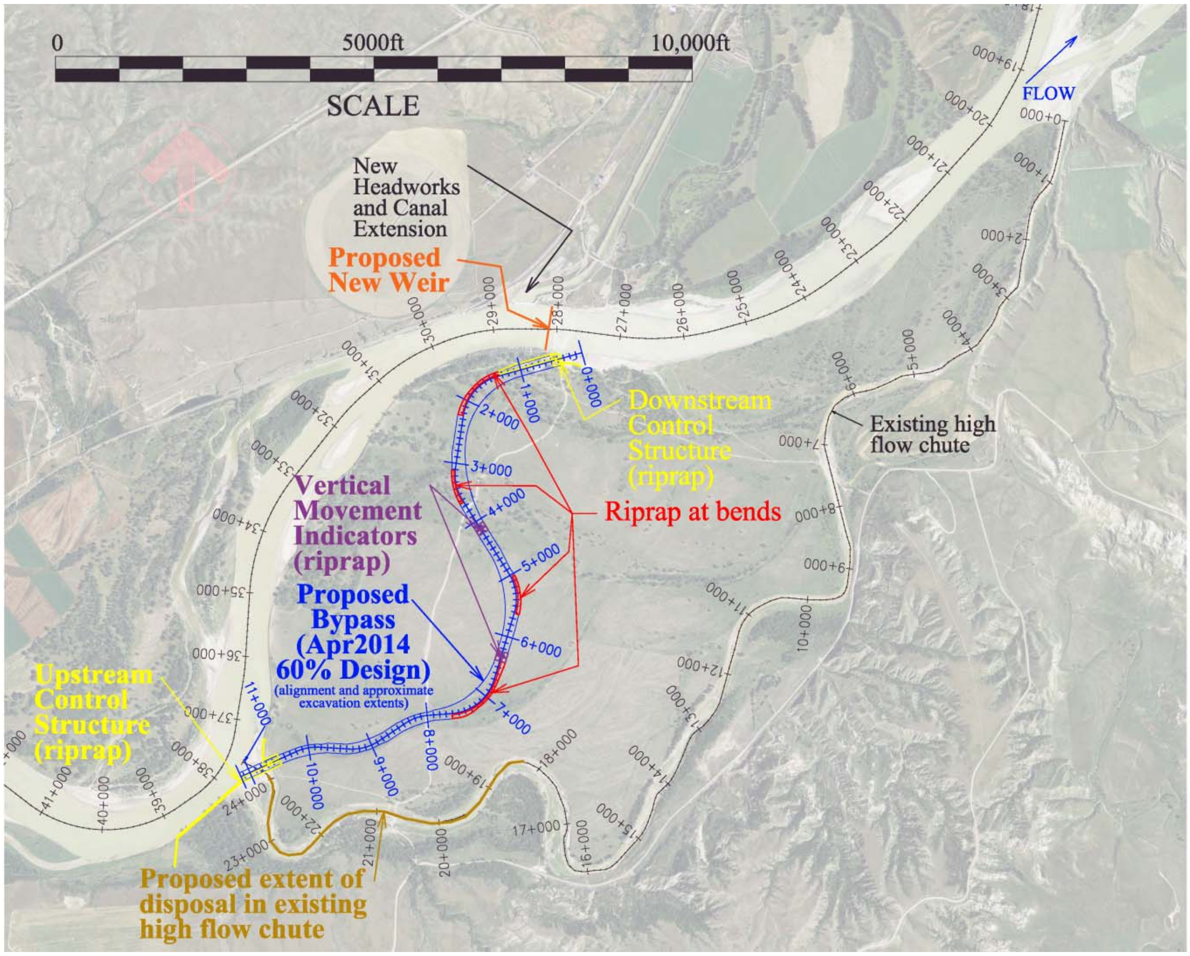


Figure 1 General Overview

Table 2 Design Changes, 30% to May 2014 60% Design to August 2014 60% Design

Bypass Channel Feature	30% Design	May 2014 60% Design	Reason for change from 30% Design to May 2014 60% Design	August 2014 60% Design	Reason/justification for change from May 2014 60% Design to August 2014 60% Design
Channel invert, downstream	1981.0 ft NAVD88	1982.0 ft NAVD88	Following 30% design, additional modeling showed low velocities and potential for deposition at the downstream end of the bypass channel, largely due to backwater effects from the main channel of the Yellowstone River. Several bypass channel downstream inverts were considered (raising the invert 1ft, 2ft, and 3ft). Raising the bypass channel invert by 1ft reduces backwater effects. When a raise of 2 ft or 3 ft was considered, undesirable high velocities, especially during low flows, were computed at the downstream end of the bypass channel, indicating both fish passage and stability concerns. Preliminary results from the physical model also confirmed better performance for the 1ft higher invert.	1981.5 ft NAVD88	Following the May 60% design, calibration data was obtained (9-11JUNE2014 by USACE and 24JUNE2014 by Reclamation). The calibration data indicated that roughness values in the main channel (and the existing right chute) in previous modeling efforts were too high. Lowering the main channel roughness from 0.030 to 0.024 (calibrated value) indicates that a slightly lower downstream bypass invert is desirable to prevent flow acceleration from the bypass to the main channel.
Cross section configuration	40ft bottom width, with side slopes going from 1V:12H to 1V:6H to 1V:4H to 1V:3H	40ft bottom width, with side slopes going from 1V:8H to 1V:6H to 1V:4H	In addition to raising the downstream invert 1 ft, the cross section shape was altered to better match the Yellowstone River stage-discharge rating curve to the bypass channel stage-discharge rating curve. The 60% design shape allows for minimal backwater effects for a large range of flows and provides equal or better depth-velocity relationships within the bypass channel compared to the 30% design. See figure comparing cross sections.	Alternative 1: 34ft bottom width, side slopes 1V:6H for 3ft vert, to 1V:12H for 5ft vert, to 1V:8H for 3ft vert to 1V:3H	Calibration data indicated lower stages on Yellowstone River. Lower roughness on river affects higher discharges more than lower discharges at diversion. Invert is lowered, but using the May 2014 60% design results in too high diversion percentage at low flows but not high enough at higher flows (30k-60kcfs). Therefore, bottom part of xsect is narrower, upper portion is wider. See cross section comparison figure.
				Alternative 2: 40ft bottom width, side slopes 1V:8H for 4ft vert, to 1V:12H for 2.5ft vert, to 1V:3H	This cross section may also accomplish the objective of meeting flow split percentage criteria as well as depths and velocities while decreasing excavation quantities. The concern with this section is flow split percentages above that desired (due to stability concerns) in the lower flow range (7,000-15,000 cfs) when evaluating sensitivity of roughness values in main channel (i.e. using n=0.030 in main channel results in flow split percentages of 17-19% for 7,000-15,000 cfs).
Cross section variation	No variation, “base” cross section used for entire length	Uses “natural” channel sections	For both stability and to create a more natural channel with depth diversity, natural channel design principles were used to develop cross sections for bend apexes as well as predicted maximum scour locations. The “base” cross section described above is used in straight sections of the channel and inflection points (crossovers). This natural section will be further refined during additional design efforts.	Uses "natural" channel sections	No change from May 60% design, still plan to use natural channel sections.
Channel invert, upstream	1990.3 ft NAVD88	1989.8 ft NAVD88	Due to the altered cross section shape, the upstream invert required lowering in order to maintain the desired flow split.	1989.3 ft NAVD88	Similar to reason for change from 30% to May 60% design, plus calibration data indicated lower roughness value required in main channel, lowers water surface (and subsequent diversion percentage)
Exit angle (upstream end)	Greater than 90°	31°	Review of 30% design indicated strong opposition to angle that pointed downstream due to fish passage concerns. The proposed 31° angle provides a smooth transition, both for fish going upstream and for water entering the bypass channel.	31°	No change from May 60% design
Channel slope	0.0006 ft/ft	0.0007 ft/ft	Reclamation sediment modeling indicated the potential for deposition, especially at the downstream end of the bypass channel. Additionally, further HEC-RAS sediment modeling showed little difference in sediment transport trends for slopes of 0.0006 to 0.0007 ft/ft. The milder slope indicated higher potential for deposition during low flow periods while both slopes showed higher velocity with the need for larger bypass channel bed material size to resist erosion during higher flows. Because a processed armor layer to reduce the risk of degradation was already considered, it was determined that a slightly steeper slope would be preferable for sediment management, length of bypass channel, and overall excavation quantities.	0.0007 ft/ft	No change from May 60% design
Channel length	15,500 ft	11,150 ft	The channel length is dictated by the channel slope and upstream/downstream inverts as discussed above.	11,150 ft	No change from May 60% design. Both upstream and downstream inverts were lowered 0.5ft, slope kept at 0.0007, no change to length
Channel alignment	Used existing high flow channel for 1/3 of its length, then cut across Joe's Island	Does not follow existing high flow channel	The reduced length of the bypass channel precludes the use of the existing high flow channel. The proposed 60% design takes advantage of existing swales/channel scars where feasible. In addition, changes in the entrance / exit angles to the Yellowstone River were included to alter flow direction in these critical locations for both stability and fish passage. Future 2D modeling will further evaluate alignment angles and flow direction in these locations. See alignment comparison figure.	-	No change from May 60% design
Approximate Excavation Quantity	1,200,000 yd^3	860,000 yd^3	Cross sectional area and length are both reduced in the May 60% design. Cursory evaluation indicates that excavation quantity is reduced.	1,100,000 yd^3	Quantity based on Alternative 1 cross section configuration. The extra width on top results in higher excavation quantities (compared to the May 60% design). Note that channel design is still evolving and there is potential that this quantity may be reduced, likelihood of it increasing is low.
Approximate Riprap Quantity	65,200 tons (bypass) + 8600tons (b/w new and old weir) + 8300 tons (u/s of new weir) = 82,100tons total	(no update)	-	64,800 tons (bypass) + 8600tons (b/w new and old weir). (Includes 8000tons temporary for coffer dams, assume re-use with 20% loss) No riprap required upstream from new dam. Total ≈ 75,000tons.	Riprap quantities in the bypass itself are very similar to the 30% design. The length of bank armoring is increased, but the slope length is decreased. Structural evaluation determined that riprap is not required upstream from the new dam, eliminating 8300 tons.

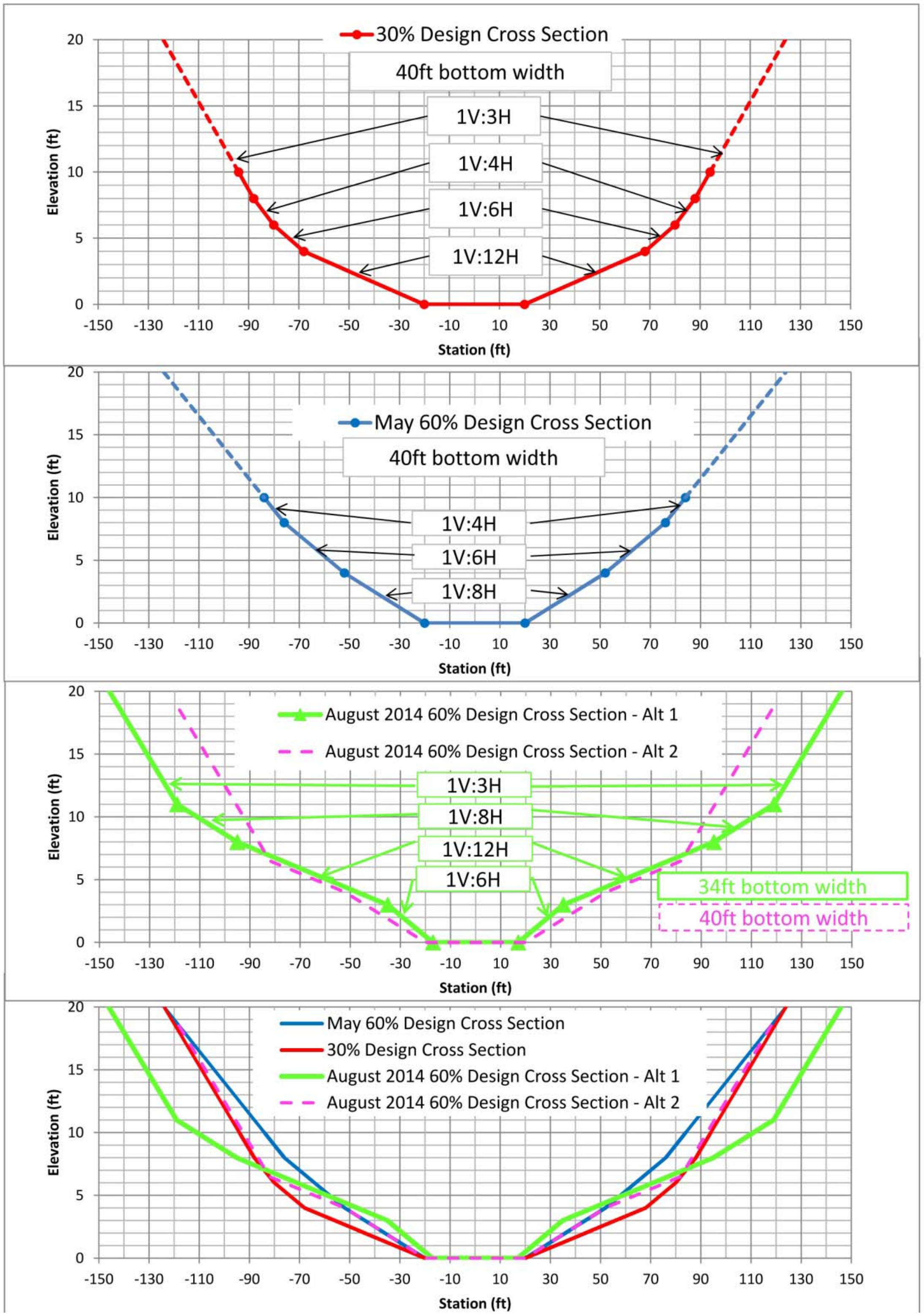


Figure 2 Channel Section Comparison

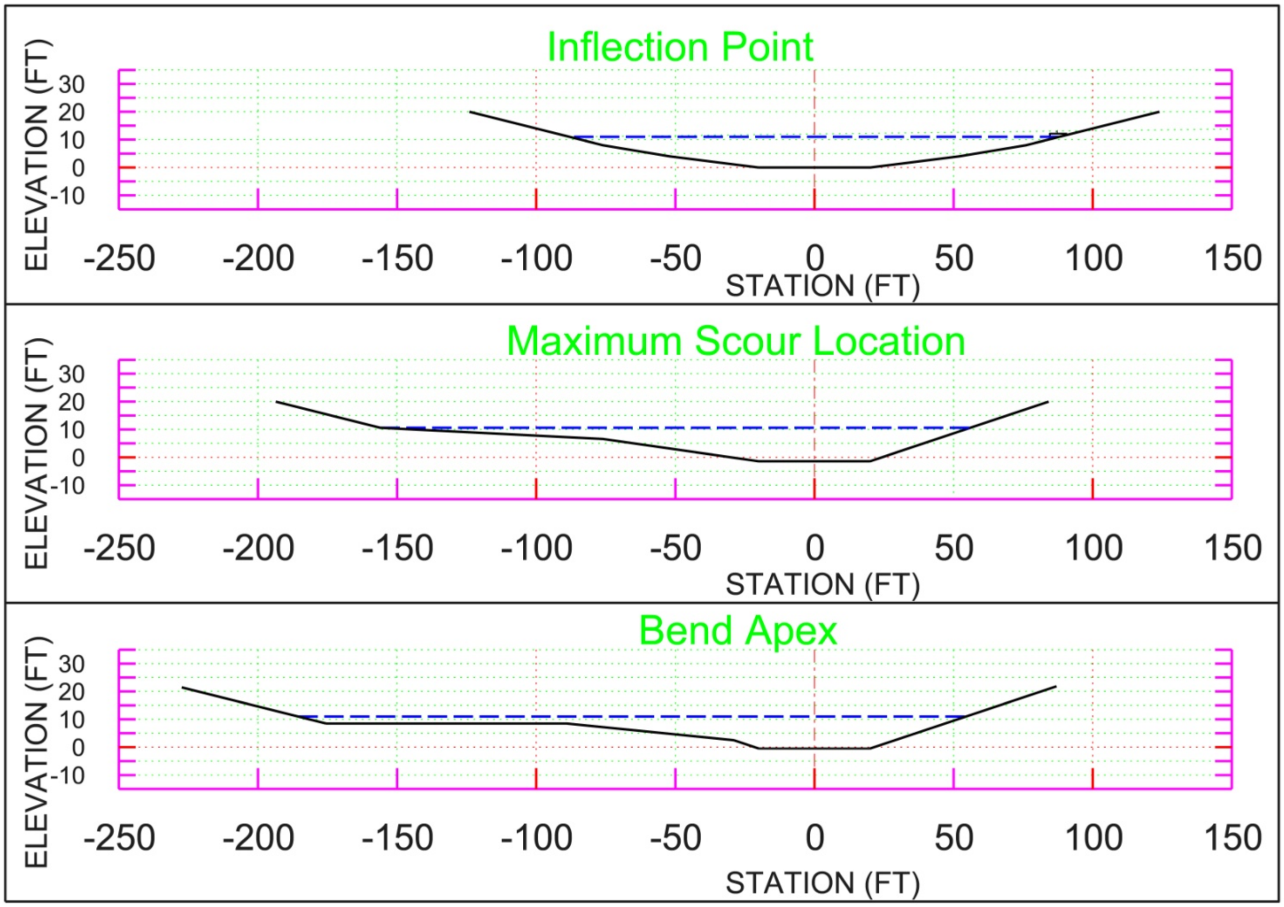


Figure 3 Natural Channel Variation

Notes: The inflection point is located in the crossing where the bend switches from one bank to the other, the bend apex is located near the center of the bend, and the maximum scour location is located between the bend apex and the downstream inflection point. Note that the inflection point cross section shown is not changed from the May 2014 60% design cross section. Natural channel design and all three cross sections will be updated during progression from 60% to final design.

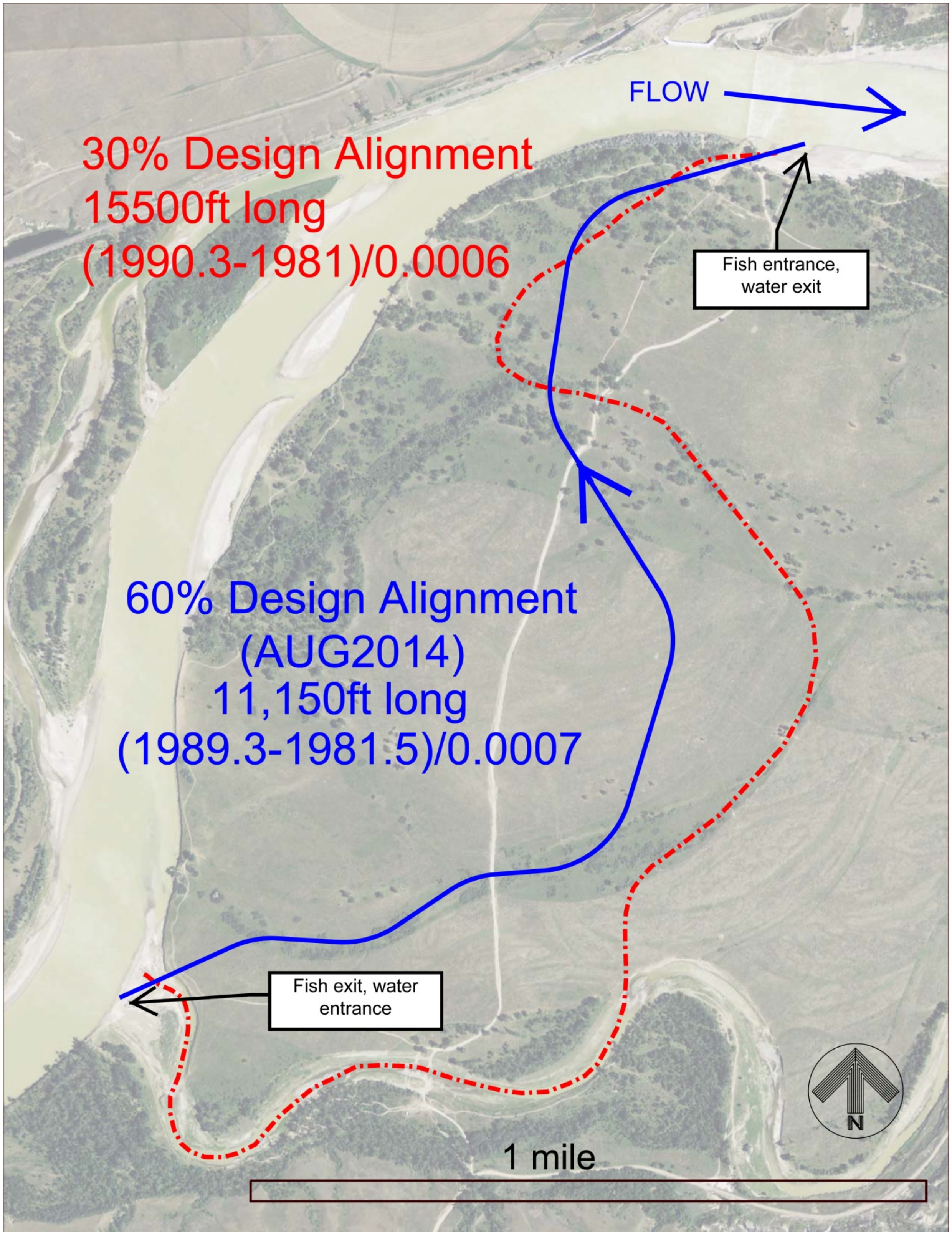


Figure 4 Alignment Comparison

4. MODELING

Since completion of the 30% design, additional numerical and physical modeling has been completed. Due to the compressed design schedule, a multifaceted approach to modeling including various models was used in an effort to reduce uncertainties, especially in sediment transport. Both one-dimensional and two-dimensional numerical modeling has been completed by both USACE and Reclamation. The USACE modeling has consisted of one-dimensional HEC-RAS modeling of both open-channel hydraulics and sediment transport as well as initial ADH two-dimensional hydraulic modeling. Reclamation has performed two-dimensional modeling of hydraulics and sediment transport with SRH-2D. Additionally, Reclamation built a 1:16 Froude scale physical model combining the downstream end of the bypass channel and half of the main channel of the Yellowstone River. The physical model is only capable of modeling open-channel hydraulics in a fixed bed mode without sediment.

Prior to June 2014, no existing condition Yellowstone River calibration data was available in the flow range above 15,000cfs. Two sets of calibration data were gathered in June 2014. A USACE team collected bathymetry and measured discharges, velocities and water surface profiles in the vicinity of Intake from 9-11JUNE2014. A Reclamation crew then surveyed water surface profiles on 24JUNE2014. Another water surface profile used in calibration at low flows was collected 14-18AUGUST2012 by Reclamation. Attachment 3 describes the calibration effort in detail. The result of the updated calibration effort is that Manning's roughness values used in the hydraulic models to match the measured data are lower than those used previously. In HEC-RAS simulations, a Manning's n value of 0.024 (compared to previously used 0.030) was used to match the measured data at a discharge of approximately 50,000 cfs (USACE 9-11JUNE2014 survey). There is some indication that the roughness decreases with an increase in depth (i.e. the roughness may be slightly higher at lower discharges). A roughness of 0.027 matches the 30,000 cfs profile (Reclamation 24JUNE2014 profile), while 0.030 may be appropriate for the low flow (4800 cfs) profiles measured by Reclamation in 2012. A decreasing roughness value with depth is consistent with many river systems. Variable roughness has been considered in development of the 60% design bypass channel, and continued consideration will be given during progression from 60% to final design.

4.1 HEC-RAS Modeling

Initial indications that the downstream invert of the 30% design bypass channel was too low were noticed when comparing the computed depths and velocities against the Biological Review Team's (BRT) design criteria (see Attachment 1). Velocities of less than 2 ft/s were computed in the downstream end of the bypass due mainly to backwater effects from the Yellowstone River main channel. In addition to not providing adequate attractive flow velocities, the low velocities indicated potential for sediment deposition. The first attempt to minimize backwater and increase velocities included raising the downstream invert of the bypass channel. Raises of 1ft, 2ft, and 3ft were modeled and evaluated while maintaining the 30% design channel slope (bypass channel length was shortened to keep the same slope). Raises of 2 ft and 3 ft showed areas of high velocity, especially at low flows, where the bypass flows into the main channel. Therefore, a 1-foot raise of the downstream invert of the bypass was initially selected. The updated modeling using the summer 2014 calibration data, which resulted in lower main channel water surfaces, indicated the need to lower the bypass invert by an additional 0.5-ft to 1981.5 ft NAVD88, the currently proposed invert in the Aug 2014 design.

4.1.1 Hydraulics

Using a downstream bypass channel invert of 1981.5 ft NAVD88 with the May 2014 design, the rating curve for the downstream end of the 30% design bypass channel cross section matched the rating curve for the main channel at low discharges but still showed backwater effects at higher discharges. Therefore, various bypass cross section shapes were evaluated to better match the main channel rating curve. An iterative process was required because when the cross section shape is varied, the flow split changes, which in turn changes the rating curve comparison. Figure 5 shows various bypass channel rating curves compared to the main channel rating curve. The computed flow splits for 30% and 60% design are given in Table 3.

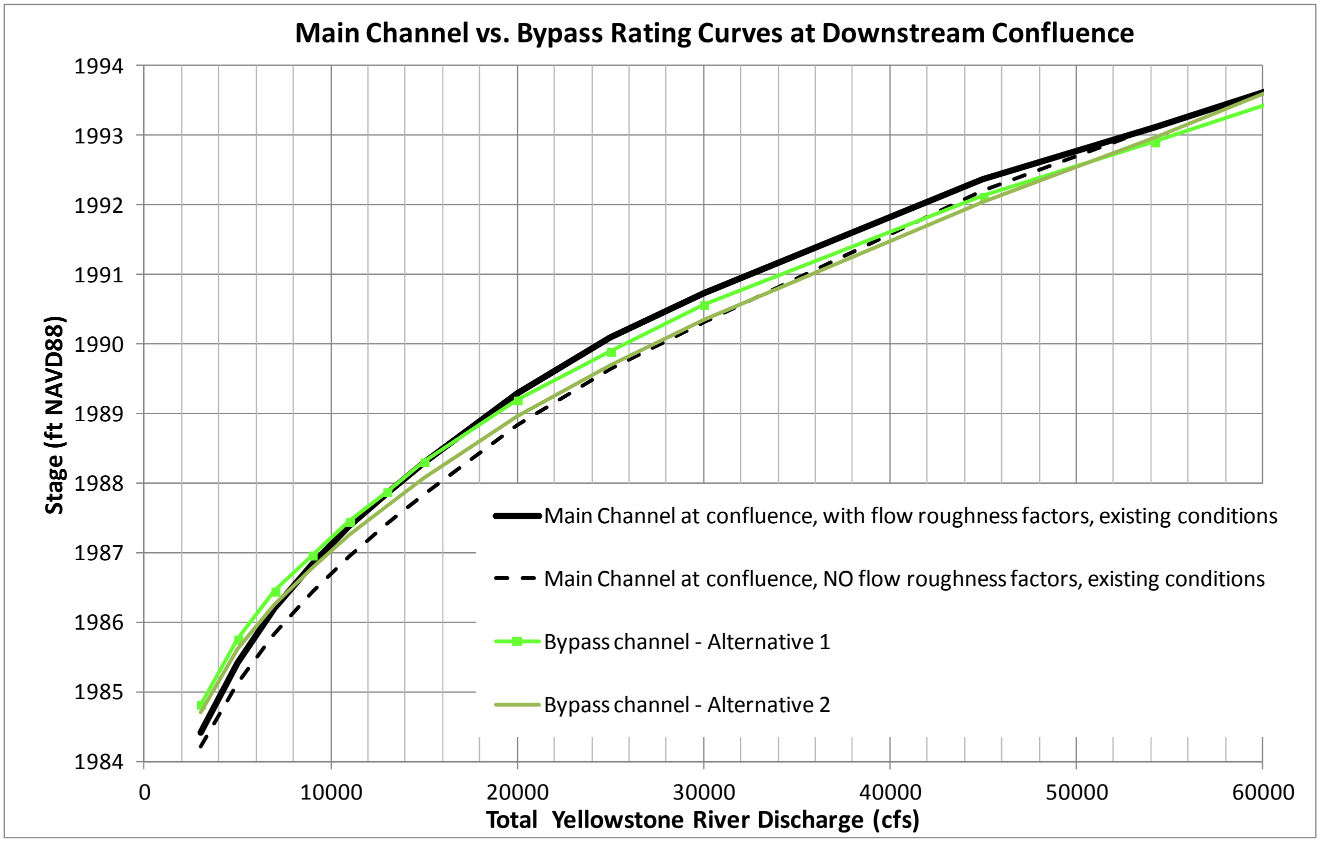


Figure 5 Rating Curve Comparison

This figure compares the Yellowstone River rating curve immediately downstream of the proposed bypass channel confluence with the bypass channel rating curve approximately 200 ft upstream of the confluence. The bypass channel rating curves shown were computed based on normal depth rather than considering the actual boundary conditions (Yellowstone River as tailwater) in an attempt to minimize backwater effects by matching the shape of the rating curves. Two Yellowstone River rating curves are included to show how stage varies with roughness. The "with flow roughness factors" curve includes variable roughness (n=0.030 at 5000cfs, 0.027 at 30,000cfs, and 0.024 at 50,000cfs and above). The "NO flow roughness factors" curve uses a Manning's n of 0.024 for the entire range of discharges.

Table 3 Flow Splits – Existing Conditions, 30% Design, and 60% Design

Total Yellowstone River Flow	Existing Conditions - Existing High Flow Channel Split		30% Design Bypass Channel Flow Split (at upstream end) [2]		May 60% Design Bypass Channel Flow Split (at upstream end) [2, 3]		August 60% Design Bypass Channel (Alt 1) Flow Split (at upstream end) [2]	
(cfs)	(cfs)	(%)	(cfs)	(%)	(cfs)	(%)	(cfs)	(%)
7000cfs [1, 4]	0	0	930	13	950	14	940	13
15000cfs [1]	0	0	2230	15	1930	13	1980	13
30000cfs [1]	390	1	4630	15	3620	12	4100	14
2-year 54200cfs	1980	4	8950	17	6750	12	7830	14
63,000cfs [4]	3340	5	10640	17	8070	13	9430	15
10-year 87,600cfs	7170	8	15010	17	11530	13	14300	16
50-year 116,200cfs	11270	10	20430	18	17360	15	19990	17
100-year 128,300cfs	12740	10	22960	18	18070	14	22480	18

1. 7000cfs is used to represent the 50% exceedance by duration discharge for the summer months; 15,000cfs is used to represent the 50% exceedance by duration discharge for the spring months, and 30,000cfs represents the 20% exceedance by duration discharge for the spring months.

2. Flow splits taken from upstream end of bypass channel. At extreme flows, some water will exceed the bypass channel bank (absent a levee) and flow overland back to either the river or the existing high flow chute.

3. Values differ from May 2014 60% design interim update because modeling includes flow roughness factors and natural channel variation that was not included in the HEC-RAS modeling prior to the May 2014 60% design interim

4. Range of flows included in the Bypass Channel Hydraulic and Physical Performance Objectives is 7,000cfs to 63,000cfs.

4.1.2 Sediment Transport

Numerous sediment transport runs were completed with HEC-RAS, version 4.2.0 Beta (July 2013 version). Sensitivity runs on multiple sediment loading values, incoming gradation, bed gradation, transport functions, sorting methods, discharges and channel slopes were completed.

In addition to running historic flows from the Sidney gage data, constant flows representing the approximate channel-forming discharge were evaluated. The approximate two-year bypass flow was selected as the channel-forming discharge used to estimate channel stability. Once a relatively stable channel configuration was selected, model analysis was performed with the post-Yellowtail Dam period of record daily flows (1967-2014). The maximum flow through the bypass during this analysis was limited to the approximate bypass chute bankfull discharge, 9,000 cfs (equivalent to approximately 60,000 cfs total Yellowstone flow) due to model instabilities when larger discharges were used. Similar instabilities occur in the main channel when modeling large flows, indicating that model limitations (rather than actual geometry or sediment loading) were the cause. Future evaluation will further investigate modeling of extreme Yellowstone River flows, mainly with 2-D modeling where overland flows can be modeled with sediment (currently HEC-RAS cannot model more than one reach with sediment).

4.1.2.1 Base Data

Base data used in the sediment transport analysis is described in detail in Reference 1 (30% DDR). The bullets below summarize the base data but are not intended to be a complete account.

- Incoming load
    - The median incoming load from the Sidney, MT, USGS gage data (USGS Gage #06329500) (see Figure 6) was used to develop a suspended sediment loading curve for the bypass channel based on the estimated flow split.
    - In addition to the Sidney gage suspended data, site measurements from 2008 and 2011 were also evaluated. The USGS collected sediment (and flow) data over several sampling periods in both 2008 and 2011. During the 2011 sampling efforts, suspended sediment point samples were collected along three transects just above, adjacent to, and just below the upstream end of the proposed bypass channel. The intent of the point sampling effort was to provide increased knowledge of the size and concentration of suspended sediment, especially as it relates to vertical distribution. Six point samples were taken in each of five equal-discharge-increment verticals for a total of 30 point samples at each cross section during each sampling run.
    - The 2008 and 2011 measured data both plot on the low end of the Sidney gage data (see Figure 6). Concerns pertaining to underestimation of the incoming load led to the development of median, high, and low loads in tons/day as shown on Figure 6. The high and low sensitivity curves are considered envelope curves that encompass the majority of all the gage data and measured site data.
    - Sediment modeling completed to date uses the same concentration for the bypass channel as that determined for the main Yellowstone River. While the point samples described above provide some insight to the distribution of incoming load and gradation, the small number of data sets (3 sampling efforts at each cross section) limits the ability to extract definite relationships.
- The gradation of the incoming suspended load is based on the estimated median of the Sidney, MT gage data. Figure 7 shows the Sidney data as well as the selected load curves for use in HEC-RAS.
- Estimated Yellowstone River bedload of approximately 5% of suspended load (varies from 0.5-7% depending on flow) with gradation based on 2008 bar samples (grab samples taken with shovel) taken by USACE and analyzed by USGS. Maximum incoming material size was limited to medium gravel (8-16mm). Figure 8 shows combined suspended load/bedload as entered into HEC-RAS. The same bedload concentration determined for the main channel of the Yellowstone River is applied to the bypass channel.
- The transport function used for the base run is Laursen-Copeland, a total load function that was generalized by Copeland for gravel transport so the equation could be used for graded beds.
- Bed gradation was based on 2008 Wolman counts representing the processed armor layer that was proposed in the 30% design (see section 5.5 for additional details). The 60% design still includes the processed armor layer. Figure 9 shows several bed gradations. The Wolman count gradation is coarser than the bar samples or test pits, but is expected

to be similar to the processed armor layer after construction. Uncertainties in the quantity and size of material from the bypass channel excavation available for processing do not allow for definition of a specific bed gradation. It is assumed that material greater than approximately one inch will be retained and used in the processed armor layer. If material similar in size to the proposed gradation is not available in sufficient quantities, consideration should be given to an increased layer thickness and/or importing additional quantities.

Figure 10 shows the results of the “base” run using both a constant discharge of 6,500 cfs (between 45,000 and 55,000 cfs in main channel) and using the gaging record discharges from the post-Yellowtail Dam period (1967-2014). Note that Figure 10 has not been updated with the August 2014 60% design cross section. Future analysis will include updating the sediment runs with the currently proposed cross section.

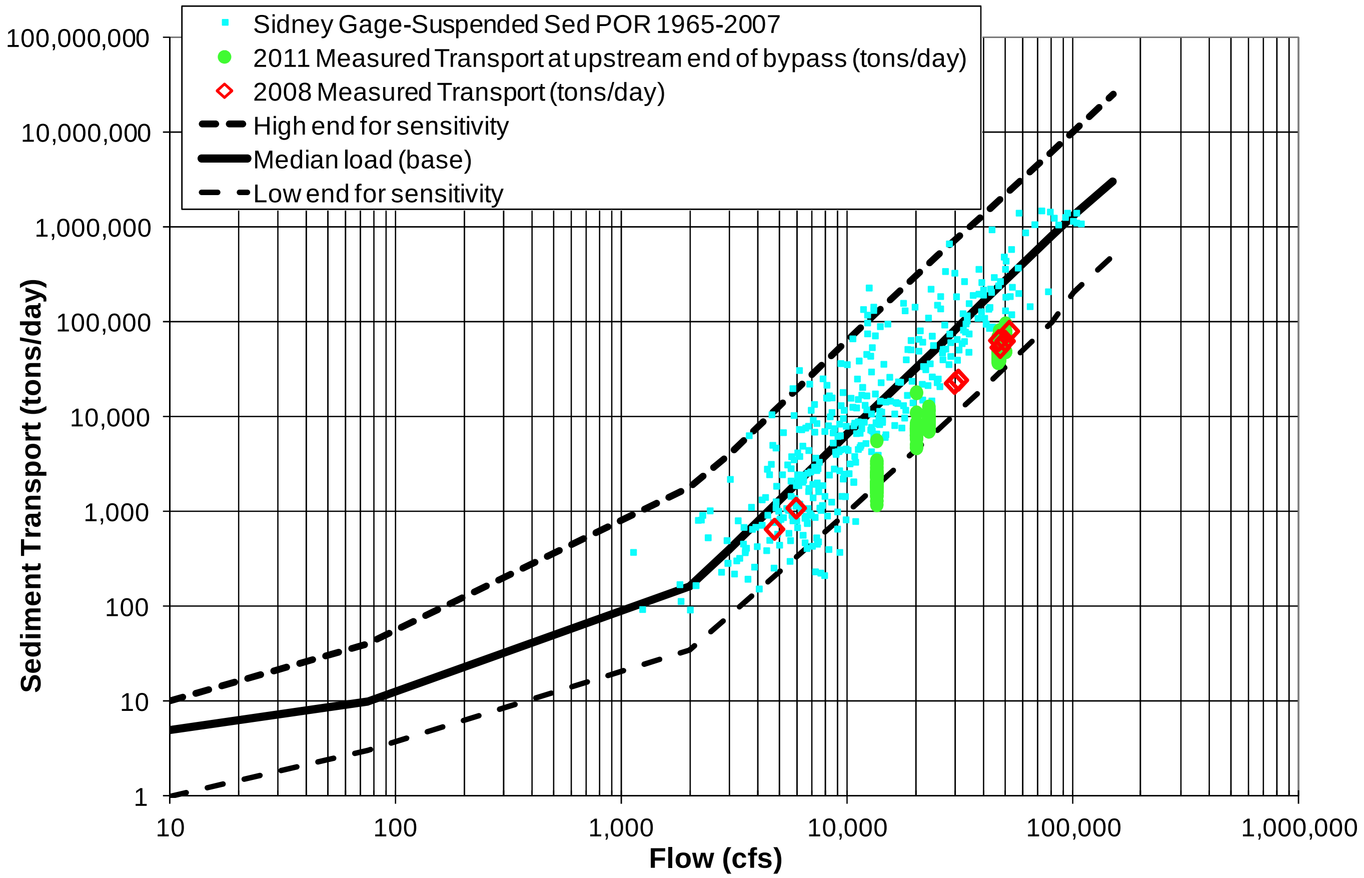


Figure 6 Incoming Load Data

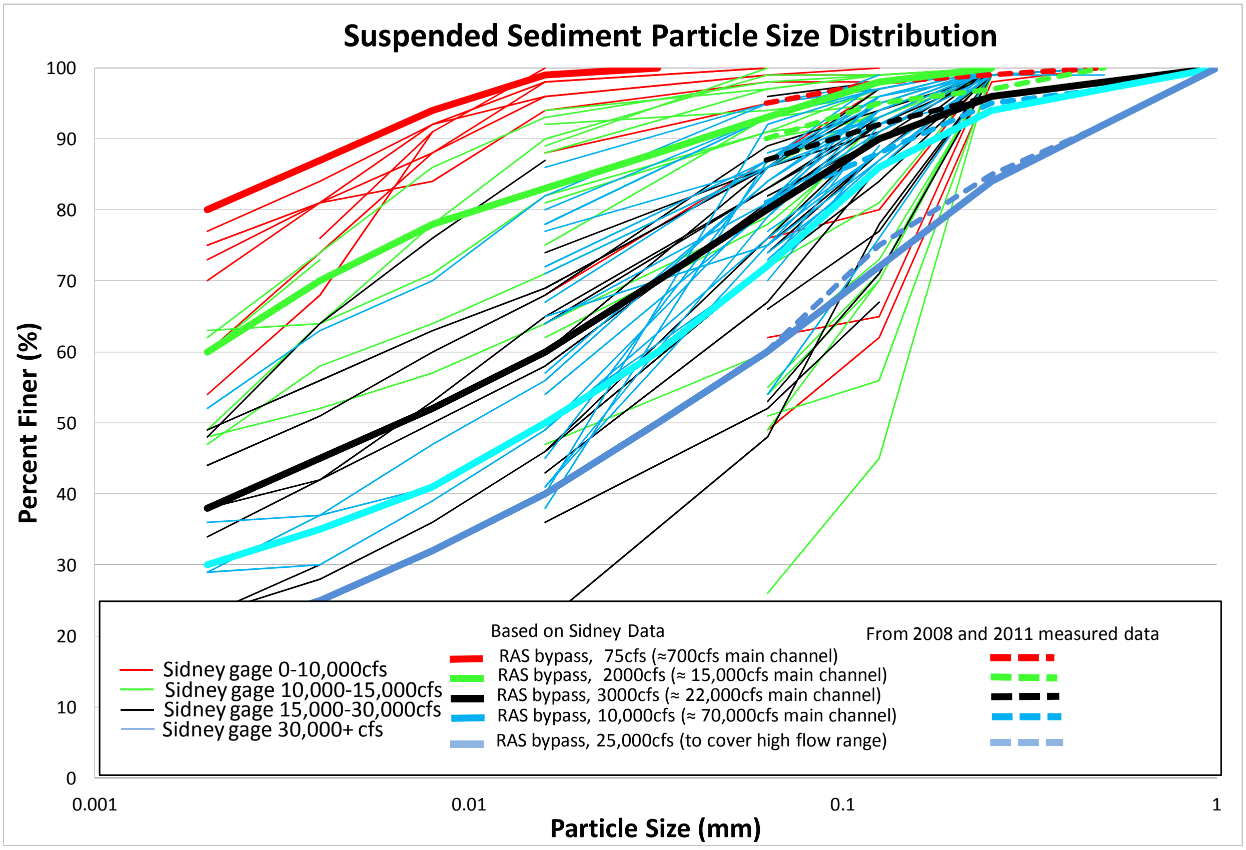


Figure 7 Suspended Load Gradations

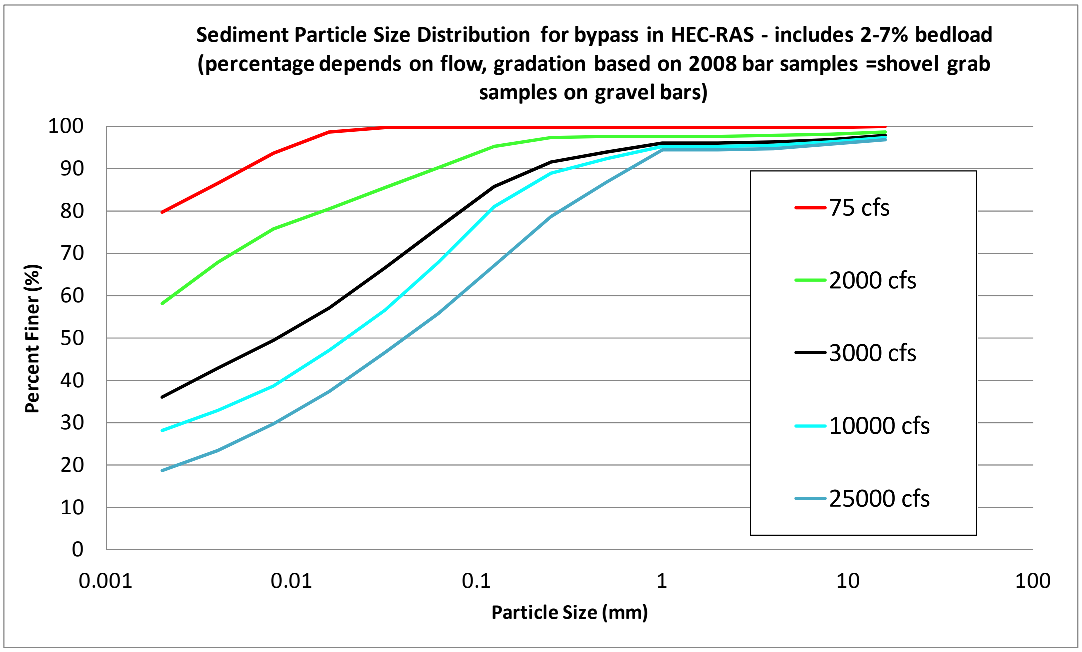
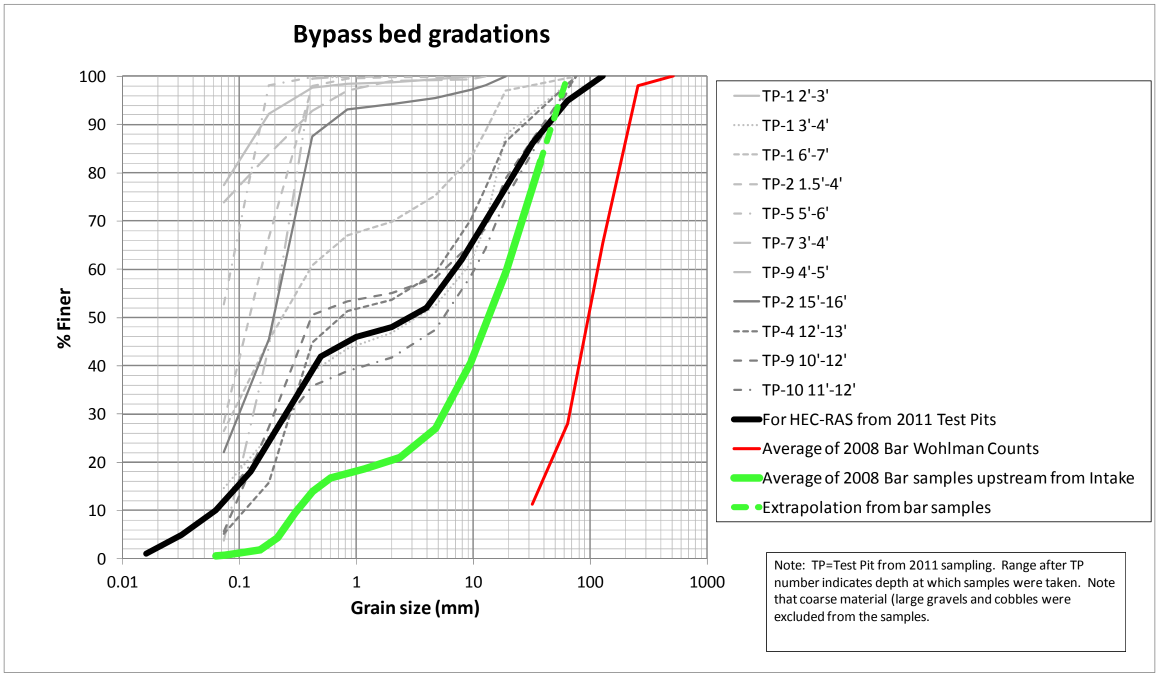


Figure 8 Combined Suspended/Bedload Used in HEC-RAS for bypass channel

Note that discharges for the various curve represent only the bypass portion of flow. The Figure 8 curves shown represent the bypass total load and are based on the "RAS Bypass" curves shown in Figure 7, with the addition of 2-7% bedload material.



Note: TP=Test Pit from 2011 sampling. Range after TP number indicates depth at which samples were taken. Note that coarse material (large gravels and cobbles were excluded from the samples.

Figure 9 Bed Gradations

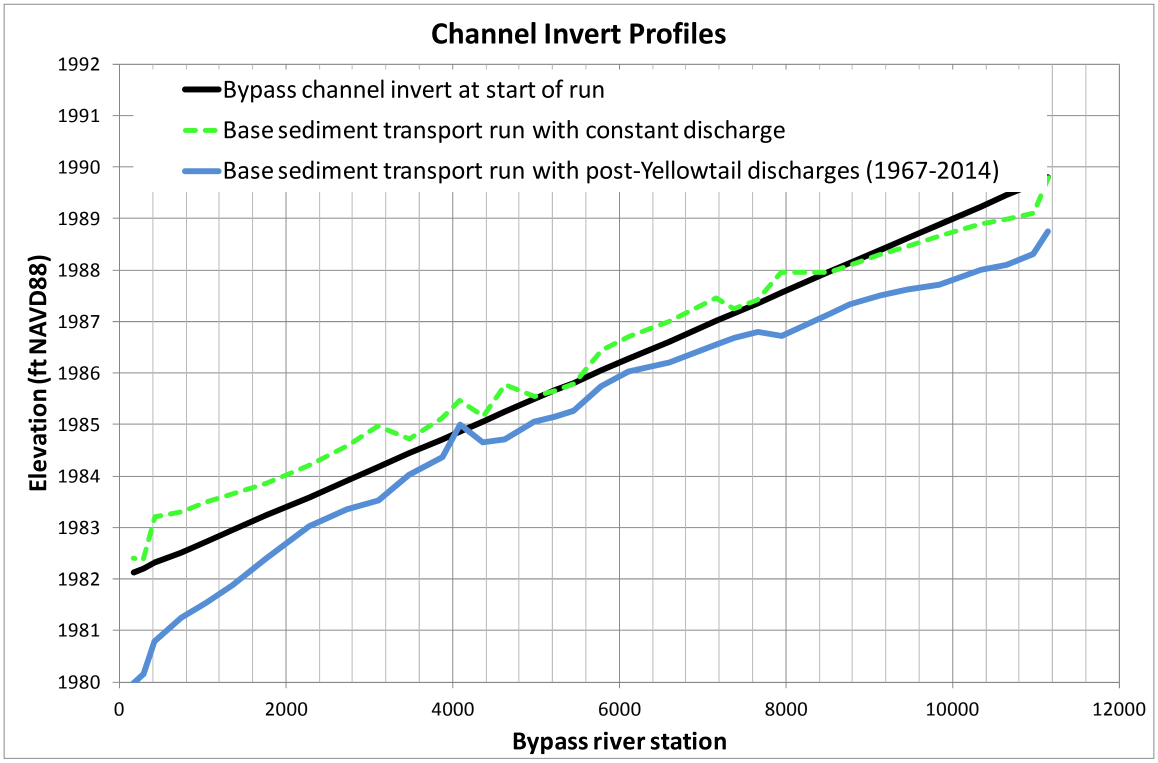


Figure 10 Invert Comparison – Base Runs for May 2014 60% Design Interim Progress Report

4.1.2.2 Sensitivities

Numerous sensitivity runs have been completed for the proposed bypass channel. Sensitivity runs on multiple sediment loading values, incoming gradation, bed gradation, transport functions, sorting methods, discharges and channel slopes were completed for the May 2014 60% design channel. While the sensitivity analysis was completed for the May 60% design cross section, trends and tendencies gleaned from those sensitivity runs are expected to be similar for the currently proposed channel configuration because the May and August designs have similar diversion percentages as well as the same slope and length. The minor adjustments to the cross section shape are not expected to result in significant changes to the model sensitivity results (i.e. invert changes).

In general, the model shows high sensitivity to the incoming gradation, transport function, and incoming load; moderate sensitivity to the bed gradation, discharge, and sorting method; and low to moderate sensitivity to the channel slope.

The model shows particularly high sensitivity to the largest size of the incoming material, especially for certain transport functions. In addition to Laursen (Copeland), Yang, Toffaleti, and Ackers-White were used. When using medium gravel (8-16mm) as the largest incoming material, Yang, Toffaleti, and Ackers-White showed unrealistic aggradation (on the order of 100+ft). However, when the maximum size of incoming material was limited to very coarse sand (1-2mm), bed movement (aggradation or degradation) with the alternative transport functions was in a more reasonable range (several feet maximum). The range of movement is considered more reasonable because the trend (extreme aggradation when medium gravel is included, but relative stability when limited to very coarse sand) was similar with the main channel of the Yellowstone River, indicating that limitations of the various transport functions are the cause rather than actual physical predictions of extreme aggradation (the Yellowstone River is relatively stable in this reach). Both Ackers-White and Toffaleti were developed primarily over sand particles (Ackers-White included some fine gravels). It is unclear why Yang predicts excessive aggradation as it includes two separate relations for sand and gravel transport. Figure 11 shows results from multiple runs using various transport functions and maximum incoming material size.

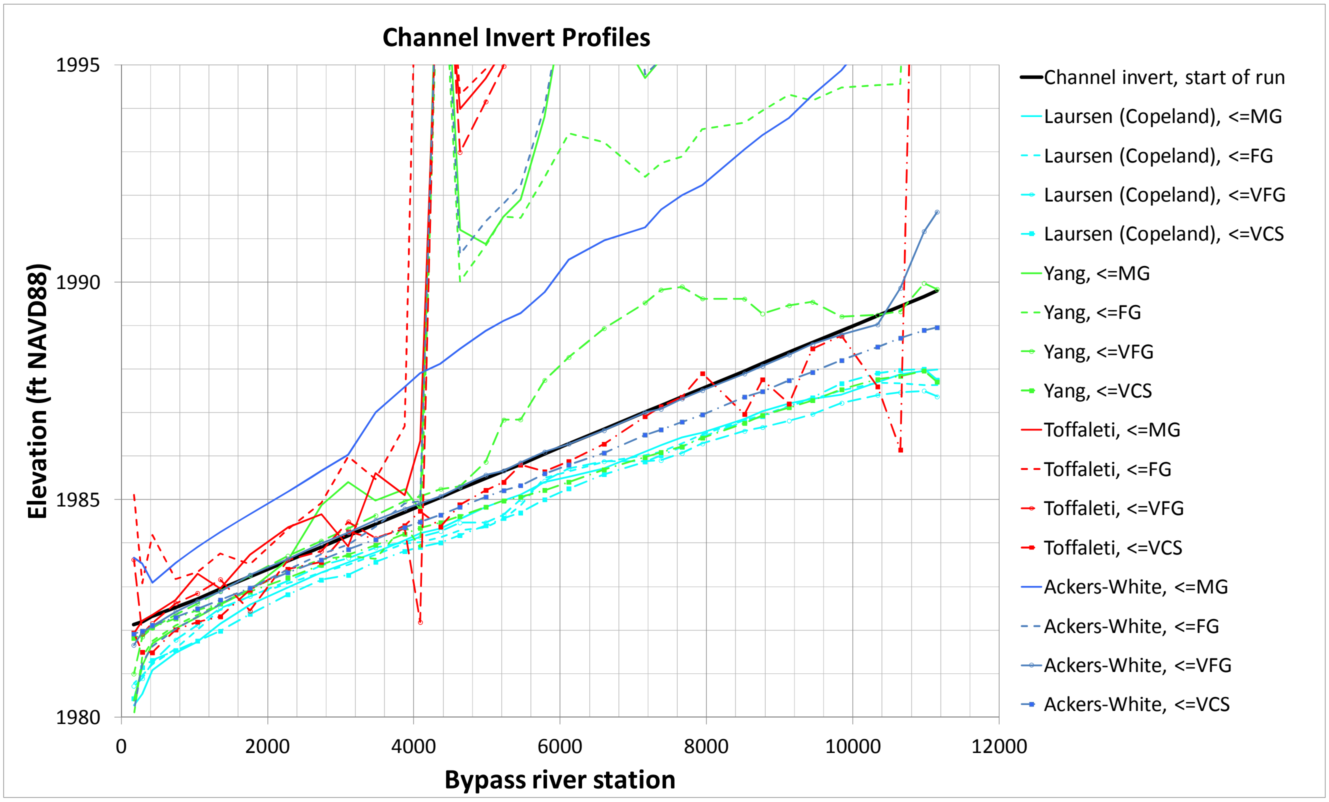


Figure 11 Transport Function and Incoming Gradation Sensitivity (s=0.0007ft/ft)

This figure shows the bypass channel bed invert following modeling the post-Yellowtail Dam daily flow record (47 years, 1967-2014) with a maximum bypass flow limited to 9,000 cfs. For all runs, initial channel slope is 0.0007 ft/ft and bed gradation is the Wohlman count gradation described above. The legend in the figure indicates which transport function was used, along with the maximum material size of the incoming load (i.e. <=MG indicates the maximum size was medium gravel; FG=Fine Gravel, VFG=Very Fine Gravel, and VCS=Very Coarse Sand).

Figure 12 is similar to Figure 11 except all runs used an initial bed slope of 0.0006 ft/ft.

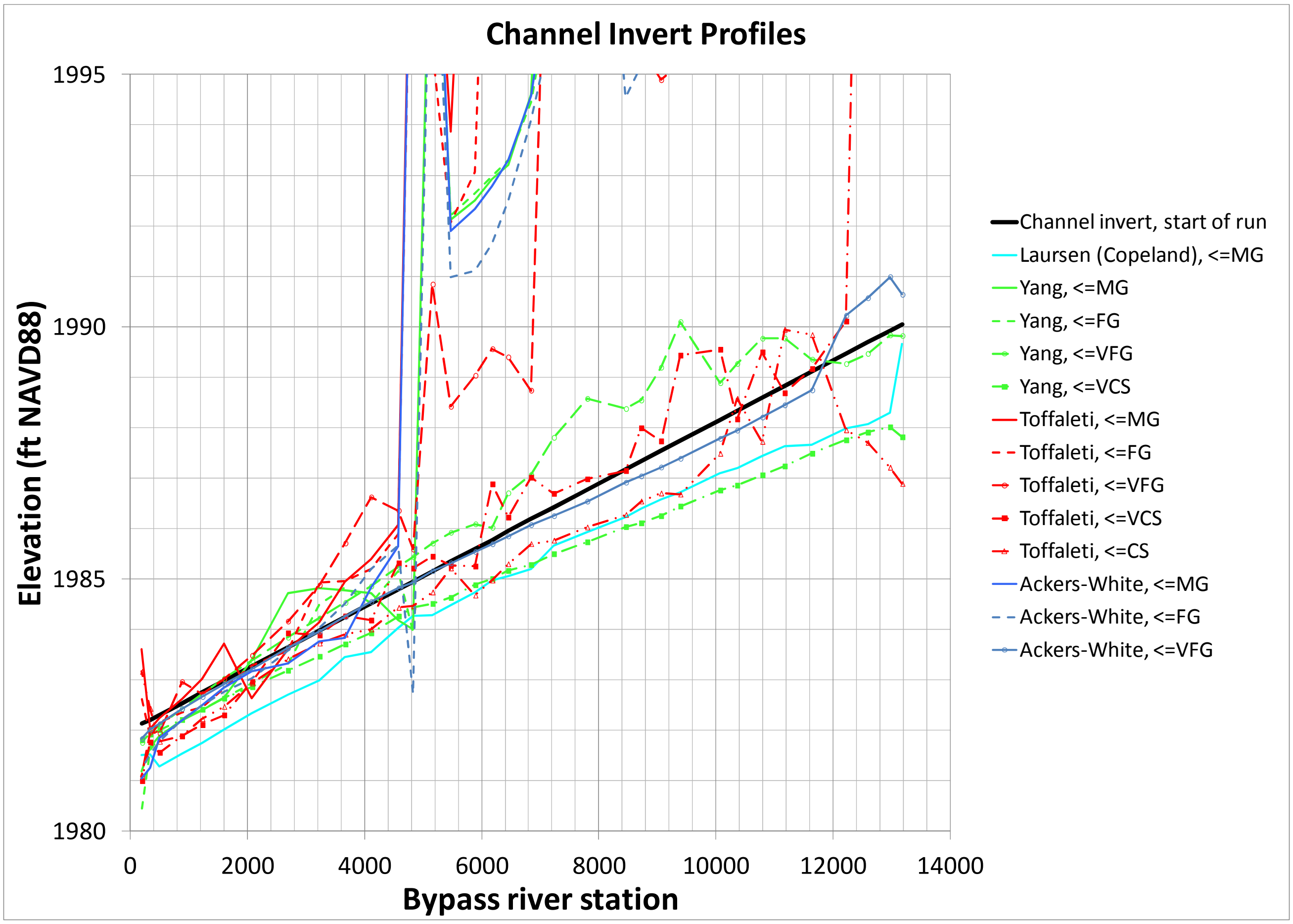


Figure 12 Transport Function and Incoming Gradation Sensitivity (s=0.0006ft/ft)

This figure shows the bypass channel bed invert following the post-Yellowtail Dam flow record (47 years, 1967-2014) limited to a bypass flow of 9,000 cfs. For all runs, initial channel slope is 0.0006 ft/ft and bed gradation is the Wohlman count gradation described above. The legend in the figure indicates which transport function was used, along with the maximum material size of the incoming load (i.e. <=MG indicates the maximum size was medium gravel; FG=Fine Gravel, VFG=Very Fine Gravel, and VCS=Very Coarse Sand).

Figure 13 shows the base runs, described in section 3.1.2.1, for slopes of 0.0006 ft/ft and 0.0007 ft/ft.

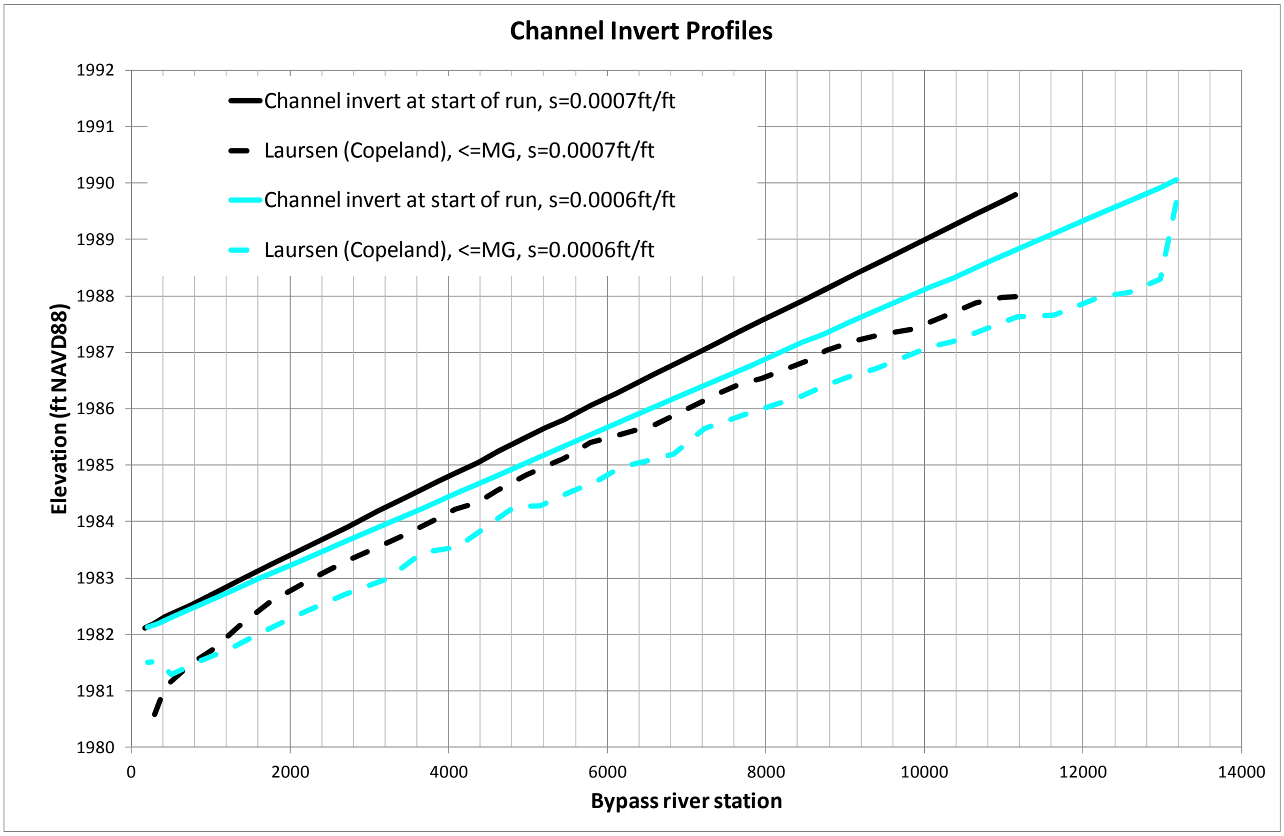


Figure 13 Slope Sensitivity

This figure shows results from base runs for slopes of 0.0006 ft/ft and 0.0007ft/ft. The intent of the figure is to show the low sensitivity to bed slope in this range. Both runs used the post-Yellowtail Dam flow record (47 years, 1967-2014) limited to a maximum bypass flow of 9,000 cfs. The legend in the figure indicates which transport function was used, along with the maximum material size of the incoming load.

4.1.3 HEC-RAS Modeling Summary

Preliminary sediment transport modeling of the proposed bypass channel indicates a slightly degradational tendency, highly dependent on model inputs. To reduce the potential for degradation, a processed armor layer (described below in section 5.5) is proposed. As design progresses from 60% to 100%, response of the model to both the expected natural bed and the processed armor layer will be evaluated.

4.2 ADH Modeling

This section will be completed after further ADH modeling is performed. Modeling completed to date includes a downstream focus model of existing conditions and the 30% design as well as an overall model of existing conditions and the 30% design. Both models showed general agreement with HEC-RAS and physical modeling.

4.3 SRH-2D Modeling

A team from Reclamation's Technical Service Center in Denver, CO, has been modeling the May 60% design bypass channel using SRH-2D. Once completed, their report will be included as an attachment with this section acting as a placeholder for a summary of results.

4.4 Reclamation Physical Model

A 1:16 Froude scale physical model was constructed and evaluated by Reclamation at their hydraulic laboratory in the Technical Service Center in Denver, CO. Initial results confirmed that the higher bypass channel invert at the downstream end provided superior performance. The physical model evaluated both the 30% Design invert (1981ft NAVD88) and a 2 ft raise (1983ft NAVD88). Once completed, Reclamation's report will be included as an attachment.

5. CHANNEL STABILITY FEATURES

Locations of the channel stability features are shown in Figure 1. Two standard riprap gradations (from Table 3-1 of EM 1110-2-1601) are proposed for the various features (not including the processed armor layer). The first gradation, with a $D_{100(max)}$ of 16 inches, is used mainly for bank armoring. The second gradation, with a $D_{100(max)}$ of 27 inches, is used in the vertical control structures as well as the upstream and downstream control structures. For both gradations, a layer thickness of $1.5D_{100(max)}$ is currently recommended to account for uncertainties with placement and ice effects. The two gradations will hereafter be referred to by their $D_{100(max)}$ size.

Sizing of the riprap is based mainly on ice impacts. Average velocities in the bypass channel generally range from 2 to 6 ft/s for all discharges up to the 10-year open water event. From the 10-year to 500-year open water event, velocities are in the 6 to 8 ft/s range. Riprap sized for 8ft/s would have a D_{50} of around 10 inches based on Isbash equations for high turbulence (HDC 712-1) or a D_{100} of around 14 inches.

During 30% design, the USACE Cold Regions Research and Engineering Laboratory (CRREL) provided a review of the project features and provided insight on ice impacts on the bypass channel. The evaluation is included as Attachment 5.

The CRREL evaluation notes that when breakup jams form (as they historically have at many locations between Glendive and Sidney), the wide floodplains and side channels serve as a relief mechanism accepting and storing flow and ice. Under these conditions, the flow area is large and overbank water velocities are relatively low ($\leq$ ~2ft/s by HEC-RAS calculations at 40,000cfs) which turns out to be a mitigation factor in terms of the design of bypass channel structures. Observations of the existing high flow channel following a large ice event in February 2014 support the theory that low velocities limit the impact ice has on overbank features. Attachment 6 is a brief trip report including photos and observations.

The CRREL review included sizing of riprap and comparing the estimated sizes to the proposed sizes. The approach produced riprap designs very similar to the riprap proposed in the 30% design and herein. While the design has changed since 30%, riprap sizing for the various features is relatively generalized. Changes made to the cross section and alignments are expected to have negligible effect on sizing.

Extents and sections of the riprap structures are shown in the project plans. Refer to Figure 1 for the location of stability features.

5.1 Upstream Control Structure

The structure designed to control discharge into the bypass channel would be situated on the upstream end of the channel. The structure would be composed entirely of the 27 inch riprap (a concrete sill was considered during 30% design but eliminated due to concerns with flexibility for future adjustments, if necessary). The control structure would be over excavated to place the 27 inch riprap top of rock at final grade. After placement of the 27 inch layer, the structure would be backfilled with natural river size rock (see processed armor layer section below) to give the appearance of a seamless channel invert. The structure has two main purposes: to control the flow split and to provide stability during extreme events.

5.2 Channel Plug

A channel "plug" would be constructed near the upstream end of the bypass in the existing high flow channel to keep normal flows in the proposed bypass so that maximum attraction flow is available in the constructed bypass channel. The proposed channel plug has a low-level discharge pipe and is designed for overtopping during larger flow (between a 5-10 year event).

The top elevation of the plug is set just above the 5-year water surface elevation. The plug is designed as an overtopping section to allow flow into the existing high flow channel during higher Yellowstone River flows to maintain its flood relief function. The high flow channel currently begins carrying water during a Yellowstone River discharge of approximately 25,000-30,000 cfs. With-project conditions would allow flow into the remaining existing high flow channel at an open-water discharge of approximately 75,000cfs. The same overtopping elevation would be reached with a discharge of approximately 30,000 cfs considering ice-affected conditions. A discharge of 30,000cfs is between a 2-year winter flow (12,300cfs) and 10-year winter flow (43,800cfs) based on Reference 3 (Glendive winter hydrology).

To accommodate overtopping flows, the crest is 15 ft wide and the downstream face of the plug is on a 1V:6H slope with the 27 inch riprap section.

The downstream toe should transition to a horizontal blanket approximately 50 ft long, then should extend on a 1V:3H slope into native ground two layer thicknesses or approximately 7.0 ft.

The upstream face is on a 1V:3H slope and should include riprap toed into existing ground two layer thicknesses (7.0ft).

Design of a low-level outlet pipe to maintain minimal flows in the existing high flow channel is not complete. Consideration for potential fish passage requires input from the BRT.

An alternative channel plug configuration would consist of spoiling much of the excavated material in the upstream mile of the existing high flow channel. The fill in the channel would act as an extended plug and would be graded with a relatively flat slope on the downstream end to allow for a smooth transition to existing ground (and to prevent erosion and headcutting when overtopped).

5.3 Vertical Control Structures

Two buried riprap sections are proposed as shown in Figure 1 with the intention of monitoring vertical movement within the channel and halting the progression of any potential headcuts through the channel.

The sections would be over-excavated. A bedding and 27 inch D_{100} riprap section would be constructed with a top elevation approximately 0.5 to 1 ft below the final invert. Material similar to that composing the processed armor layer would be used to backfill the 27 inch rock and bring the section up to final grade.

5.4 Riprap Bank Protection

Riprap is proposed at four outside bends and in the downstream 1000 ft on the left bank of the bypass to prevent significant lateral movement. Proposed riprap at the bends is the 16 inch D_{100} section, while the downstream section uses the 27 inch D_{100} section.

The section would extend from the channel invert to approximately 15 ft above the invert (approximate 10yr depth). The section includes a weighted toe along the invert to provide protection for future scour along the bank. The area of the weighted toe is 1.5 times the area required to extend the 24 inch layer on a 1V:3H slope down two layer thicknesses (4 ft). (Note- the area was multiplied by 1.5 to account for self-launching of the weighted toe).

Design guidance is generally lacking in the area of upstream and downstream extents. Engineer Manual (EM) 1110-2-1601 suggests that the downstream end of protection should depend on where the flow crosses to the opposite bank for a natural channel. Model tests referenced in EM 1110-2-1601 indicate that the downstream end of the revetment should be about 1.5 channel widths downstream of the end of the bend. This recommendation is based on a relatively constant cross section, and may not fully apply to a variable cross section; however, absent additional design guidance, the recommendation is taken into consideration.

Using an estimated channel width of approximately 200 ft, the downstream end of the riprap protection should extend 300 ft downstream of the end of the bend. At the four bends that include protection, riprap on the upstream and downstream armored bends extends over 300 ft downstream of the end of the bend. The middle two bends do not extend past the downstream end of the bend. Some movement is allowable (and likely desirable) in the middle section of the bypass channel.

The upstream end of the riprap should extend past the upstream end of the bend and key into the bank approximately 50ft to reduce the chance of flanking.

5.5 Processed Armor Layer

Preliminary sediment transport modeling of the proposed bypass channel indicates a slightly degradational tendency, highly dependent on model inputs. The proposed armor layer would be similar to naturally formed armor layers found in the Yellowstone River on bars and would represent what would be expected were the newly excavated channel be allowed to form the layer naturally.

The intent of the armor layer would be to prevent degradation immediately following construction of the project. Excessive channel adjustment from proposed final grades could possibly lead to poor fish passage performance as well as diverting too much water into the bypass with possible impacts to irrigation diversion operation and maintenance.

The alternative to constructing an artificial armor layer is to under-excavate the channel and allow the armor layer to develop over time. Risks associated with this method include the potential for too little or not enough degradation prior to attaining a stable armor layer. In addition, bypass flow split would likely be less than desired during this adjustment period.

The armor layer gradation would be similar to available measured data from 2008 Yellowstone River bar samples in the vicinity of Intake Dam. Material greater than approximately 1-inch diameter would be screened during excavation and replaced in the channel bottom. The armor layer would be continuous from upstream to downstream (i.e. the vertical control structures would be covered with the armor layer so as to minimize flow discontinuities). Appendix A, Attachment 5 of the 30% DDR includes additional details on the armor layer.

Uncertainties in the quantity and size of material from the bypass channel excavation available for processing do not allow for definition of a specific gradation. It is assumed that material greater than approximately one inch will be retained and used in the processed armor layer. If material similar in size to the proposed gradation (shown in Figure 9 as the Wolman count gradation) is not available in sufficient quantities, consideration should be given to an increased layer thickness and/or importing additional quantities. Additional subsurface sampling has been requested by geotechnical personnel in order to evaluate the quantity and size of available material along the proposed bypass alignment.

The proposed processed armor layer consists of a 9 inch layer thickness approximately 90ft wide installed across the entire length of the bypass channel.

5.6 Downstream Control Structure

The downstream vertical control structure is configured similar to the vertical control structures described above in section 4.3.

Lateral stability of the downstream end requires revetments on both banks. The left bank revetment, constructed using the 27 inch riprap, is intended to prevent lateral movement of the bypass towards the main channel and ultimately flanking of the Intake Dam into the bypass channel.

The right bank revetment is located downstream of the vertical control structure and is constructed using the 16 inch riprap. The right bank revetment has two functions: to provide a smooth transition from the main channel of the Yellowstone River into the bypass channel and to prevent the downstream end of the bypass channel from migrating eastward (downstream).

5.7 Summary

Table 4 provides a summary of all riprap structures. See Figure 1 for stationing and locations.

Table 4 Riprap Summary

STRUCTURE NUMBER	BEGINNING STATION	ENDING STATION	DESCRIPTION	LENGTH (FT)	AREA (FT^2)	D_{100} (IN)	LAYER THICKNESS (FT)	MASS (TONS)
1	80	325	D/S Entrance RB bank protection	245	2500	16	2	336
2	325	480	D/S Grade Control R Abutment	155	10500	16	2	1,412
3	325	480	D/S Grade Control L Abutment	155	2500	27	3.375	567
4	385	447.25	D/S Grade Control Vertical Control	62.25	9500	27	3.375	2,155
5	480	1340	LB Revetment/Overflow Protection	860	70000	27	3.375	15,881
6	1340	2240	LB Revetment/Bend Migration Prevention	900	44500	16	2	5,983
7	3110	3630	LB Revetment/Bend Migration Prevention	520	22000	16	2	2,958
8	4060	4214	Vertical Movement Indicator #1 R Abutment	154	10000	16	2	1,344
9	4060	4214	Vertical Movement Indicator #1 L Abutment	154	10000	16	2	1,344
10	4120	4160	Vertical Movement Indicator #1 Sill	40	2500	27	3.375	567
11	5030	5620	RB Revetment/Bend Migration Prevention	590	27000	16	2	3,630
12	6250	6405	Vertical Movement Indicator #2 R Abutment	155	10000	16	2	1,344
13	6250	6405	Vertical Movement Indicator #2 L Abutment	155	10000	16	2	1,344
14	6310	6350	Vertical Movement Indicator #2 Sill	40	2500	27	3.375	567
15	6405	7610	RB Revetment/Bend Migration Prevention	1205	57000	16	2	7,663
16	10490	10750	U/S Grade Control L Abutment	260	18000	27	3.375	4,084
17	10490	11155	U/S Grade Control R Abutment	665	44500	27	3.375	10,096
18	11155	-	RB Yellowstone Revetment/Bend	1300	31000	27	3.375	7,033
19	-	-	RB Yellowstone Refusal	450	225	27	15'x10'	6,188
							TOTAL	**75,000**

6. WEIR

The proposed weir concept has been changed from a gravity structure to a deep foundation (see Structural Appendix). The deep foundation allows for a narrower crest which is preferable for fish passage. At this time, the 30% design weir crest geometry has not been changed with an elevation of 1990.5 ft NAVD88 and a length of approximately 700ft.

The 30% design weir crest uses a constant elevation that is adequate for providing irrigation diversion. During the 60% design, varying the weir crest elevation was identified as a method to improve sediment transport and fish passage characteristics of the weir diversion structure. Cursory evaluation of crest notches has been completed to evaluate various notch width and depth configurations in conjunction with raising the remainder of the weir to maintain diversion head (see Attachment 1). Additional two-dimensional modeling is required as design progresses from 60% to final to evaluate notch hydraulics with respect to sediment transport and both upstream and downstream fish passage. The proposed weir described in the Structural Appendix does not include a notch, but the concept is adaptable considering a maximum notch depth of approximately 3 ft with the remainder of the weir raised approximately 0.5 ft. Further discussion pertaining to the proposed new weir crest is not included herein.

7. FUTURE WORK

The following items are expected to be completed as the design moves from 60% to 100% completion:

- Selection of final bypass channel cross-section based on changes to hydraulic models due to additional calibration data collected in June of 2014. It is not anticipated that the final section will increase project quantities as currently defined.
- Additional field test pits will be collected to provide existing bed material size along the bypass channel alignment.
- Additional HEC-RAS sediment modeling is to be conducted on the proposed natural channel. The proposed natural channel includes variable cross sections (width and depth) and is described in detail in Attachment 2. The natural channel design is based mainly on "*Channel Restoration Design for Meandering Rivers*" (USACE, ERDC/CHL CR-01-1, 2001).
- Additional ADH modeling (focus models) of upstream and downstream ends (hydraulics only).
- ADH modeling (hydraulics and sediment) of entire bypass channel using the proposed natural channel.
- SRH-2D modeling (hydraulics and sediment) of main channel and entire bypass channel using the proposed natural channel from Attachment 2 (performed by Reclamation).
- Evaluation of channel stability features.
- Evaluation of new weir and associated notch configuration to optimize sediment transport and fish passage.

8. SUMMARY

This document updates the 30% DDR Hydraulics Appendix. The document describes the 60% design with notable changes to the bypass channel design since the 30% DDR was completed. Changes to the cross section shape, upstream and downstream inverts, channel slope, entrance and exit angles, channel length, and channel alignment have been evaluated and are summarized in Table 2. The changes were necessary to meet biological design criteria as well as for long term stability of the bypass channel. Design analysis will continue during progression from 60% to final design that may result in additional modifications to the current design.

9. REFERENCES

1. **USACE, 2012.** "Intake Diversion Dam Modification, Lower Yellowstone Project, Montana, Bypass Channel Design Documentation Report, 30% Design".

2. **USACE, 1994.** EM 1110-2-1601 "Hydraulic Design of Flood Control Channels."

3. **USACE, 2008.** "Glendive, Montana Winter Flow Frequency Update".

4. **USACE, 2001.** ERDC/CHL CR-01-1, "Channel Restoration Design for Meandering Rivers." Philip J. Soar and Colin R. Thorne.

5. **USGS, 2013.** "Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928-2002."

6. **USACE, 2001.** ERDC/CHL TR-01-28, "Hydraulic Design of Stream Restoration Projects." Copeland, Ronald et al.

Intake Diversion Dam Modification

Lower Yellowstone Project, Montana

Bypass Channel 60% Design – August 2014

Hydraulics Appendix

ATTACHMENT 1

U.S. FISH AND WILDLIFE SERVICE GUIDANCE

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Mountain-Prairie Region

IN REPLY REFER TO:
FWS/R6/ES

MAILING ADDRESS:
P.O. BOX 25486, DFC
Denver, Colorado 80225-0486

STREET LOCATION:
134 Union Boulevard
Lakewood, Colorado 80228-1807

MAR 19 2014

David Ponganis
Director, Programs
U.S. Army Corps of Engineers, Northwestern Division
PO Box 2870
Portland, Oregon 97208-2870

Dear Mr. Ponganis:

The U.S. Fish and Wildlife Service (Service), in conjunction with the Lower Yellowstone Intake Project (Intake) Biological Review Team (BRT), has been working closely with the U.S. Army Corps of Engineers (Corps) to define performance objectives and subsequent design criteria for the Intake bypass channel. This letter serves to formally revise portions of the Reasonable and Prudent Alternative (RPA) in the 2003 amended Biological Opinion (BiOp) to the Corps. By this letter I am formally conferring the hydraulic and physical conditions the Service believes will maximize the probability of successful passage of pallid sturgeon at the Intake Dam and Irrigation Headworks Project on the Yellowstone River, Montana. As stated in my letter to you dated February 6, 2013, with the construction and successful performance of the project to these hydraulic and physical conditions, the Corps will achieve its responsibility under the Flow Enhancement below Fort Peck Dam – Intake Montana River Restoration BiOp RPA element.

Bypass Channel Hydraulic and Physical Performance Objectives

> The following, unless subsequently modified based on new data, apply to conditions as measured at the United States Geological Survey (USGS) stream gauge at Sidney, Montana, regardless of date, over the discharge ranges specified. In order to maximize the probability of success, two sets of design criteria are recommended below; one set applies to discharges less than 15,000 ft^3/s and one set applies to discharges equal or greater than 15,000 ft^3/s (see also Table 1).
>
> **Bypass Channel Flow Split:**
> The flow split, or proportion of Yellowstone River discharge the Bypass Channel is designed to convey will influence many aspects of the Bypass Channel design and overall scale. Given the variability of the unregulated flows in the Yellowstone River, we recognize that the flow split will vary with river discharge.

As such, the general flow split percentage target for the Bypass Channel design should be 15% with final design attaining at least 12% over the discharge range of 7,000 to 14,999 ft^3/s (198– 424 m^3/s) and 13% to ≥ 15% over the discharge range of 15,000 to 63,000 ft3/s (424– 1784 m3/s).

Bypass Channel Cross-sectional velocities:
Mean bypass channel cross-sectional velocities at all sampled cross-sections must be equal or greater than 2.0 feet per second (ft/s) or 0.61 meters per second (m/s), but less than or equal to 6.0 ft/s (1.8 m/s) over the discharge range of 7,000 to 14,999 ft^3/s (198– 424 m^3/s).

Mean bypass channel cross-sectional velocities (measured as mean column velocities) at all sampled cross-sections must be equal or greater than 2.4 ft/s (0.73 m/s), but less than or equal to 6.0 ft/s (1.8 m/s) over the discharge range of 15,000 to 63,000 ft^3/s (424– 1784 m^3/s). The proportion of the channel exceeding maximum velocities should be minimized to the extent possible. Channel characteristics that maintain variability of flow within or on the margins of the Bypass Channel, without introducing significant turbulence are highly valued.

Bypass Channel Cross-sectional depths:
Minimum cross-sectional depths measured at the lower discharge range of 7,000 to 14,999 ft^3/s (198– 424 m^3/s) at any sampled cross-section must be greater than or equal to 4.0 feet (1.2 m) across 30 contiguous feet of the measured channel cross sectional profile. Minimum cross-sectional depth over the discharge range of 15,000 to 63,000 ft^3/s (424– 1784 m^3/s) at any sampled cross-section must be greater than or equal to 6.0 feet (1.8 m) across 30 contiguous feet of the measured channel cross sectional profile. Adult Pallid Sturgeon typically use depths greater than 1 meter throughout their range. Although adult sturgeon have occasionally been observed shallower, depths greater than 1 meter will reduce the likelihood that significant numbers of adult Pallid Sturgeon may fail to pass through the Bypass Channel.

Bypass Channel Fish Entrance and Exit:
The downstream entrance to the Bypass Channel (i.e., HEC-RAS station 136) is critical to the performance of the structure. Significant efforts remain to adequately characterize suitable conditions at the downstream and upstream openings. To provide sufficient attractant flows, the downstream fish entrance should have a mean cross sectional velocity of greater than or equal to 2.0 ft/s (0.61 m/s) (measured as mean column velocity) through the lower discharge range of 7,000 to 14,999 ft^3/s (198– 424 m^3/s) and mean cross sectional velocity greater than or equal to 2.4 ft/s (0.91 m/s) (measured as mean column velocity) through the range of discharge of 15,000 to 63,000 ft^3/s (424– 1784 m^3/s). Mean cross sectional velocities (measured as mean column velocity) at both the upstream and downstream Channel Bypass openings should be less than or equal to 6.0 ft/s (1.8 m/s) for river discharges ranging from 7,000 – 63,000 ft^3/s (198 – 1784 m^3/s) .

The proportion of the channel exceeding maximum velocities should be minimized to the extent possible.

Characteristics that maintain variability of flow within or on the margins of the Bypass Channel openings, without introducing significant turbulence are highly valued.

Table 1: Tabular Summary of design criteria

Discharge at Sidney, Montana USGS Gauge	7,000 -14,999 ft^3/s	15,000-63,000 ft^3/s
Bypass Channel Flow Split	≥ 12%	13% to ≥ 15%
Bypass Channel cross-sectional velocities (measured as mean column velocity)	2.0 – 6.0 ft/s	2.4 – 6.0 ft/s
Bypass Channel Depth (minimum cross-sectional depth for 30 contiguous feet at measured cross-section)	≥ 4.0 ft	≥ 6.0 ft
Bypass Channel Fish Entrance (measured as mean column velocity at HEC-RAS station 136)	2.0 – 6.0 ft/s	2.4 – 6.0 ft/s
Bypass Channel Fish Exit (measured as mean column velocity)	≤ 6.0 ft/s	≤ 6.0 ft/s

As you are aware, inevitable uncertainties remain that are inherent in both the hydraulic modeling upon which the project design is based and the monitoring and measurement needed to verify that the constructed bypass channel meets the hydraulic and physical conditions stated above. The Service requests that the Corps in coordination with the Service and the U.S. Bureau of Reclamation (BOR) develop the monitoring and measurement plan that will be used to verify that the completed project meets the hydraulic and physical conditions. As you are aware, the conditions on the river have inherent variability that is difficult to predict. This plan should account for this variability and be completed prior to completion of the construction phase of the project.

The Service further requests that the BRT remain involved throughout the remaining project design in order to provide recommendations on how the Corps can best meet the projects objectives and to keep the Corps apprised of the evolving science related to Pallid Sturgeon use of side channels as it relates to potential bypass channel design improvements.

It is my anticipation that the Service will continue to work closely with the Corps during the post-construction warranty period as you verify the bypass channel performance. We think that our continued involvement will be beneficial in helping to achieve pallid sturgeon passage, and would provide valuable lessons learned as we work with the BOR to develop a monitoring and adaptive management plan to ensure the long-term performance of the bypass channel.

As we have discussed previously, this project represents the most biologically superior project in the upper Missouri River Basin for the recovery of the Pallid Sturgeon. I appreciate your commitment to this effort to date and look forward to completing design and construction of the remaining features for a successful fish bypass project.

Sincerely,

Noreen E. Walsh

Regional Director

Intake Diversion Dam Modification

Lower Yellowstone Project, Montana

Bypass Channel 60% Design – August 2014

Hydraulics Appendix

ATTACHMENT 3

BYPASS CHANNEL GEOMETRY-SUMMARY OF EVALUATION

NOTE – This evaluation was originally completed as a standalone document. References to "Attachment 1" throughout this document refer to the Reference Reach Comparison that follows, NOT to Attachment 1 of this DDR Appendix. Additionally, references to the DDR in this attachment are referring to the 30% DDR and the cross section used is the 30% design cross section. However, the method used as well as the comparison to reaches in the vicinity are still applicable.

Lower Yellowstone Modification Project
Intake

Bypass Channel Geometry
Summary of Evaluation

U.S. Army Corps of Engineers
Omaha District
Original DRAFT DEC2013
Updated 6MAY2014 with proposed 60% alignment

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1. PURPOSE

The purpose of this document is to describe the evaluation of geometry of the proposed bypass channel.

2. BACKGROUND

A bypass channel has been proposed at the Lower Yellowstone Irrigation Project (Intake) for fish passage. The proposed bypass channel is described in detail in the 2013 EA Addendum as well as in the 30% Design Documentation Report (DDR). The intent of this document is to describe the evaluation of the bypass channel geometry in more detail than reported in the EA or DDR.

During progression from 30% to 60% design, a modification to the bypass channel is being considered to eliminate concerns with low velocities (less than 2ft/s) at the downstream end of the bypass during low flows (7000-11,000cfs). The modification consists of a revised cross section shape, raised downstream invert (1ft), lowered upstream invert (0.5ft), increased invert slope (from 0.0006 ft/ft to 0.0007 ft/ft) and shortened channel length (15,500ft to 11,150ft).

3. COMPARISONS

As described in the DDR (Appendix A, Attachment 4), eleven reference reaches were evaluated using primarily GIS techniques to determine various geometric parameters (length, width, sinuosity, etc.) of similar and nearby side channels. The previous analysis did not evaluate individual bends within each of the side channels. The only selection criterion for the reference reaches was proximity to Intake.

Another set of nine side channels was provided to the design team by the Biological Review Team (BRT) for evaluation of fishway entrance angles (downstream end). The side channels provided by the BRT were selected because of known pallid sturgeon usage.

For clarity, the reaches from the DDR are referred to as the Reference Reaches, while the reaches provided by the BRT are referred to as the Side Channels (even though reaches from both sets are similar). A total of 19 reaches were evaluated (eleven Reference Reaches and nine Side Channels, but one reach was included in both sets).

Attachment 1 shows the information presented in the DDR with the addition of an evaluation of the Side Channel entrance/exit angles and the bends within both sets of reaches.

General conclusions from the comparisons include:

- The geometry of natural side channels on the Yellowstone River near Intake varies greatly
- The geometry of the proposed bypass channel falls within the range of all parameters evaluated, including length, width, sinuosity, bend radius, and meander wavelength.

4. REACH AVERAGE DIMENSIONS AND LAYOUT

4.1 Channel-Forming Discharge

For purposes of this analysis, the 0.5 annual chance of exceedance (ACE) flow (2-year) will be considered the channel-forming discharge (USACE 2001).

Several analyses were considered in selecting the 0.5 ACE discharge. Hydrologic studies have been completed by USACE for the Intake project as well as for the Yellowstone Corridor Study. In 2013, the USGS completed a hydrologic analysis of streamflow statistics for the Yellowstone River considering water years 1928-2002 (USGS 2013). Computed discharges are given in Table 1.

Table 1. Computed Discharges

Percent Chance Exceedance	Return Period (yrs)	Discharges (cfs) for various scenarios. Recommended values are Annual Post Yellowtail Dam; seasonal values used in evaluation of various construction timelines to lower risk. Study was conducted using data through 2005.						2013 USGS Study **	
		Seasonal: Aug-Feb	Seasonal: Aug-Mar	Annual (period of record)	**Annual-Post Yellowtail Dam**	Winter (1Jan-15Apr) Post Yellowtail Bulletin 17b	Winter (1Jan-15Apr) Post Yellowtail Top Half	Unregulated	Regulated
0.2	500	128,507	192,400*	192,400	**114000**	249000	213000	174800	156200
0.5	200	96,637	172,300*	172,300	**105000**			157600	140200
1	100	77,223	148,907	156,900	**97200**	128000	123000	144900	128300
2	50	61,117	114,710	141,400	**89400**	94600	94100	132300	116200
5	20	43,967	78,968	120,600	**78700**	61500	62800		
10	10	33,515	57,696	104,200	**70100**	43100	43800	103000	87600
20	5	24,764	40,334	86,900	**60600**			89800	74400
50	2	14,982	21,709	60,400	**45300**	14900	12300	69600	54200
80	1.25	9,961	12,688	41,200	**33300**				
90	1.11	8,334	9,886	33,400	**28200**				
95	1.05	7,314	8,171	28,000	**24500**				
99	1.01	5,949	5,925	19,800	**18600**				

* Discharges reduced to not exceed annual discharges

** "Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928-2002" (USGS)

The 0.5 ACE discharge ranges from 45,300cfs to 69,600cfs. A value of 50,000 cfs (1420m^3/s=cms) is used herein, approximately the average of the USACE and USGS regulated values (45,300cfs and 54,200cfs, respectively).

Using 50,000cfs for the Yellowstone River discharge results in a flow split through the proposed bypass channel of between 5200cfs and 7500cfs (range based on sensitivity analyses). A value of 6500cfs (180cms) is used for the proposed bypass channel.

4.2 Bankfull Width

Chapter 5 of Reference 1 provides a number of width-discharge relationship equations for evaluating bankfull width based on bankfull discharge. The relationships are broken out into sand bed and gravel bed streams. The sand bed streams are further broken out by a typing system based on bank vegetation density. The equations generally follow a power relationship, $W=aQ^b$, where W=width, Q=discharge, a=discharge coefficient, and b=discharge exponent.

The bed material of the proposed bypass is expected to be composed of a sandy matrix with gravels and cobbles included. An armor layer composed of material screened from the excavation with a diameter greater than about one inch is proposed in the 60% design to prevent excessive initial degradation. The proposed armor layer is similar to natural bed material in adjacent reaches of the Yellowstone River and would be expected to develop naturally if not placed during construction.

The degree of vegetation on the banks of the proposed bypass channel will initially be minimal, but will likely increase over time.

The full range of relationships was evaluated and is compared in Table 2. The bold rows in Table 2 indicate relationships that were developed using datasets from sites that are not geographically remote from Intake. See Reference 1 for a full description of data used to develop the relationships.

Reference 1 also provides design equations for channel width incorporating natural variability. The equations are presented as both a best-fit power function and a linear function. Table 3 compares all of the equations presented. Assuming a gravel bed and banks with thin vegetation, the estimated bankfull width is approximately 180-190 ft, similar to the proposed bypass channel.

Table 2. Bankfull Width – Comparison of Relationships

Width-Discharge Relationships in Sand-bed and Gravel-bed Rivers

(from Reference 1)

Type	Data Source	a	b	W (m)	W (ft)
Sand Bed	**Simons and Bender**	**4.02**	**0.54**	**66**	**218**
	Schumm - Aus	11.01	0.31	55	181
	Schumm - USA	**1.85**	**0.84**	**145**	**476**
	Chitale	**15.58**	**0.36**	**101**	**331**
	Kellerhalls et al.	**15.96**	**0.23**	**53**	**173**
	Annable	4.81	0.4	38	126
	Composite	4.13	0.55	72	236
	Type T1 (<50% tree cover on banks)	4.88	0.51	69	226
	Type T2 (≥50% tree cover on banks)	3.27	0.5	44	144
	All sand bed sites	3.76	0.52	56	184
	Osterkamp and Hedman, type v	2.14	0.58	43	143
Gravel Bed	Wolman	5.68	0.36	37	121
	Nixon	1.59	0.64	44	145
	Emmett (1972)	2.97	0.57	57	188
	Kellerhalls et al.	5.47	0.49	70	229
	Emmett (1975)	**3.34**	**0.49**	**43**	**140**
	Charton et al.	4.32	0.4	34	113
	Williams	**3.55**	**0.53**	**56**	**183**
	Griffiths	2.1	0.64	58	191
	Andrews	**3.71**	**0.52**	**55**	**181**
	Hey and Thorne	3.67	0.45	38	125
	Annable	2.45	0.66	75	248
	Osterkamp and Hedman, type vi	1.3	0.64	36	118
	Osterkamp and Hedman, type vii	1.63	0.6	37	121
	Osterkamp and Hedman, type d	1.41	0.63	37	122

Maximum:	476
Average:	186
Minimum:	113

Proposed bypass:	≈180

Table 3 Bankfull Width – Comparison of Design Equations

Design Equations for Channel Width Incorporating Natural Variability (from Reference 1)

	Bed	Bank	Source	F	a	b	W (m)	W (ft)
Best-fit power function of bankfull discharge	S	all	USA	1.051	3.76	0.52	59	193
	S	E_1	USA	1.026	4.88	0.51	71	232
	S	R_1	USA	1.023	3.27	0.5	45	147
	G	all	USA	1.054	3.39	0.53	56	184
	G	E_2	USA	1.013	4.18	0.5	57	186
	G	R_2	USA	1.004	3.88	0.46	42	139
	G	all	UK	1.033	3.52	0.46	40	130
	G	E_3	UK	1.014	4.25	0.46	47	154
	G	R_3	UK	1.009	2.00	0.55	35	115
	G	E_4	UK	1.014	4.25	0.46	47	154
	G	R_4	UK	1.009	1.85	0.57	36	118
Linear function of square root of bankfull discharge	S	all	USA	1.050	4.24	0.5	60	196
	S	E_1	USA	1.026	5.19	0.5	71	234
	S	R_1	USA	1.022	3.31	0.5	45	149
	G	all	USA	1.054	3.68	0.5	52	171
	G	E_2	USA	1.011	4.12	0.5	56	183
	G	R_2	USA	1.003	3.66	0.5	49	162
	G	all	UK	1.033	2.99	0.5	41	136
	G	E_3	UK	1.015	3.70	0.5	50	165
	G	R_3	UK	1.010	2.46	0.5	33	109
	G	E_4	UK	1.014	3.69	0.5	50	165
	G	R_4	UK	1.010	2.45	0.5	33	109

Maximum:	234
Average:	161
Minimum:	109

Proposed bypass:	≈180

Note: G=gravel, S=sand, E_1=<50% tree cover, R_1=≥50% tree cover, E_2='thin' vegetation, R_2='thick' vegetation, E_3=<5% tree/shrub cover or 'grass-lined' banks, R_3=≥5% tree/shrub cover or 'tree-lined' banks, E_4=<5% tree/shrub cover, R_4=≥5% tree/shrub cover.

4.3 Bankfull Depth

Bankfull depth, slope, and sinuosity are discussed in Chapter 6 of Reference 1. Chapter 6 discusses analytical channel design, but essentially defers to Copeland's approach as modeled in SAM (Stable channel Analytical Method) which is now incorporated into the HEC-RAS Hydraulic Design Module.

The Copeland method uses a trapezoidal channel; the proposed bypass channel shape is approximated using a bottom width of 60ft and side slopes of 5H:1V as shown in Figure 1.

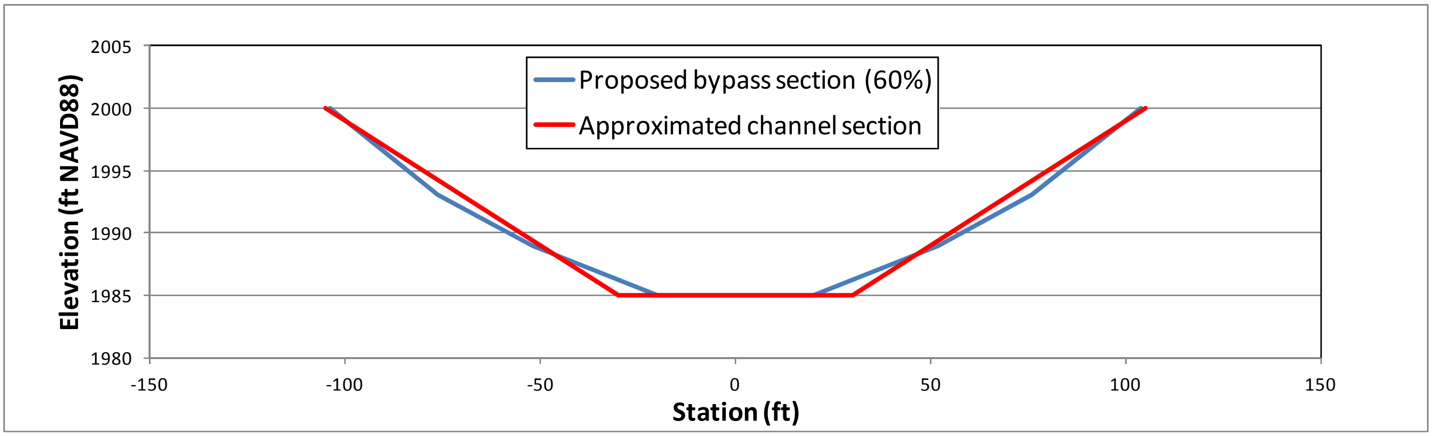


Figure 1 Proposed vs. Approximated Channel for Stable Channel Analysis

The Copeland method is applicable to sand beds only; the bed material of the bypass channel is expected to be sandy with gravel and potentially some cobbles. Because of the uncertainty associated with the bed material of the proposed bypass channel, a range of analyses were conducted to evaluate the sensitivity of a stable channel to incoming load concentration as well as bed material gradation.

Using a discharge of 6500cfs, stable channel dimensions as shown in Table 4 were computed. Results shown in Table 4 indicate that for a bottom width of 60ft and 5H:1V side slopes (approximate shape of complex proposed bypass cross section), a bankfull depth range of 8-14ft is computed, with a depth of approximately 10-12ft when using the best estimate of proposed parameters. Computations indicate the proposed bypass channel will have an average depth in the thalweg at the channel-forming discharge of approximately 11ft.

Table 4 Stable Channel Dimensions

Trial	INPUT						*OUTPUT*			
	Discharge	Inflow sediment concentration		Side Slopes	Roughness	Bed Material Gradation*	*Bottom Width*	*Depth*	*Energy Slope*	*Velocity*
	(cfs)	(ppm)	Source	(_H:1V)	(Manning's n)		*(ft)*	*(ft)*	*(ft/ft)*	*(ft/s)*
1	6500	**300**	Approximate minimum suspended sediment concentration during 2011 USGS point sampling effort during flows of 46,000-50,000cfs	5	0.027	Fine	50	14.3	0.0003	3.7
							60	13.9	0.0002	3.6
							70	13.4	0.0002	3.5
2	6500			5	0.03	Medium	50	13.77	0.0004	4.0
							60	13.36	0.0004	3.8
							70	12.93	0.0004	3.7
3	6500			5	0.033	Coarse	50	12.9	0.0007	4.4
							60	12.6	0.0007	4.2
							70	12.2	0.0006	4.1
4	6500	**415**	Average suspended sediment concentration during 2011 USGS point sampling effort during flows of 46,000-50,000cfs	5	0.027	Fine	50	13.7	0.0003	4.0
							60	13.27	0.0003	3.9
							70	12.84	0.0003	3.8
5	6500			5	0.03	Medium	50	13.2	0.0005	4.3
							60	12.8	0.0005	4.1
							70	12.4	0.0004	4.0
6	6500			5	0.033	Coarse	50	12.4	0.0009	4.7
							60	12.0	0.0009	4.5
							70	11.6	0.0008	4.4
7	6500	**700**	Approximate maximum suspended sediment concentration during 2011 USGS point sampling effort during flows of 46,000-50,000cfs	5	0.027	Fine	50	12.9	0.0003	4.4
							60	12.4	0.0005	4.3
							70	12.0	0.0004	4.2
8	6500			5	0.03	Medium	50	12.3	0.0007	4.7
							60	11.9	0.0006	4.6
							70	11.5	0.0006	4.5
9	6500			5	0.033	Coarse	50	11.5	0.0012	5.2
							60	11.1	0.0011	5.0
							70	10.8	0.0011	4.9
10	6500	**1800**	Median of Sidney gage data	5	0.027	Fine	50	11.3	0.0005	5.4
							60	10.7	0.0005	5.3
							70	10.3	0.0005	5.2
11	6500			5	0.03	Medium	50	10.7	0.0008	5.8
							60	10.2	0.0007	5.7
							70	9.8	0.0007	5.6
12	6500			5	0.033	Coarse	50	10.0	0.0014	6.6
							60	9.5	0.0013	6.4
							70	9.0	0.0012	6.3
13	6500	**7700**	Upper end of Sidney gage data	5	0.027	Fine	50	9.0	0.0013	7.6
							60	8.5	0.0012	7.4
							70	8.1	0.0011	7.3
14	6500			5	0.03	Medium	50	8.6	0.0019	8.2
							60	8.1	0.0018	8.0
							70	7.6	0.0017	7.9
15	6500			5	0.033	Coarse	50	7.9	0.0034	9.2
							60	7.5	0.0032	9.0
							70	7.0	0.0030	8.8

* Fine: D_{84}=0.3mm, D_{50}=0.1mm, D_{16}=0.05mm; Medium: D84=1.5mm, D50=0.2mm, D16=0.09mm; Coarse: D84=10mm, D50=0.5mm, D16=0.1mm

Fine, medium, and coarse based on range of estimates of proposed bypass channel bed material following construction. Fine represents the soil matrix as measured from shallow test pit samples (2-6ft) in 2011. Medium represents bank samples taken in 2008. Coarse represents average of 2011 test pit sampes taken in approximately the same depth range as the proposed bypass excavation (10-16ft). Note that the coarse gradation includes gravels and is outside of the range of the Copeland method (shown here for information only).

4.4 Bed Slope

The bed slope of the proposed bypass channel was originally computed using an iterative process with HEC-RAS. Geometries with a range of bed slopes were modeled and computed depths and velocities were evaluated for fish passage suitability. The elevation of the upstream and downstream ends of the bypass were selected based on existing river bed geometry. The length of the bypass channel was then varied to obtain a bed slope of approximately 0.0006 ft/ft (elevation change of approximately 9.3ft over 15,500ft) during the 30% design.

During progression from 30% to 60% design, additional sediment transport modeling has indicated the potential for an aggradational trend using a slope of 0.0006ft/ft. Additional HEC-RAS modeling indicates that a slope of 0.0007ft/ft would be less prone to aggradation.

As shown in table 4, the computed stable channel bed slope ranges from 0.0002 to 0.002, with a best estimate of between 0.0006 and 0.0008.

4.5 Sinuosity

Estimated sinuosity of the proposed bypass during 30% design, from ratio of bypass length to straight line distance is approximately 15,500ft / 8300ft = 1.87.

The 60% design bypass has a sinuosity of 11,150ft/8300ft = 1.34

From the proposed bed slope of 0.0007 ft/ft and the estimated valley slope of 0.0011 ft/ft, the sinuosity, represented by valley slope / bed slope, is approximately 1.6.

4.6 Meander Wavelength

Figure 7.1 of Reference 1, reproduced below as Figure 2, shows the relationship of meander wavelength to bankfull width. The relationship can be expressed as $L_m=8.36W^{1.05}$ where L_m= meander wavelength in meters and W=bankfull width in meters. Using a bankfull width of 180 ft (55m), the meander wavelength is computed as approximately 1840ft (560m). The 90% single response confidence limits are approximately 650ft (200m) to 5000ft (1500m).

An equation presented in both References 1 and 3 is simply L_m=(11.26 to 12.47)W, resulting in a range from 2030ft to 2250ft.

As shown in Figure 3, the meander wavelength of the proposed 60% design bypass channel varies from roughly 1700ft to 3500ft, falling into the confidence intervals based on available datasets. As shown in Attachment 1, the proposed bypass meander wavelengths fall within the range of wavelengths observed in existing natural side channels in the vicinity of Intake.

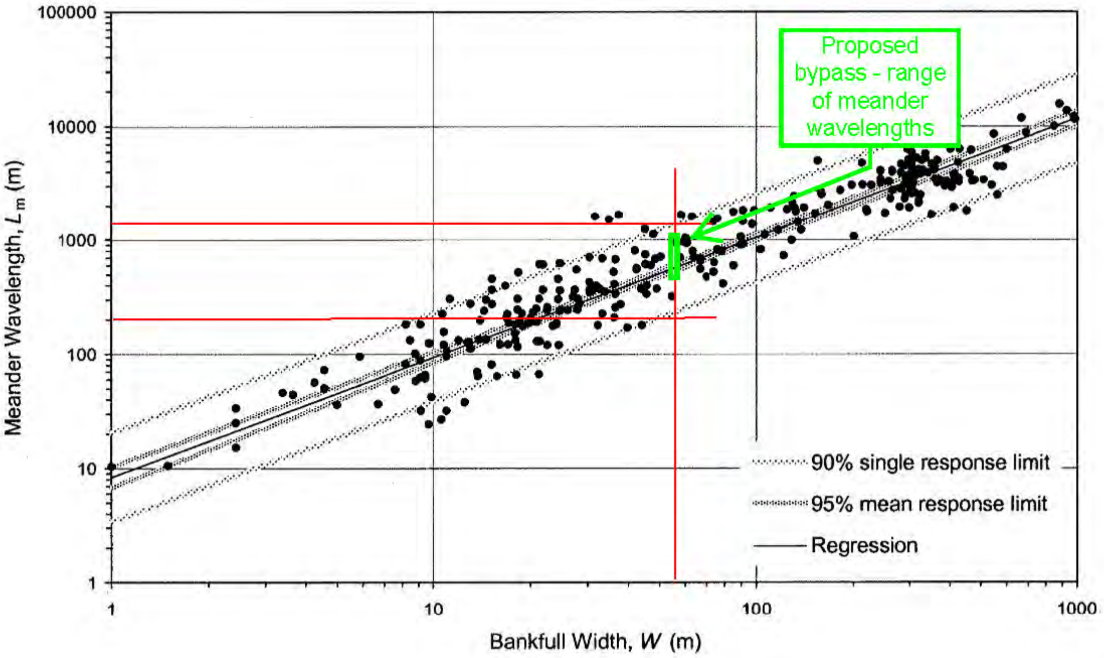


Figure 7.1 Confidence intervals applied to the relationship between meander wavelength and bankfull width, $L_m = 8 \cdot 36 W^{1 \cdot 05}$, based on a composite data set of 438 sites.

Figure 2 Meander Wavelength vs. Bankfull Width

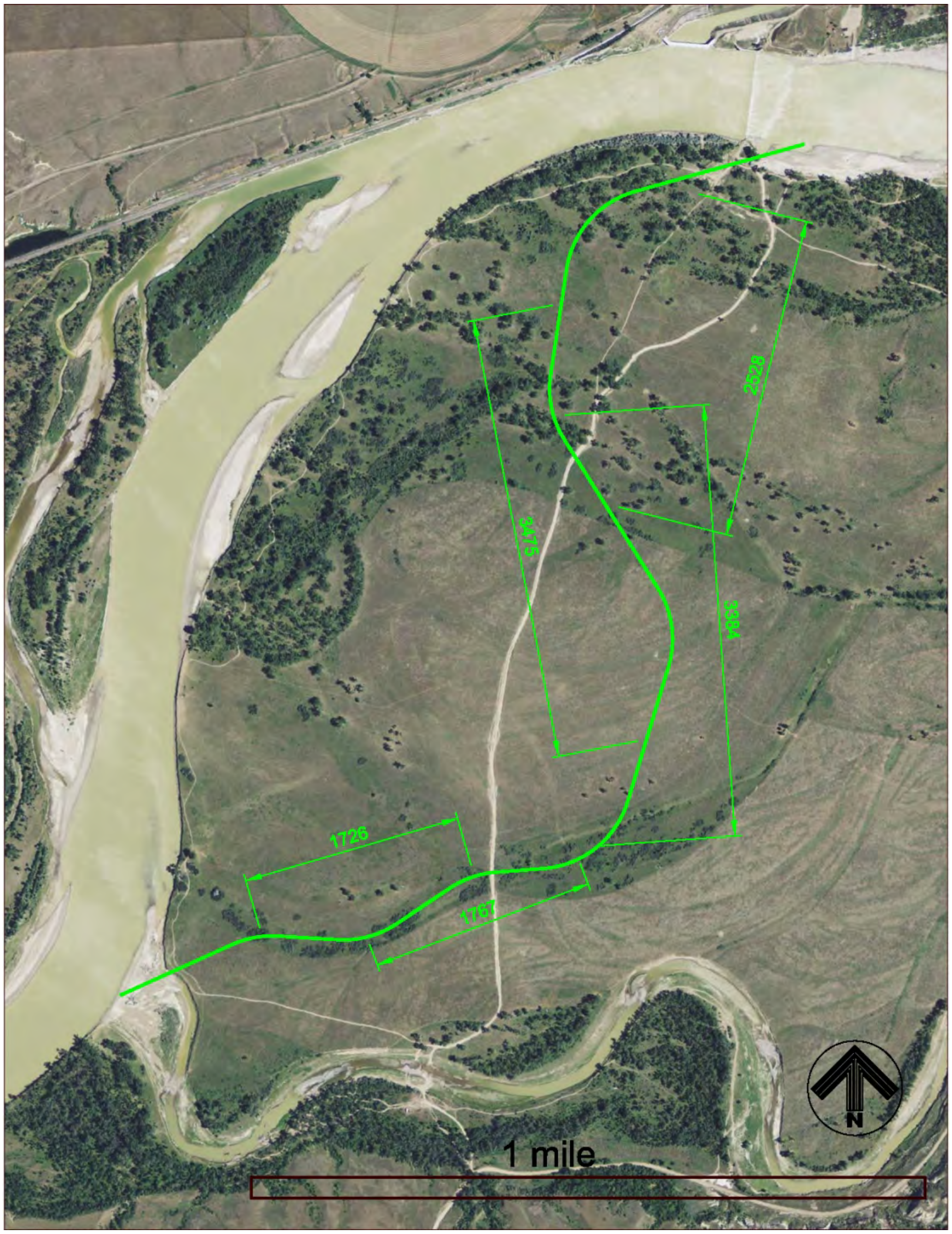


Figure 3 Proposed Bypass Meander Wavelengths

5. LOCAL MORPHOLOGICAL VARIABILITY AROUND MEANDER BENDWAYS

5.1 Radius of Curvature

Chapter 7 of Reference 1 gives the radius of curvature as R_c=(2.25 to 2.49)W, assuming an average sinuosity of 1.5 (proposed bypass sinuosity is 1.3-1.6), where W is the bankfull width.

Using W=180ft, R_c would range from 405 to 450ft for the proposed bypass. The R_c/W ratio of the proposed bypass bends is approximately 4.2 (R_c = 750ft). As discussed in Chapter 7 of Reference 1, approximately 53% of the 263 sites evaluated for R_c had R_c/W values between 2 and 4. The radii of the bends in the proposed bypass alignment are larger than the value given by the design equation; however, it is noted that nearly half of the sites evaluated were outside of the design range. Additionally, the average radius of curvature in the reference reaches in Attachment 1 is 812ft while the average of the side channels is 1136ft.

5.2 Variable Width

Equations are presented in Section 7.4.1 of Reference 1 to assist in evaluating the width variability between riffles and pools. Unlike many of the preceding parameters, width variability was not considered in the 30% design; the estimates given below are used in the 60% design of the proposed bypass channel.

5.2.1 Bend Apex

The ratio of bend apex width to inflection point width, W_a/W_i, is expressed as a function of sinuosity and meander type. Three meander types are considered: type-e=equiwidth meanders, type-b=meanders with point bars, and type-c=meanders with point bars and chute channels. The proposed bypass channel is expected to be meander type-b.

For a sinuosity of 1.3-1.6 and assuming meandering with point bars (b-type meander bends), W_a/W_i with 95% confidence ranges from approximately 1.2 to 1.4.

The practical design equation proposed in Reference 1 is given as:

$$\frac{W_a}{W_i} = 1.05T_e + 0.30T_b + 0.44T_c \pm u$$

Where: T_e, T_b, and T_c are binary parameters representing e-type, b-type, and c-type bends and u refers to confidence limits on the mean response.

For design purposes, T_e and T_b are set to 1 while T_c is set to 0. For 95% confidence, the value of u is given as 0.05. Then $W_a/W_i=1.05+0.3\pm0.05=1.3$ to 1.4; use 1.35.

Assuming an inflection point width of 180ft, the bend apex width (at channel-forming discharge) is then ≈230 to 250ft, ***use 240ft***.

5.2.2 Pool

The ratio of pool width (at maximum scour location) to inflection point width, W_p/W_i, is approximately 1.3 to 1.4 for b-type meander bends.

The practical design equation proposed in Reference 1 is given as:

$$\frac{W_p}{W_i} = 0.95T_e + 0.20T_b + 0.14T_c \pm u$$

Where: T_e, T_b, and T_c are binary parameters representing e-type, b-type, and c-type bends and u refers to confidence limits on the mean response.

For design purposes, T_e and T_b are set to 1 while T_c is set to 0. For 95% confidence, the value of u is given as 0.12. Then $W_p/W_i=0.95+0.2\pm0.12=1.03$ to 1.27; use 1.15.

Assuming an inflection point width of 180ft, the pool width (at channel-forming discharge) is then ≈185 to 230ft, ***use 210ft***.

5.3 Location of Pools and Riffles

Reference 1 expresses the location of pools and riffles as a pool-offset ratio, defined as the ratio of the channel distance between bend apex and maximum scour location to the channel distance between bend apex and downstream inflection point, $Z_{a\text{-}p}/Z_{a\text{-}i}$. Reference 1 notes that evaluation of available data suggested that the pool-offset ratio is independent of both sinuosity and bend type, and a single relationship is suitable for all meander bend types studied.

The offset ratio given in Reference 1 is 0.36, with 95% confidence bands extending from 0.28 to 0.44. Unlike many of the preceding parameters, pool and riffle location was not considered in 30% design of the bypass channel; a value of ***0.36*** will be used in the 60% design of the proposed bypass channel.

5.4 Maximum Scour Depth in Pools

Reference 1 defines the maximum scour depth, D_{max}, scaled on the mean depth at the upstream inflection point, D_m, as a function of the ratio of radius of curvature, R_c, to channel top width, measured at the upstream inflection point, W_i ($D_{max}/D_m=f(R_c/W_i)$).

Reference 1 gives a practical design equation as:

$$\frac{D_{max}}{D_m} = 1.5 + 4.5\left(\frac{R_c}{W_i}\right)^{-1}$$

However, observed data varies widely as shown in Figure 4, taken from Reference 1.

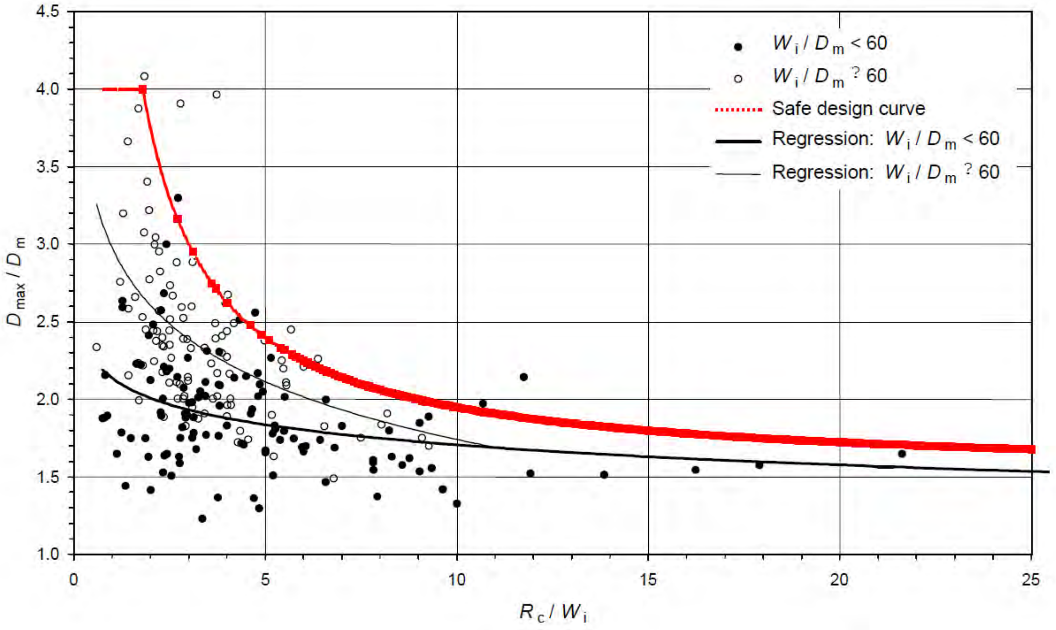


Figure 7.21 Dimensionless maximum scour depth in meander pools as a function of radius of curvature-to-width ratio. Source data: Thorne and Abt (1993); Maynord (1996).

Figure 4 Scour Depth vs. Radius of Curvature to Width Ratio

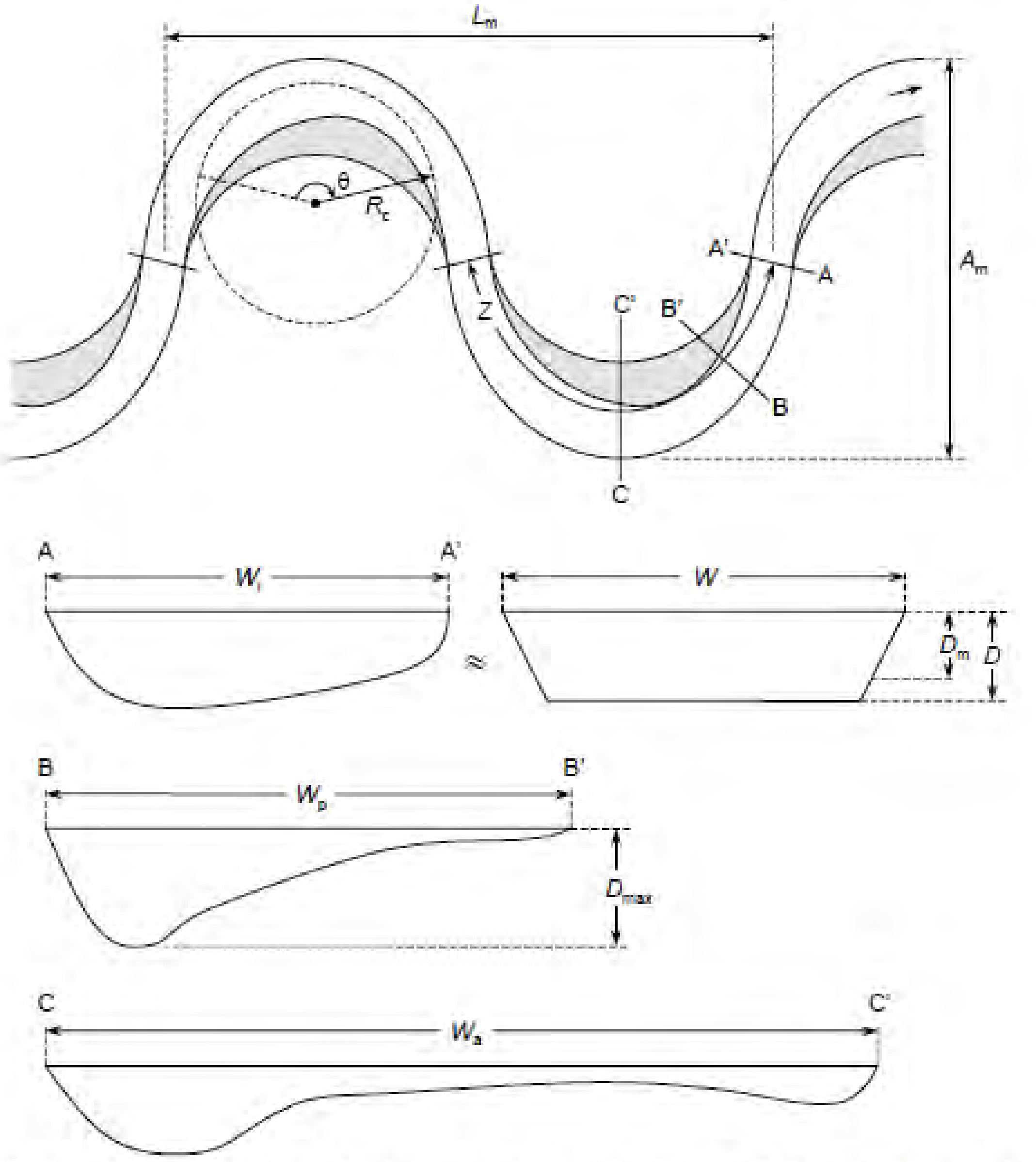
The practical design equation gives a D_{max} of approximately 19ft using R_c/W_i=4.2 and D_m=7.3ft. However, as shown in Figure 4, the observed data for R_c/W_i=4.2 ranges from D_{max}/D_m=1.2 to 2.6, giving D_{max} a range of 8.8 to 19.0 ft.

Because of the large uncertainty in maximum scour depth in the pools, the proposed method of evaluation is to start with a lower value for D_{max} that is slightly deeper than the maximum depth at the inflection point. Then, the computed geometry will be used as the starting point in a sediment simulation within the 2-dimensional model ADH. The ADH model will be used to evaluate the tendency of the channel to scour or deposit material in the pools. If the model indicates large scour in the pools, the proposed design will include deeper pools; however, if the pools remain relatively stable during the model runs, the lower D_{max} value will be used in final design.

For modeling purposes, ***a*** D_{max} ***of 12.ft is used*** (i.e. 1ft deeper than "base" cross section where average maximum channel depth is 11.0ft (range=10.6ft to 11.8ft)).

Figure 5, taken from Reference 1, shows the conceptual channel width and depth variation. Plate 1 shows the actual cross sections used in the 60% design. The sections in Plate 1were developed by matching the general shape of the sections shown in Figure 5 while maintaining similar cross sectional area at the channel forming discharge.

Figure 6 shows a general overview of the proposed bypass channel, including the channel thalweg, bend apexes, inflection points, and locations of maximum scour.



Note: point bars are defined by shaded regions; L_m = meander wavelength, Z = meander arc length (riffle spacing); A_m = meander belt width, R_c = radius of curvature; θ = meander arc angle; W = reach average bankfull width; D = depth of trapezoidal cross section; D_m = mean depth (cross-sectional area / W); D_{max} = maximum scour depth in bendway pool; W_i = width at meander inflexion point; W_p = width at maximum scour location; W_a = width at meander bend apex.

Figure 3.7 Meander planform and cross section dimensions for restoration design.

Figure 5 Cross Section Variation

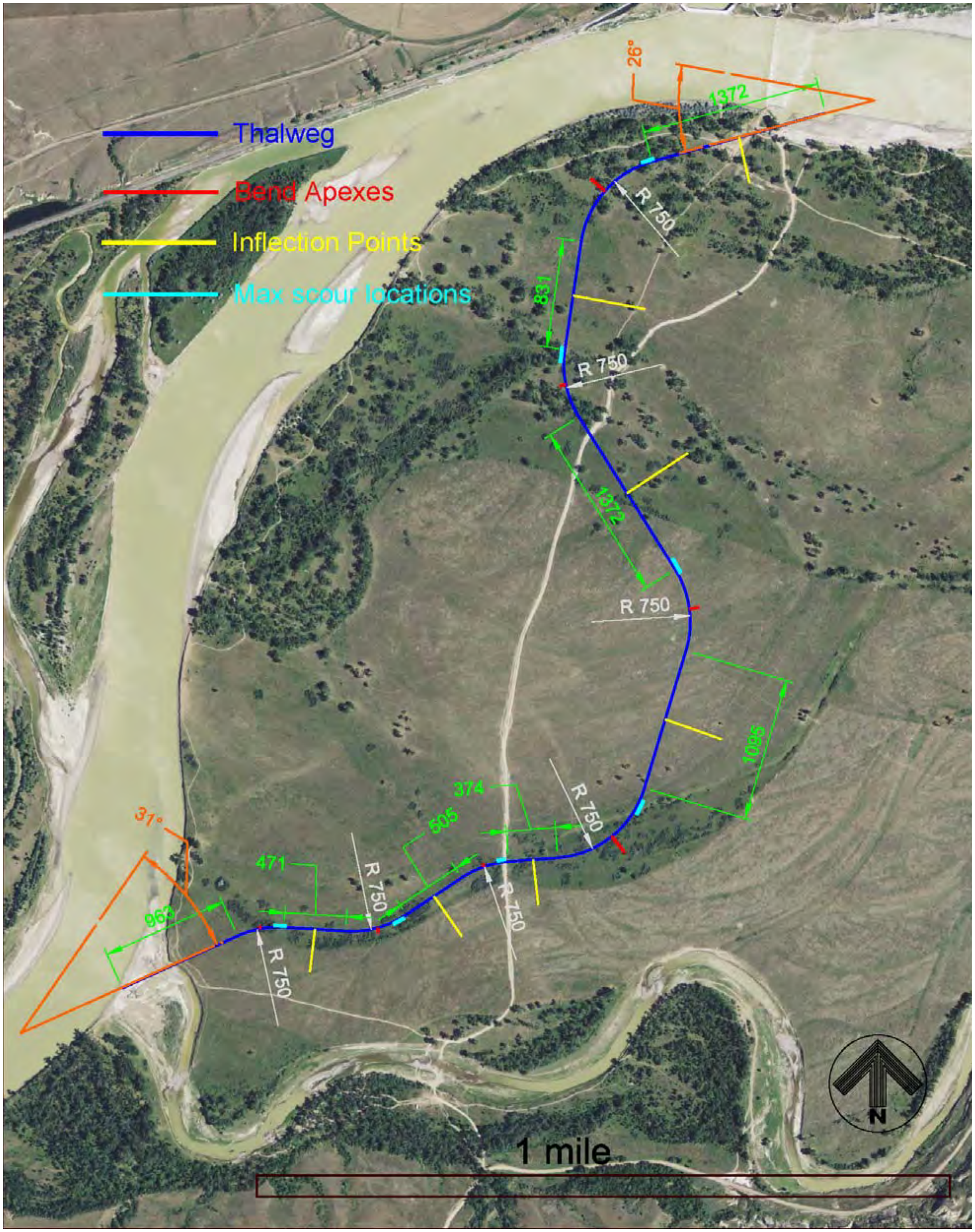


Figure 6 Proposed Bypass Channel Conceptual Sketch

5.5 Adjustments to Layout due to Natural Variability and Site Constraints

The general layout of the 30% bypass channel was based primarily on the existing topography and the desire to minimize excavation quantities. The upstream end of the 30% proposed bypass followed the existing high flow chute for approximately 1 mile, then the bypass followed existing channel scars/swales where feasible.

Comments received pertaining to the 30% Design Documentation Report resulted in modification to the originally proposed alignment. The angle of the upstream end was modified to include a more upstream oriented exit. The modifications result in additional excavation but are intended to add stability and fish passage enhancement to the bypass.

Minimal site constraints exist with regard to real estate availability because the majority of the island where the proposed bypass channel sits is owned by the Bureau of Reclamation.

Based on the proposed slope and upstream and downstream inverts, a length of 11,150ft was determined (slope = 0.0007ft/ft, downstream invert = 1982ft NAVD88, upstream invert = 1989.8ft NAVD88). The shortened alignment essentially prevents the use of the existing high flow channel. However, favorable topographic features (old channel scars) were used where feasible.

6. SUMMARY AND CONCLUSIONS

The following bullets summarize the analysis presented herein:

- The geometry of natural side channels on the Yellowstone River near Intake varies greatly
- The geometry of the proposed bypass channel falls within the range of all parameters evaluated for observed natural side channels, including length, width, sinuosity, bend radius, and meander wavelength.
- A channel-forming discharge of 6500cfs was selected for the bypass channel.
- The proposed bypass water surface top width at the channel-forming discharge, ≈180ft, falls within the range and near the average predicted by a host of relationships provided in Reference 1.
- The proposed bed slope and bankfull depth fall within the range of stable channel parameters predicted by the Hydraulic Design Functions within HEC-RAS.
- The proposed meander wavelengths are longer than the design equation proposed in Reference 1; however, the proposed lengths fall within the observed range of wavelengths for existing natural side channels in the vicinity of Intake.
- The radius of curvature for the proposed bypass bends is approximately 750 ft, larger than the design equation given in Reference 1 but well within the observed range of natural sites given in Reference 1 and shown in Attachment 1.
- Using a water surface top width of 180ft at the inflection point, widths of 240ft and 210ft are estimated for the bend apexes and pools, respectively.
- Based on the concept of a pool-offset ratio, the ratio of channel distance between bend apex and maximum scour location to the channel distance between bend apex and downstream inflection point equal to 0.36 was used (i.e. the maximum scour location is 36% of the distance between the bend apex and downstream inflection point).

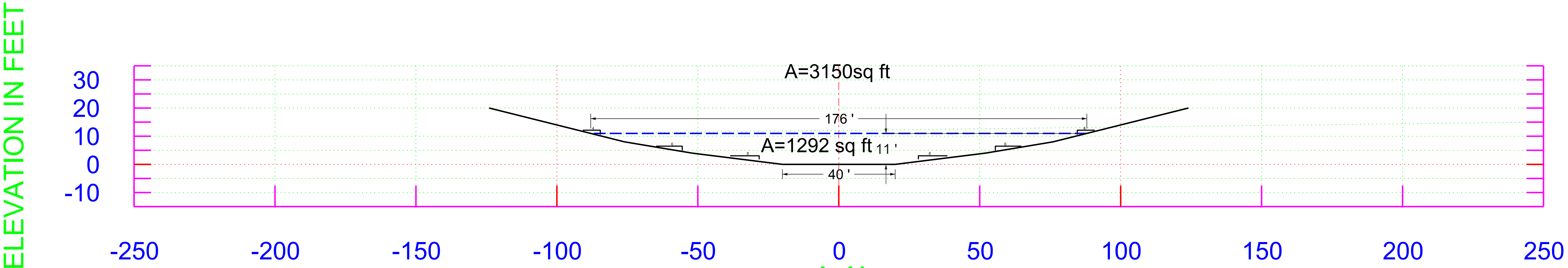
- A maximum scour depth of 12.0 ft is proposed based on the average maximum depth of 11.0ft and the desire to be slightly deeper at the pools than the average. This value will be used for initial modeling and revised as necessary, depending on results of sediment modeling.

7. REFERENCES

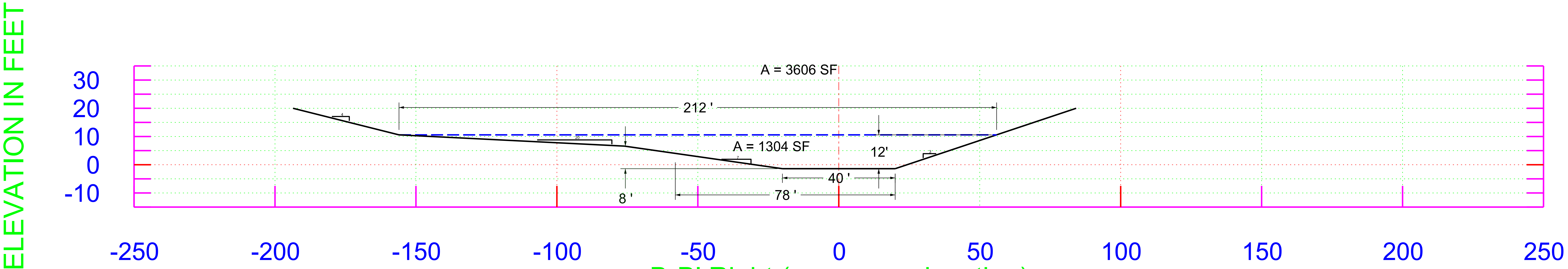
1. United States Army Corps of Engineers, 2001. *ERDC/CHL CR-01-1, Channel Restoration Design for Meandering Rivers*. Philip J. Soar and Colin R. Thorne.

2. United States Gelogical Survey, 2013. *Streamflow Statistics for Unregulated and Regulated Streamflow Conditions for Selected Locations on the Yellowstone, Tongue, and Powder Rivers, Montana and Wyoming 1928-2002.*

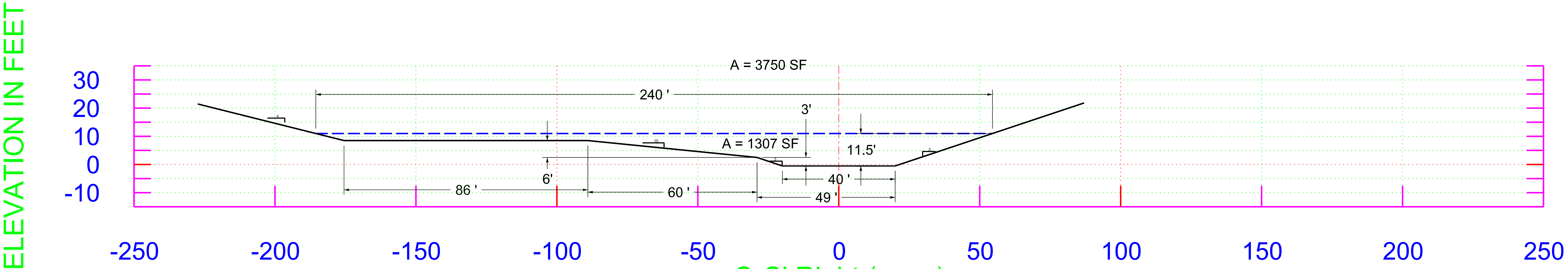
3. Unites States Army Corps of Engineers, 2001. *ERDC/CHL TR-01-28, Hydraulic Design of Stream Restoration Projects.* Copeland, Ronald et al.



A-A'



B-B' Right (max scour location)



C-C' Right (apex)

ATTACHMENT 1

REFERENCE REACH COMPARISON

US Army Corps of Engineers
Omaha District

Project:	Lower Yellowstone-Intake					Sheet No.	1/4
Subject:	Reference Reach Comparison						
Computed by:	CJM	Date:	DEC2013	Checked by:		Date:	
Updated by:	CJM	Date:	MAY2014				

INTRODUCTION

This document describes an evaluation of nineteen side channels on the Yellowstone River, including the existing high flow chute at Lower Yellowstone, Intake. Eleven of the side channels were previously evaluated and described in the 30% Design Documentation Report (DDR) and are referred to as the Reference Reaches. Nine additional reaches (one of which was included in the Reference Reaches) were provided by the Biological Review Team (BRT) for evaluation of fishway entrance angles (downstream end) because of known pallid sturgeon usage and are referred to as the Side Channels for distinction from the Reference Reaches.

Six of the Reference Reaches evaluated are downstream from Intake, four are upstream. All nine of the Side Channels are downstream from Intake.

The intent of the evaluation is to compare existing, natural side channels to the proposed 60% design bypass channel at intake. It should be stressed that the comparison is simply a GIS exercise and does not guarantee project performance. Additional data and a more in-depth analysis are required to determine the long term stability of the project.

COMPARISON

Available GIS data, aerial photography, and HEC-RAS data were used to compare 19 natural side channels within 60 river miles of Intake Dam. The comparison consisted mainly of measuring side channel length, width, entrance/exit angles, bend radii, and meander wavelength and using HEC-RAS or available LiDAR data to estimate energy grades. Dates of aerial photography were used to estimate discharges at certain sites based on the USGS gages at Glendive and Sidney.

Plate 1 consists of a table summarizing the previously completed Reference Reach evaluation along with assumptions used.

Plate 2 shows a general overview of the area.

Plates 3-13 show the Reference Reaches as shown in the 30% DDR.

Plate 14 is a table summarizing the entrance/exit angles of the Reference Reaches and Side Channels.

Plates 15-24 show images of the Reference Reach entrance/exit angles.

Plates 25-33 show images of the Side Channel entrance/exit angles.

Plates 34-35 show the 60% design proposed bypass channel entrance/exit angles.

Plate 36 is a table summarizing the bend radii within the Reference Reaches, Side Channels, and 60% design proposed bypass channel.

Plate 37 is a summary plot of bend radii comparing the Reference Reaches, Side Channels, and 60% design proposed bypass channel.

Plates 38-48 show the Reference Reaches with individual bend radii.

Plates 49-56 show the Side Channels with individual bend radii.

Plate 57 is a table summarizing meander wavelengths in the Reference Reaches, Side Channels, and 60% design proposed bypass channel.

Plates 58-68 show the meander wavelengths of each Reference Reach.

Plates 69-76 show the meander wavelengths of each Side Channel.

Plate 77 shows the meander wavelengths of the 60% design proposed bypass channel.

CONCLUSIONS

The bullet points and table below summarize the comparison.

Length, width, sinuosity

- The proposed bypass channel length (11,150 ft) falls in the relative range of the Reference Reaches compared.
- The chute to main channel length ratio for the proposed bypass, is within the range and near the average of the reference reaches compared.
- The proposed bypass channel has a slightly higher energy grade slope than the estimated energy grades in the reference reaches compared.
- Chute sinuosity for the proposed bypass falls in the range of the reference reaches considered.
- The top width of the proposed bypass channel falls in the range of the reference reaches.

Entrance/Exit Angles

- The angle of the reference reach entrances (downstream end) ranges from 12 to 98 degrees with an average of 56 degrees.
- The angle of the reference reach exits (upstream end) ranges from 29 to 90 degrees with an average of 56 degrees.
- The angle of the side channel entrances (downstream end) ranges from 12 to 57 degrees with an average of 39 degrees while the 60% design proposed bypass fishway entrance angle is approximately 26 degrees.

- The angle of the side channel exits (upstream end) ranges from 38 to 85 degrees with an average of 56 degrees while the 60% design proposed bypass fishway exit angle is approximately 31 degrees.
- The proposed angles are subject to change if 2-dimensional numerical and/or physical modeling results suggest that a different angle would be preferable considering fish passage, hydraulics, sediment transport, and ice concerns.

Bend Radii

- Bend radii in the Reference Reaches ranges from 160ft to 2220ft with an average of just over 810ft.
- Bend radii in the Side Channels ranges from 300ft to 2730ft with an average of 1140ft.
- The existing high flow chute at Intake has 9 bends with radii ranging from 340ft to 1630ft (average = 650ft)
- The proposed bypass channel has 7 bends with 750ft radii.
- The proposed bend radii are well within the range of radii in existing natural side channels.

Meander Wavelengths

- Meander wavelengths in the Reference Reaches range from 1370ft to 6240ft with an average of 3020ft.
- Meander wavelengths in the Side Channels range from 950ft to 7490ft with an average of 2980ft.
- The proposed bypass meander wavelengths range from 1730ft to 3480ft, well within the range of wavelengths observed in the existing natural side channels.

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SUMMARY TABLE

		Fishway Entrance Angles (downstream end)	Fishway Exit Angles (upstream end)	Bend Radii	Meander Wavelength
		(degrees)	(degrees)	(ft)	(ft)
Side Channels	Maximum	57	85	2730	7490
	Average	39	56	1140	2980
	Minimum	12	38	300	950
Reference Reaches	Maximum	98	90	2220	6240
	Average	56	56	810	3020
	Minimum	12	29	160	1370
Proposed Bypass	Maximum	-	-	-	3480
	Average	-	-	-	2580
	Minimum	-	-	-	1730
	Proposed	26	31	750	-

Reach Identifier	River Mile[1]	Bank	Orientation and distance from Intake Dam[2]	Approximate chute length	Approximate main channel length	Chute to Main Channel length ratio	Approximate energy grade slope in main channel[3]	Estimated energy grade slope in reference reach chute	Straight line distance, end to end of chute	Sinuosity (in this context, used ratio of chute length to straight line distance)	Approximate range of chute top width		Approximate Yellowstone River discharge at which chute flows (rough estimates broken into broad classes)
											Low flow[4]	Mid range flow[5]	
				(ft)	(ft)		(ft/ft)	(ft/ft)	(ft)		(ft)	(ft)	(cfs)
1	18.3-19.8	Right	54 miles d/s	9900	7900	1.3	0.0001	0.00008	6400	1.5	50-110	140-200	≤5000
2	34.0-35.7	Left	38 miles d/s	9400	8900	1.1	0.0004	0.0004	8100	1.2	15-30	30-50	≤5000
3	37.7-39.4	Right	34 miles d/s	11400	9000	1.3	0.0003	0.0002	7500	1.5	20-50[6]	50-120	20,000<x<40,000
4	41.0-43.3	Left	31 miles d/s	22100	12400	1.8	0.0006	0.0004	11300	2.0	20-90[7]	100-160	5000<x<20,000
5	52.7-54.6	Right	19 miles d/s	10600	10000	1.1	0.0006	0.0006	9200	1.2	60-200[7]	250-400	5000<x<20,000
6	62.7-64.6	Right	9 miles d/s	8700	9800	0.9	0.0005	0.0006	5700	1.5	120-280[8]	N/A	<5000
7	70.8-74.3	Right	Existing chute at Intake	24700	18400	1.3	0.0007	0.0005	16200	1.5	40-120[6]	N/A	25,000-30,000
8	90.0-90.8	Left	17 miles u/s	5000	4500	1.1	0.00065	0.0006	4200	1.2	40-120[7]	N/A	5000<x<20,000
9	94.5-96.5	Left	23 miles u/s (at Glendive)	13600	10800	1.3	0.0004	0.0003	10000	1.4	60-200	N/A	<5000
10	99.8-101.8	Right	28 miles u/s	10400	10500	1.0	0.0005	0.0005	9500	1.1	40-150[9]	N/A	>5000[10]
11	105.8-107.1	Right	33 miles u/s	7500	6800	1.1	0.0007	0.0006	6400	1.2	70-100[9]	N/A	>5000[10]
Averages				12100	9900	1.2	0.0005	0.0004	8600	1.4			
PROPOSED BYPASS (60% Design)	72.4-47.3	Right	Proposed bypass at Intake	11150	9600	1.2	0.0007	0.0007	8300	1.3	100	180	≤5000

Footnotes:

1	Approximate downstream and upstream extents of chute based on main channel river station in miles from mouth
2	Intake Dam is located at approximately RM 73
3	For reaches 1-6 (located in Richland County), used 2007 LiDAR survey data assuming data in river reflects approximate water surface elevation. For reaches 7-11 (located in Dawson County), used USACE created HEC-RAS model and averaged energy grade slope from range of profiles.
4	Based on measurements using aerial photography from 15Oct2007 to 2Nov2007 for reaches 1-6 (Richland County), discharges at Glendive (and Sidney)≈5000-7000cfs; aerials from 1-2May2004 for reaches 7-11 (Dawson County), discharges at Glendive≈4000-6000cfs, at Sidney≈3000cfs.
5	Based on measurements using Google Earth imagery from 22June2009, discharge at Glendive≈48,000cfs, Sidney≈46,000cfs where available.
6	Appears that chute is intermittent; i.e. may not be carrying water at low Yellowstone River flow. Using aerial photography from ArcGIS Map Service, ESRI_Imagery_World_2D, still shows intermittent flow in chute but with additional area inundated; date noted for imagery is 14July2005, discharge at Glendive≈17,000cfs, Sidney≈16,000cfs. July 2005 imagery was on receding limb of hydrograph that reached >40,000cfs near the end of June/beginning of July.
7	Appears that chute is intermittent; i.e. may not be carrying water at low Yellowstone River flow. However, aerial photography from ArcGIS Map Service, ESRI_Imagery_World_2D, shows continuous flow in chute; date noted for imagery is 14July2005, discharge at Glendive≈17,000cfs, Sidney≈16,000cfs
8	Contains mid channel bars
9	Appears that chute is intermittent; i.e. may not be carrying water at low Yellowstone River flow. Only other available aerial photography from ArcGIS Map Service, ESRI_Imagery_World_2D, still shows intermittent flow in chute; date noted for imagery is 31July2005, discharge at Glendive≈6300cfs. July 2005 imagery was on receding limb of hydrograph that reached >40,000cfs near the end of June/beginning of July.
10	May be much larger than 5000cfs; lack of available data prevents determination of range.

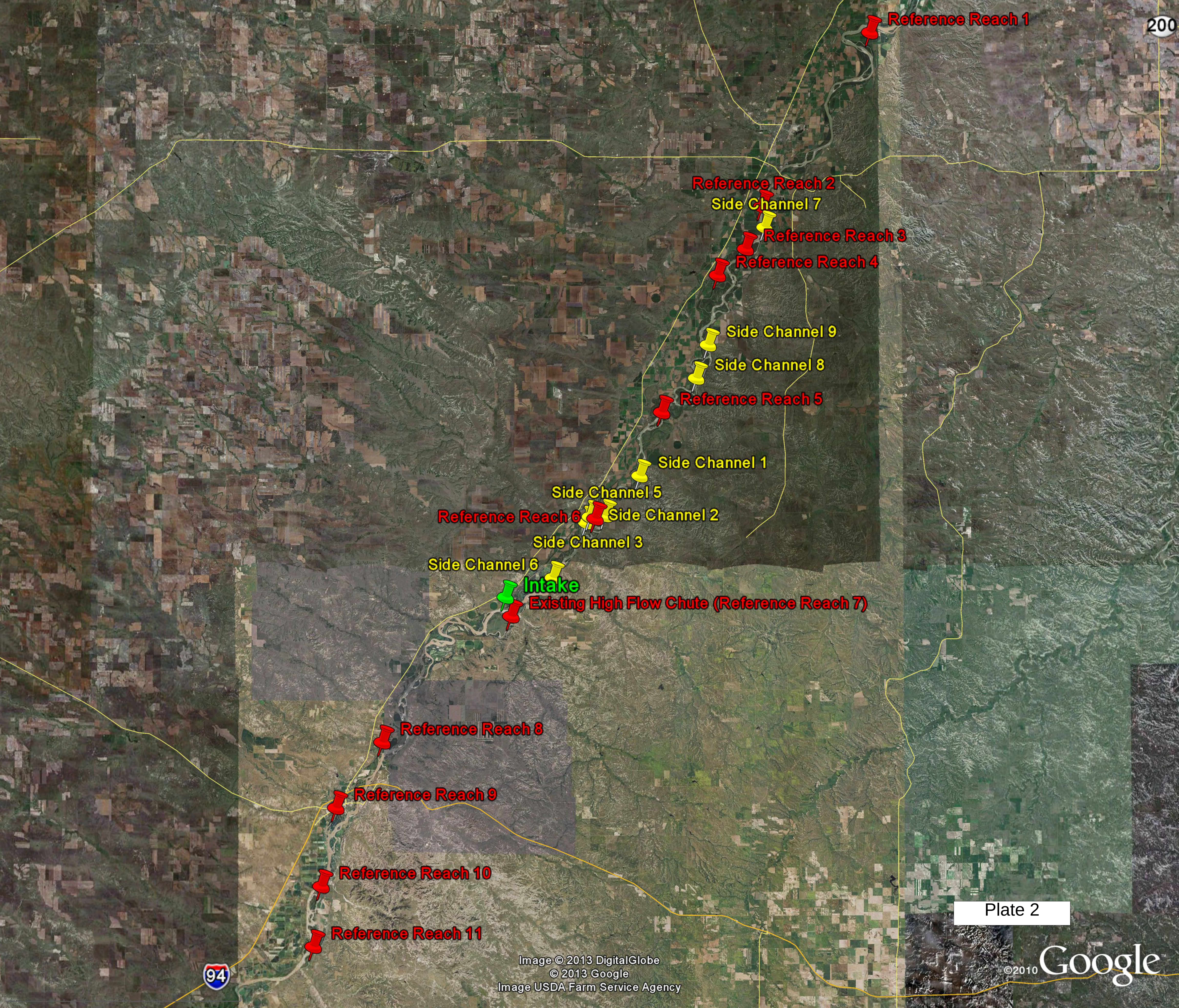

Image © 2013 DigitalGlobe
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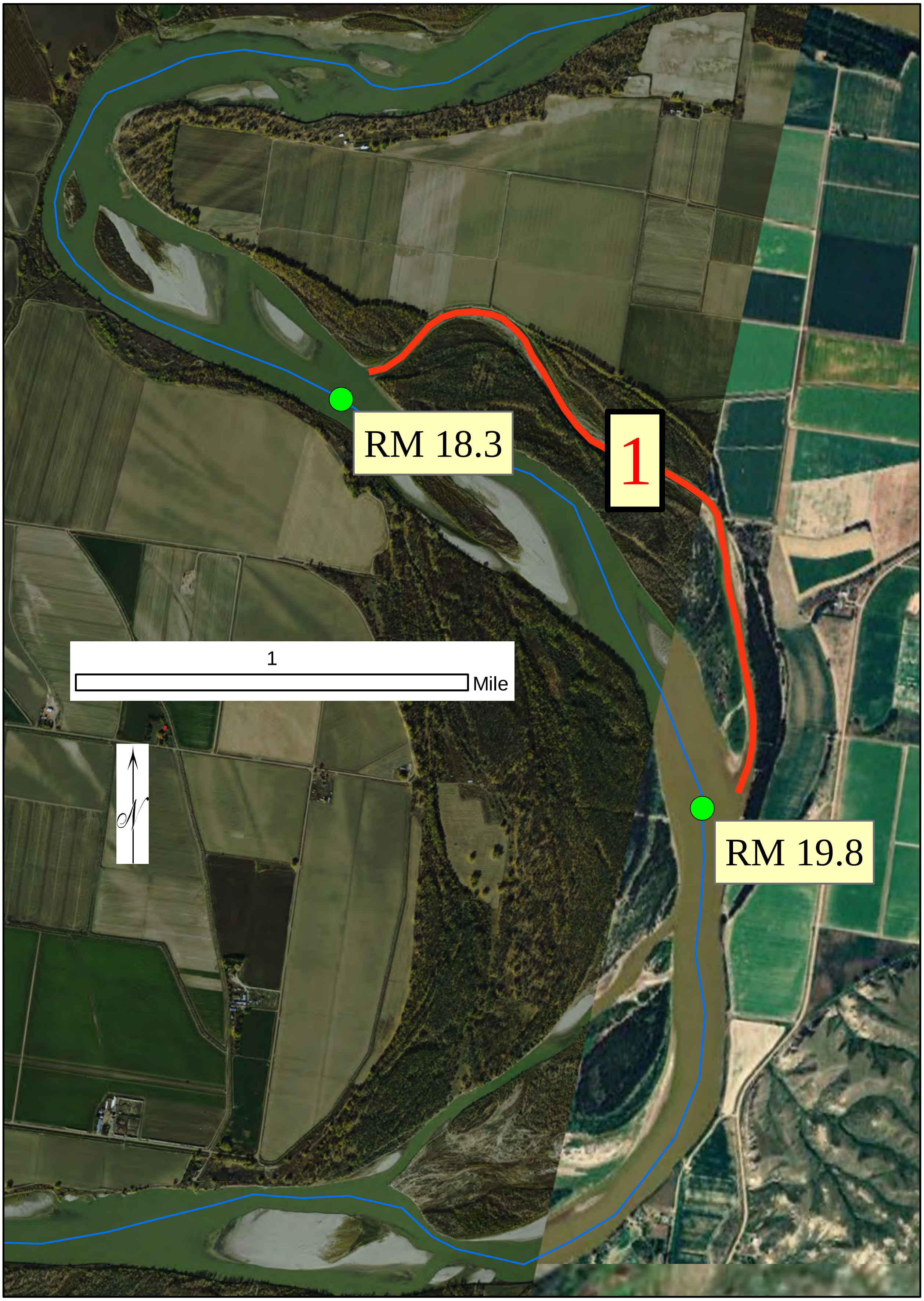
Image USDA Farm Service Agency

Plate 2



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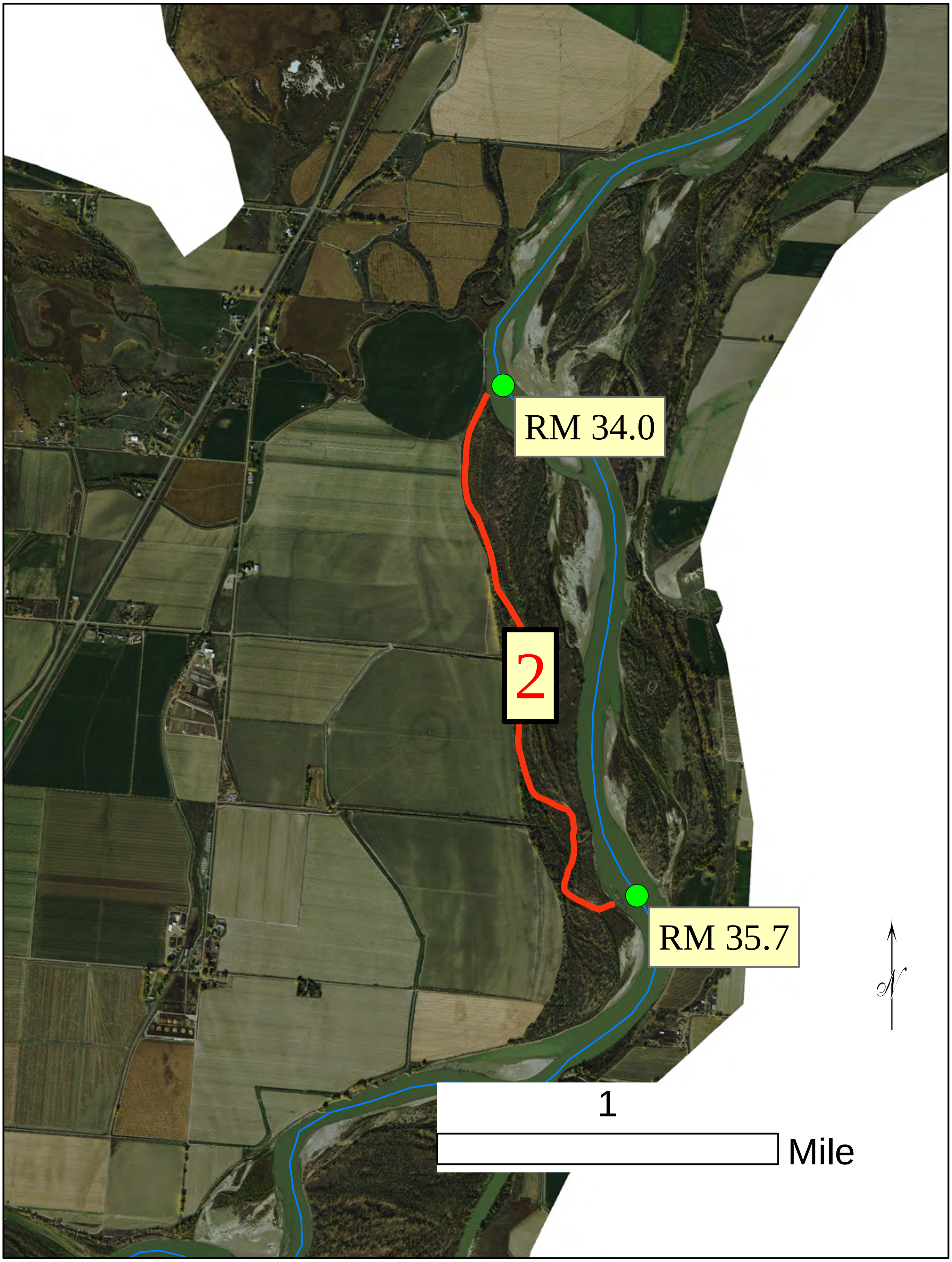

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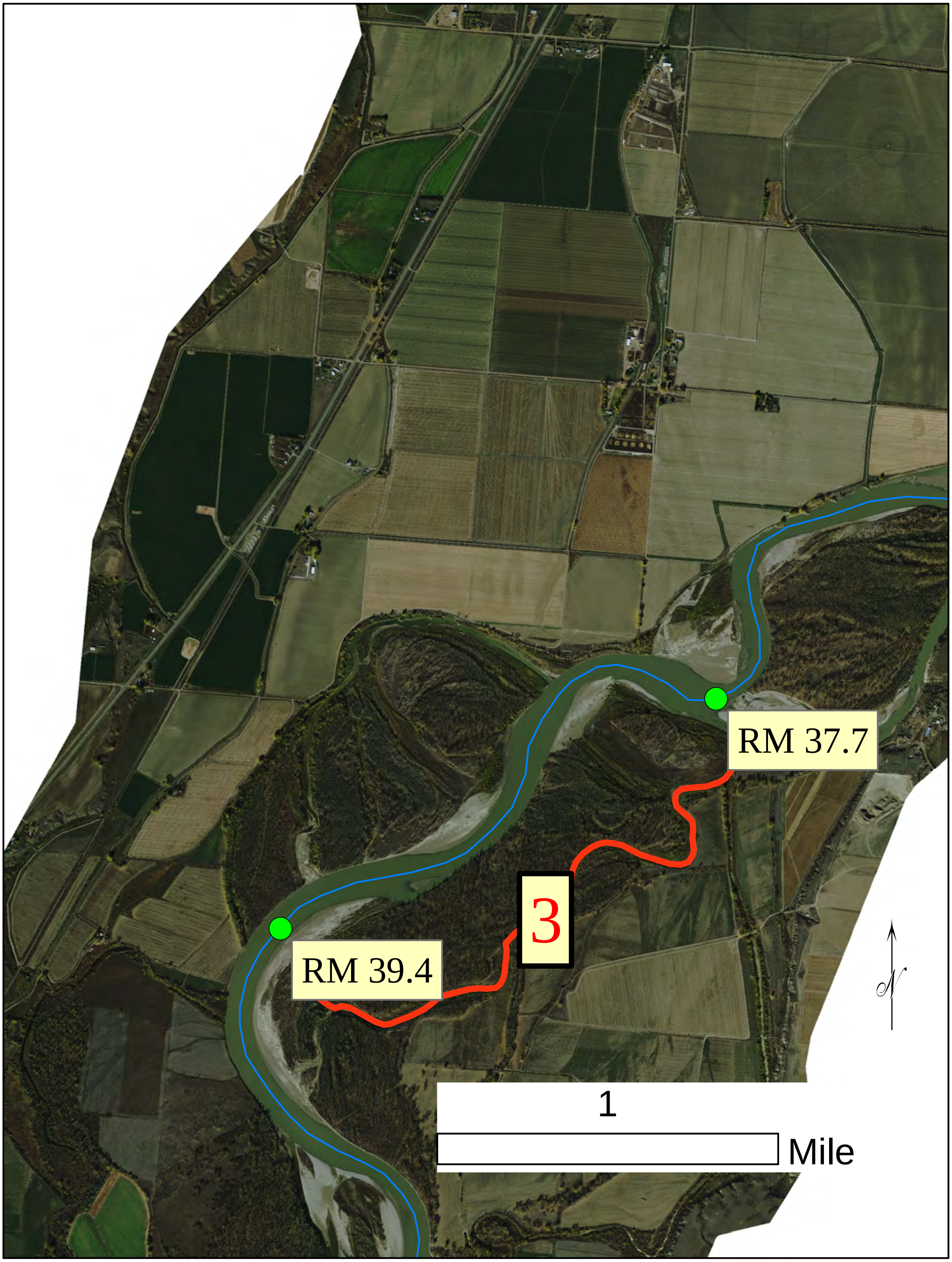

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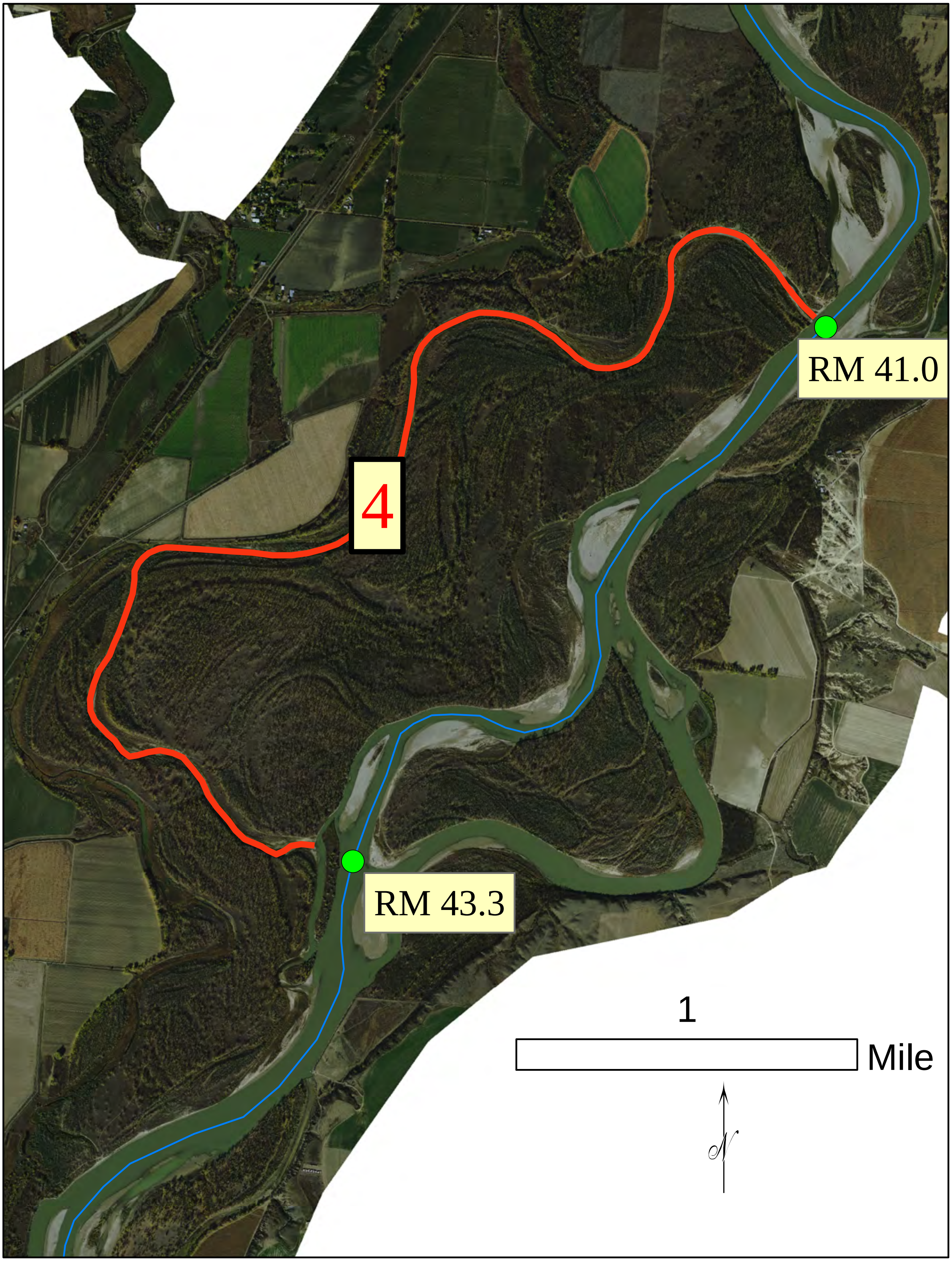

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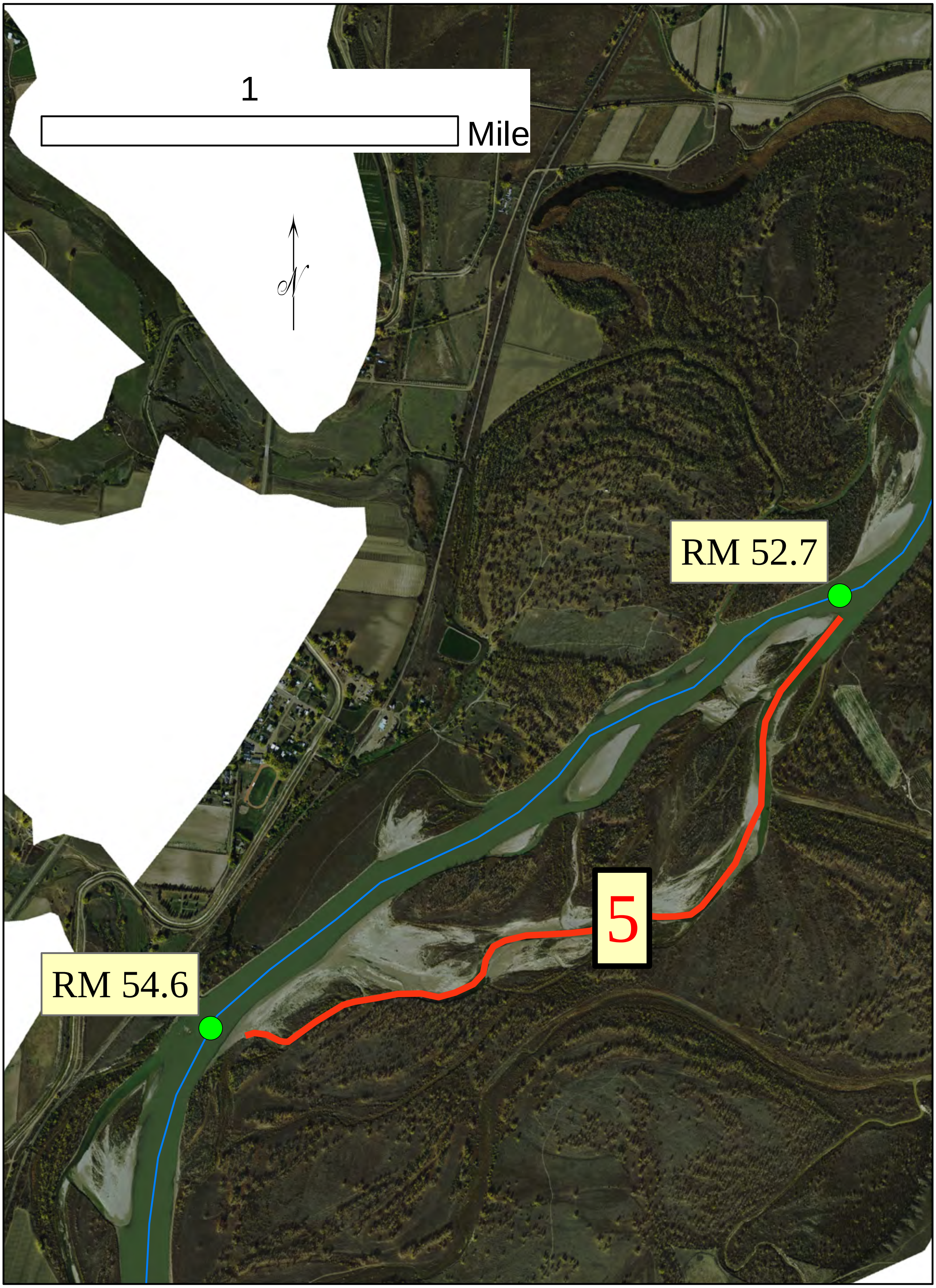

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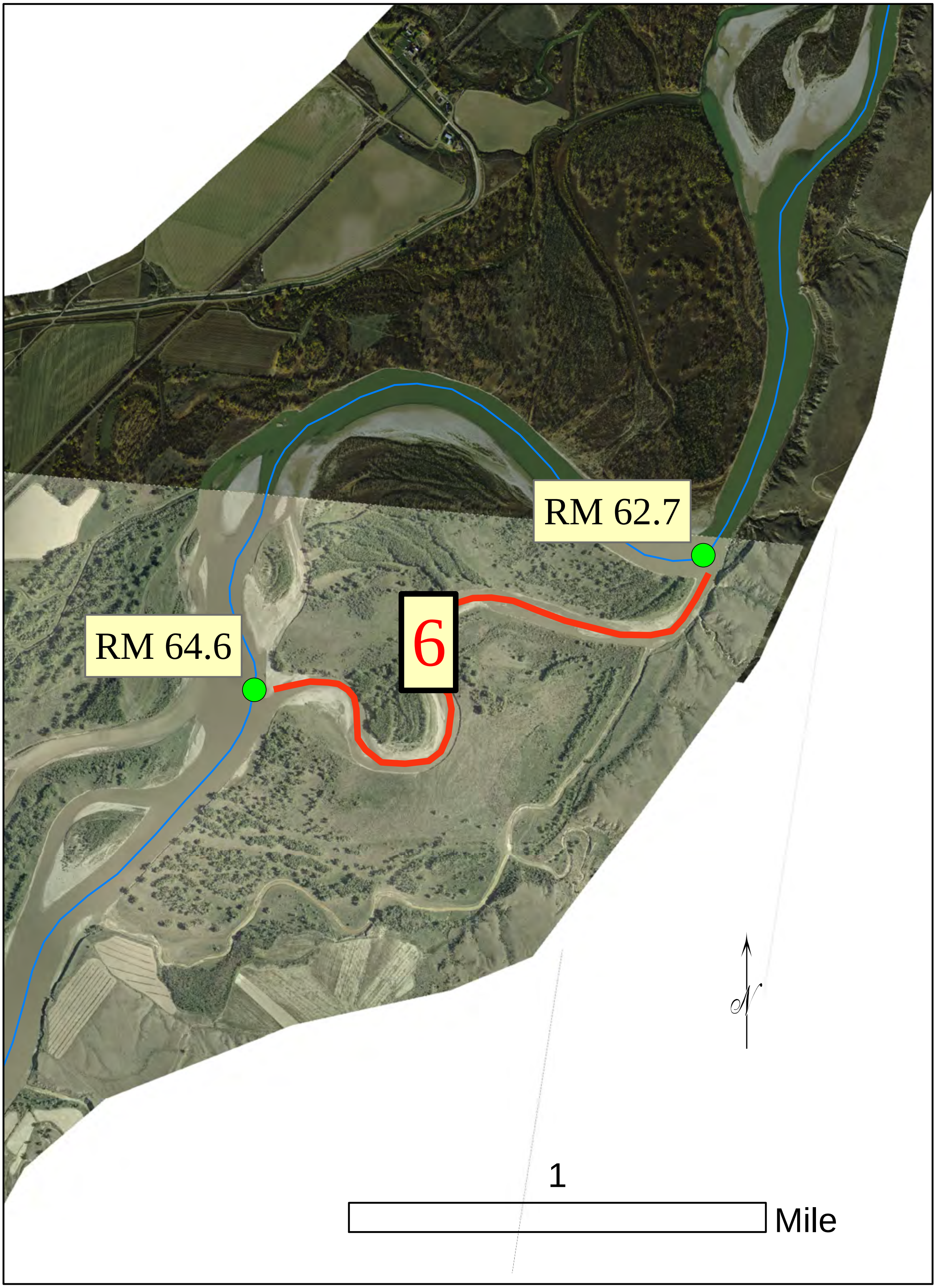
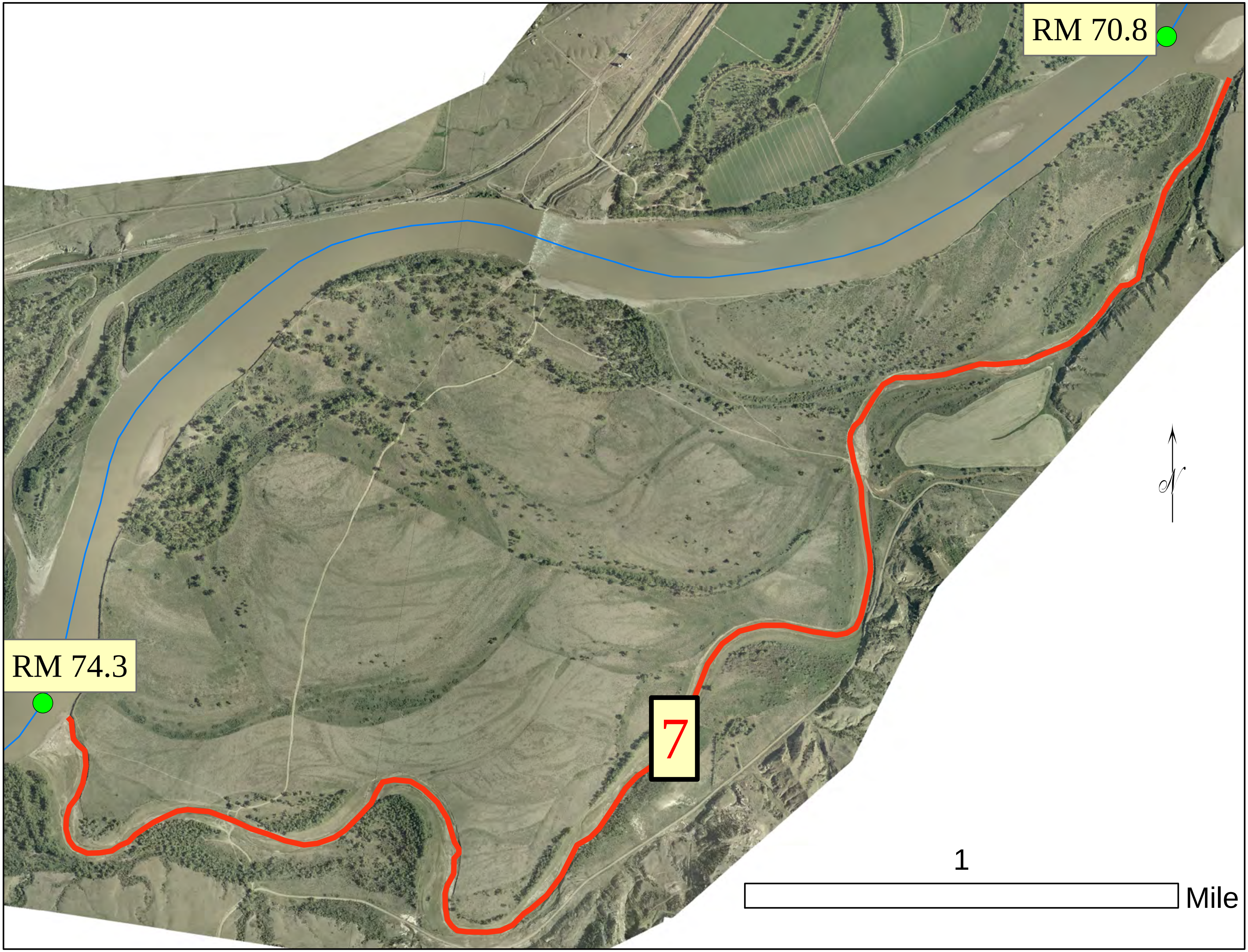
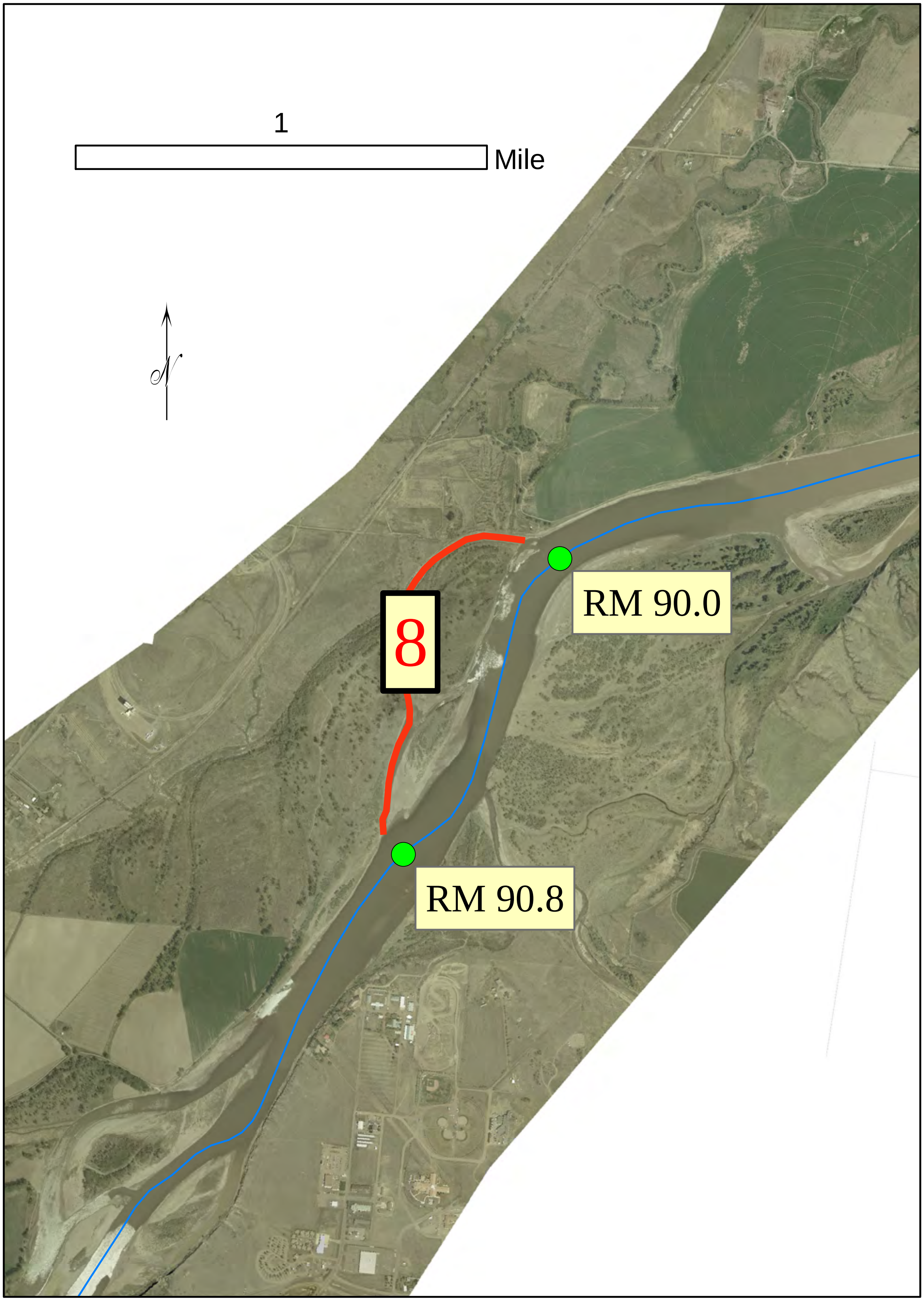
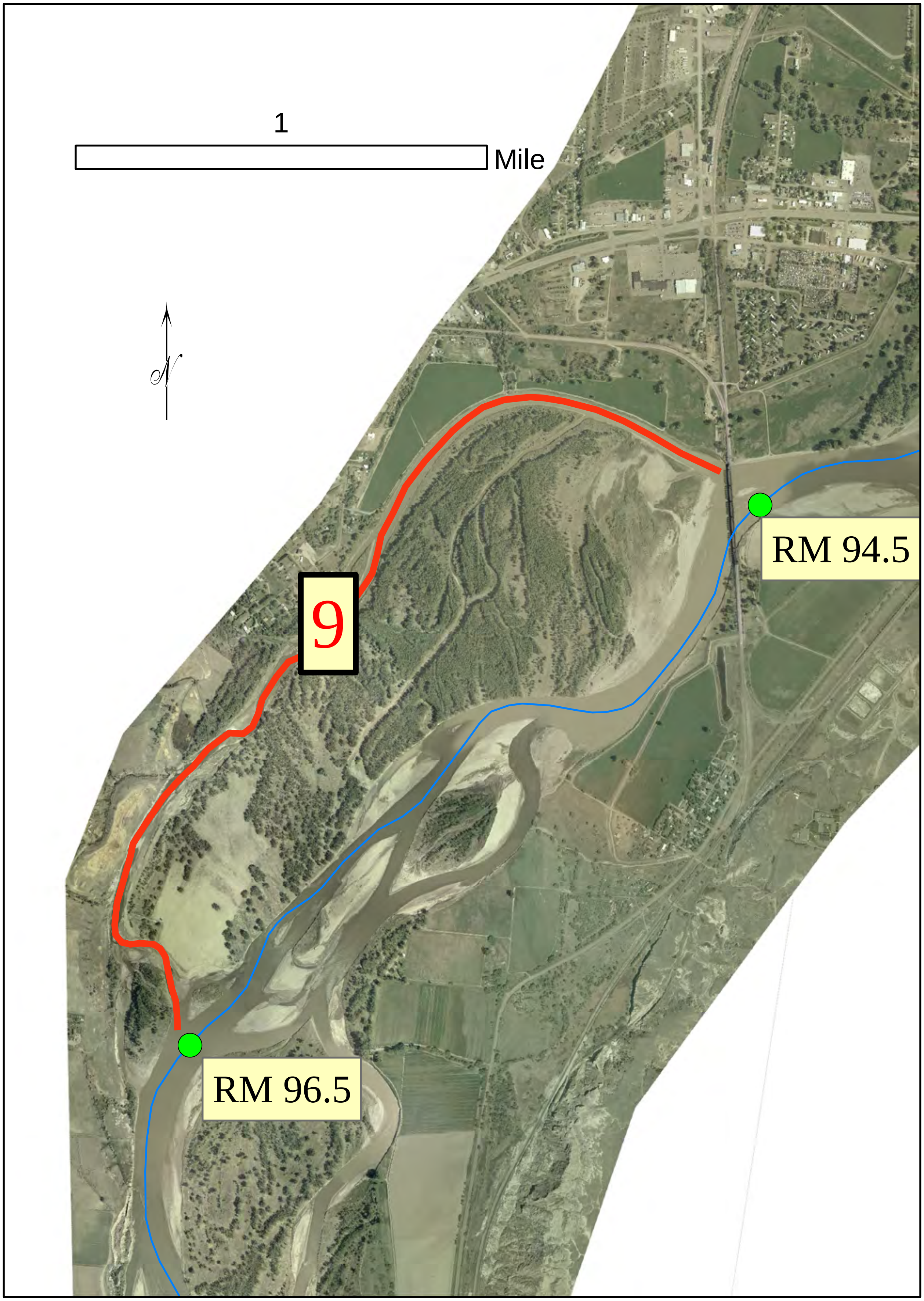
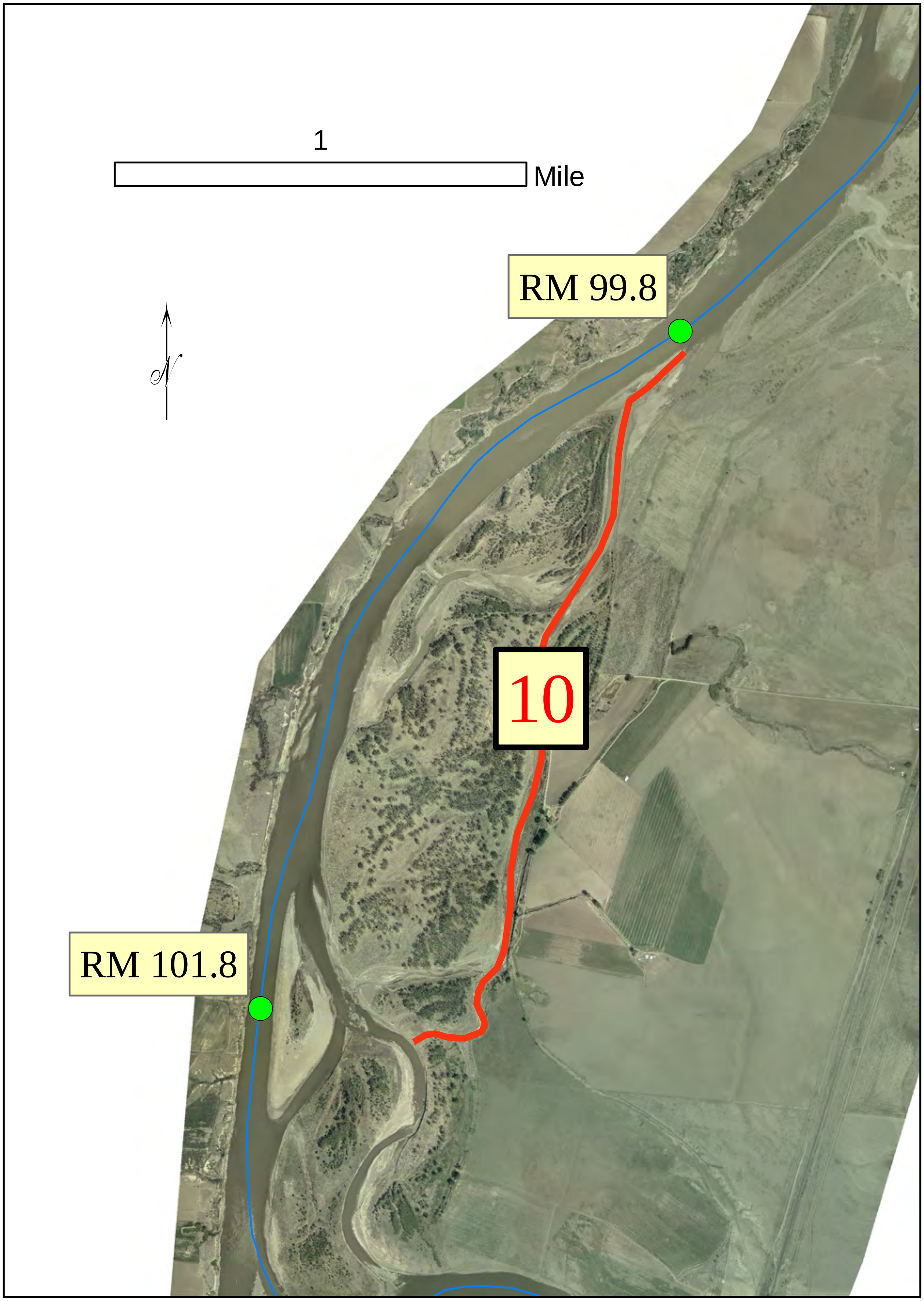

RM 62.7
RM 64.6
6
N
1
Mile


RM 70.8
RM 74.3
7
N
1
Mile


1
Mile
N
8
RM 90.0
RM 90.8


1
Mile
N
9
RM 94.5
RM 96.5


1
Mile
N
RM 99.8
10
RM 101.8

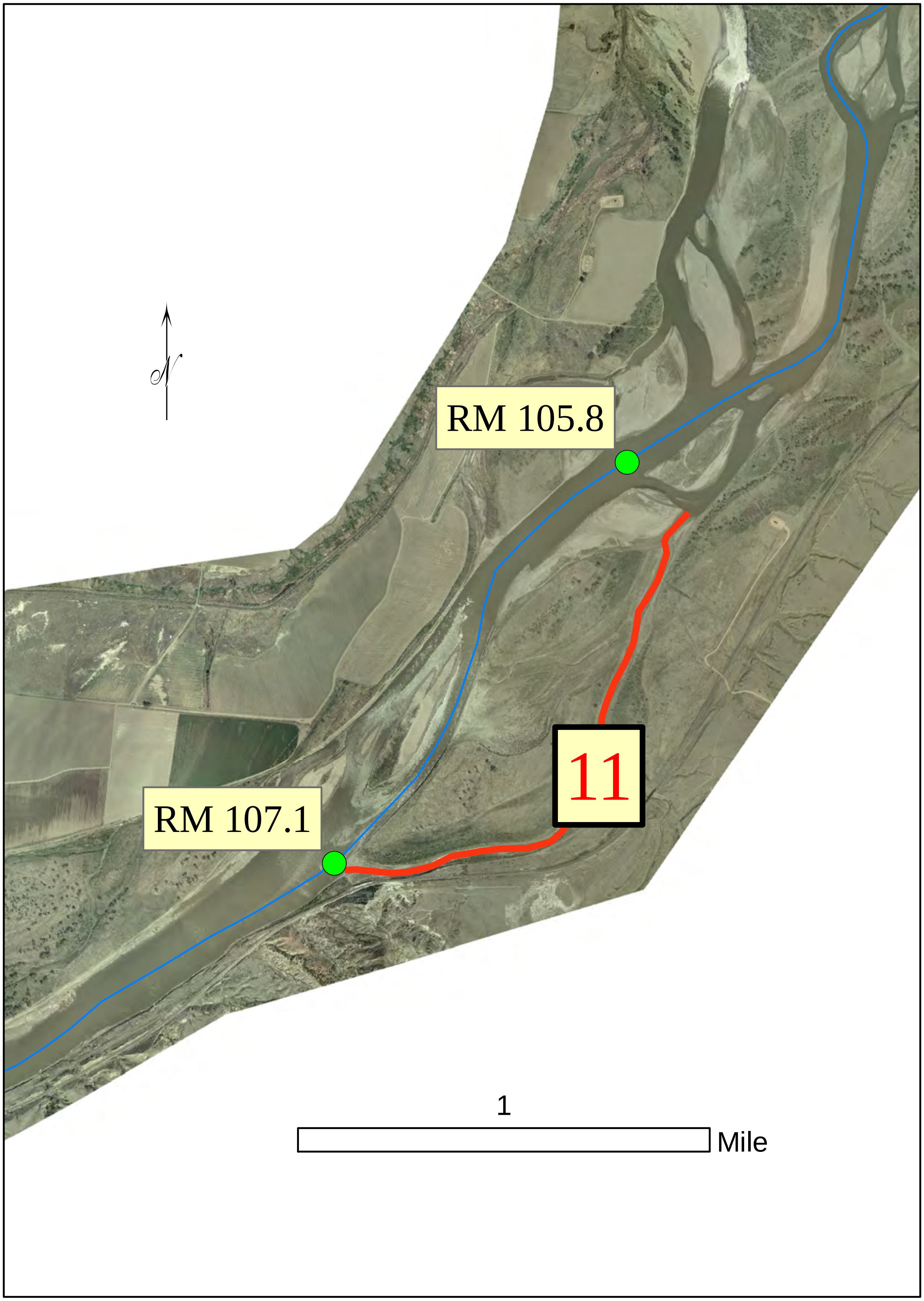
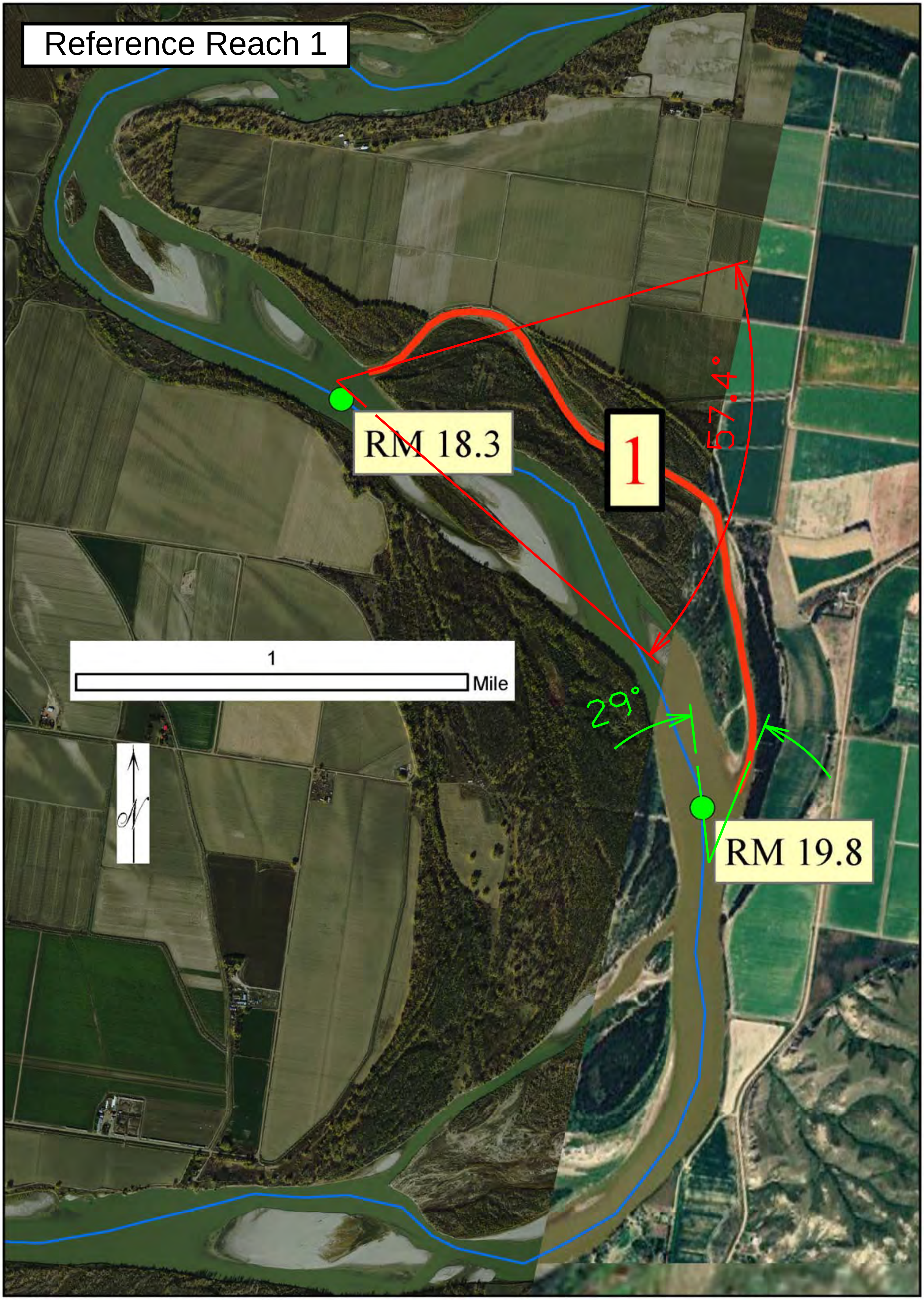


Plate 13

	Downstream End (fish entrance)	Upstream End (fish exit)
Side Channel	Approximate angle (degrees)	
1	27	45
2	38	44
3	38	55
4	12	38
5	39	85
6	37	53
7	53	38
8	48	85
9	57	65
Maximum	57	85
Average	39	56
Minimum	12	38
Proposed bypass	26	31

	Downstream End (fish entrance)	Upstream End (fish exit)
Reference Reach	Approximate angle (degrees)	
1	57	29
2	43	77
3	90	61
4	98	35
5	32	42
6	39	85
7	37	79
8	55	34
9	98	46
10	12	90
11	59	40
Maximum	98	90
Average	56	56
Minimum	12	29
Proposed bypass	26	31



Reference Reach 1
RM 18.3
1
57.4°
29°
1
Mile
N
RM 19.8

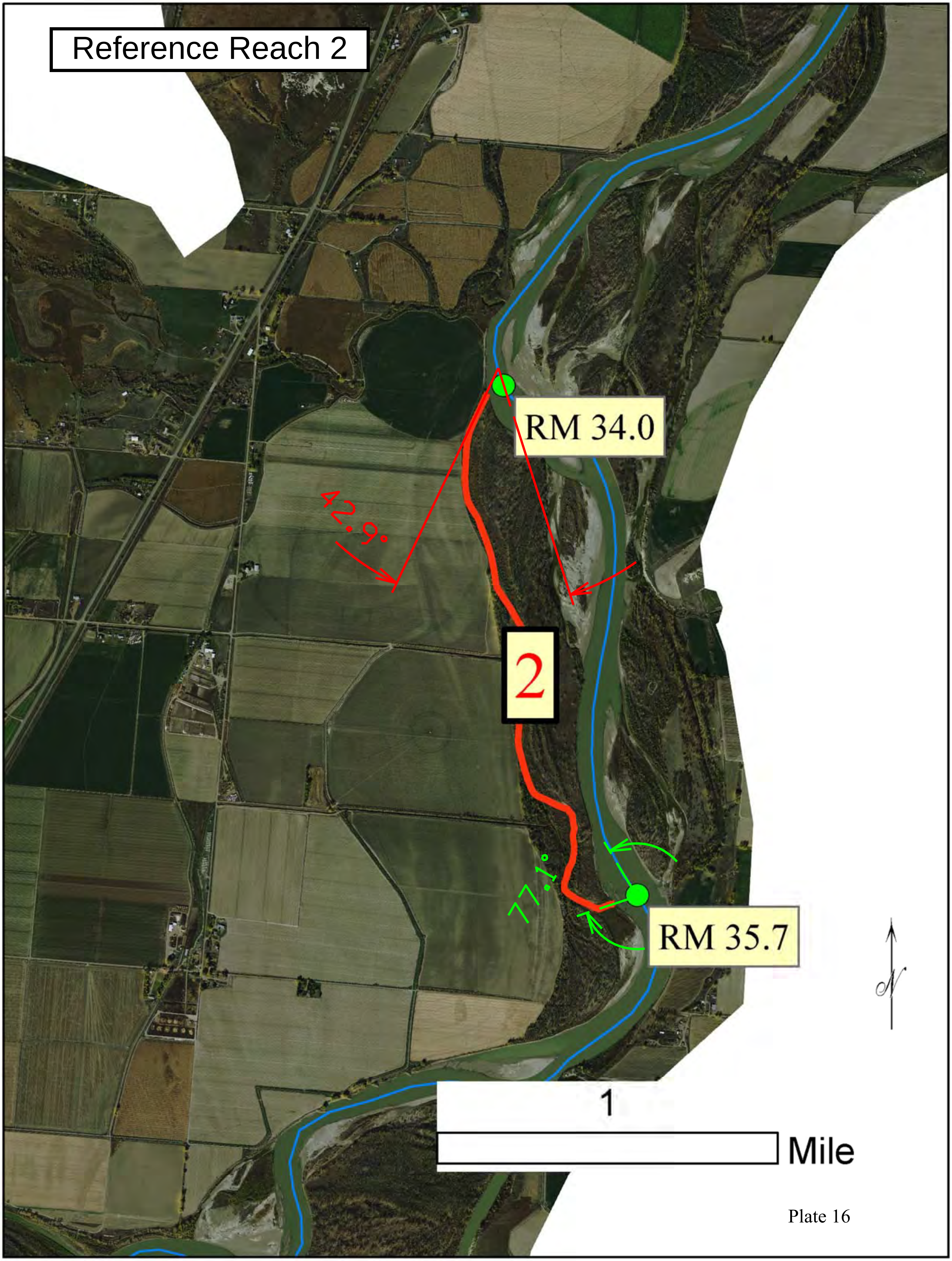
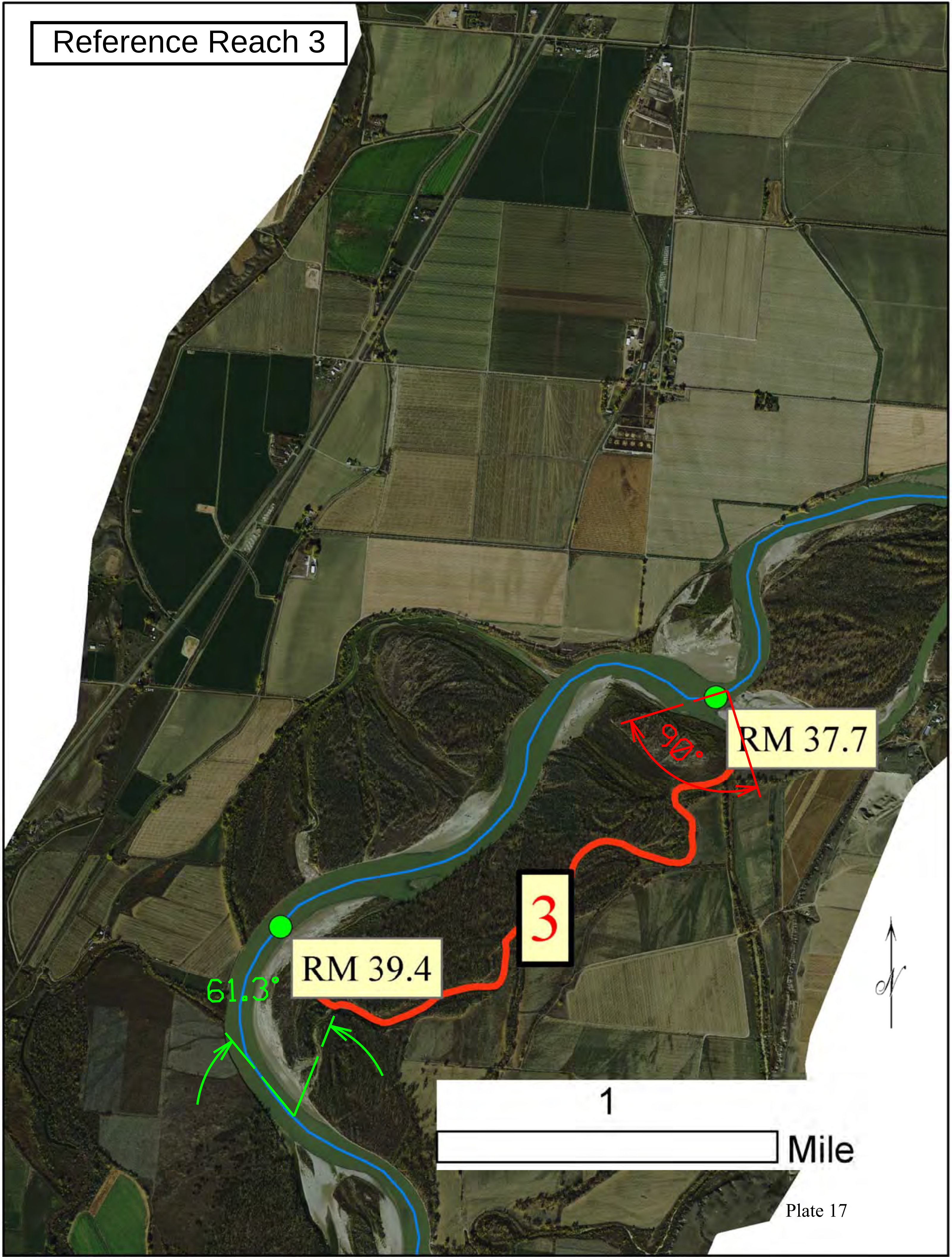


Plate 16

Reference Reach 3



Reference Reach 4

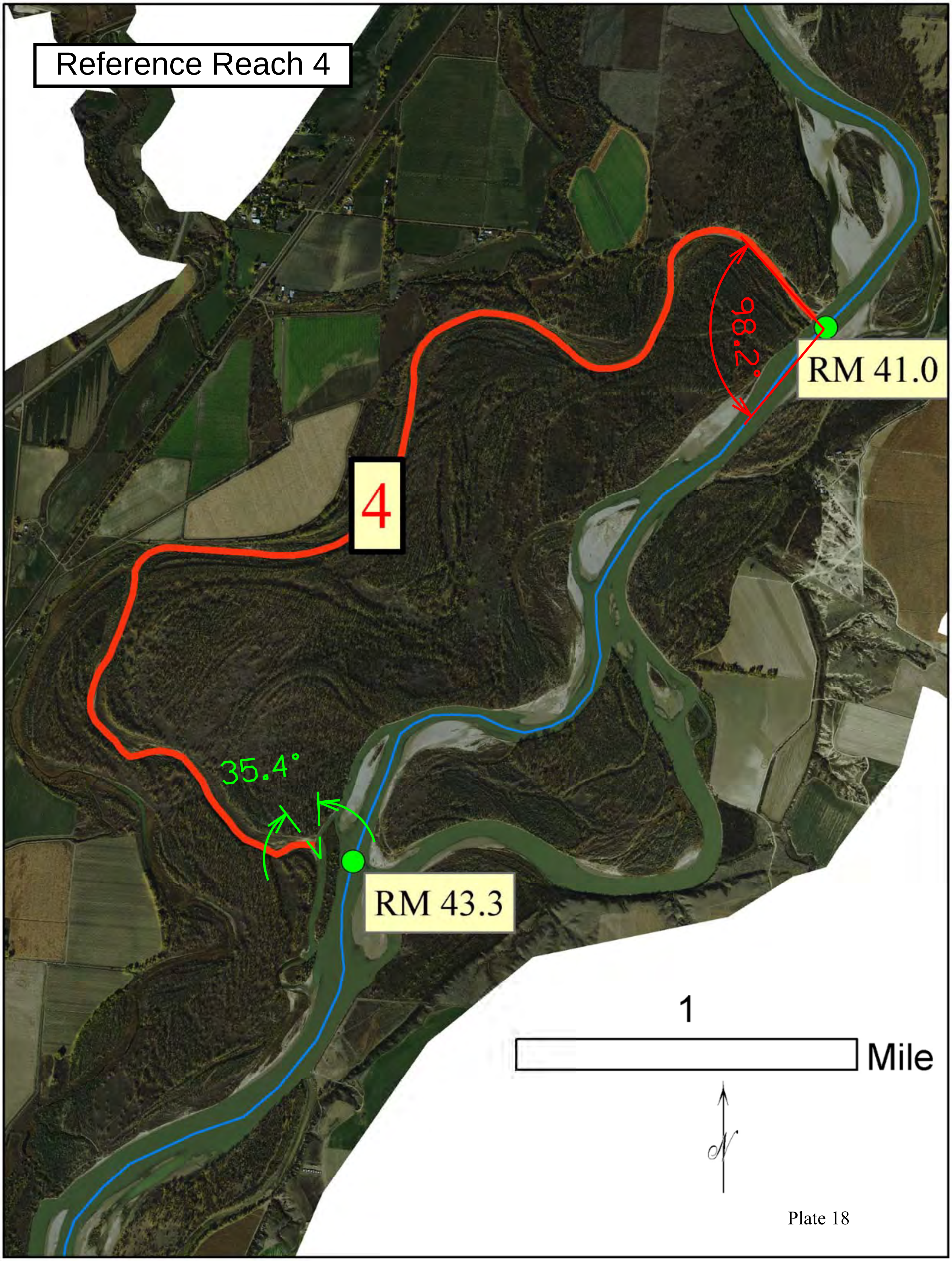
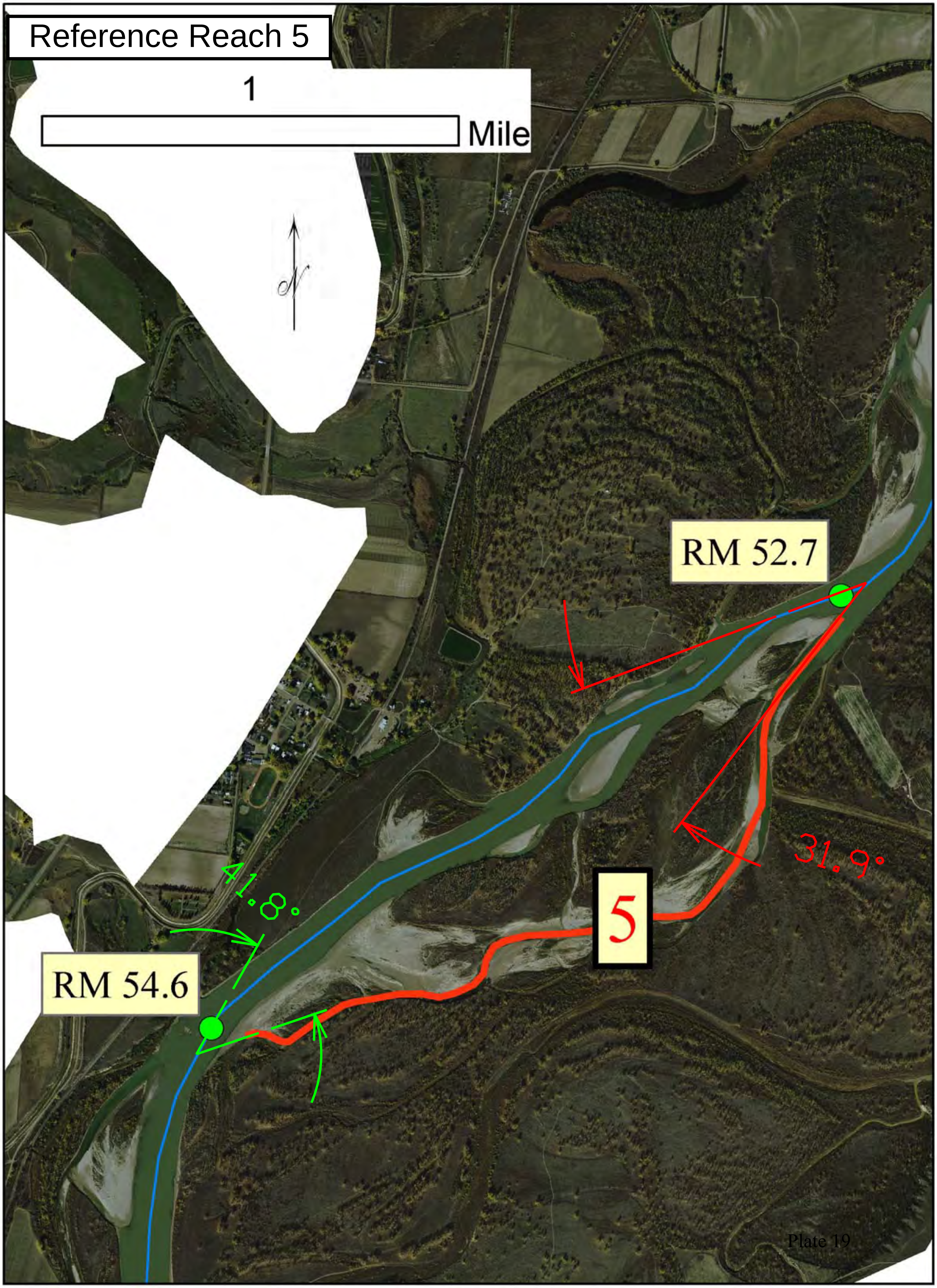
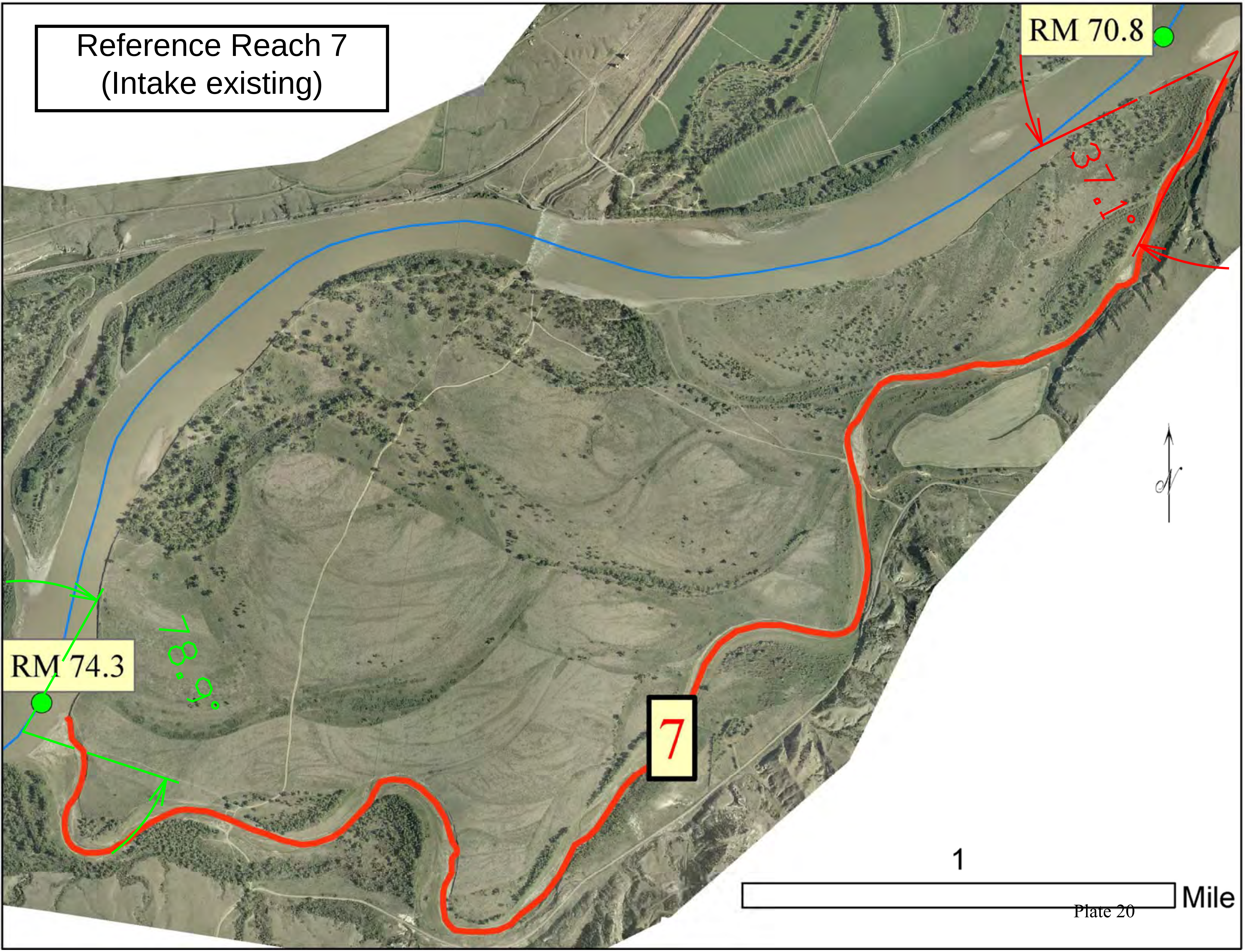
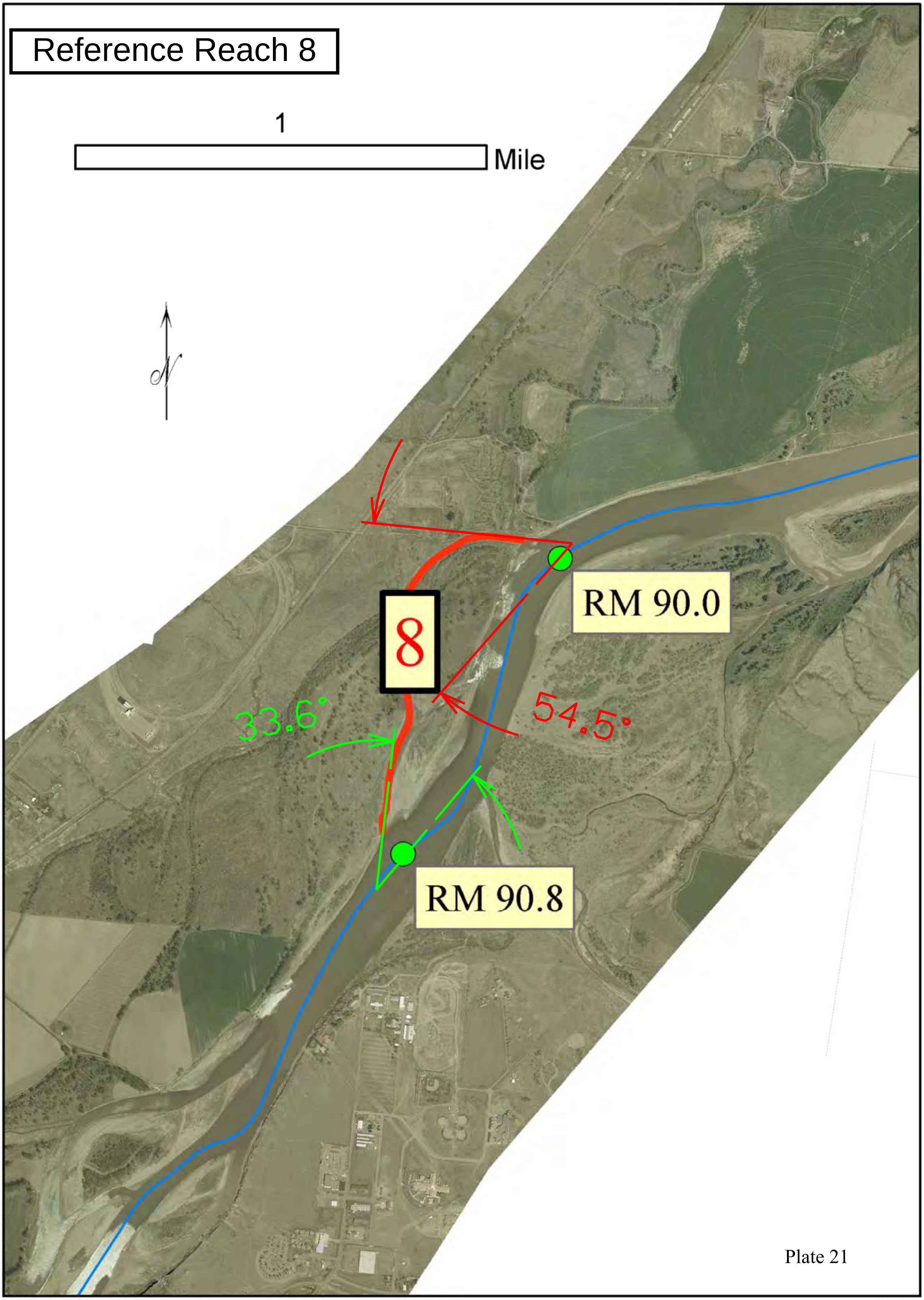
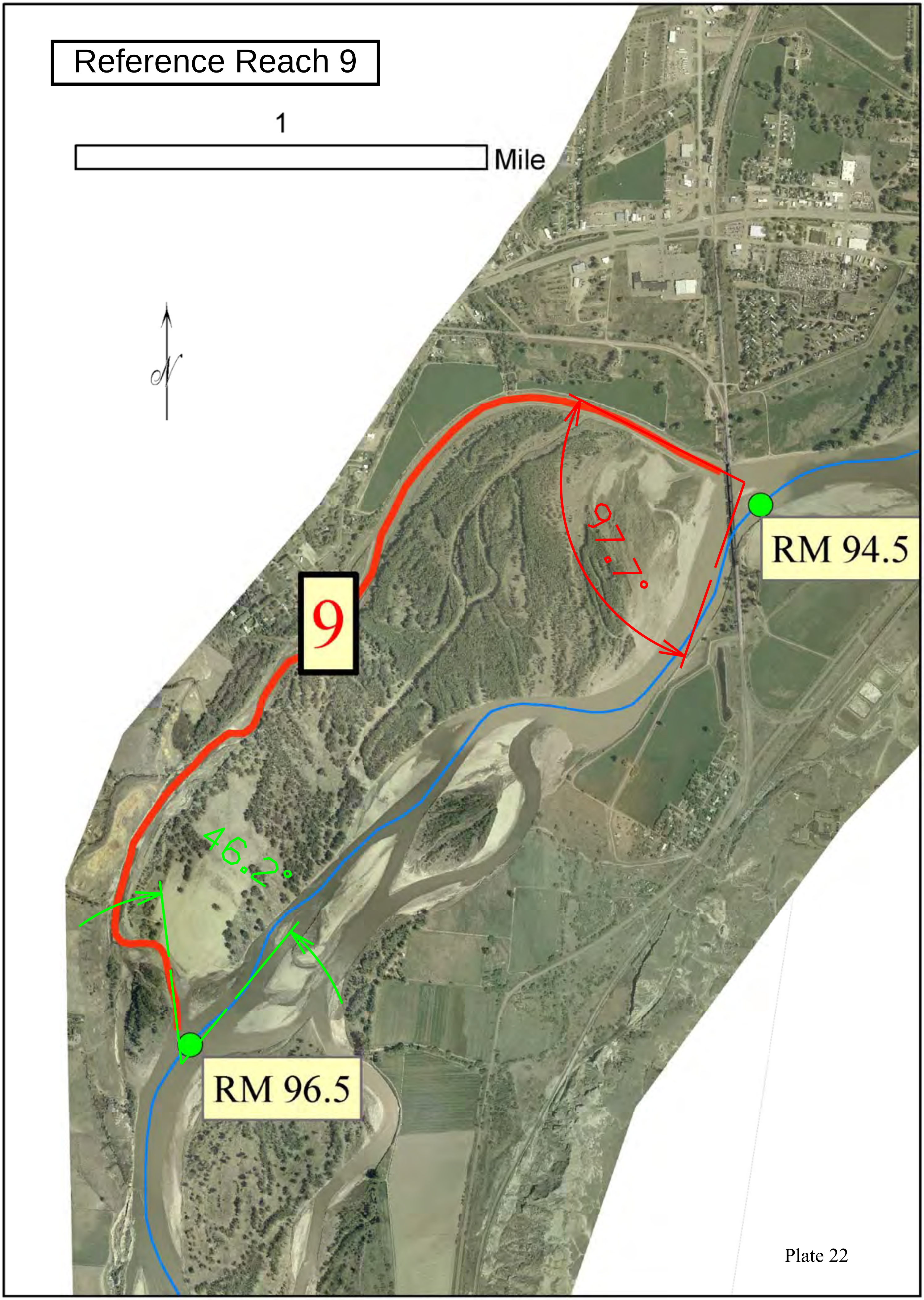


Plate 18


Reference Reach 5
1
Mile
N
RM 52.7
RM 54.6
41.8°
31.9°
5


Reference Reach 7
(Intake existing)
RM 70.8
37.1°
RM 74.3
78.9°
7
1
Mile


Reference Reach 8
1
Mile
N
8
33.6°
54.5°
RM 90.0
RM 90.8


Reference Reach 9
1
Mile
N
9
97.7°
46.2°
RM 94.5
RM 96.5

Reference Reach 10

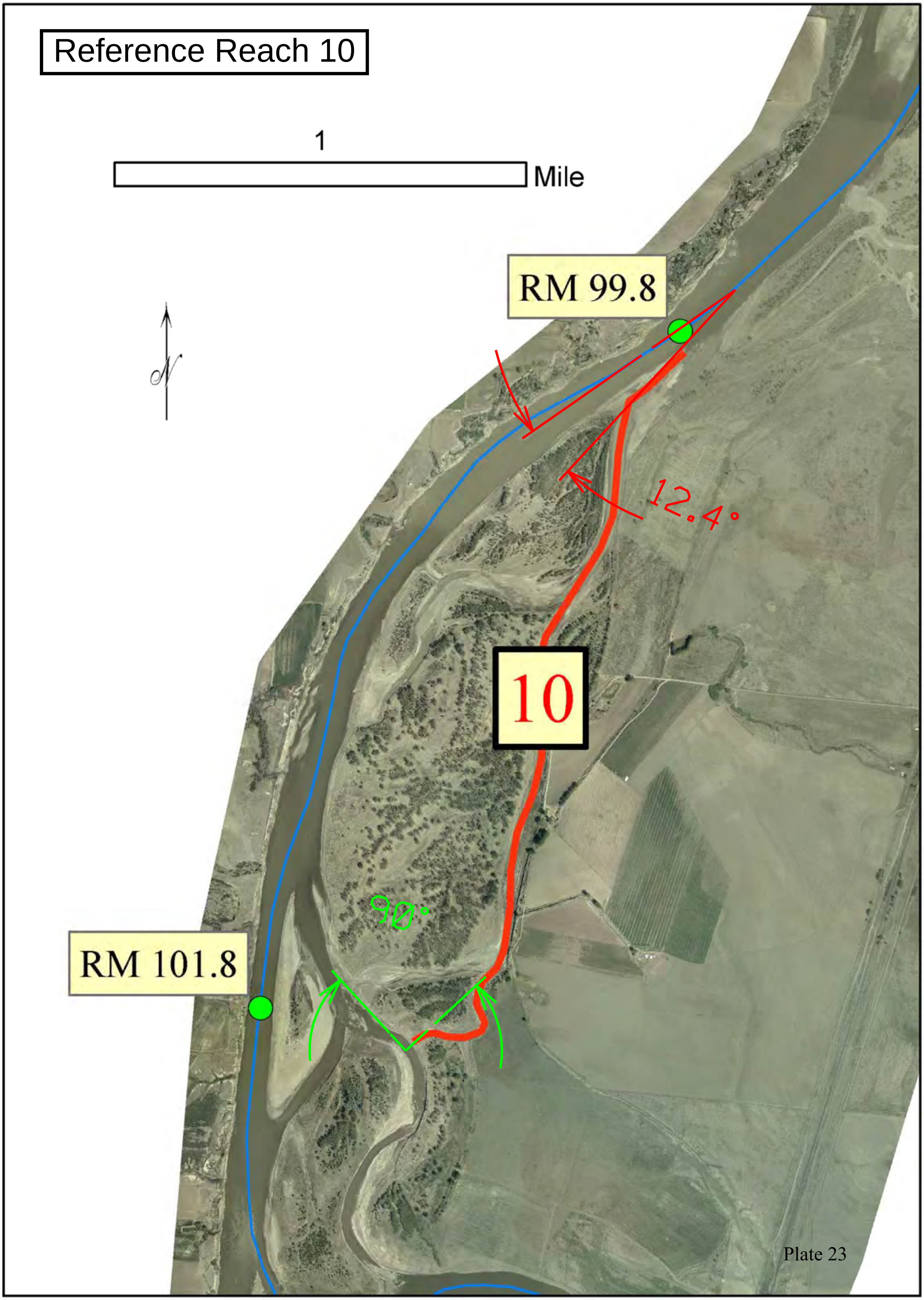
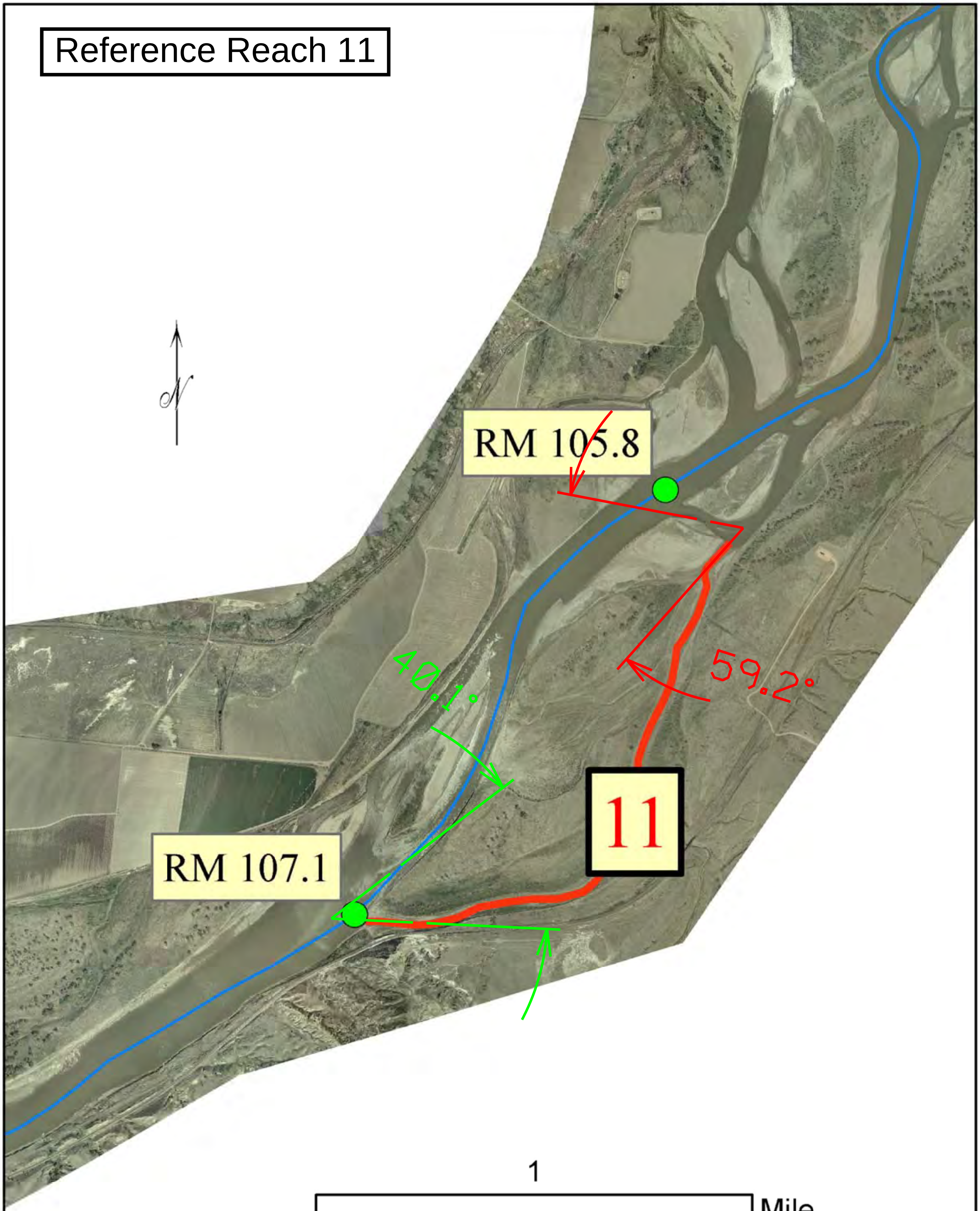
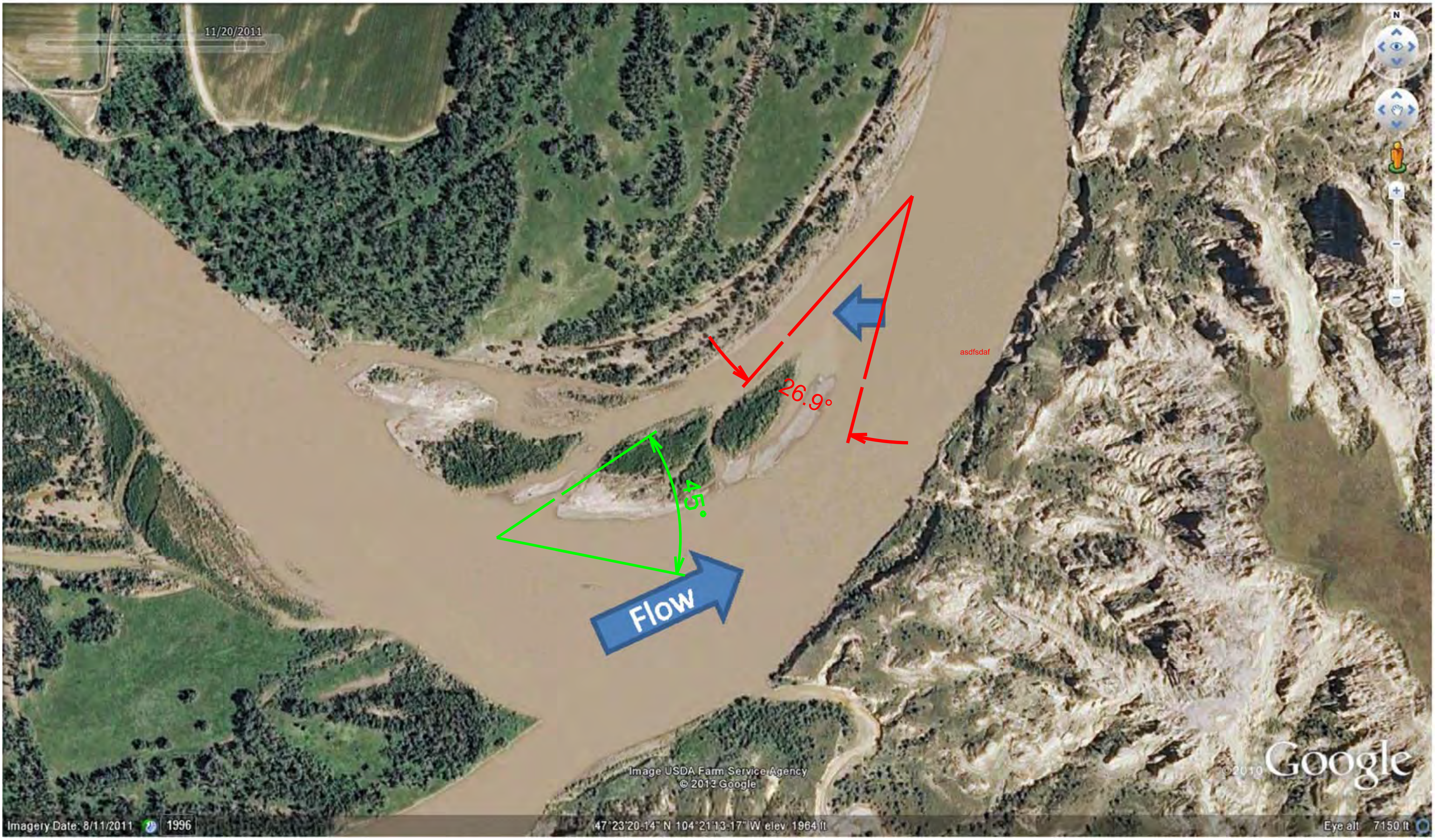


Plate 23

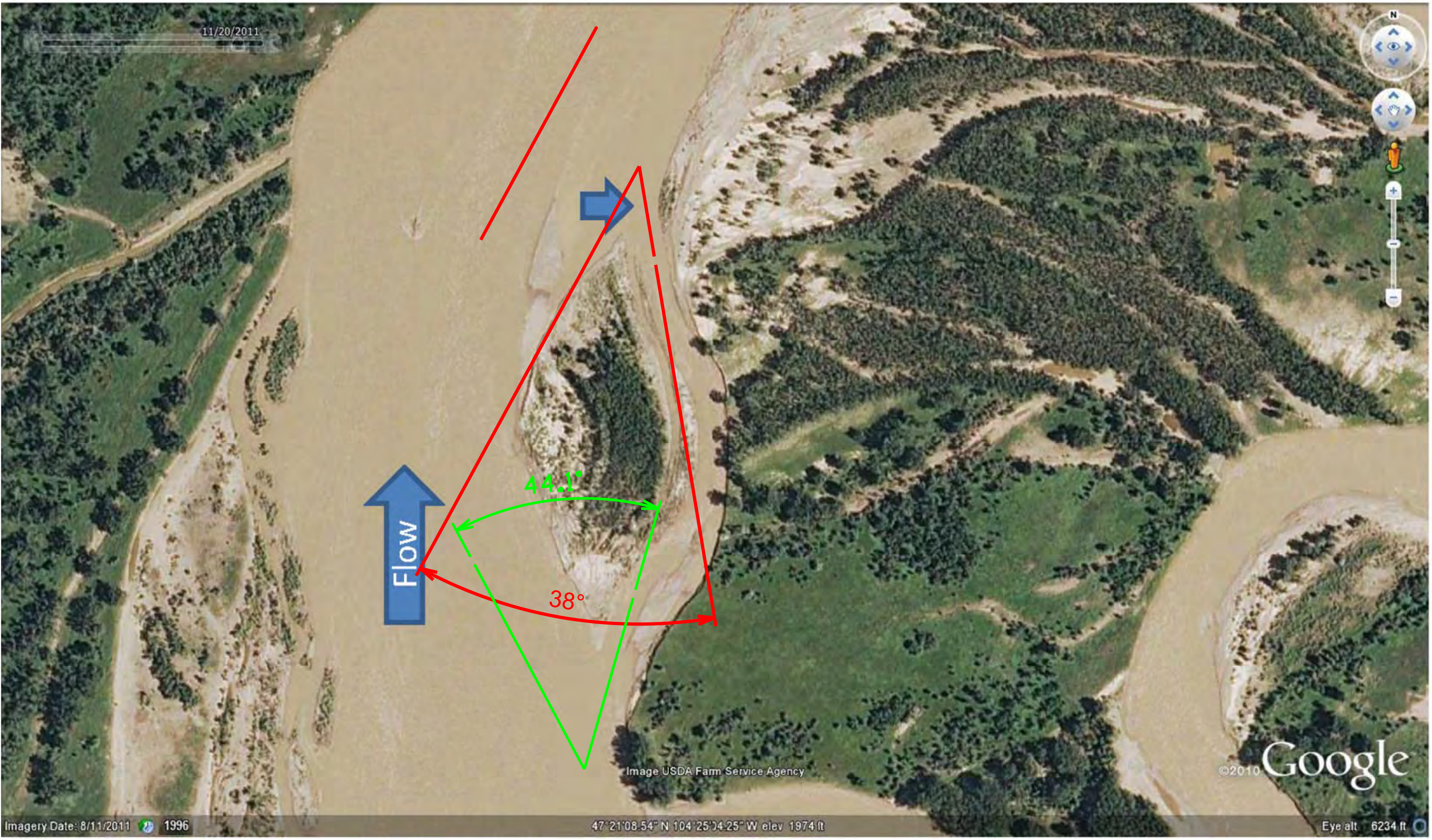
Reference Reach 11



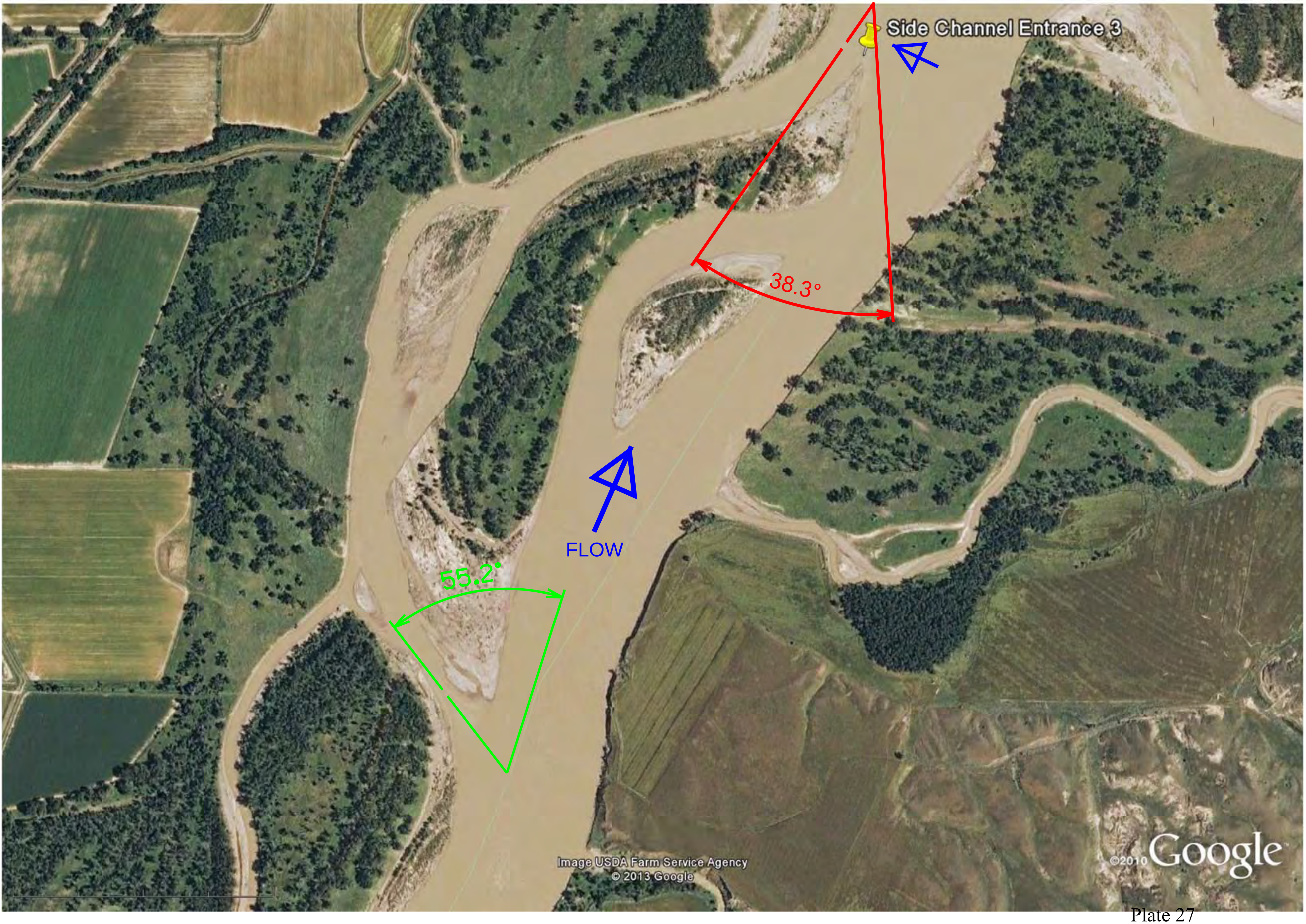
Side Channel 1



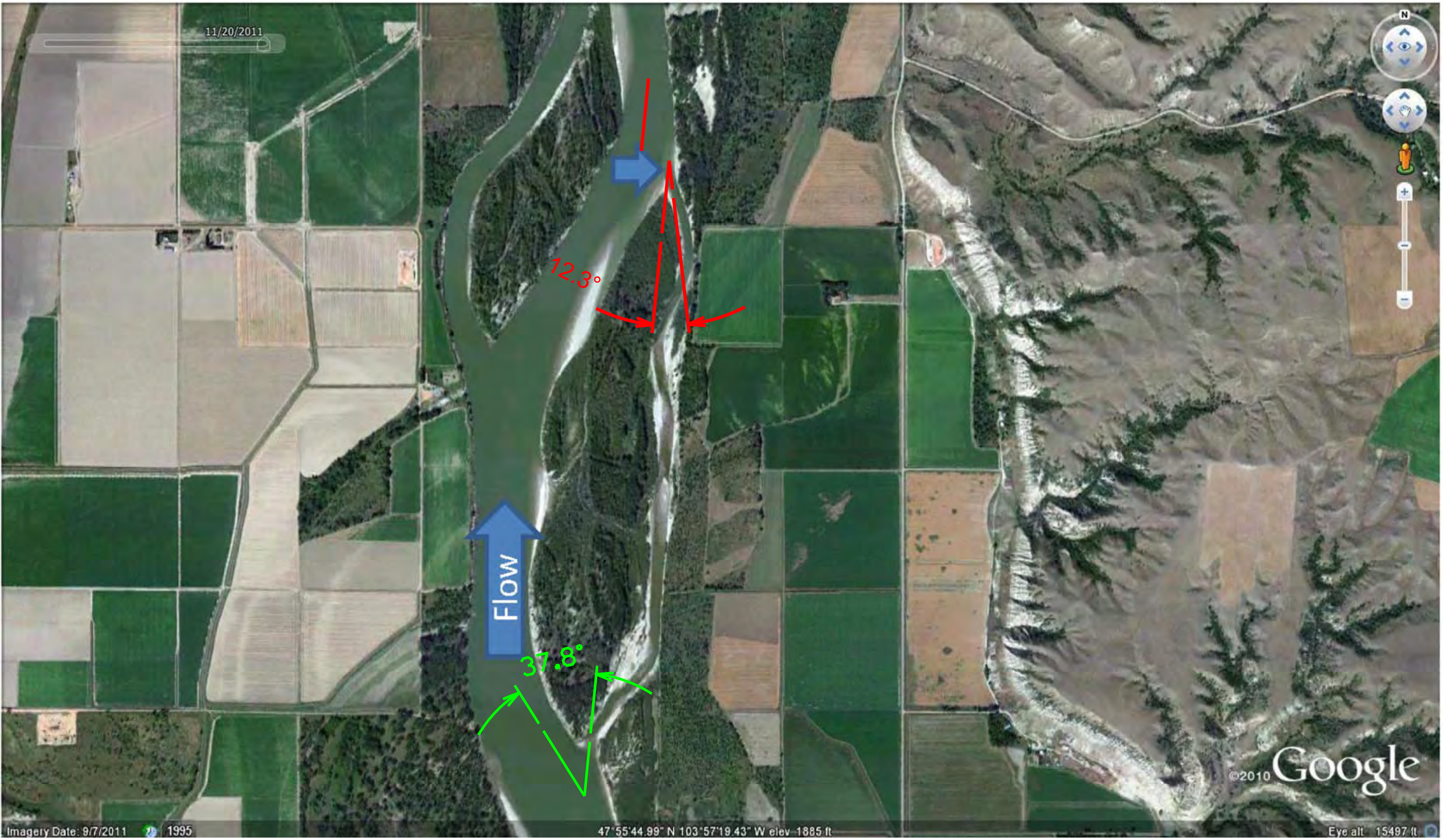
Side Channel 2



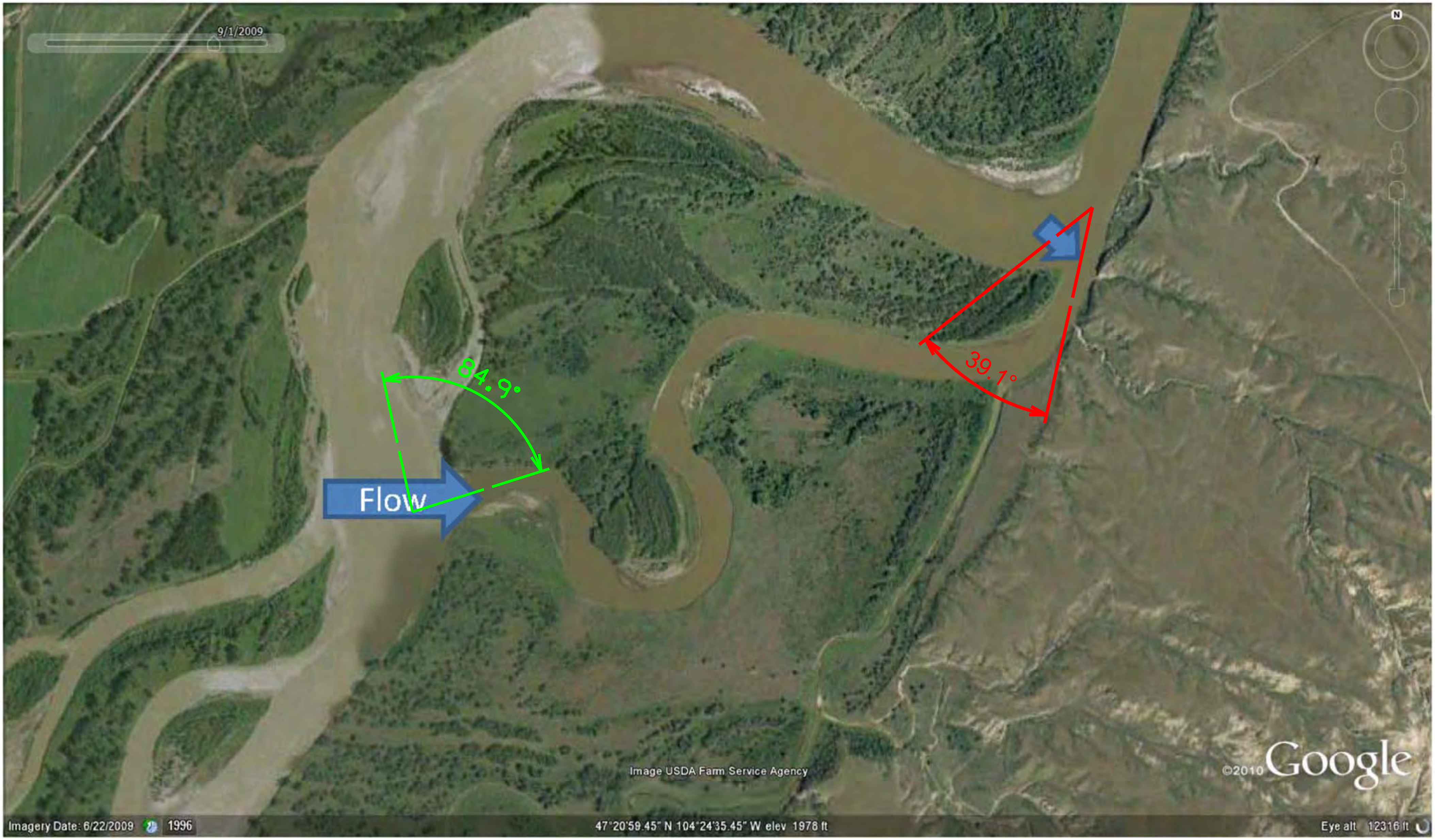
Side Channel 3



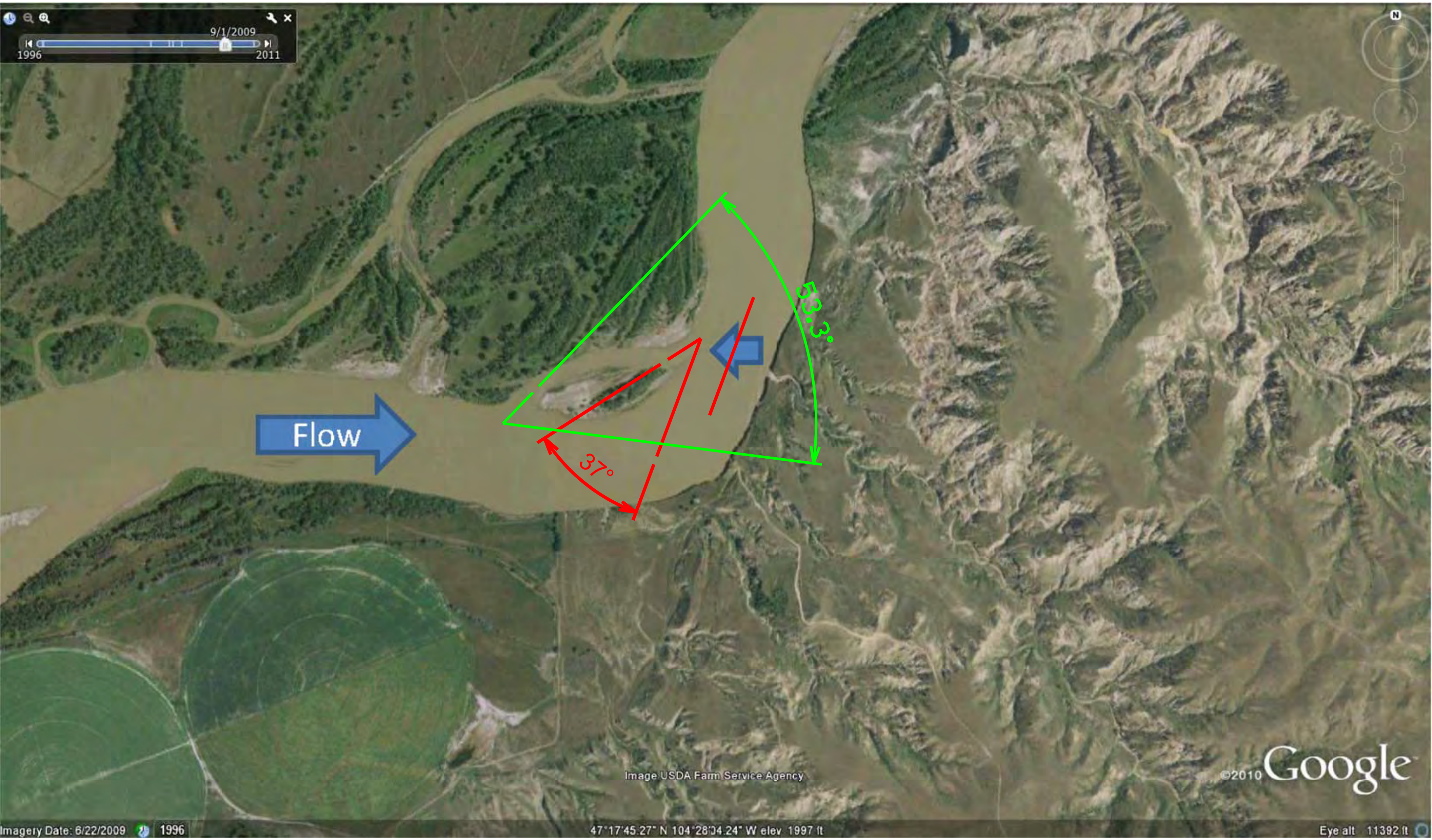
Side Channel 4



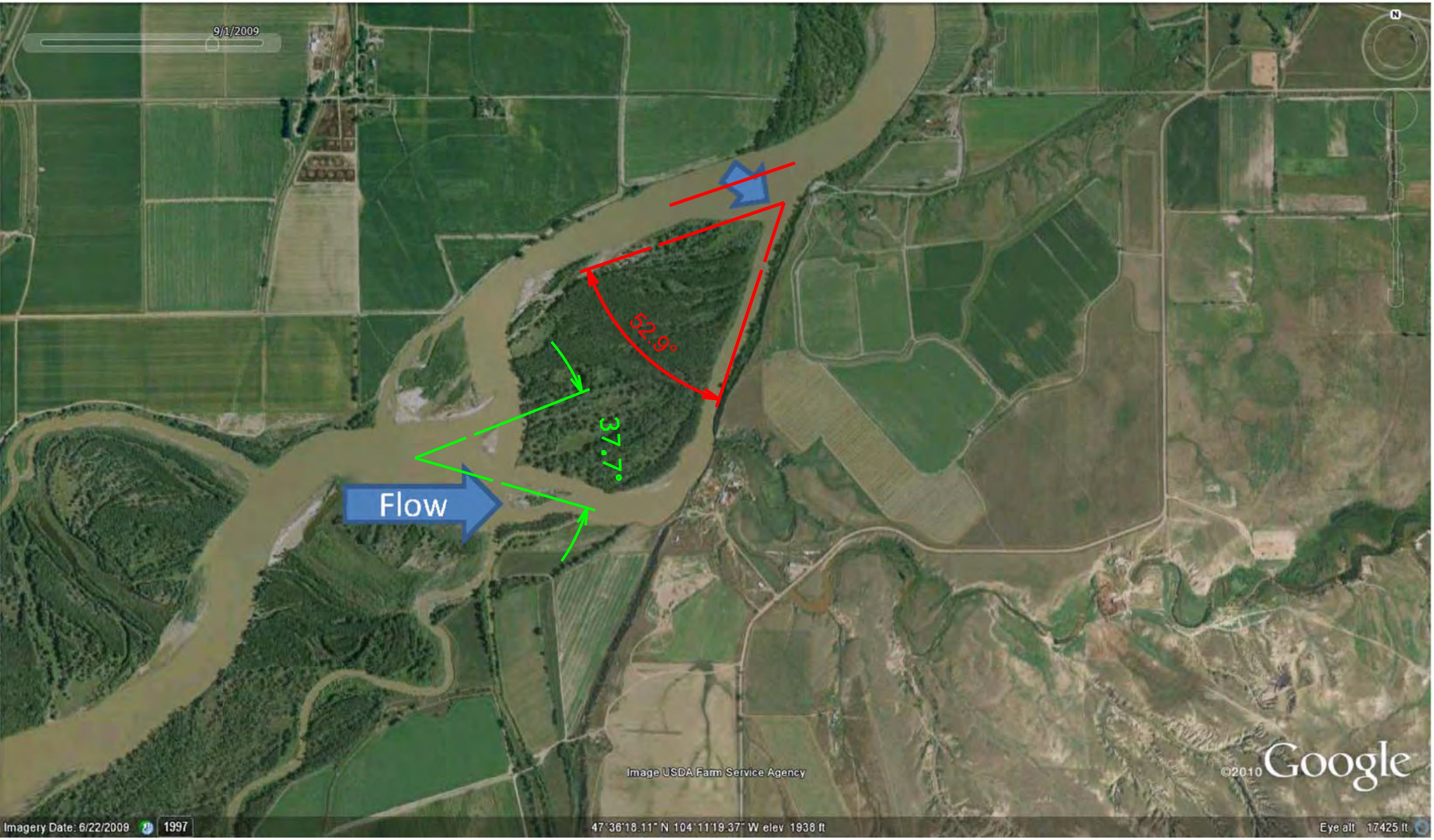
Side Channel 5



Side Channel 6



Side Channel 7



Side Channel 8

Side Channel 9

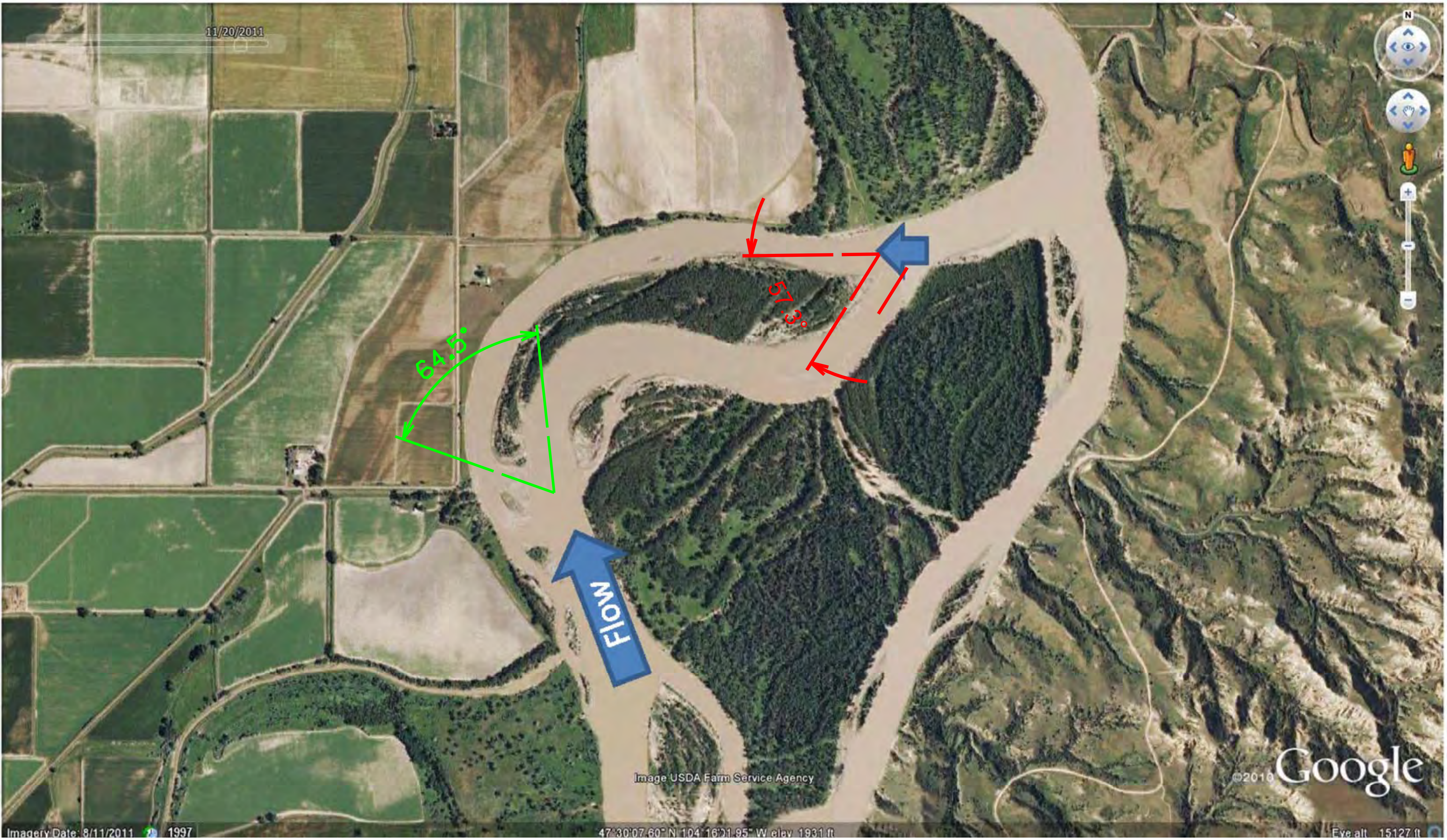
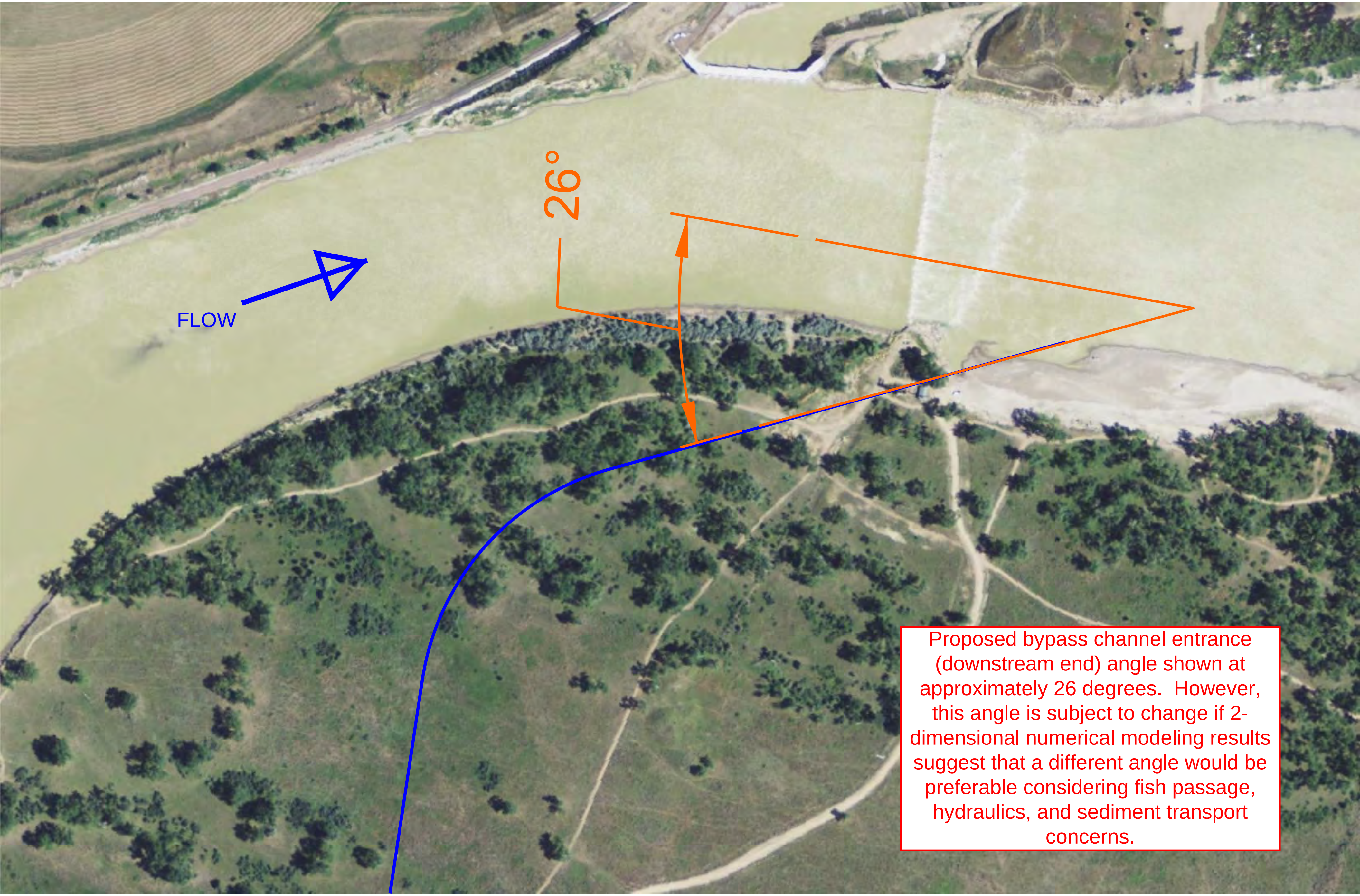


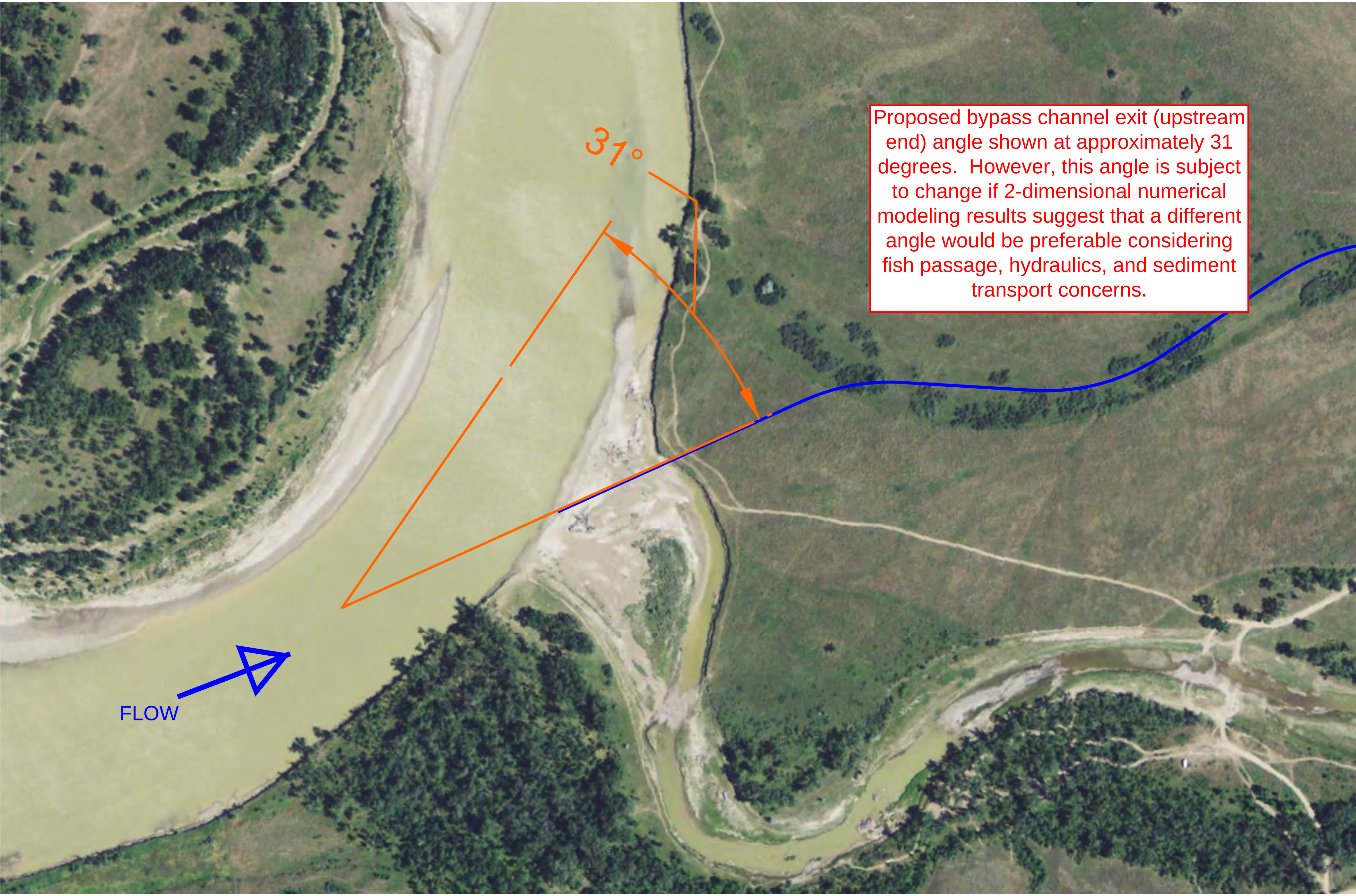
Plate 33

Proposed Bypass - Downstream end



Proposed bypass channel entrance (downstream end) angle shown at approximately 26 degrees. However, this angle is subject to change if 2-dimensional numerical modeling results suggest that a different angle would be preferable considering fish passage, hydraulics, and sediment transport concerns.

Proposed Bypass - Upstream end



Proposed bypass channel exit (upstream end) angle shown at approximately 31 degrees. However, this angle is subject to change if 2-dimensional numerical modeling results suggest that a different angle would be preferable considering fish passage, hydraulics, and sediment transport concerns.

Reference Reach (from 30% DDR)	Bend# (d/s to u/s)	Approx. Radius	Avg
		(ft)	(ft)
1	1	790	1030
	2	1290	
	3	530	
	4	1520	
2	1	1390	930
	2	1350	
	3	1420	
	4	330	
	5	180	
3	1	510	430
	2	190	
	3	250	
	4	540	
	5	240	
	6	870	
	7	410	
4	1	740	700
	2	860	
	3	1210	
	4	1790	
	5	500	
	6	550	
	7	210	
	8	560	
	9	200	
	10	350	
5	1	800	890
	2	1230	
	3	330	
	4	660	
	5	2130	
	6	190	
6 (Same as side channel 5)	1	800	620
	2	590	
	3	620	
	4	470	

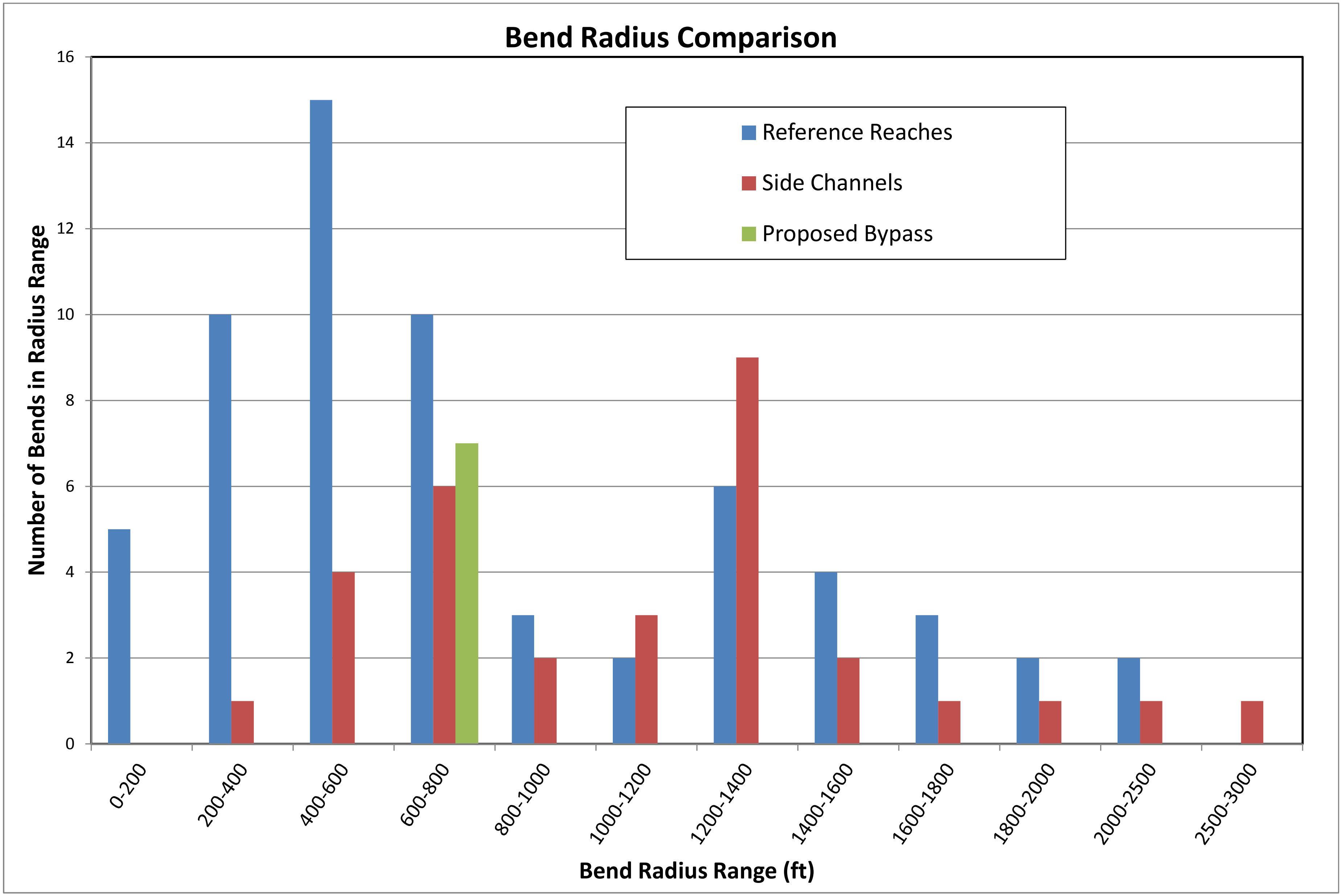
Reference Reach (from 30% DDR)	Bend# (d/s to u/s)	Approx. Radius	Avg
		(ft)	(ft)
7 (Intake existing high flow chute)	1	1630	650
	2	710	
	3	370	
	4	720	
	5	410	
	6	480	
	7	700	
	8	450	
	9	340	
8	1	1120	810
	2	490	
9	1	1600	1160
	2	1820	
	3	1860	
	4	280	
	5	230	
10	1	520	960
	2	1570	
	3	1030	
	4	1270	
	5	1750	
	6	450	
	7	160	
11	1	750	1260
	2	2220	
	3	820	

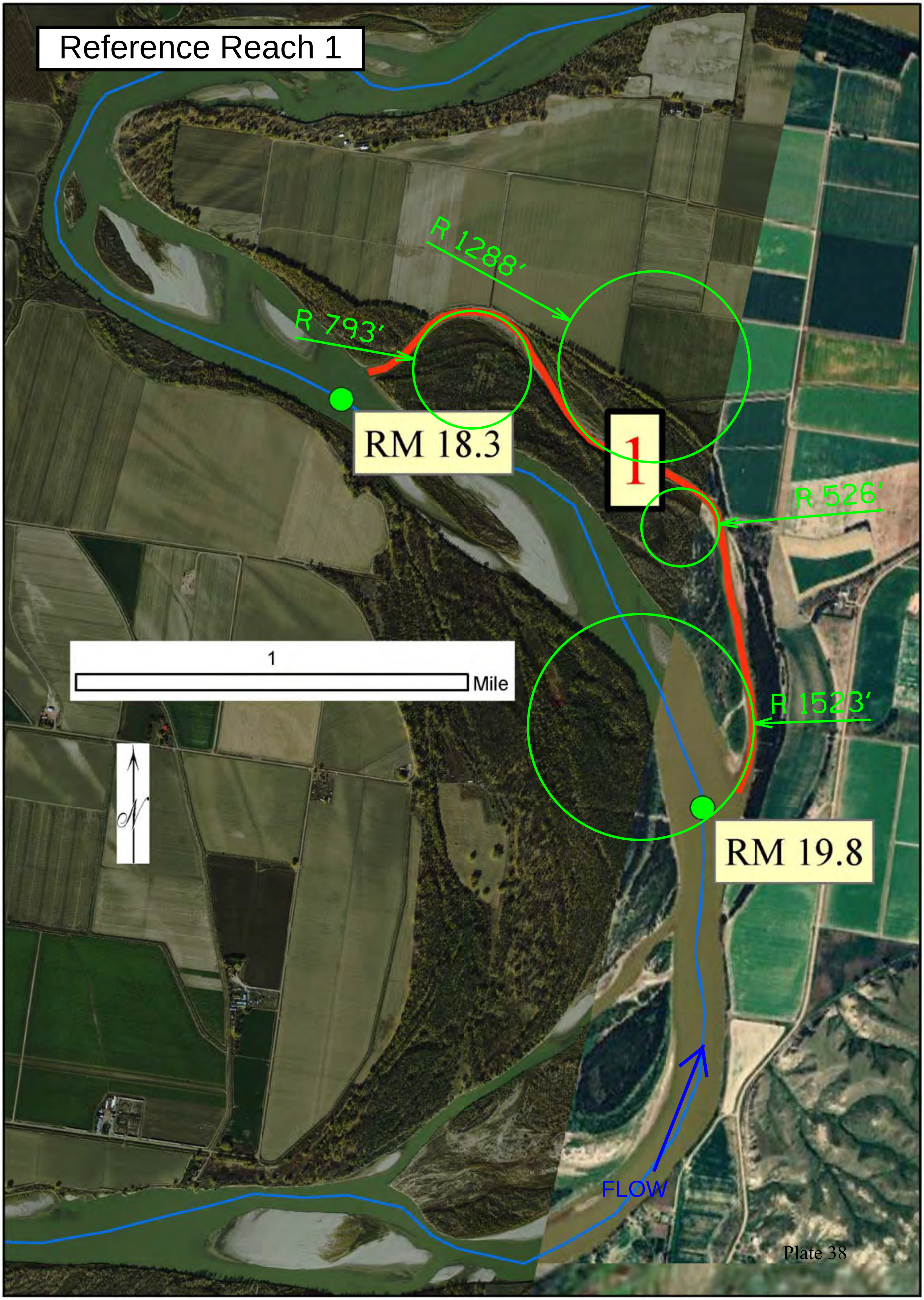
Reference Reach Minimum:	160
Reference Reach Average:	812
Reference Reach Maximum:	2220

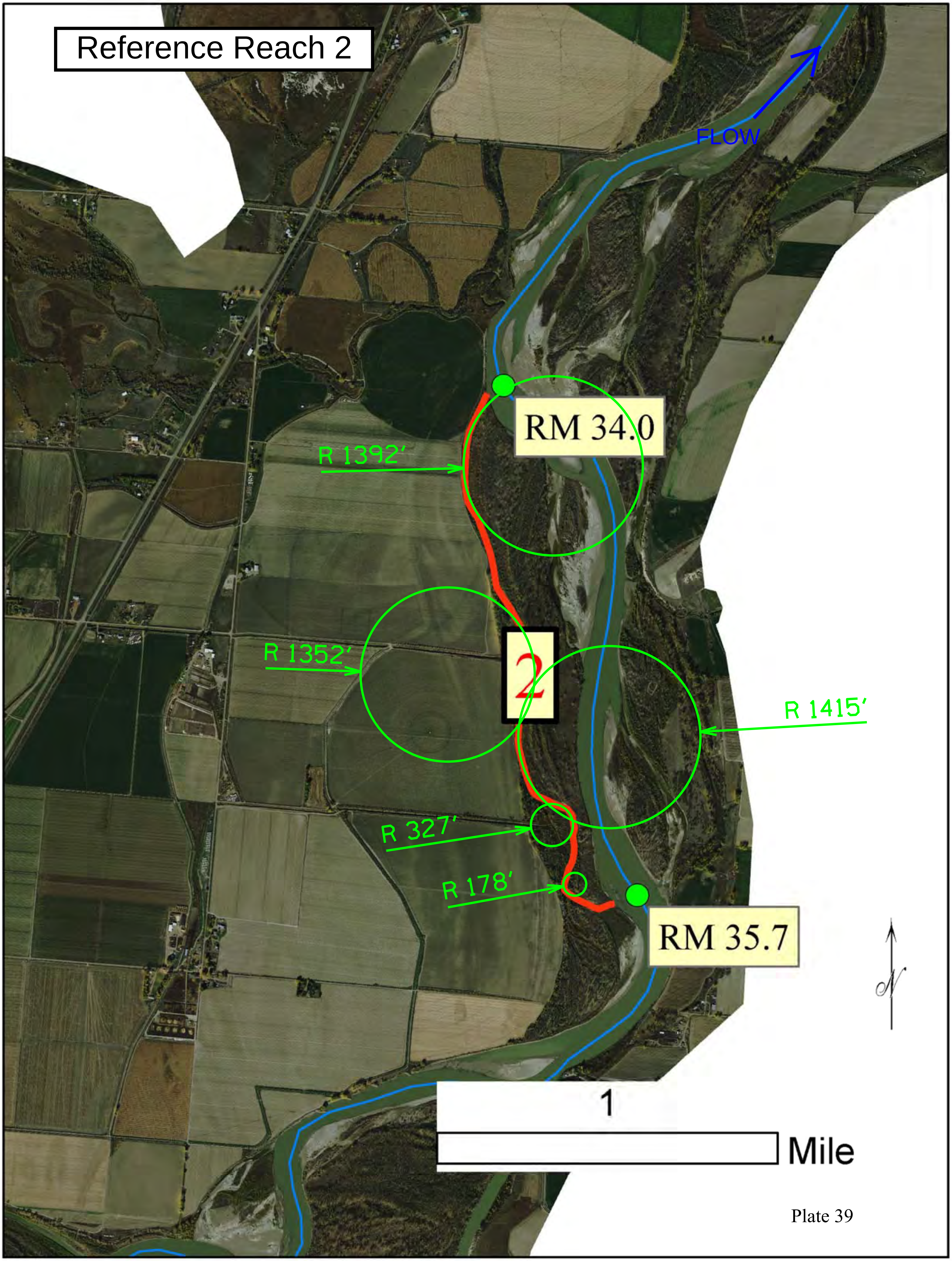
Proposed Bypass	**1-7**	**750**	**750**

Side Channel	Bend# (d/s to u/s)	Approx. Radius	Avg
		(ft)	(ft)
1	1	1330	1020
	2	580	
	3	1150	
2	1	700	720
	2	740	
3	1	1045	940
	2	1340	
	3	300	
	4	810	
	5	1220	
4	1	1210	940
	2	840	
	3	1270	
	4	610	
	5	760	
5 (same as reference reach 6)	1	800	620
	2	590	
	3	620	
	4	470	
6	1	1220	1220
7	1	2450	1690
	2	1050	
	3	1570	
8	1	1360	1320
	2	560	
	3	1380	
	4	1370	
	5	1710	
	6	1560	
9	1	2730	2300
	2	1870	

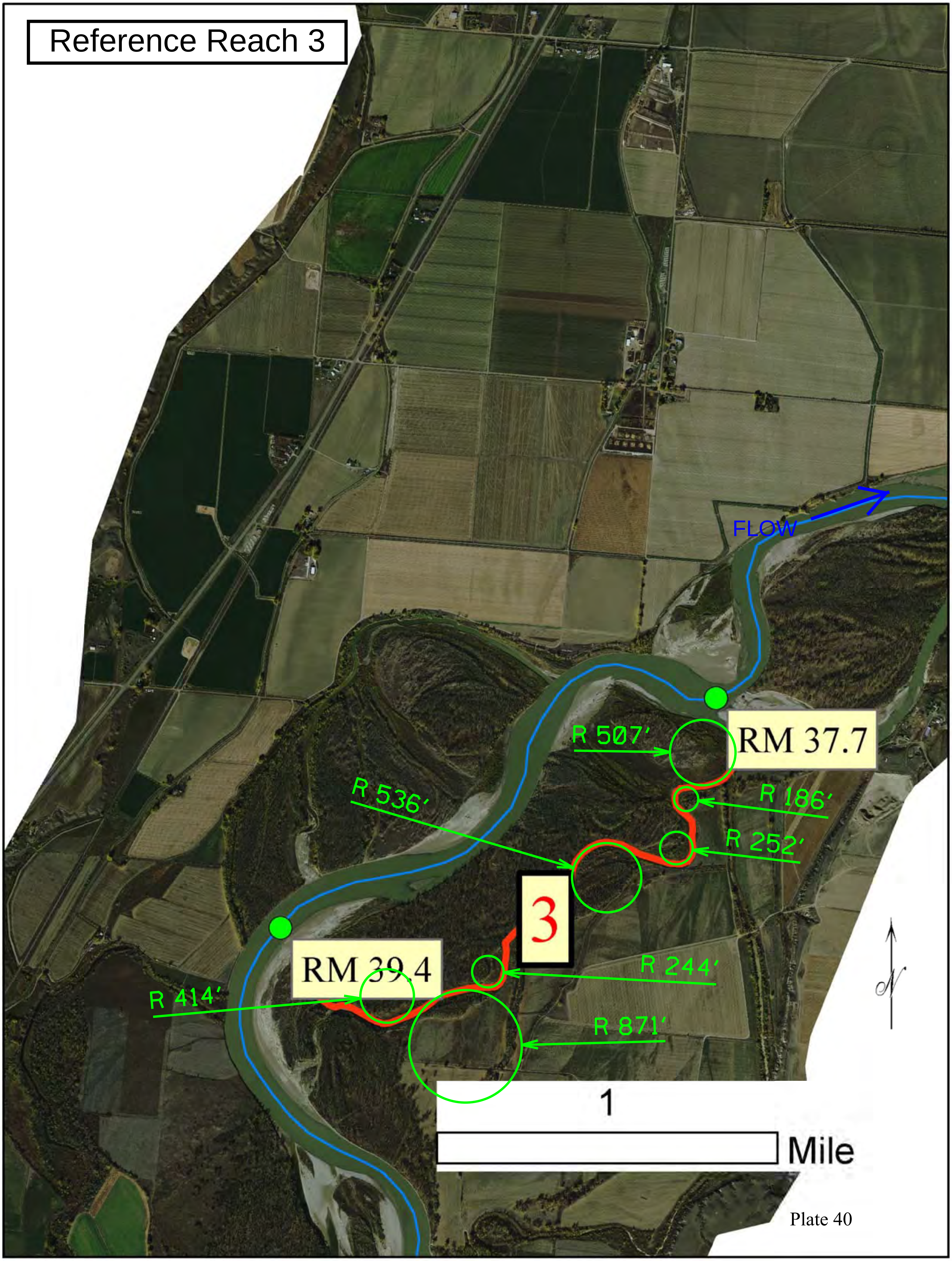
Side Channel Minimum:	300
Side Channel Average:	1136
Side Channel Maximum:	2730


Bend Radius Comparison
Reference Reaches
Side Channels
Proposed Bypass
Number of Bends in Radius Range
Bend Radius Range (ft)
0
2
4
6
8
10
12
14
16
0-200
200-400
400-600
600-800
800-1000
1000-1200
1200-1400
1400-1600
1600-1800
1800-2000
2000-2500
2500-3000


Reference Reach 1
R 1288'
R 793'
RM 18.3
1
R 526'
1
Mile
R 1523'
N
RM 19.8
FLOW


Reference Reach 2
FLOW
RM 34.0
R 1392'
R 1352'
2
R 1415'
R 327'
R 178'
RM 35.7
1
Mile
N

Reference Reach 3



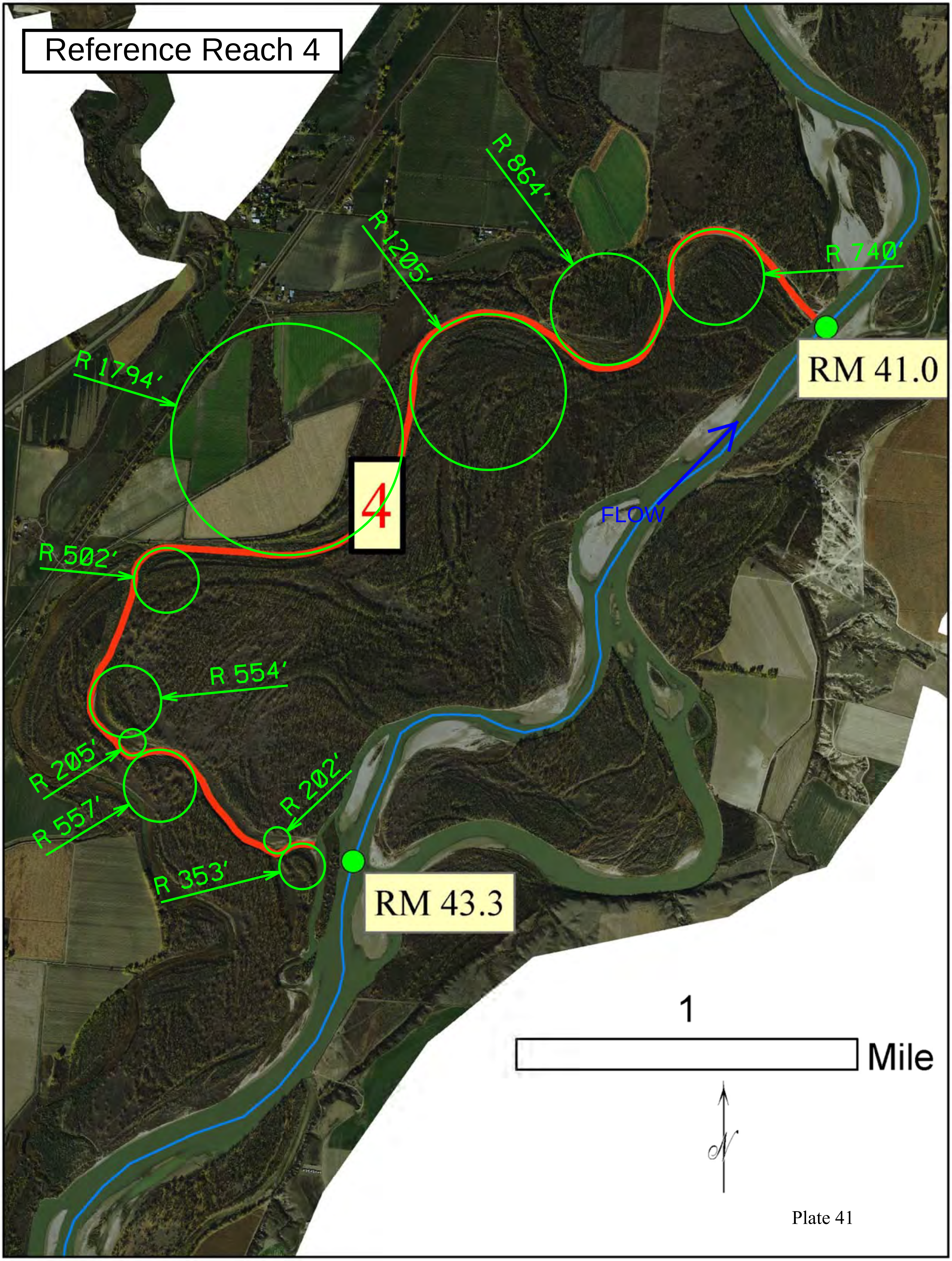
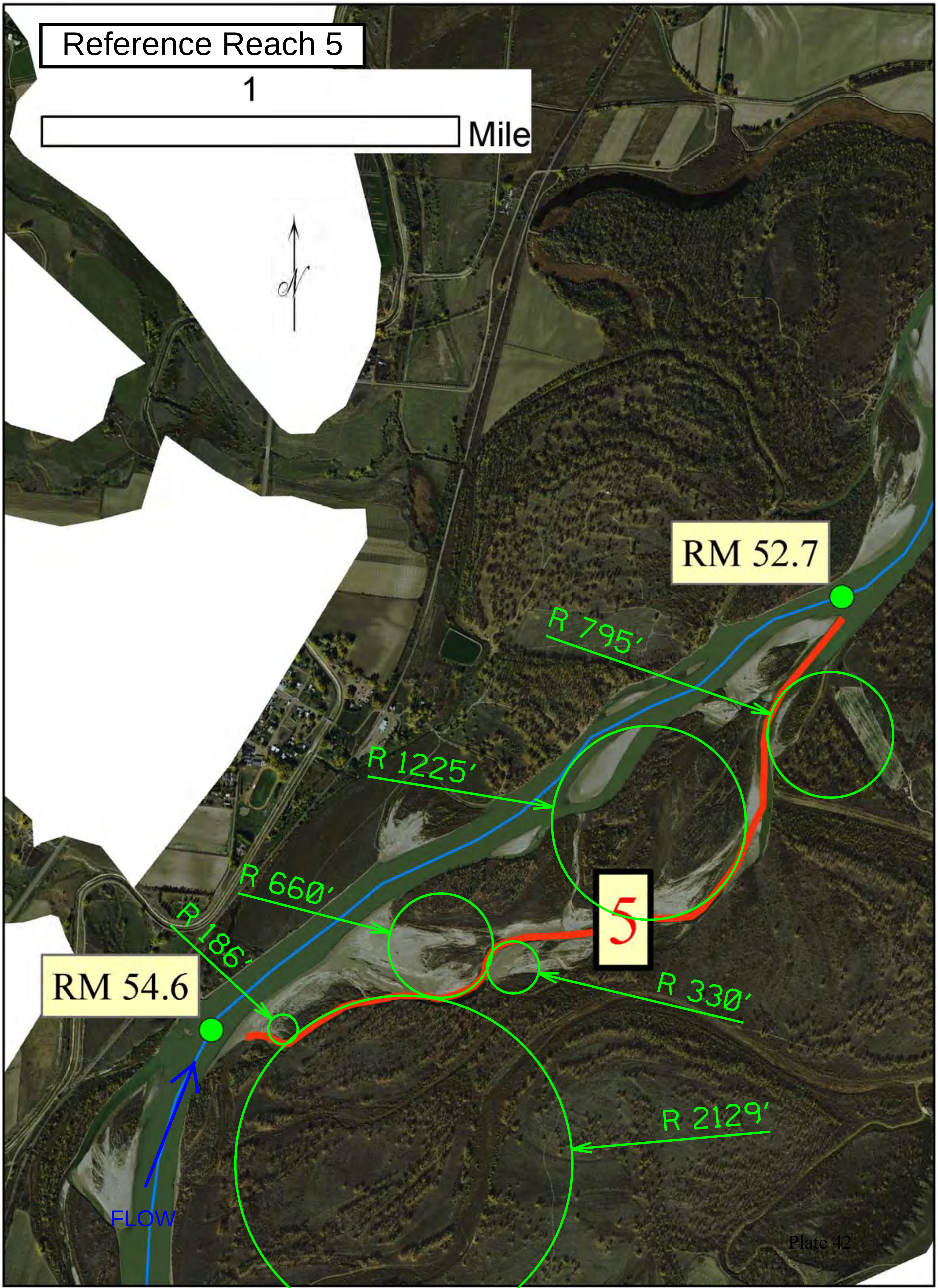

Reference Reach 4
R 864'
R 1205'
R 740'
R 1794'
RM 41.0
4
FLOW
R 502'
R 554'
R 205'
R 202'
R 557'
R 353'
RM 43.3
1
Mile
N

Plate 41


Reference Reach 5
1
Mile
N
RM 52.7
R 795'
R 1225'
R 660'
R 186'
5
R 330'
RM 54.6
R 2129'
FLOW

Reference Reach 6

(note-this reach is the same as Side Channel 5)

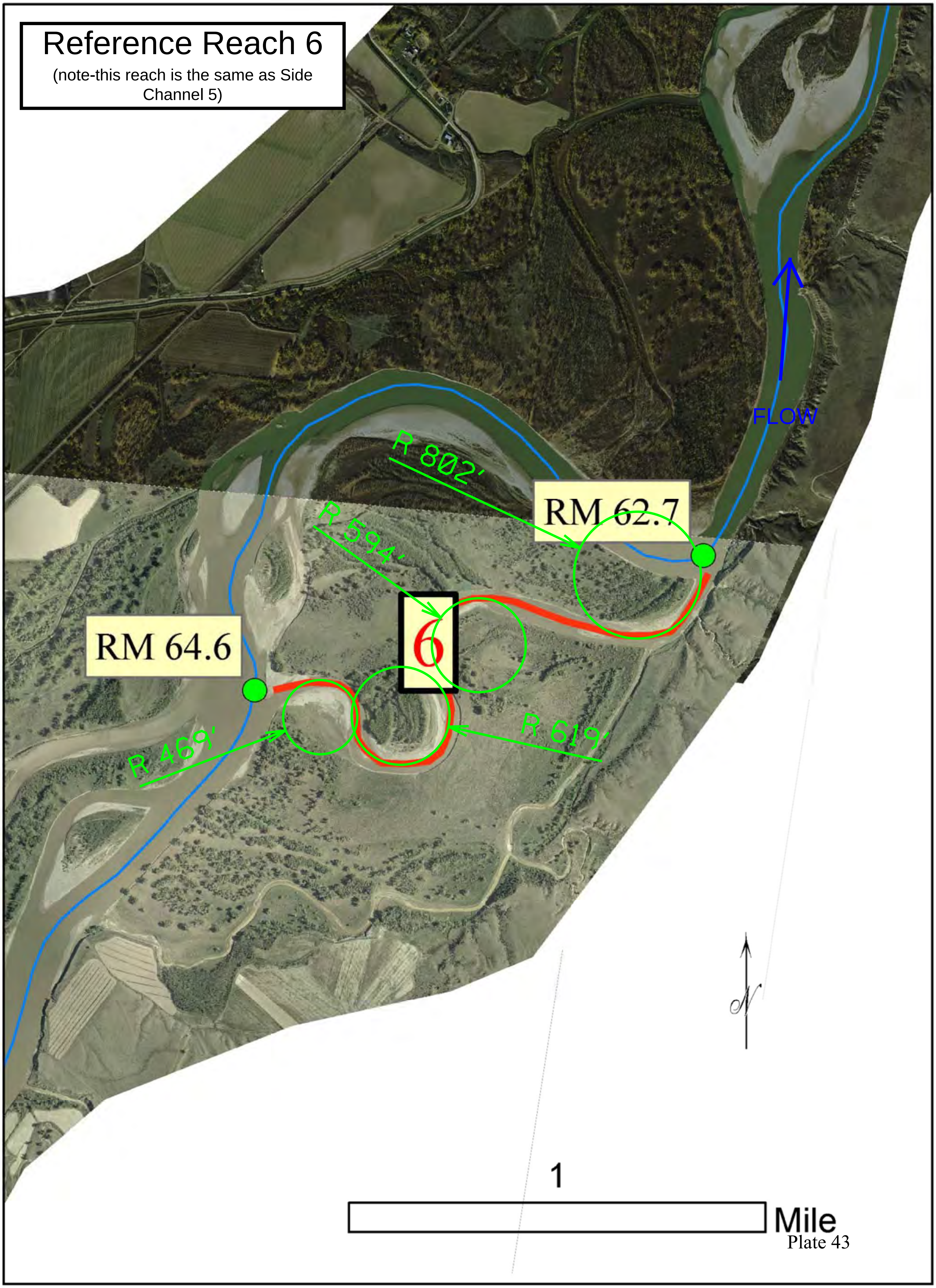
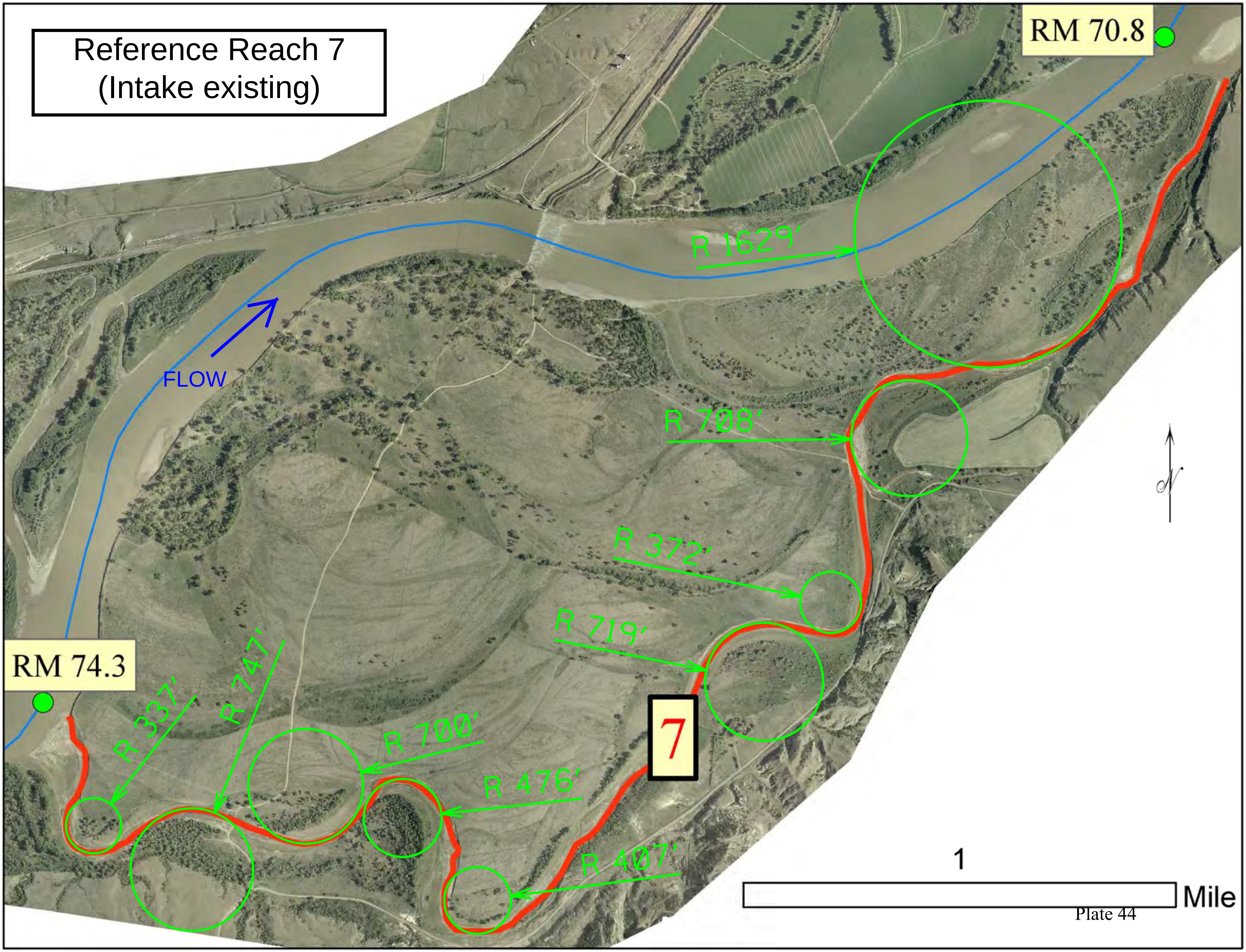
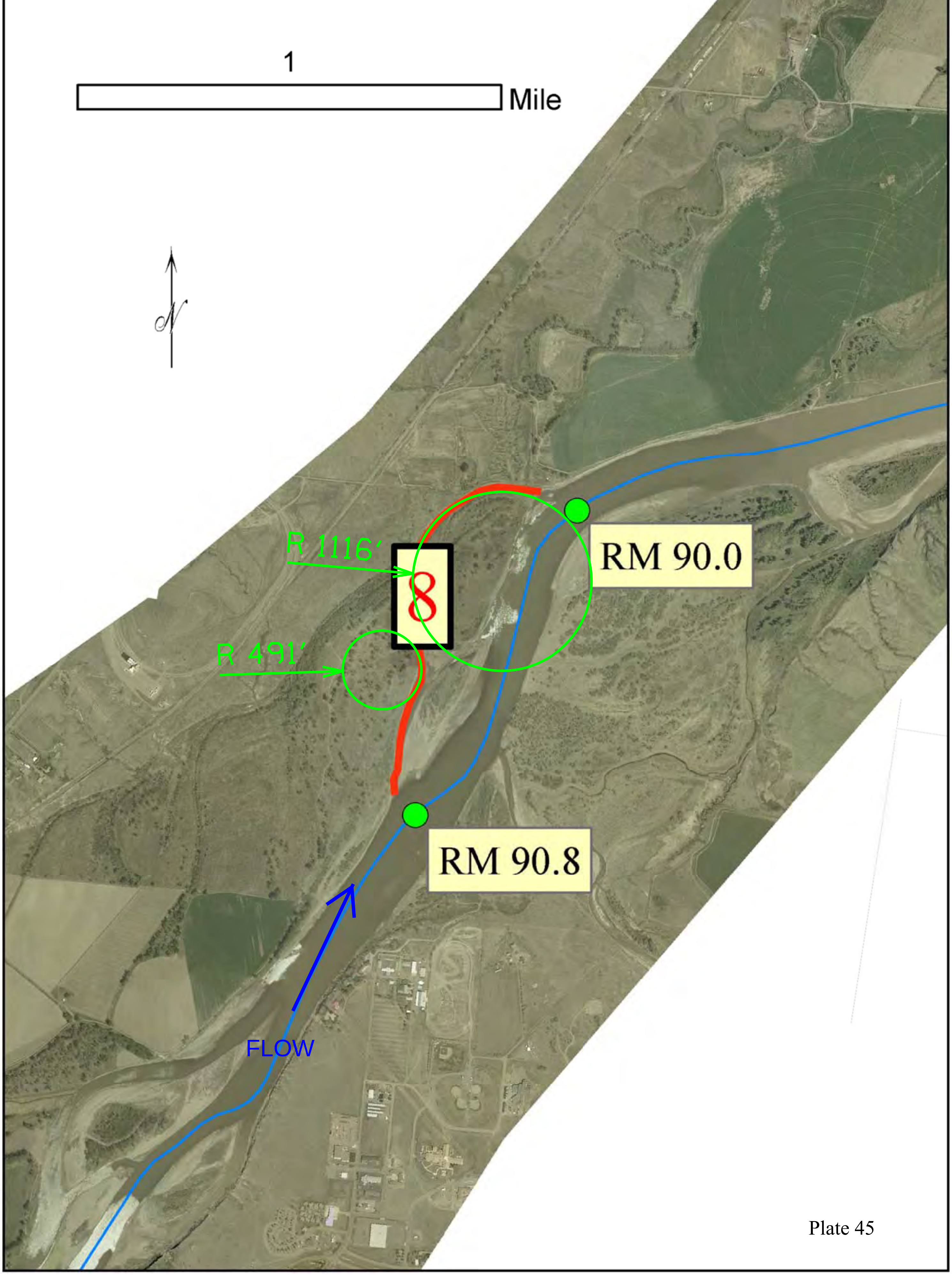


Plate 43

Reference Reach 7
(Intake existing)



Reference Reach 8



Reference Reach 9

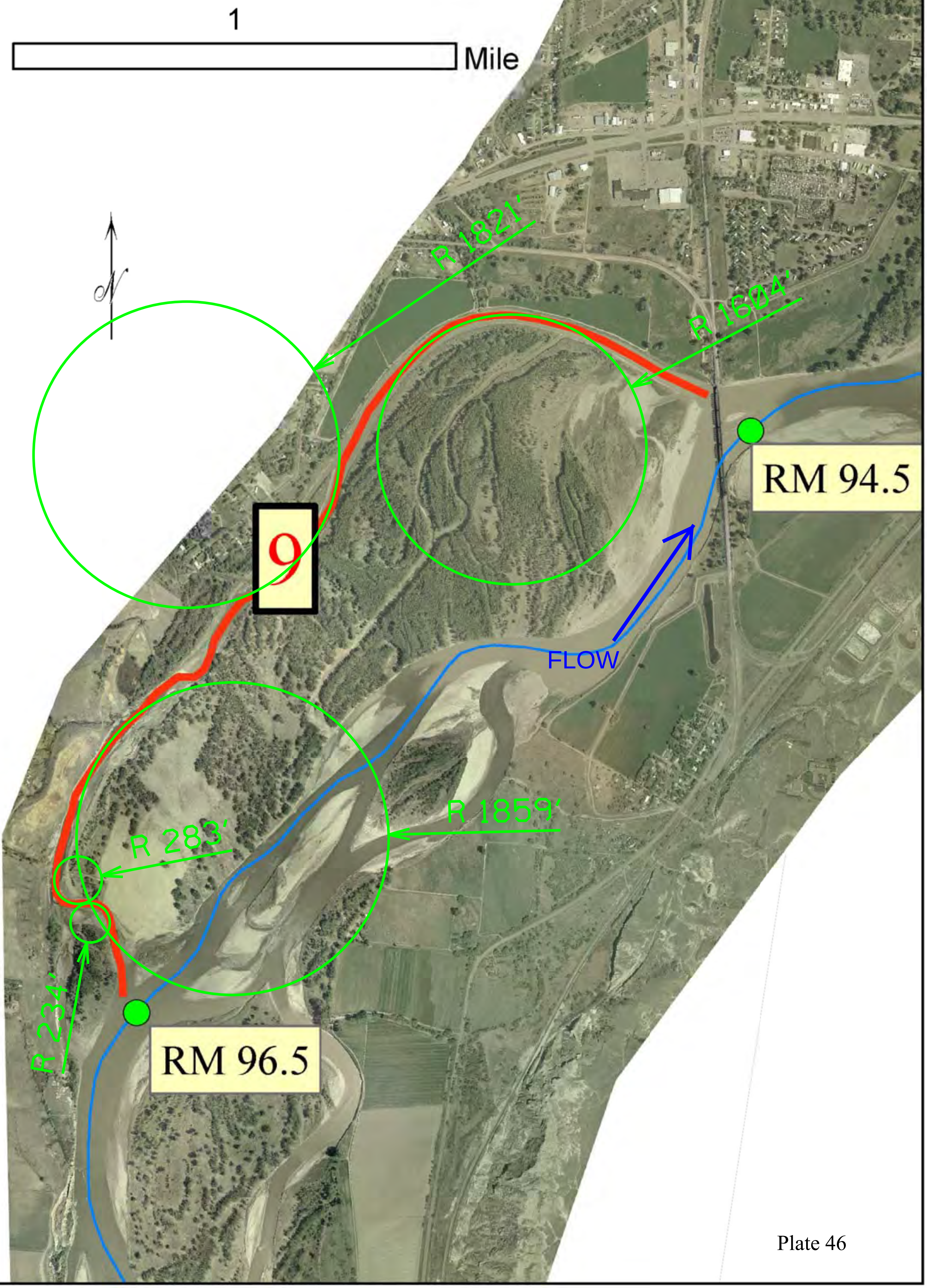
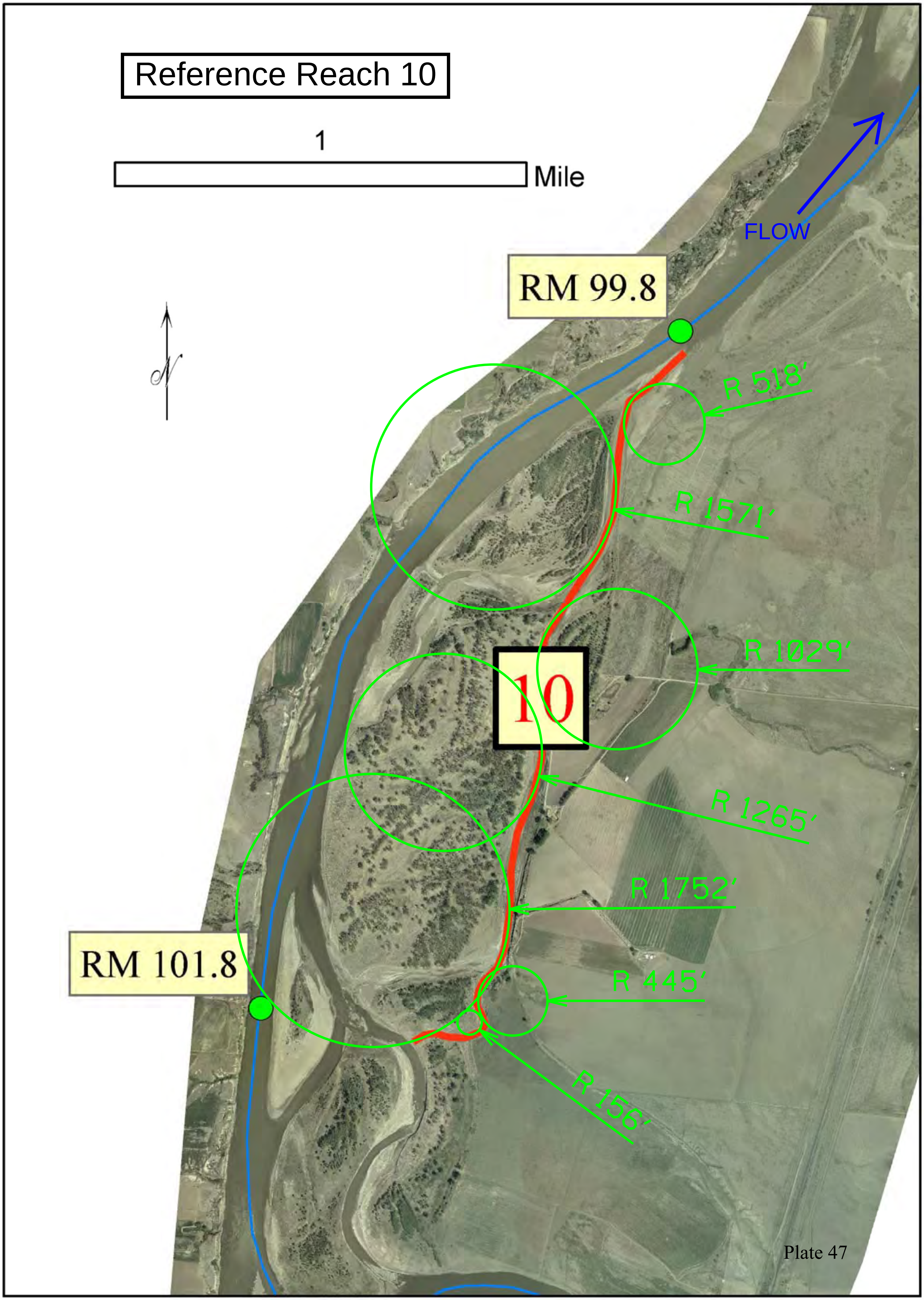
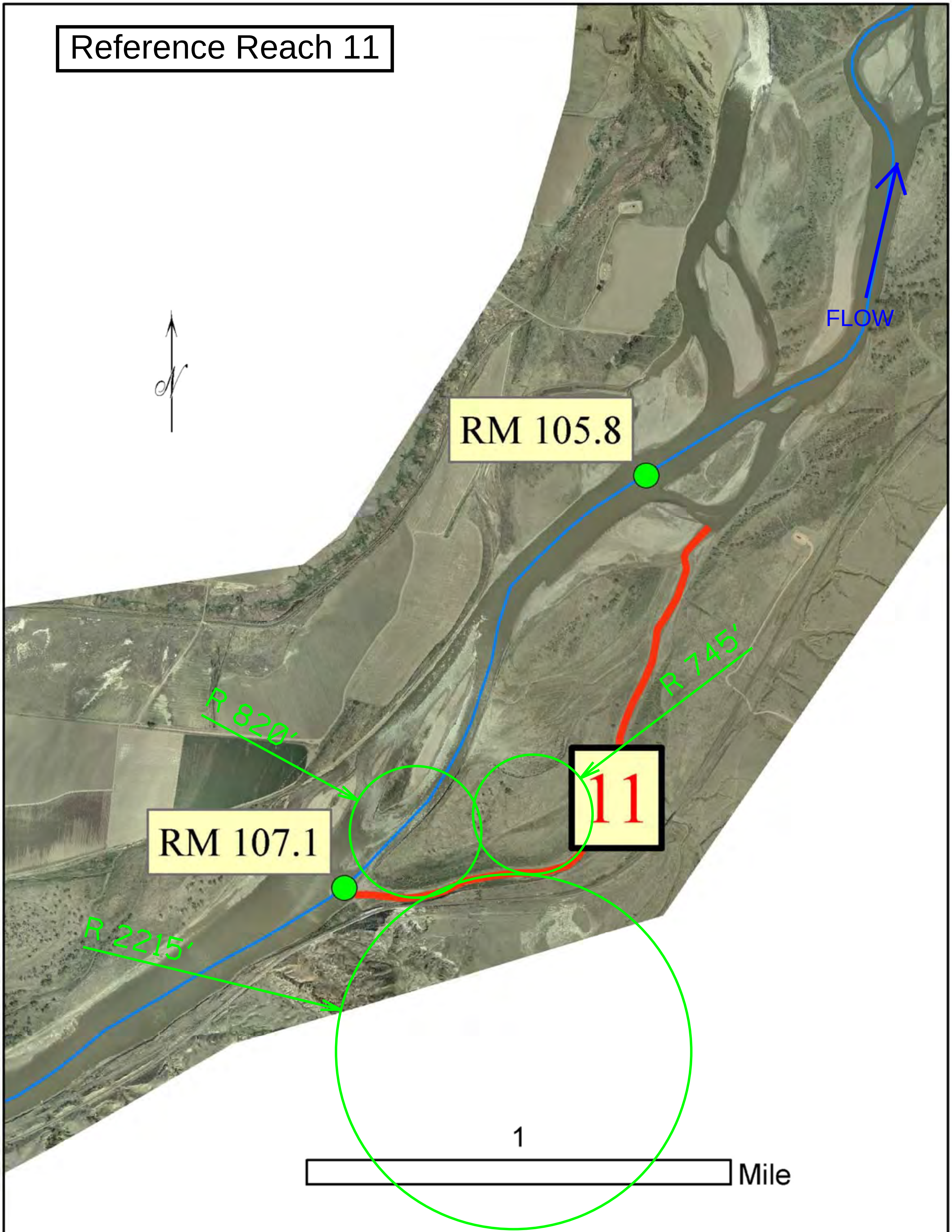
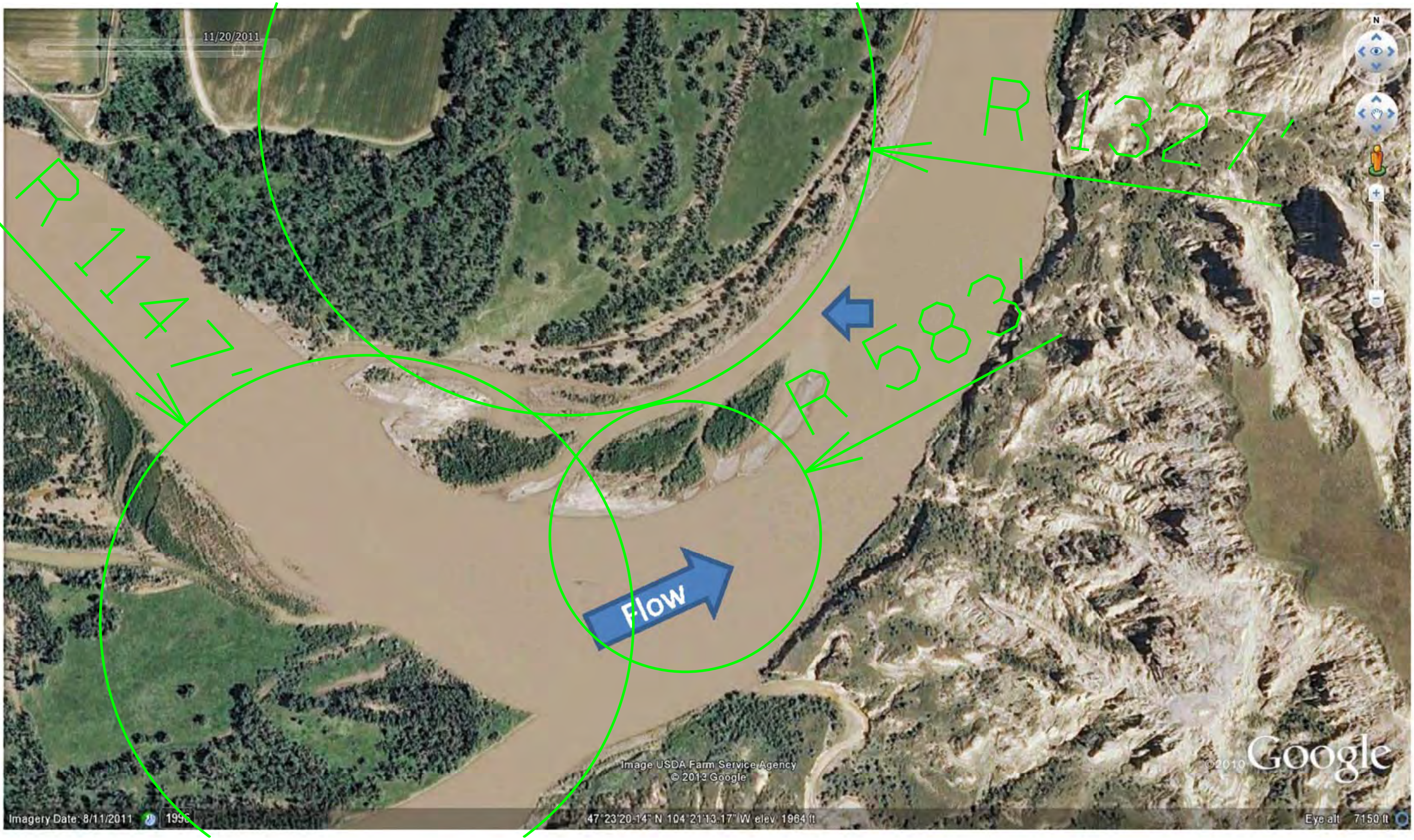


Plate 46

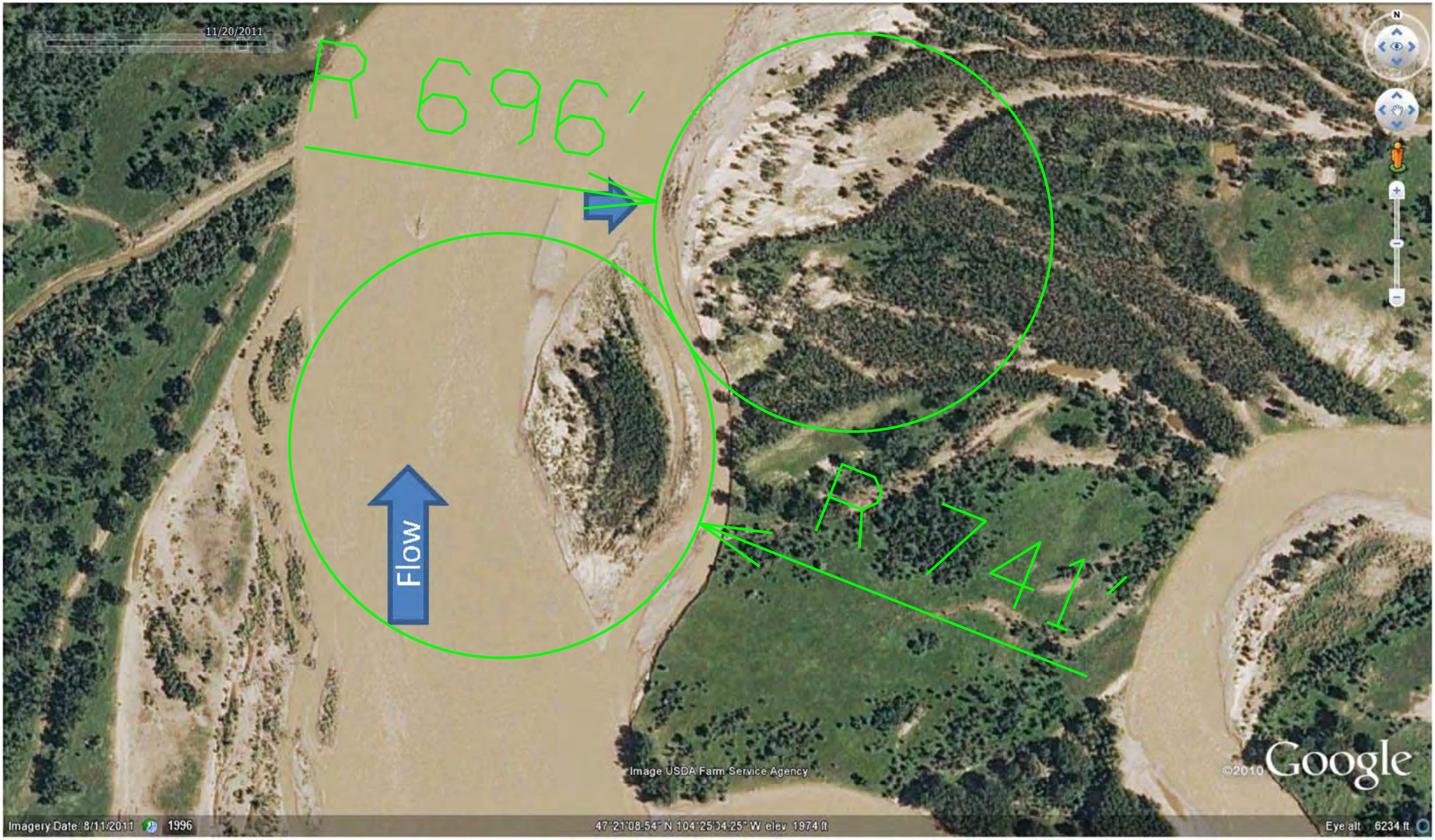

Reference Reach 10
1
Mile
FLOW
RM 99.8
R 518'
R 1571'
R 1029'
10
R 1265'
R 1752'
R 445'
RM 101.8
R 156'


Reference Reach 11
N
RM 105.8
FLOW
R 745'
R 820'
11
RM 107.1
R 2215'
1
Mile

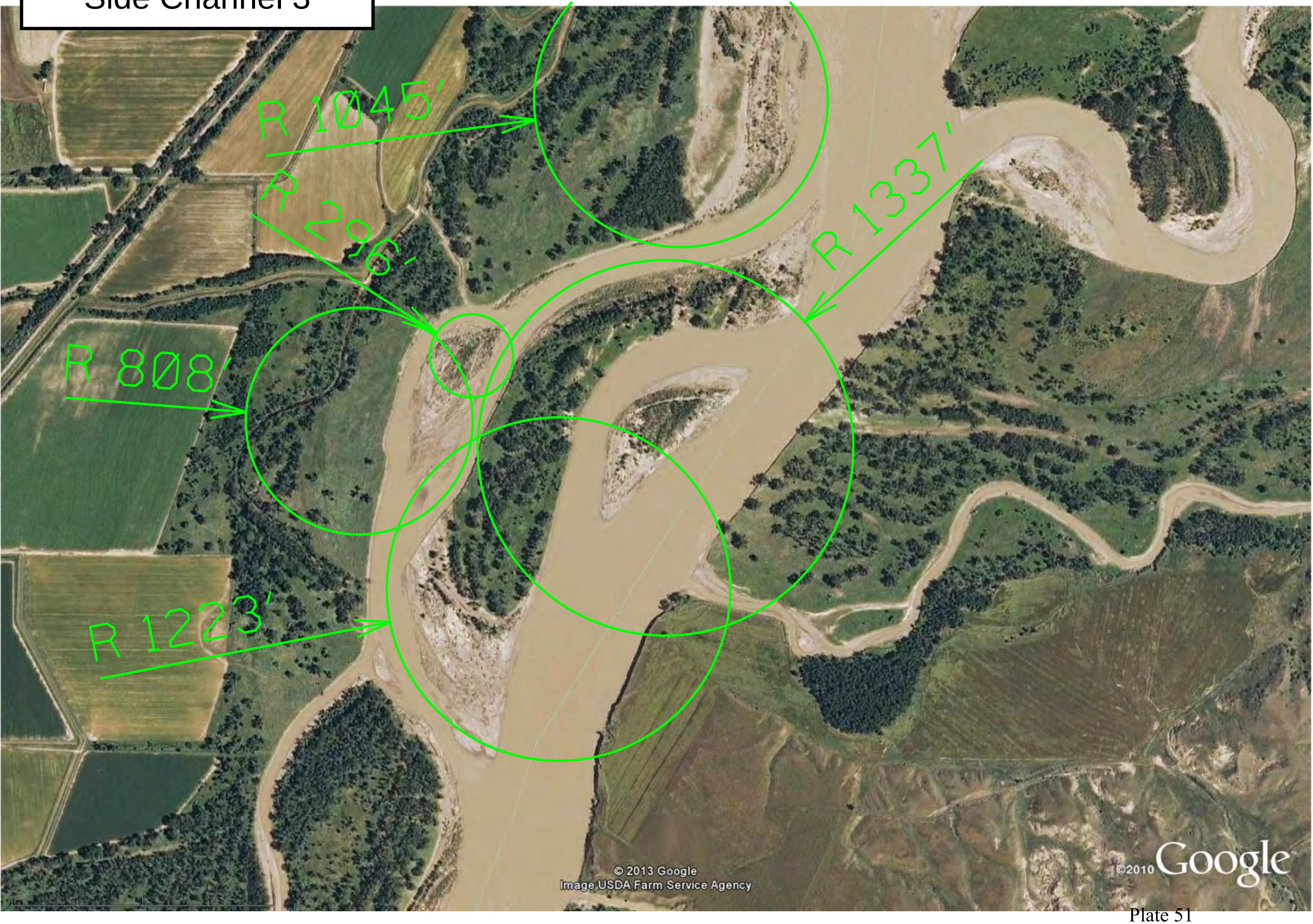
Side Channel 1



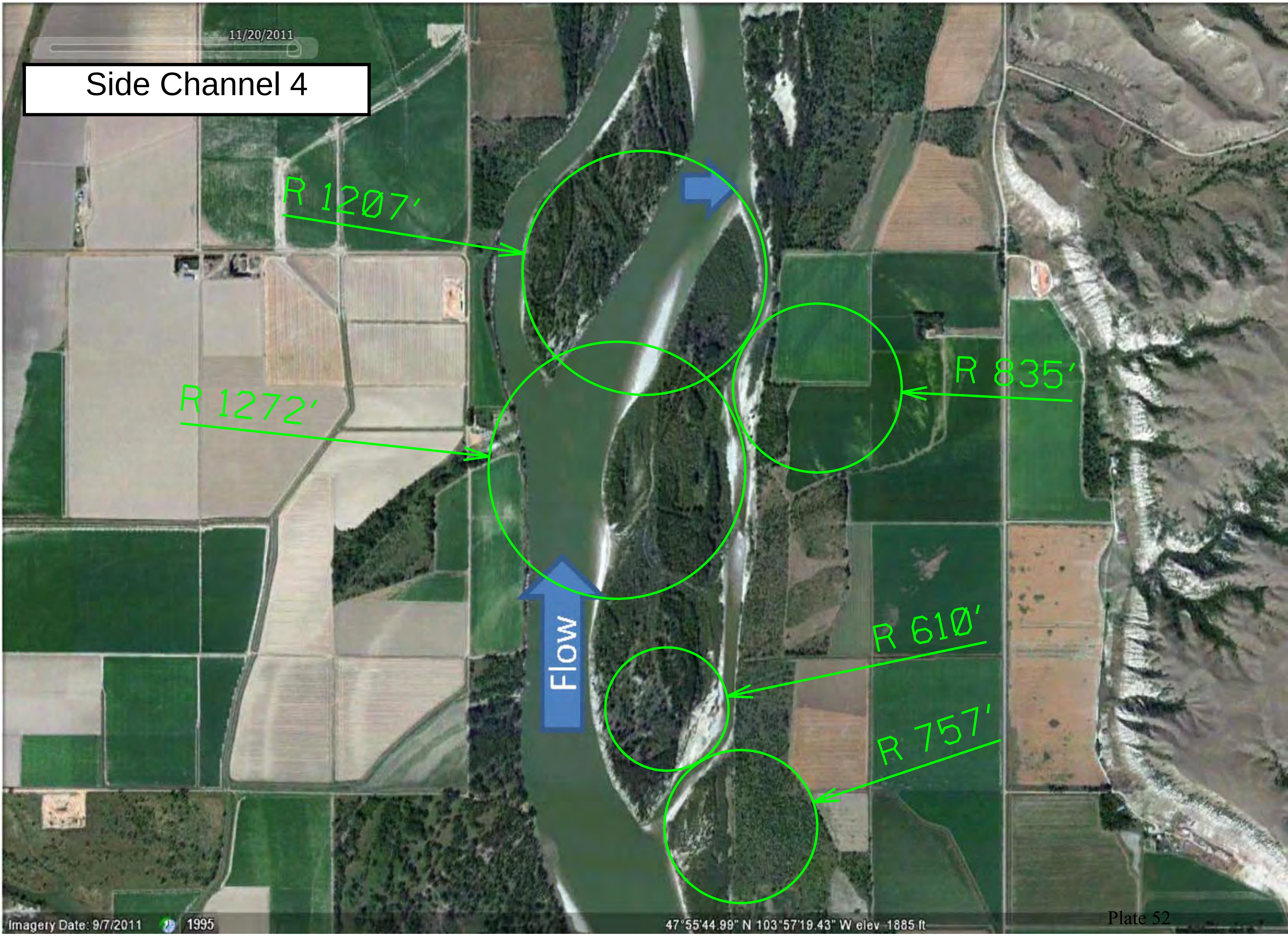
Side Channel 2

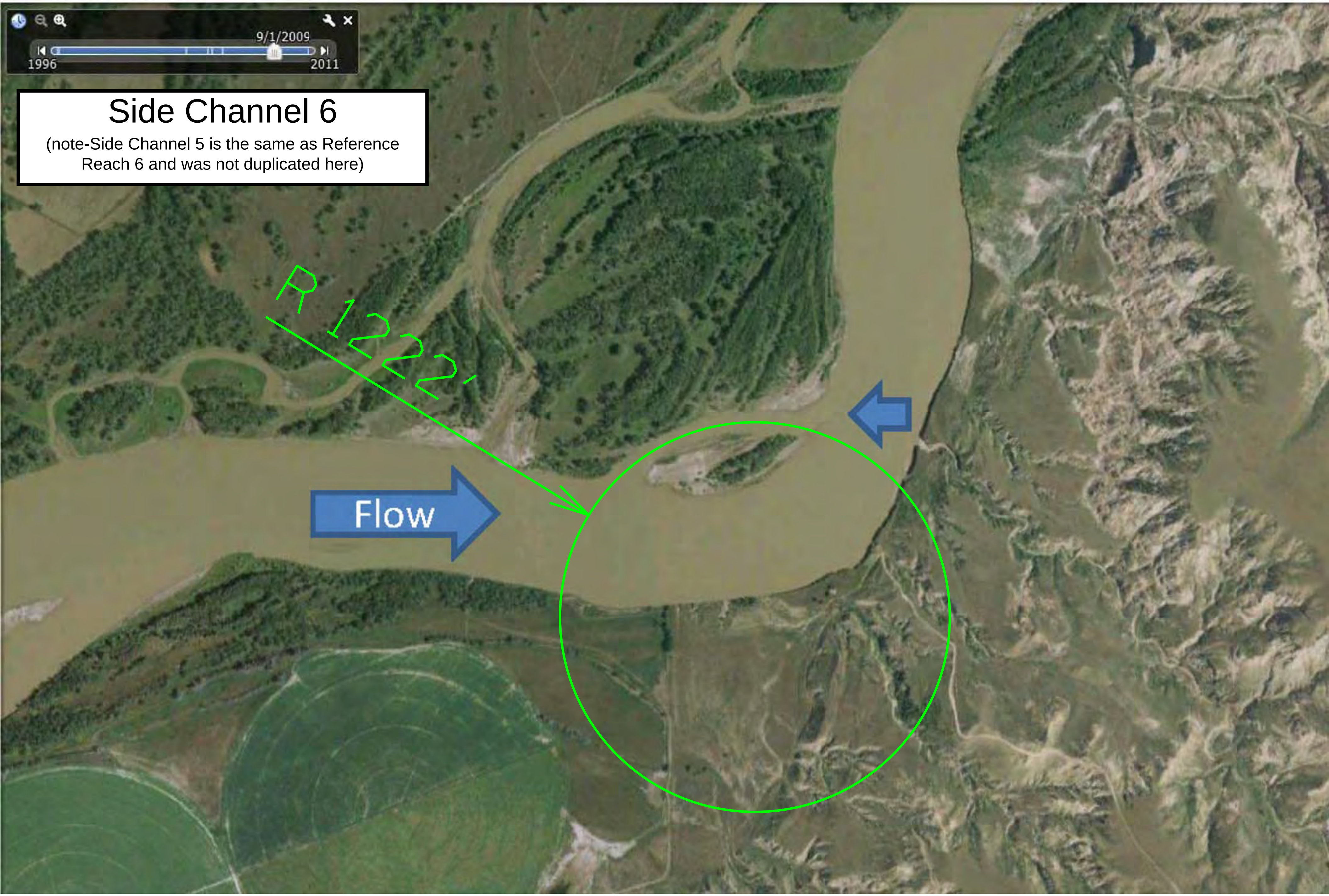


Side Channel 3



Side Channel 4

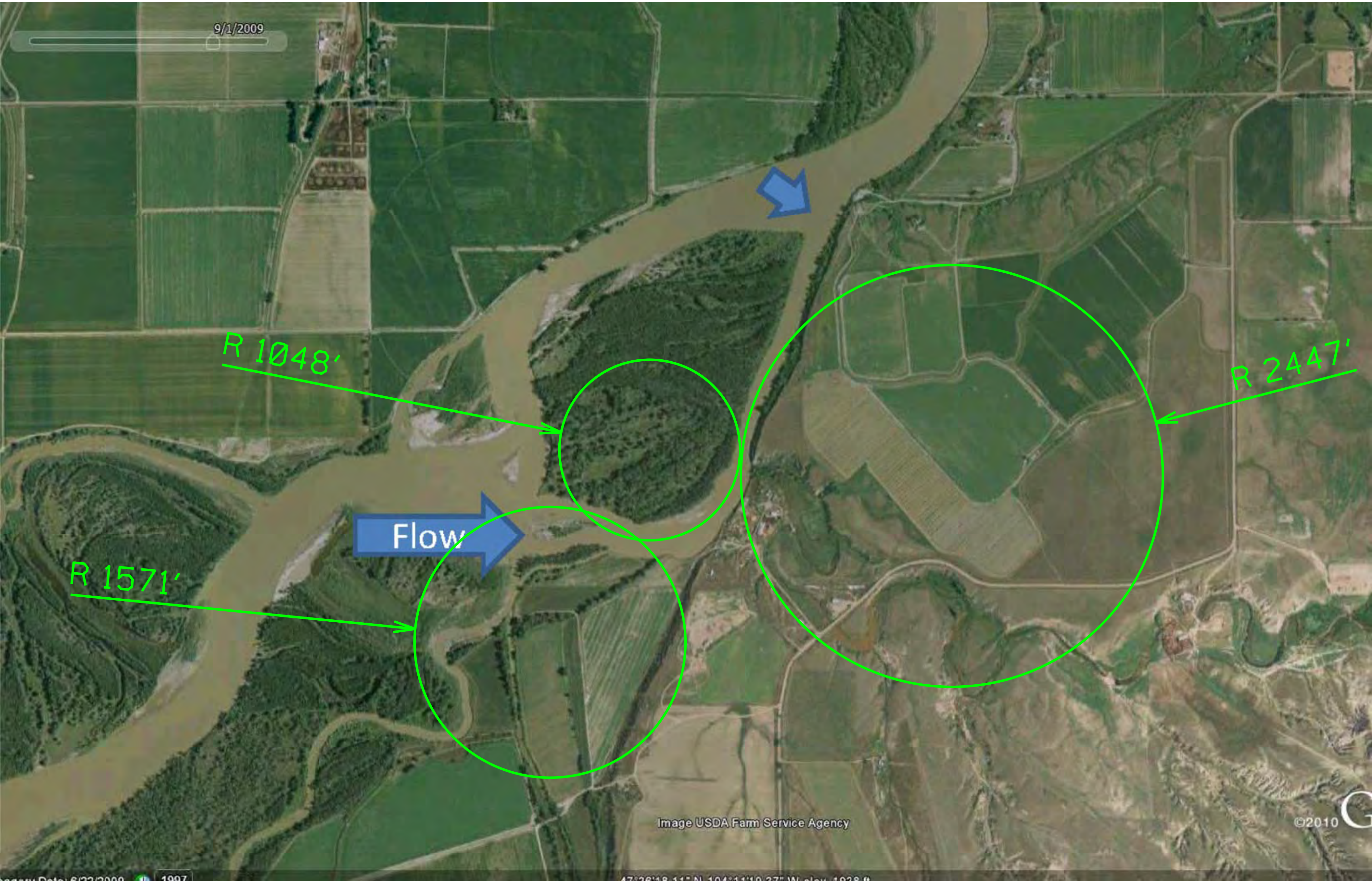




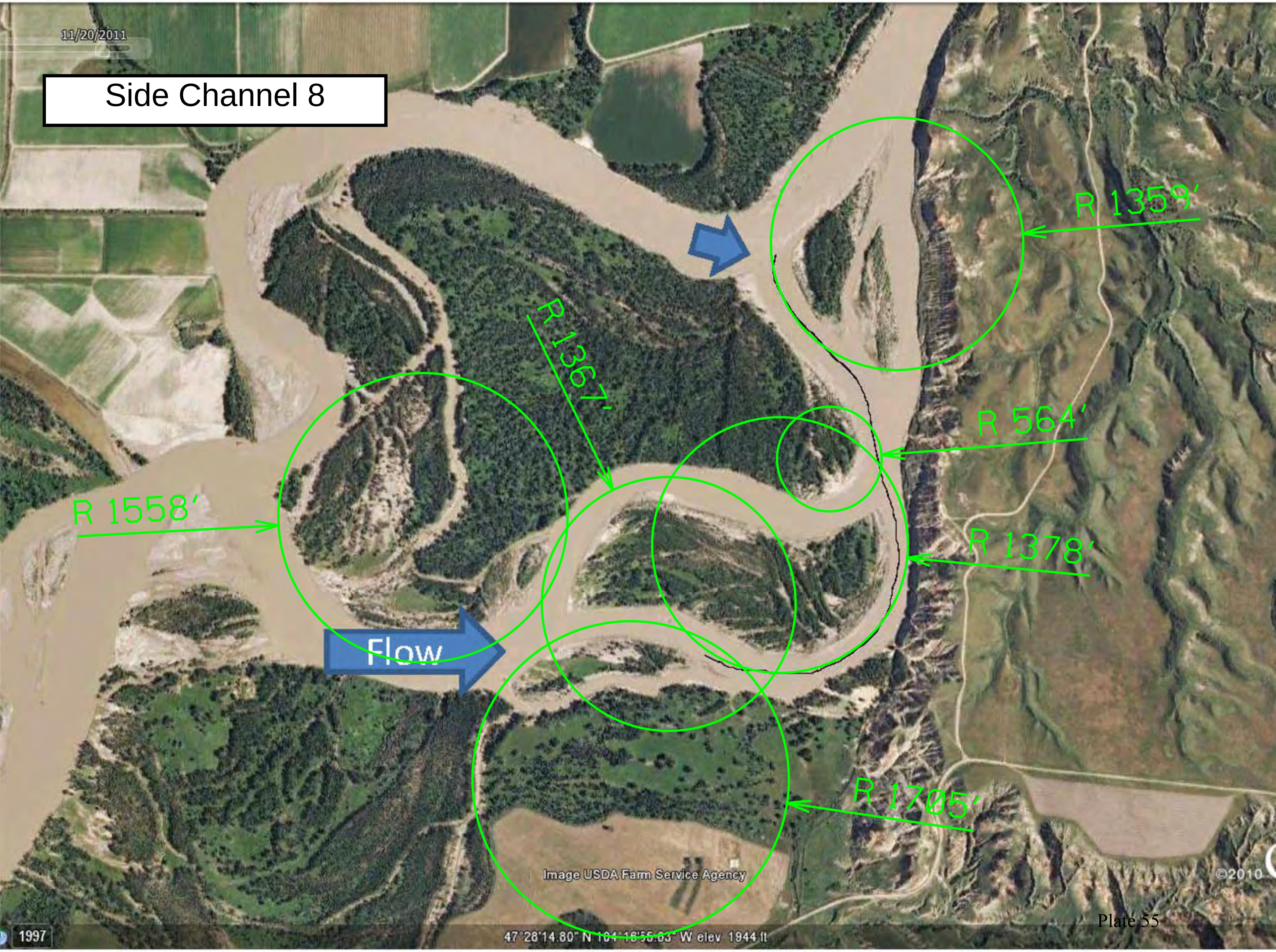
Side Channel 6

(note-Side Channel 5 is the same as Reference Reach 6 and was not duplicated here)

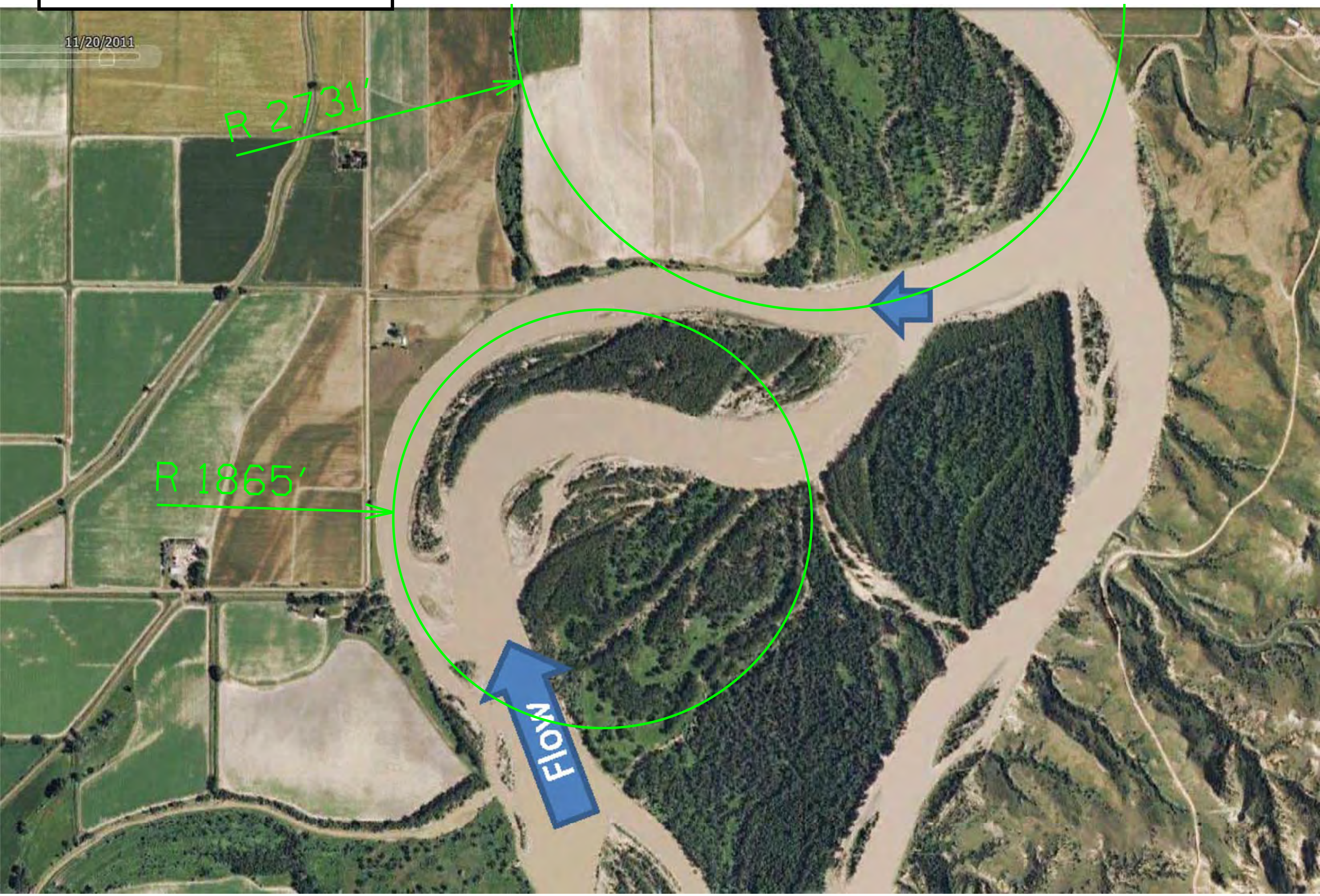
Side Channel 7



Side Channel 8



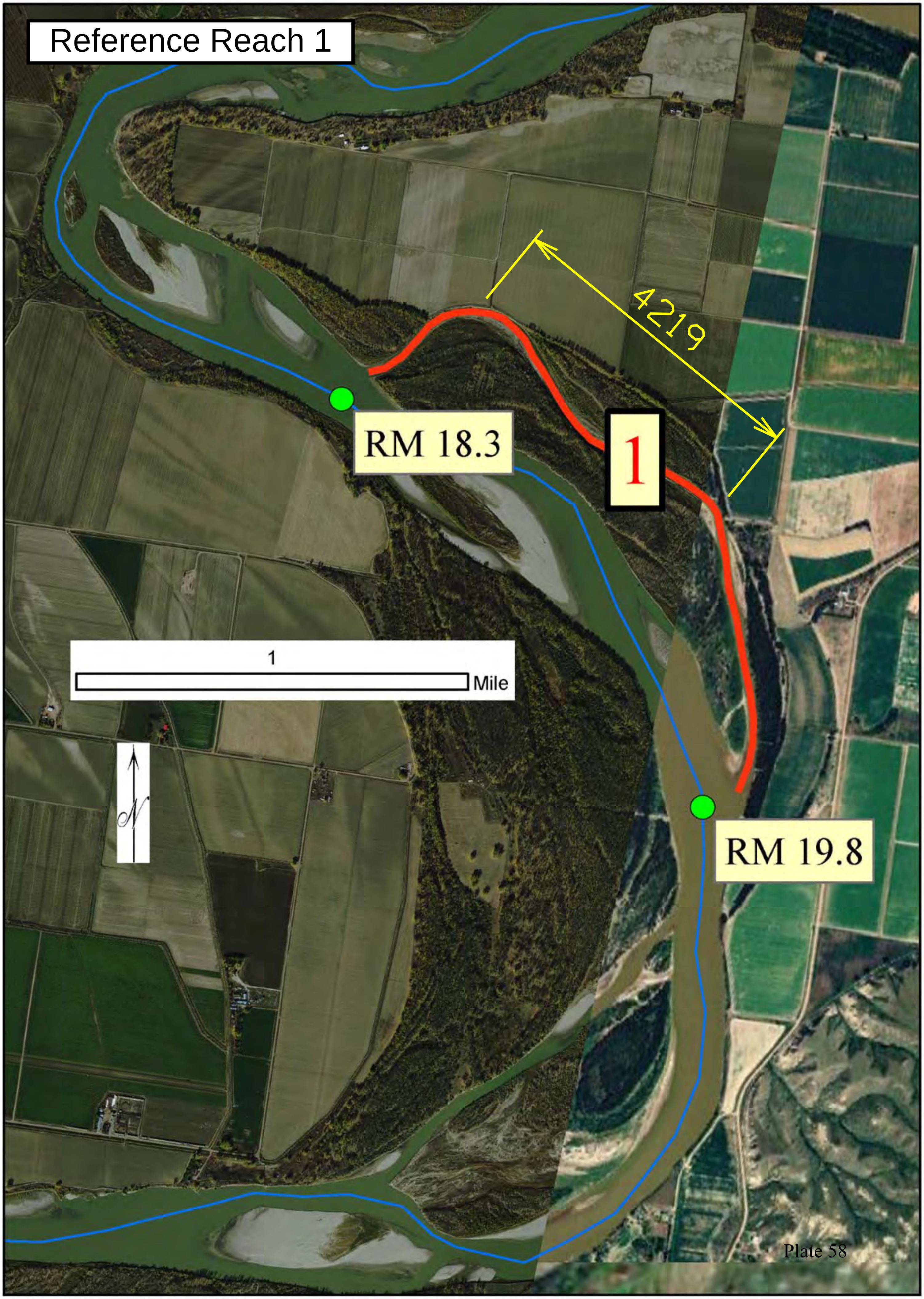
Side Channel 9

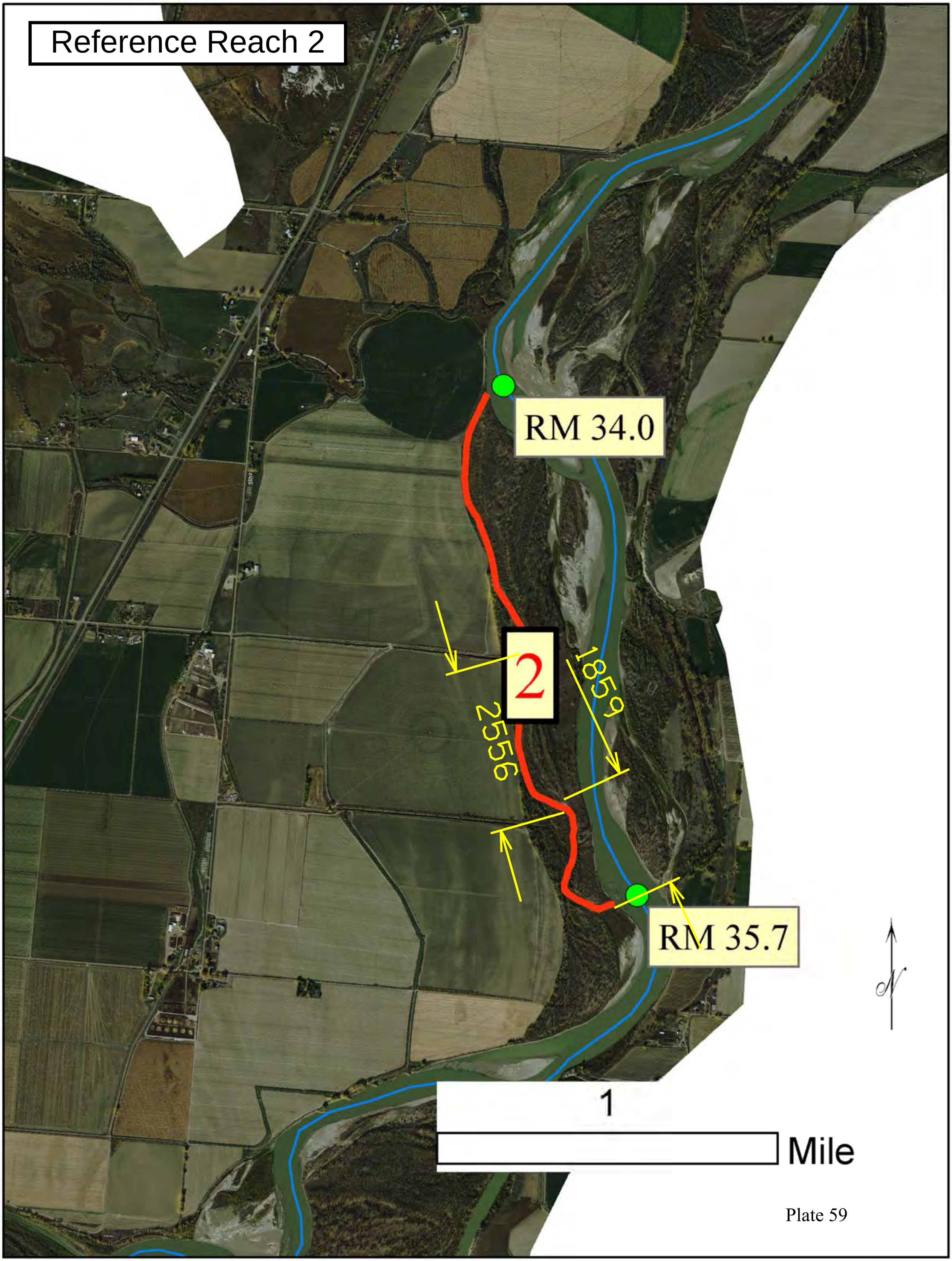


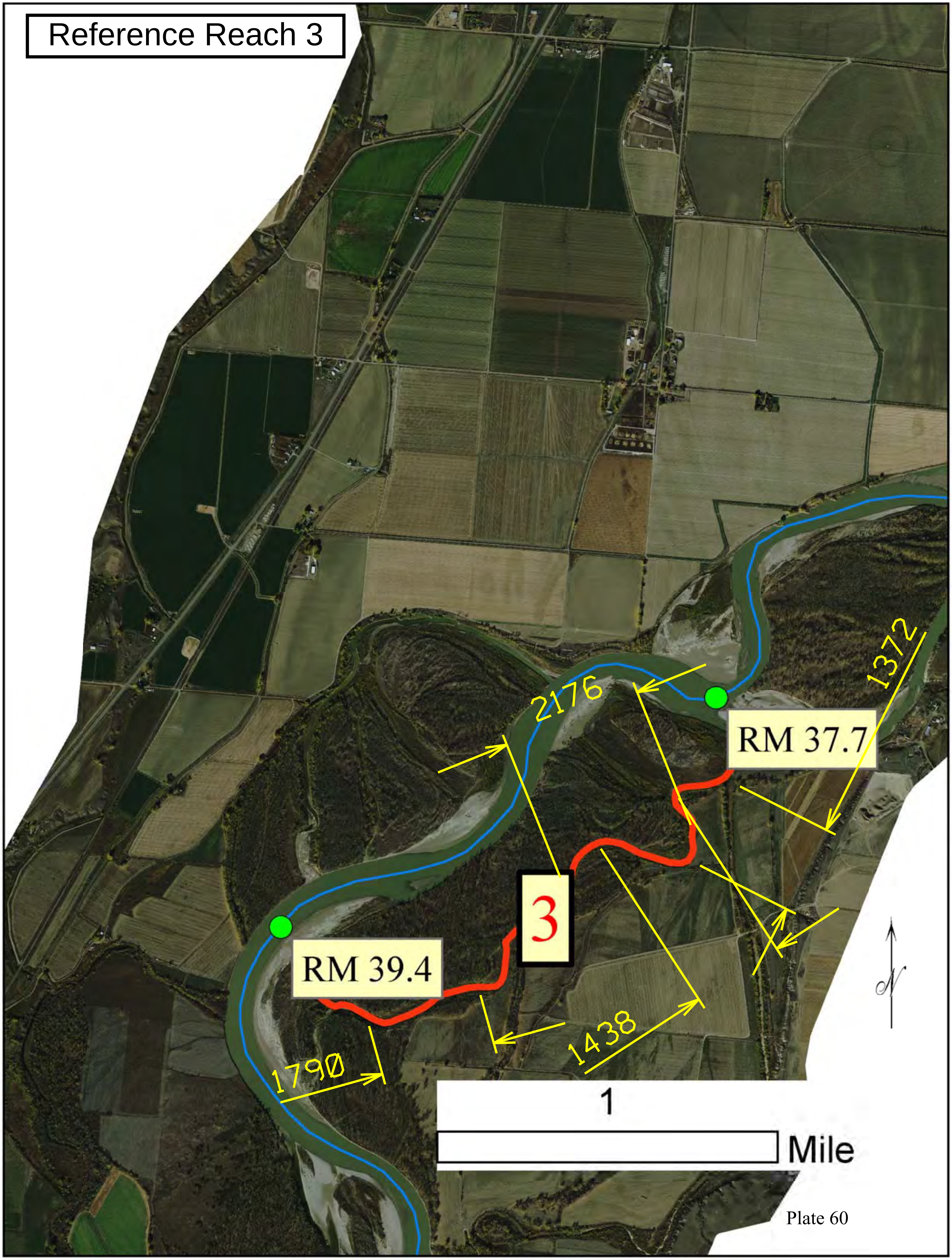
Reference Reach	Measured Meander Wave	Wavelength
		(ft)
1	1	4220
2	1	2560
	2	1860
3	1	1370
	2	1440
	3	2180
	4	1790
4	1	3830
	2	3930
	3	5250
	4	6240
	5	3180
5	1	4460
	2	3530
	3	2160
6	1	3430
	2	1670
	3	2180
7 (Intake existing high flow chute)	1	5110
	2	3410
	3	1940
	4	2980
	5	2860
8	1	2580
9	1	4370
	2	2650
10	1	3390
	2	2500
	3	1970
11	1	2700
	2	1820
	Maximum:	6240
	Average:	3018
	Minimum:	1370

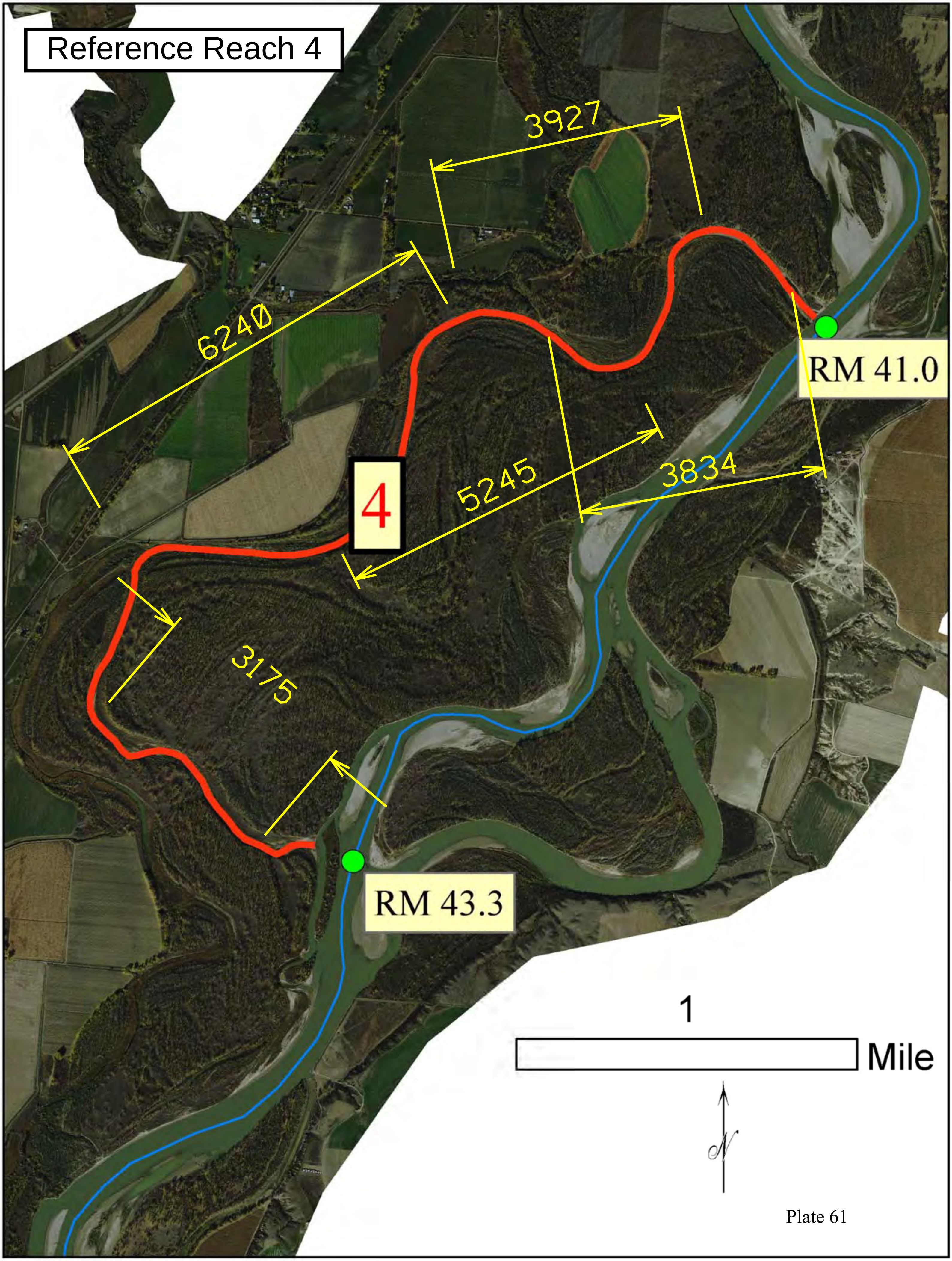
Side Channel	Measured Meander Wave	Wavelength
		(ft)
1	1	950
2	1	1140
3	1	2540
	2	2420
4	1	2090
	2	1570
5 (same as Reference Reach 6)	1	3430
	2	1670
	3	2180
6	1	2700
7	1	2410
8	1	5360
	2	4630
	3	4150
9	1	7490
	Maximum:	7490
	Average:	2982
	Minimum:	950

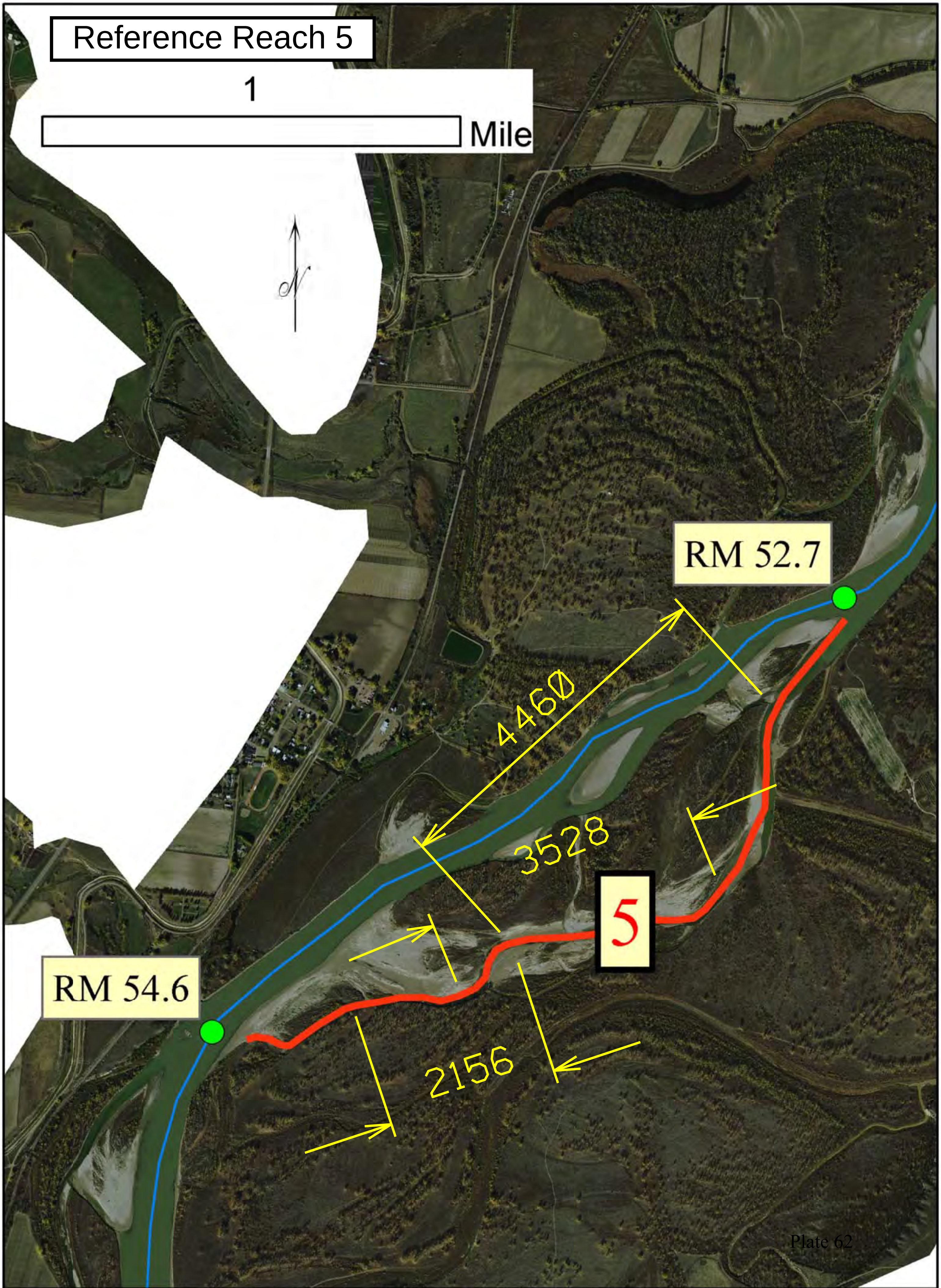
Proposed Bypass		
	Measured Meander Wave	Wavelength
		(ft)
	1	2530
	2	3480
	3	3380
	4	1770
	5	1730
	Maximum:	3480
	Average:	2578
	Minimum:	1730


Reference Reach 1
4219
1
RM 18.3
RM 19.8
1
Mile
N


Reference Reach 2
RM 34.0
2
1859
2556
RM 35.7
N
1
Mile

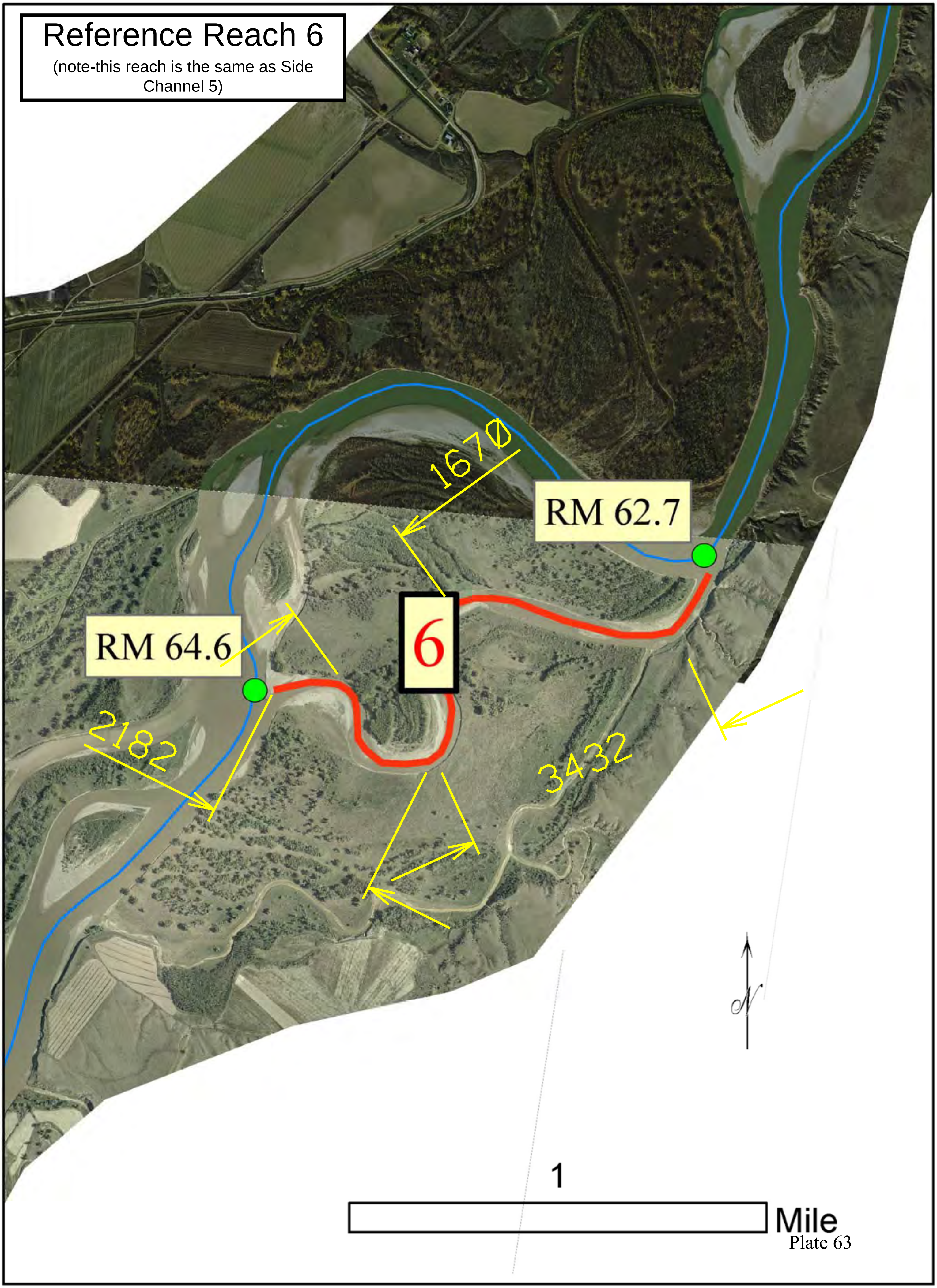

Reference Reach 3
2176
1372
RM 37.7
3
RM 39.4
1438
1790
1
Mile
N


Reference Reach 4
3927
6240
RM 41.0
4
5245
3834
3175
RM 43.3
1
Mile
N

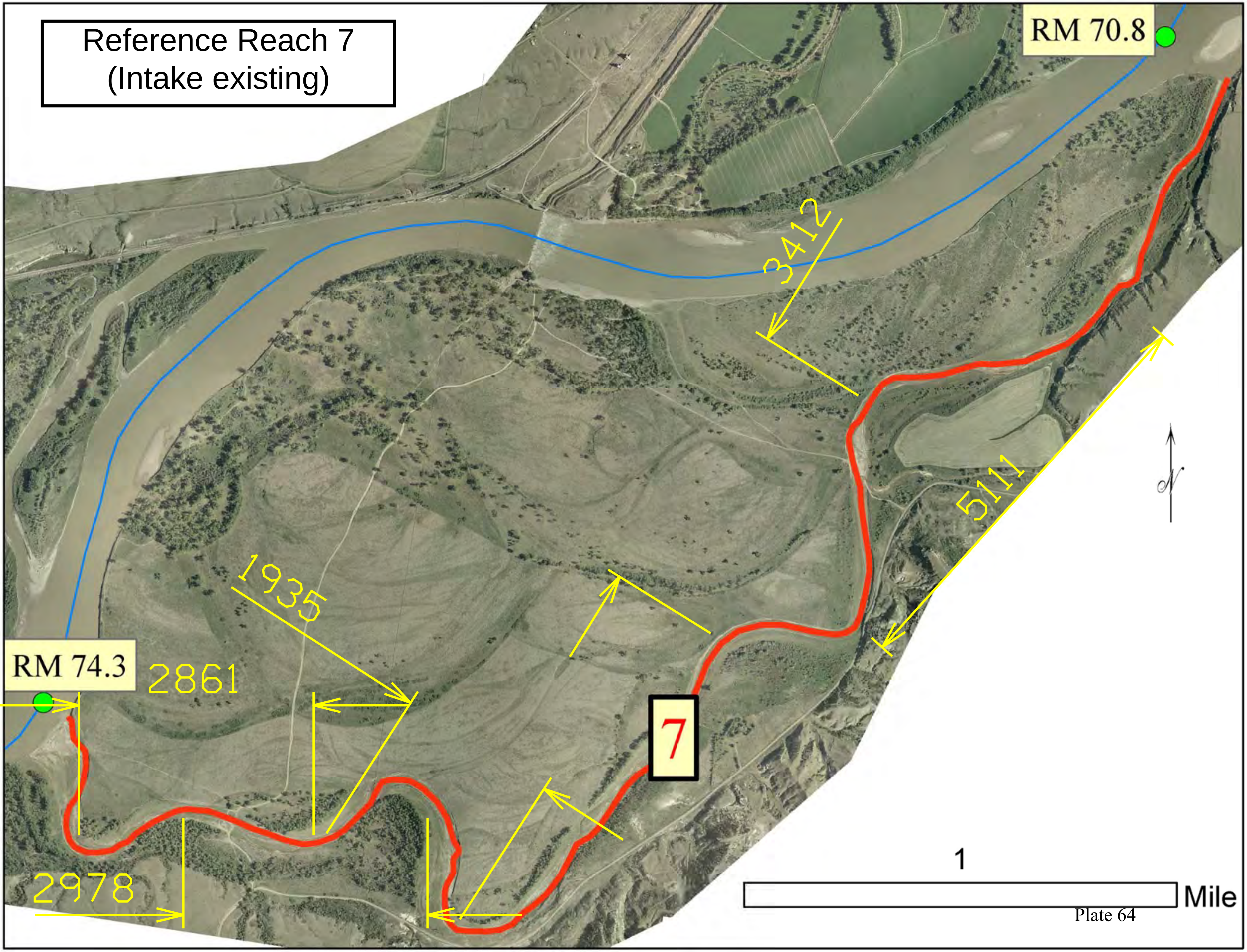

Reference Reach 5
1
Mile
N
RM 52.7
RM 54.6
4460
3528
2156
5

Reference Reach 6

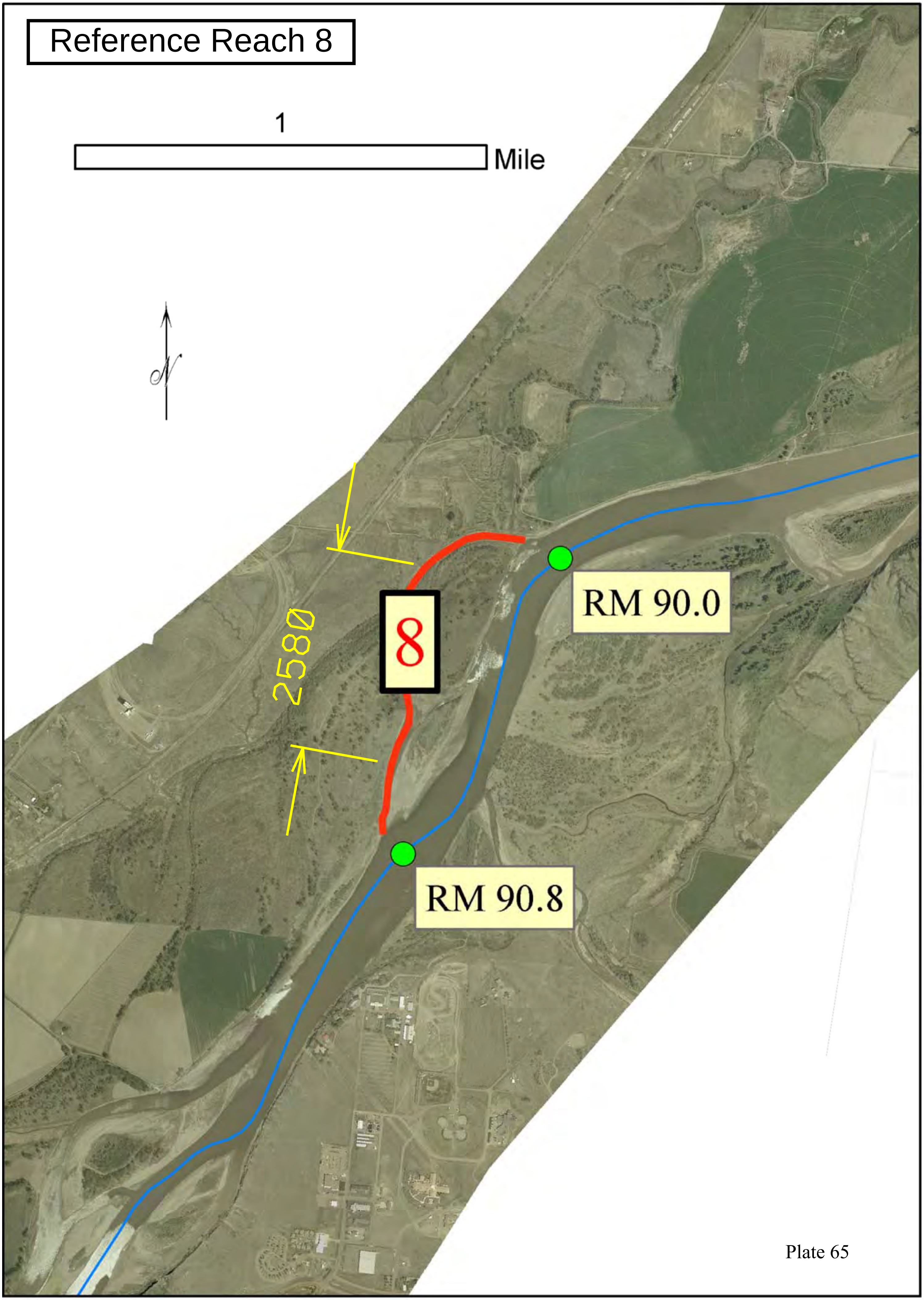
(note-this reach is the same as Side Channel 5)



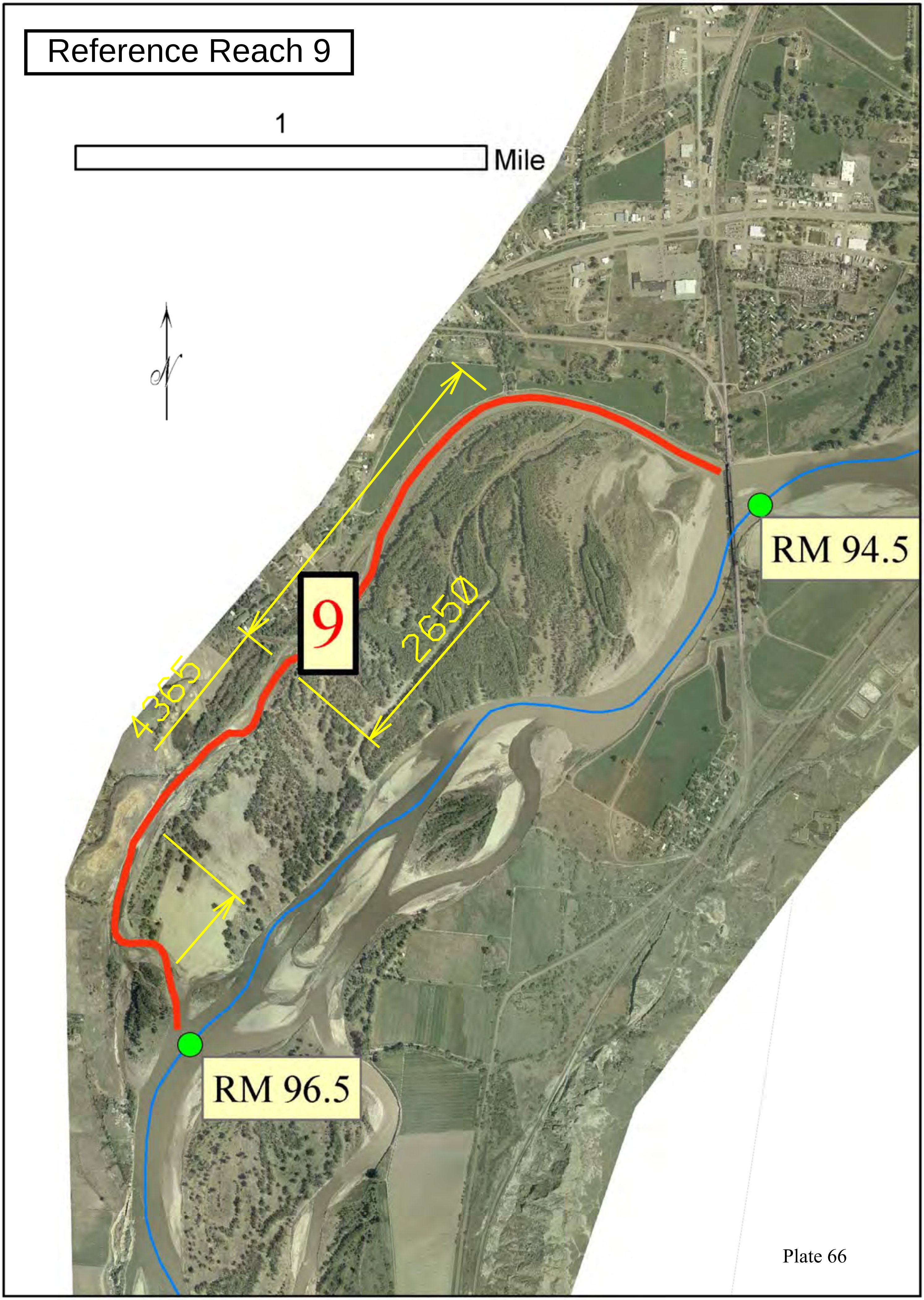
Reference Reach 7
(Intake existing)



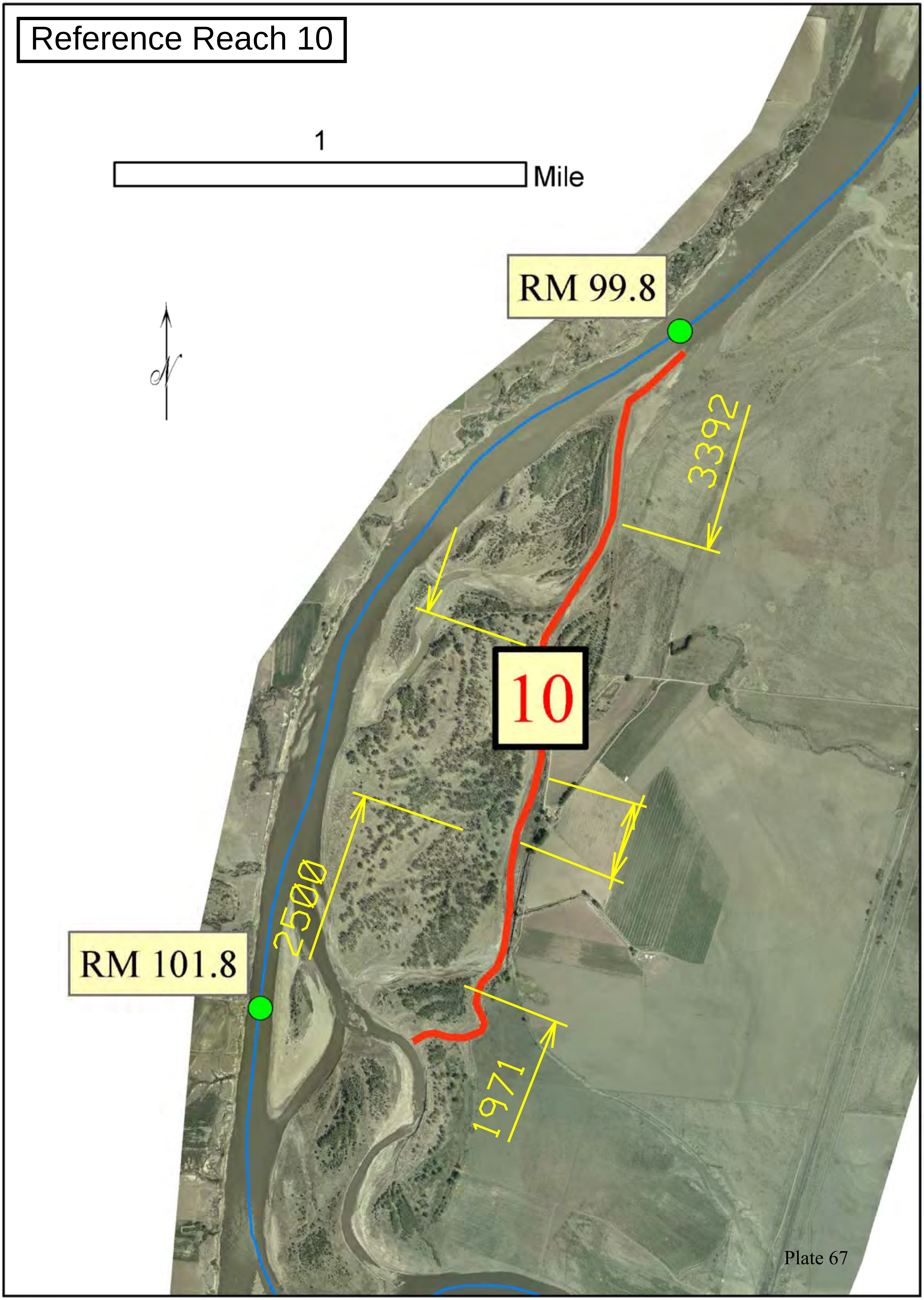
Reference Reach 8



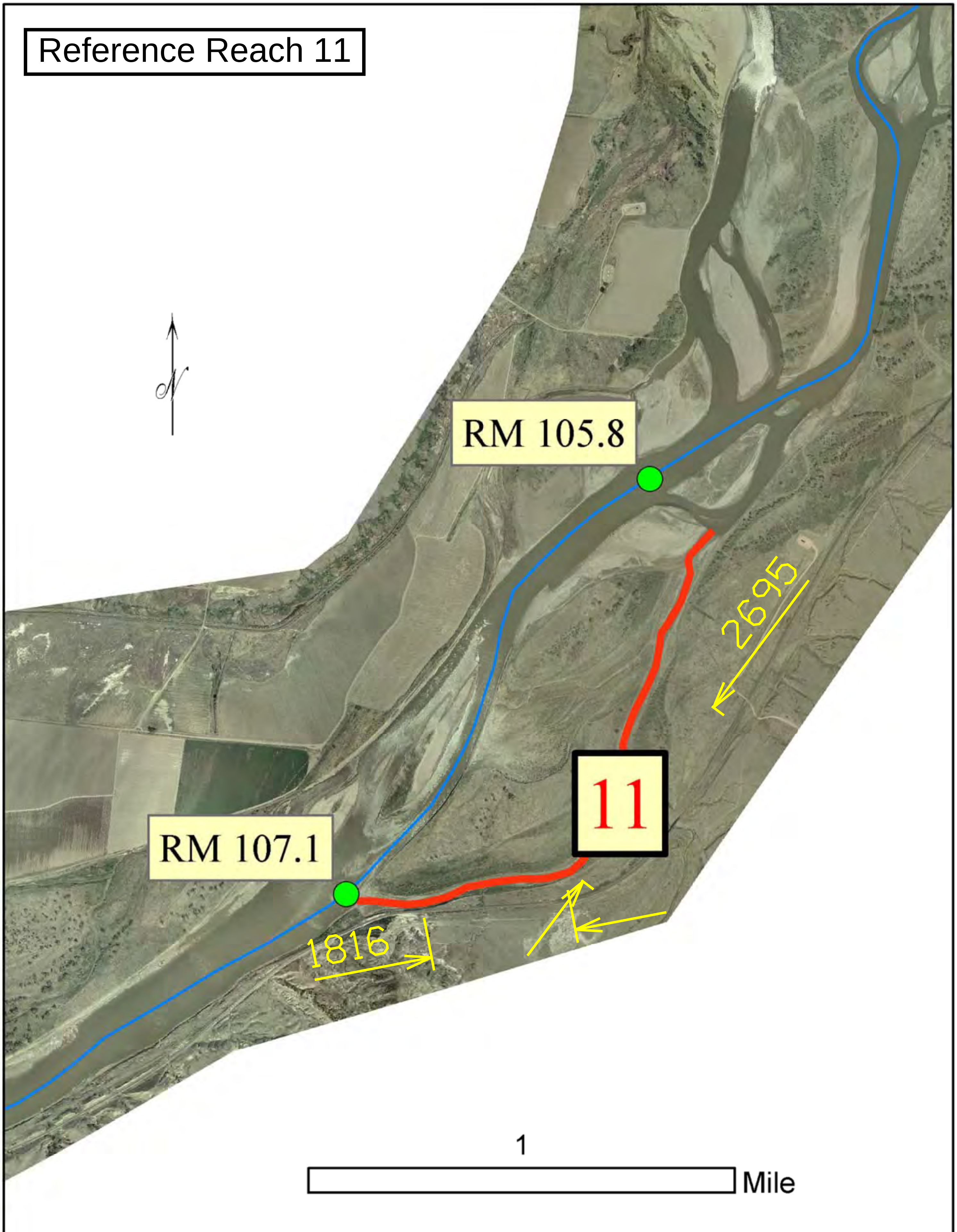
Reference Reach 9



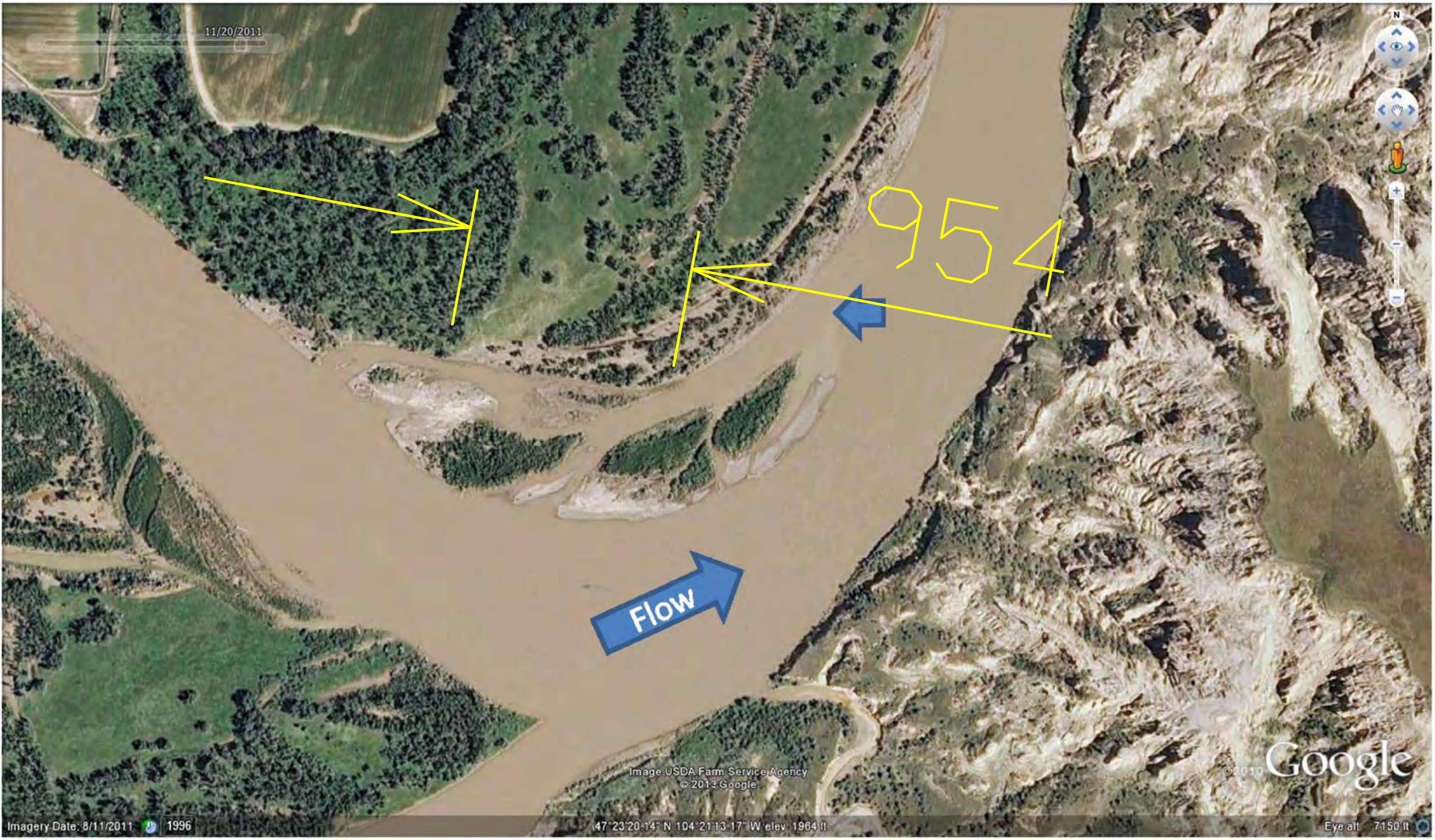
Reference Reach 10



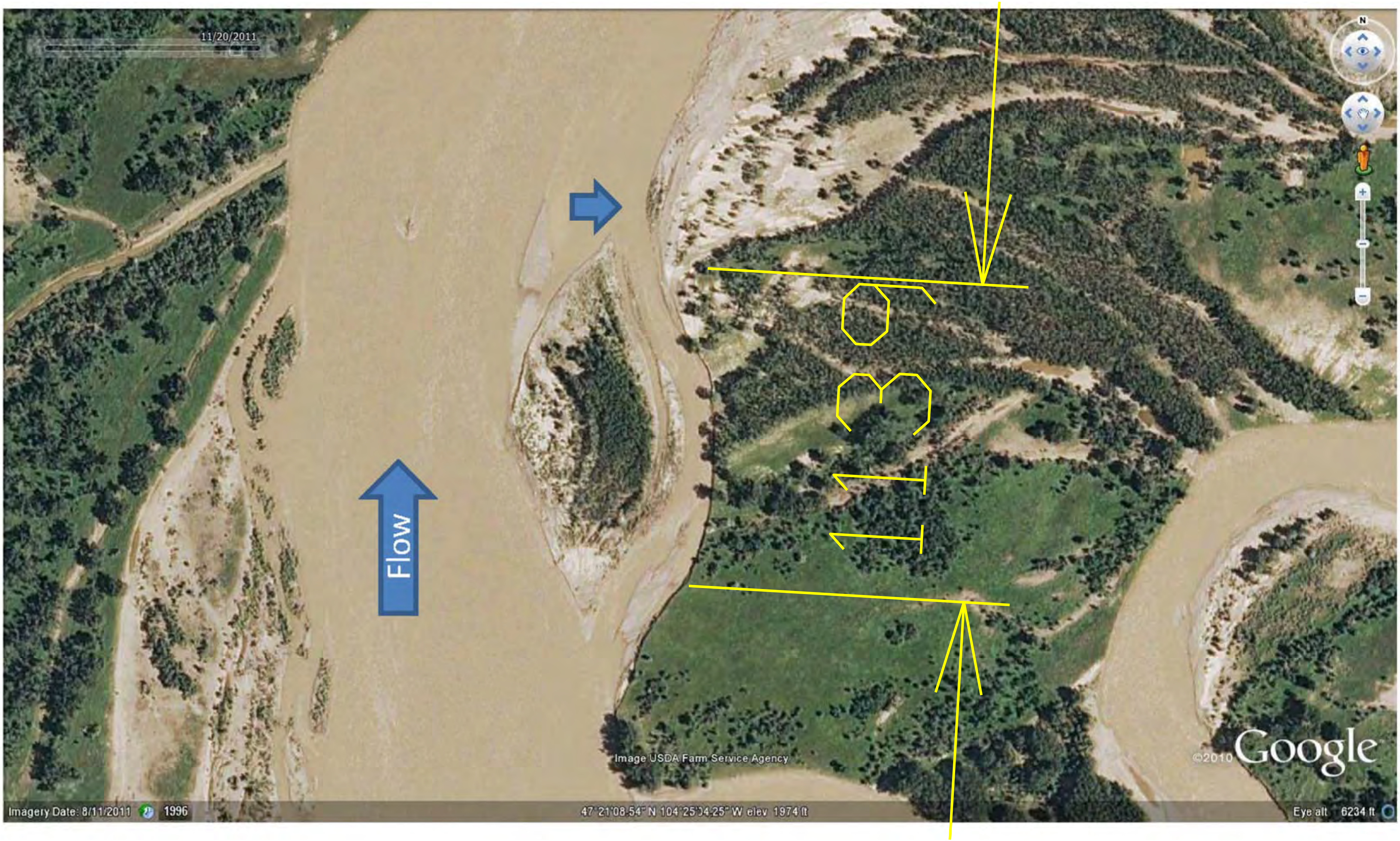
Reference Reach 11



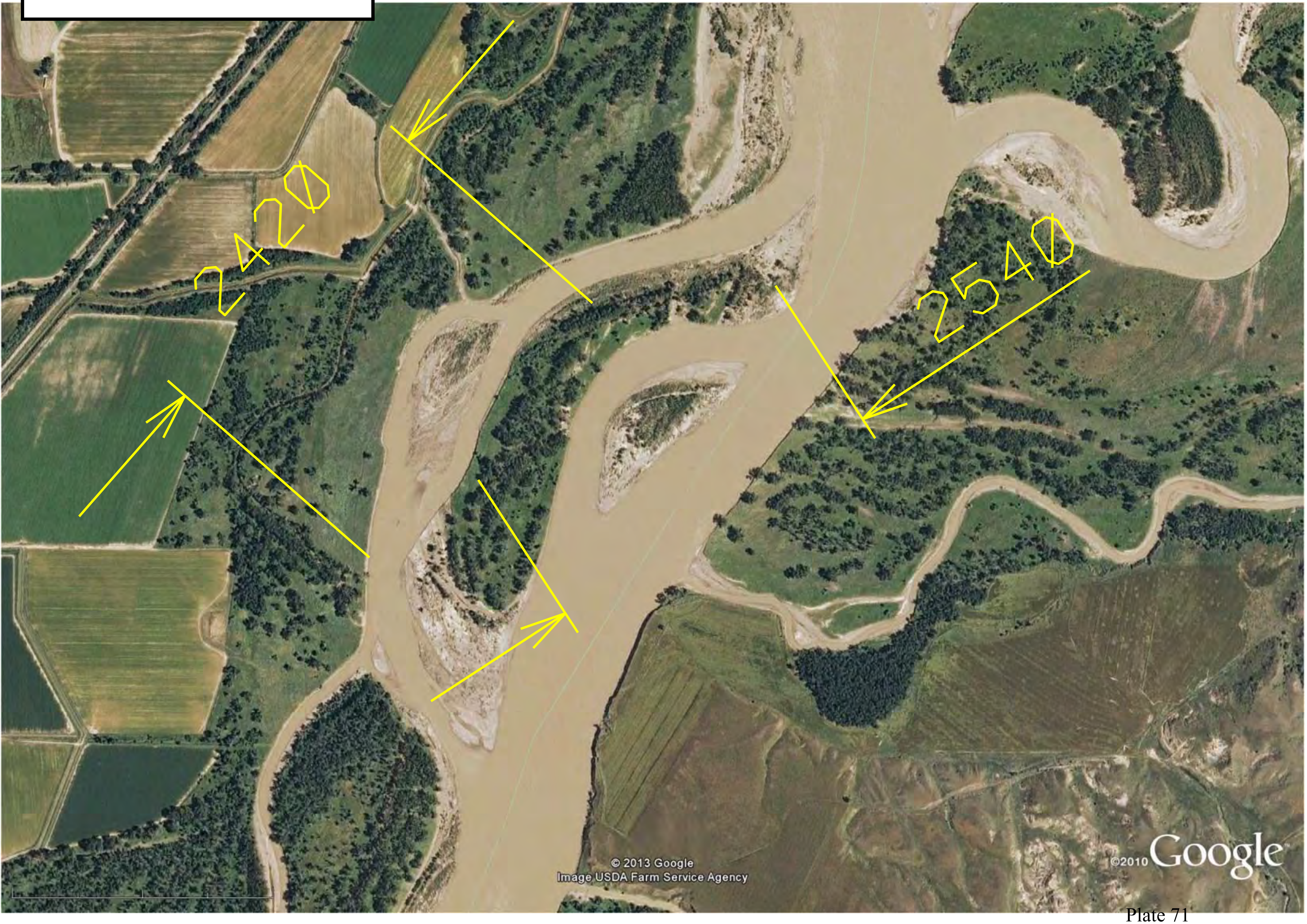
Side Channel 1



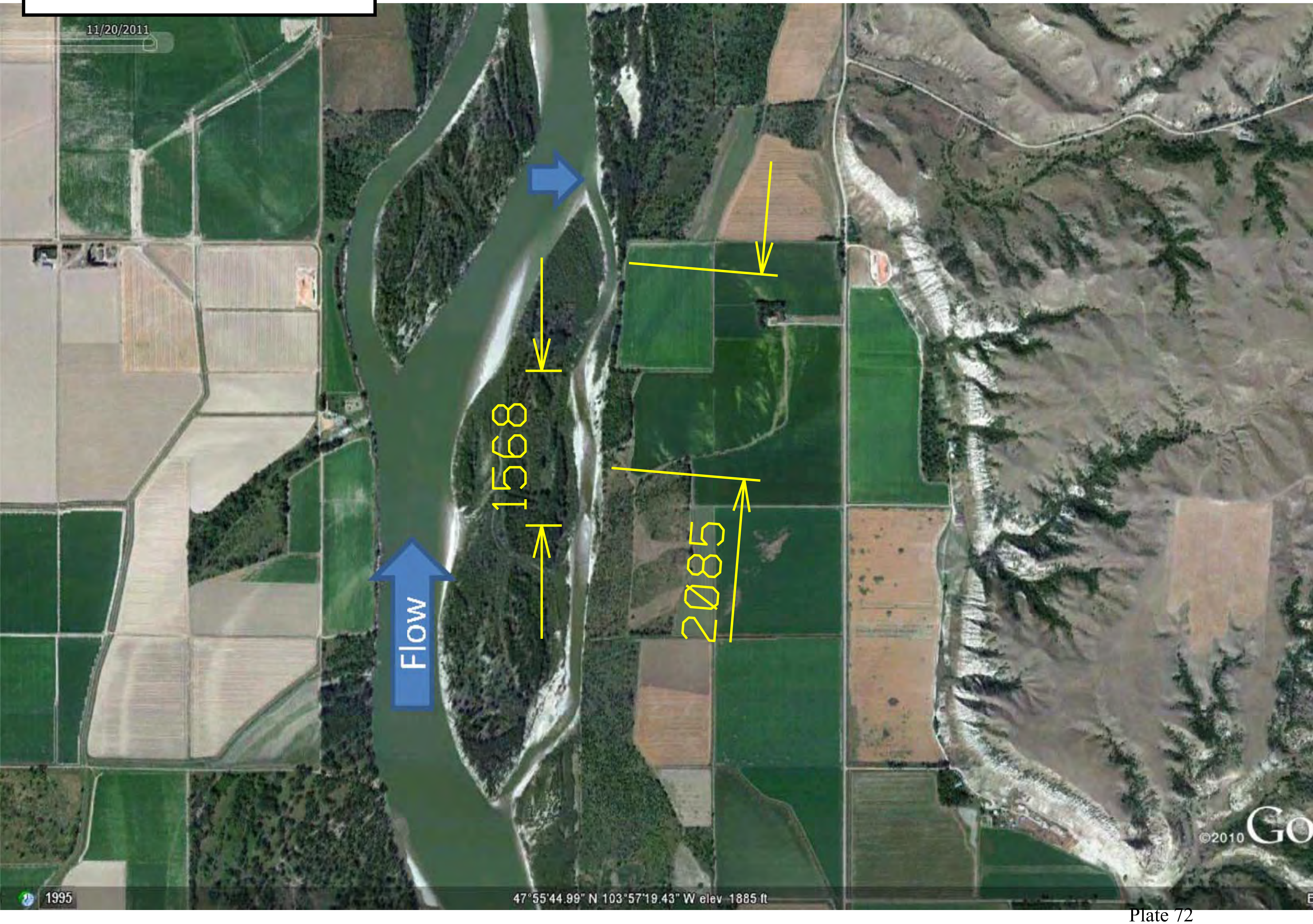
Side Channel 2

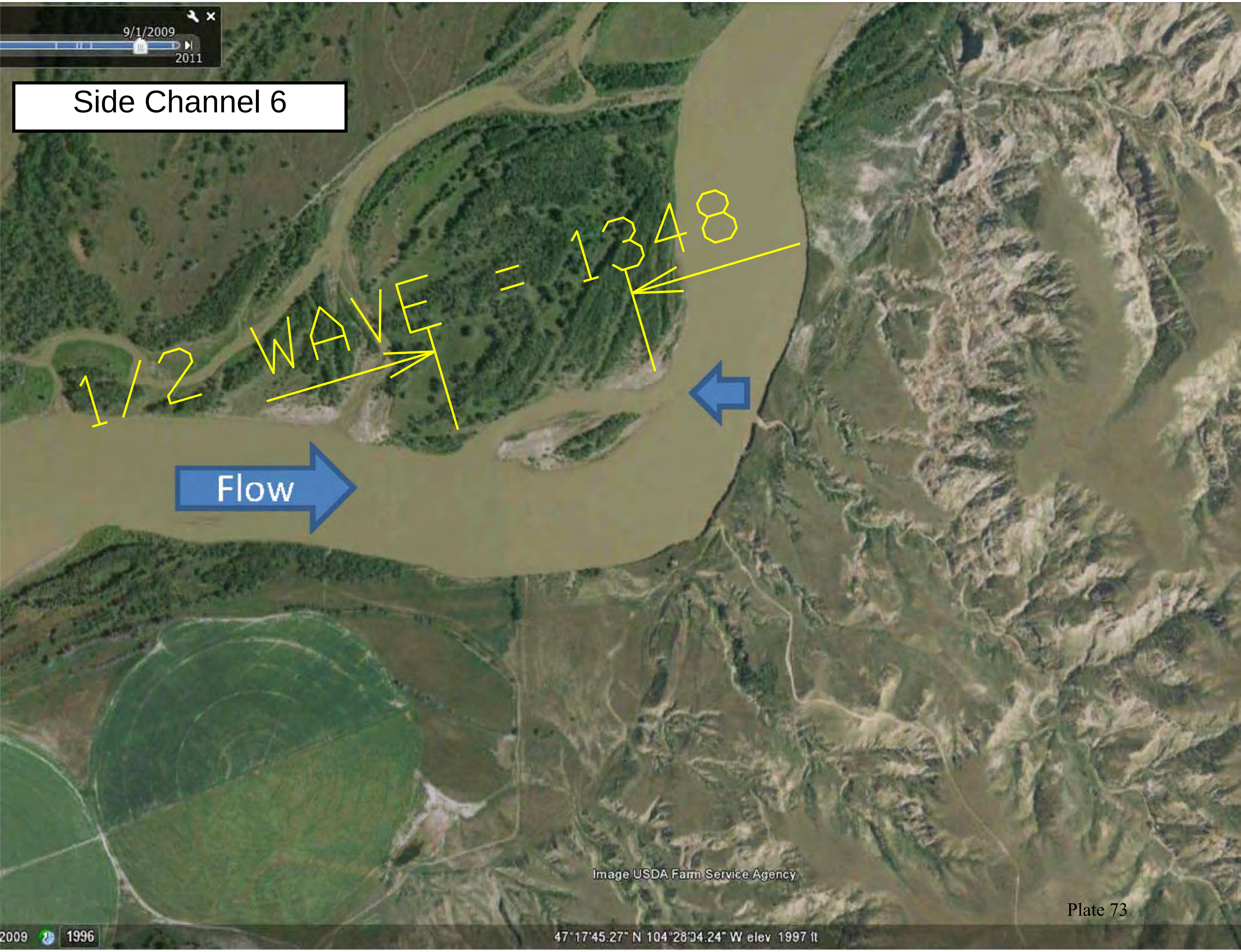


Side Channel 3



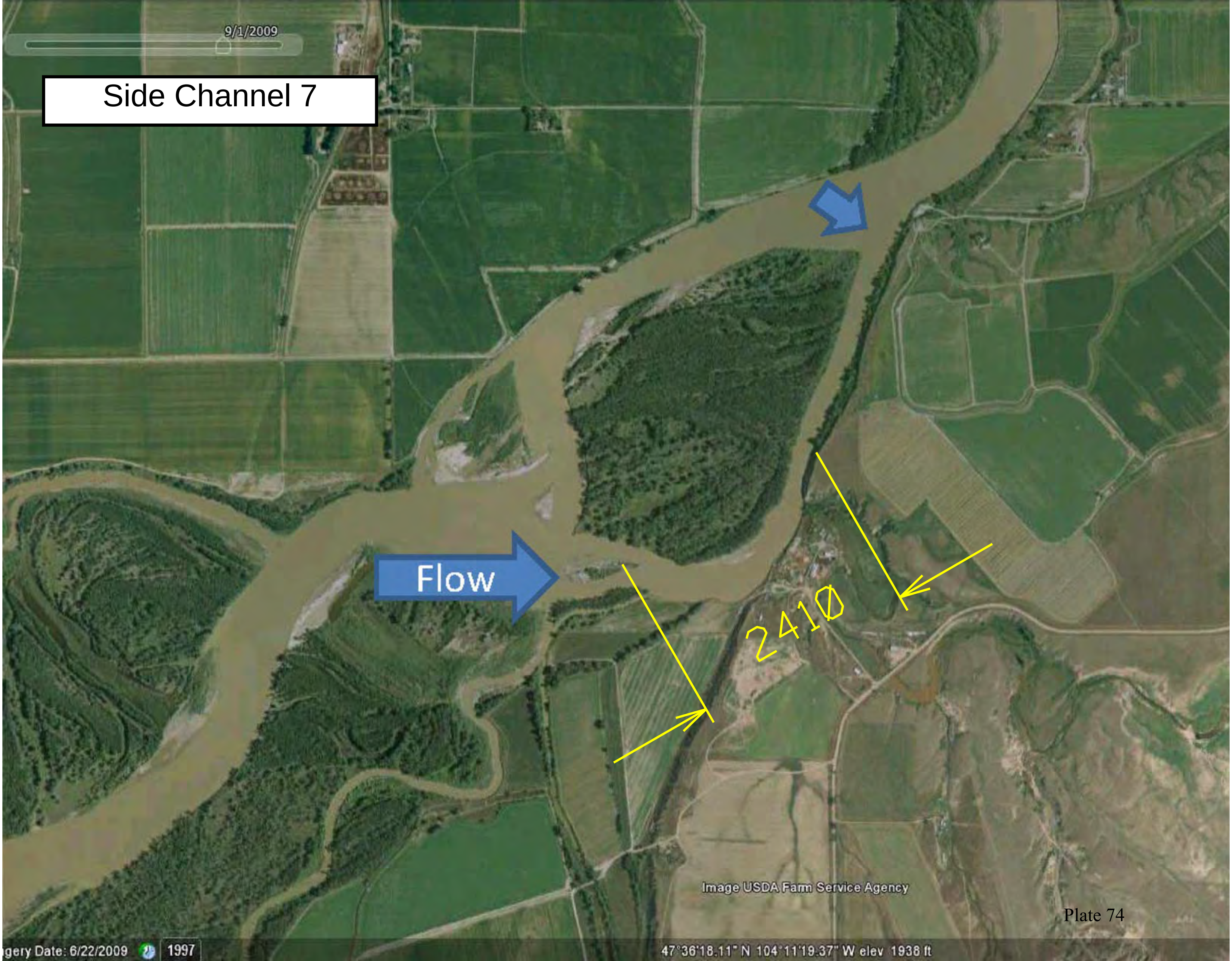
Side Channel 4





Side Channel 6

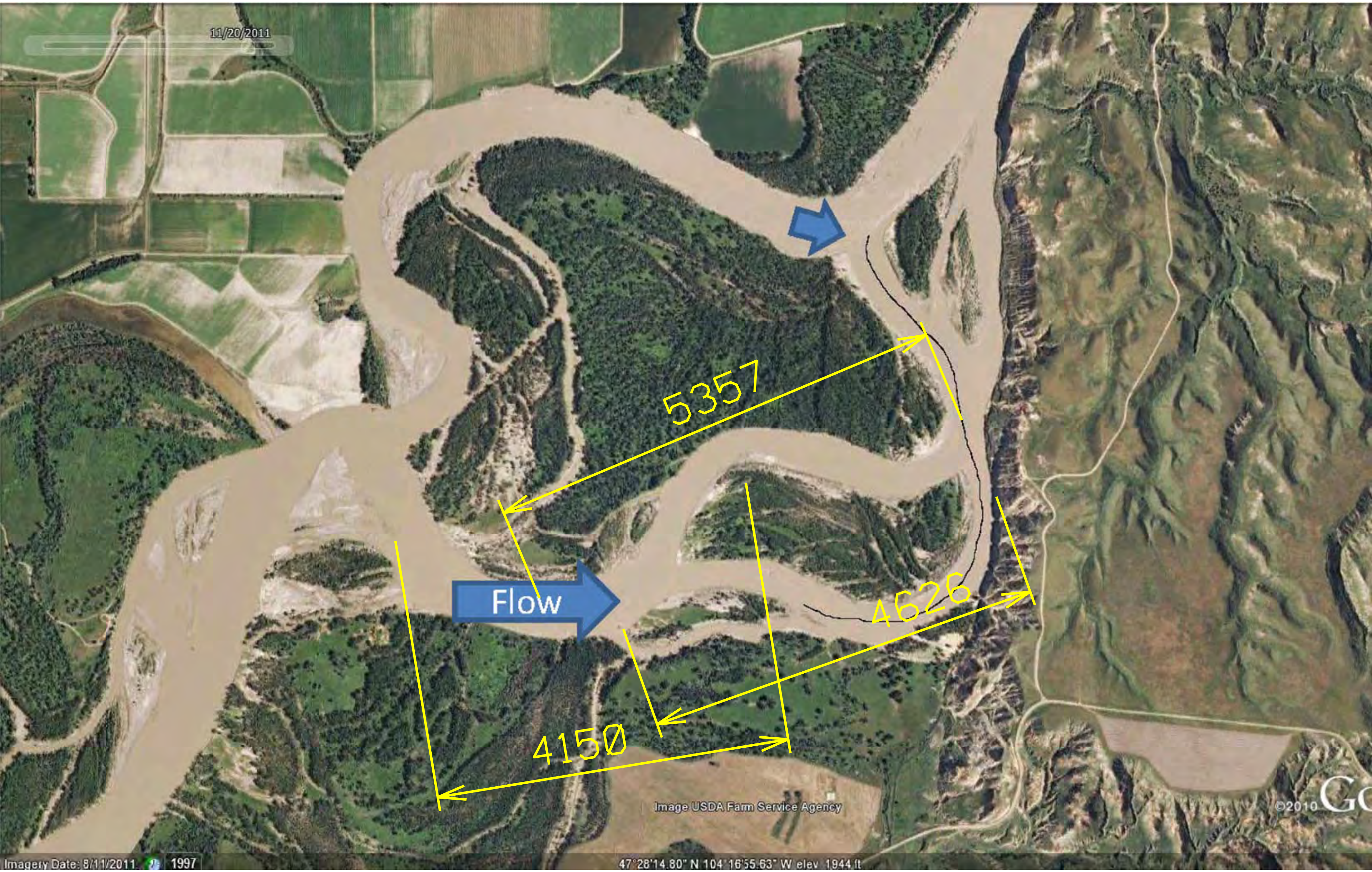
Plate 73

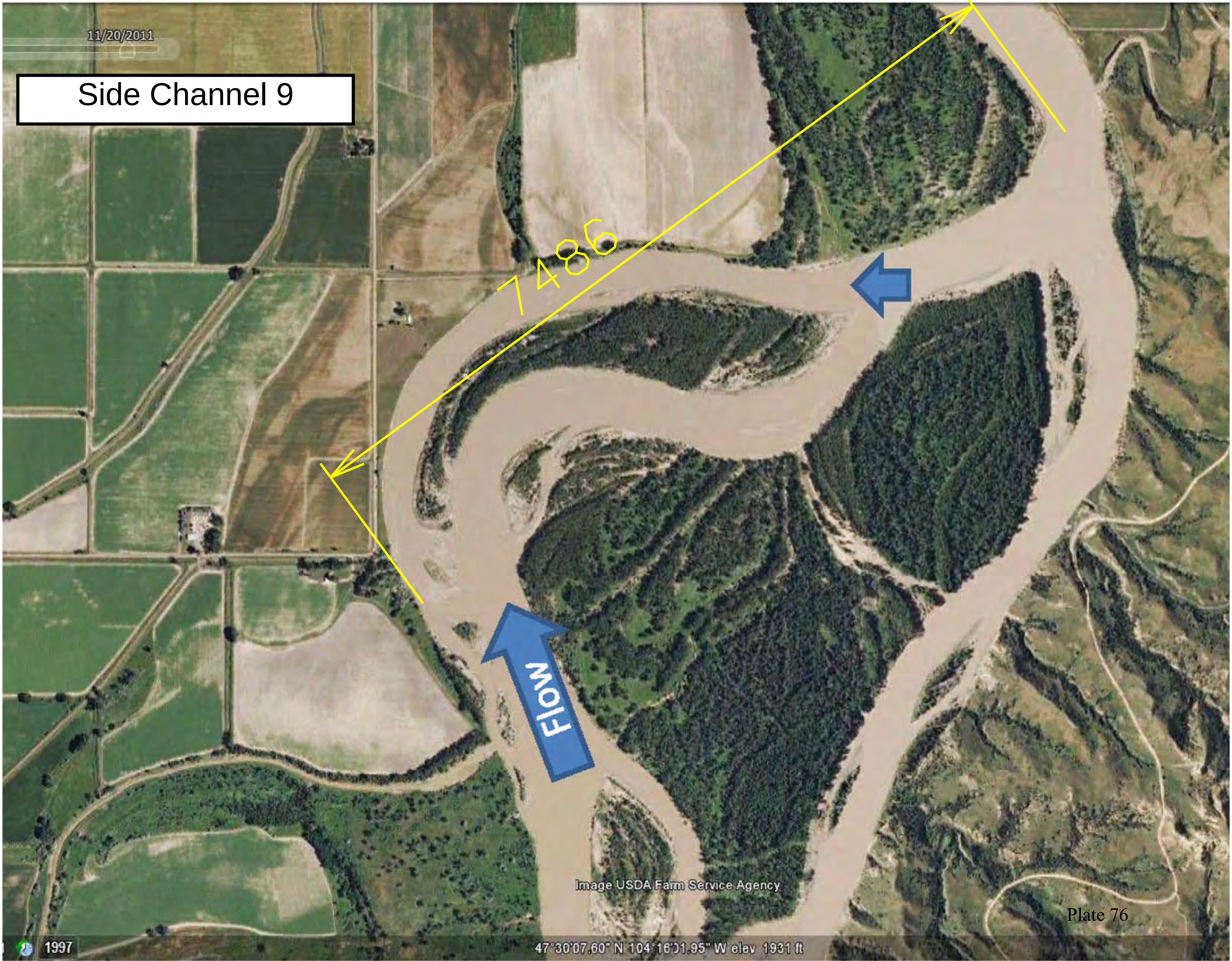


Side Channel 7

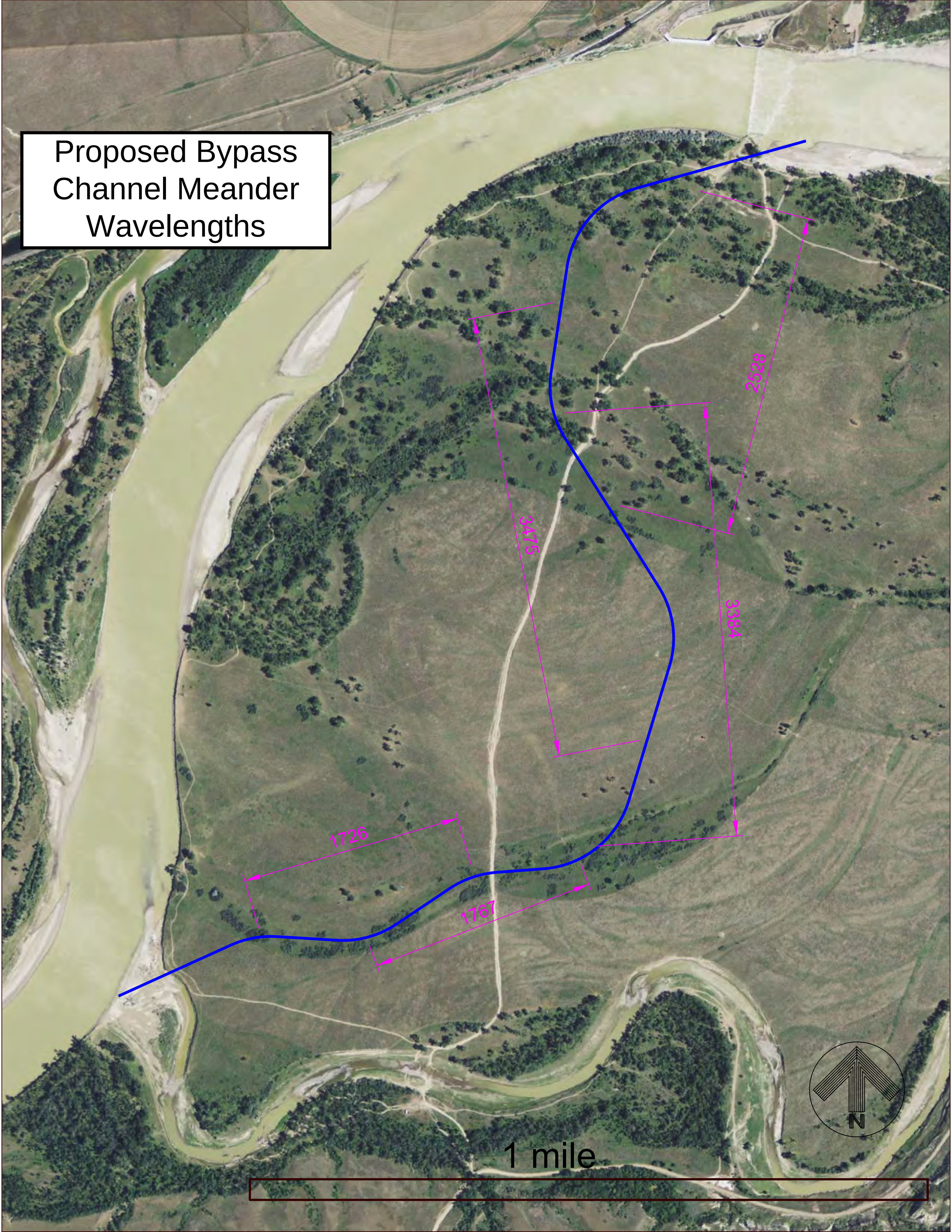
Plate 74

Side Channel 8





11/20/2011
Side Channel 9
7486
Flow
Image USDA Farm Service Agency
1997
47°30'07.60" N 104°16'01.95" W elev 1931 ft



Proposed Bypass Channel Meander Wavelengths

Intake Diversion Dam Modification

Lower Yellowstone Project, Montana

Bypass Channel 60% Design – August 2014

Hydraulics Appendix

ATTACHMENT 5

EVALUATION OF ICE IMPACTS ON FISH BYPASS CHANNEL AT INTAKE DAM, LOWER YELLOWSTONE RIVER (CRREL)

Draft Report

Evaluation of Ice Impacts on Fish Bypass Channel at Intake Dam, Lower Yellowstone River

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Meredith L. Carr

US Army Corps of Engineers
Cold Regions Research and Engineering Laboratory
72 Lyme Road, Hanover, NH 03755

February 12, 2012

1. Introduction

The Lower Yellowstone Project at Intake is a Bureau of Reclamation irrigation project located on the Yellowstone River approximately 70 miles upstream from the confluence with the Missouri River. The project consists of a low-head diversion dam, a diversion headworks structure, and an irrigation canal system to deliver water to approximately 53,000 acres in Eastern Montana and Western North Dakota.

The diversion dam is a known barrier to native fish migration including endangered pallid sturgeon. The canal has been documented to entrain many thousands of fish during diversion operations (April through September). Bureau of Reclamation has an obligation, under the Endangered Species Act, to modify the structure or the operation of this facility to address pallid sturgeon concerns raised by USFWS and the Montana Department of Fish, Wildlife, and Parks. The Corps has been working with the Bureau of Reclamation to develop plans to construct a new headworks with screens and also provide fish passage. Two fish passage alternatives under consideration consist of a full river width rock ramp at an average slope of 0.5 to 1% and a bypass channel of 10,000 to 15,000 feet in length that would provide habitat similar to existing natural chutes. Figure 1 shows the preferred alignment of the bypass channel and its structural components.

Omaha District requested ERDC/CRREL[1] to provide engineering design guidance related to ice on the bypass channel and associated structures. This effort follows previous work by CRREL in 2011 that estimated ice forces on the intake dam and the new headworks structure and provided ice related design guidance for the rock ramp.

2. Design Background

The new headworks structure is currently under construction and will be in service for the 2012 irrigation season. A preliminary diversion dam and rock ramp fish passage concept design was completed in spring 2010. The next engineering phase identified unacceptable cost escalation associated with the rock ramp design however. This led to consideration of additional fish passage alternatives during preparation of a Decision Document

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[1] Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory

(USACE March 2011a). One alternative is the construction of a bypass channel. The preliminary design assessed performance based on bypass channel geometry and hydraulic conditions needed for fish passage (USACE March2011b). An updated design (USACE January 2012) provided greater detail on various project components with slight revisions to channel geometry. The ice design information presented in this report will be incorporated in a 30% concept level design due in April 2012.

The ice force design effort draws on previous ice analyses done in 10% and 30% designs of the intake headworks, new dam and rock ramp as well as HEC-RAS modeling of hydraulic and ice processes in the preferred bypass channel and adjacent river.

3. Approach

This study began with a review of previous design efforts for the bypass channel (USACE March 2011a) as well as earlier ice analyses associated the design of the headworks, diversion dam and rock ramp. (USACE, March 2011a and January 2012). The previous literature review of related ice issues will be updated to include information on ice processes associated with bypass channels and chutes.

Ice-interaction was analyzed for the following project components:

a. Upstream control structure at bypass channel inlet (referred to as “exit” from fish perspective)
b. Channel plug where bypass channel diverges from path of existing natural chute.
c. Riprap at bypass channel bends for lateral stability
d. Vertical grade control structures along bypass channel
e. Downstream vertical control structure (referred to as “entrance” from fish perspective) where bypass channel re-enters Yellowstone River below dam.
f. Lateral stability structure along Yellowstone R. below bypass channel outlet.
g. New dam
h. Flow augmentation weir parallel to the Yellowstone River right bank immediately upstream of the diversion dam. This weir would provide additional attractive flow to the bypass channel entrance downstream of the dam during high flow events.

These structures are shown on Figure 1 and described in USACE, March 2011a and USACE January 2012.

For the purpose of design for ice forces, a worst case ice formation, breakup, jam and release scenario was developed similar to the approach in previous ice design analyses. Figure 2 shows the hydrograph for the Yellowstone River at Miles City and Sidney for the winter of 1996 which had the most severe ice jamming in recent history. The ice scenario starts with a hydraulically thickened ice cover forming during the early winter at flows in the 8-10 Kcfs range that remains in place until mid-March-early April when flow increases to an assumed breakup level of about 20 Kcfs. A large ice jam is assumed to form downstream of the Intake Dam as it has historically. As discharge continues to increase the jam in the main river channel forces flow and ice into the right overbank and bypass channel. It is assumed that the ice cover breaks up and formas a smaller jam in the bypass channel. At about 40 Kcfs the jams are assumed to release and the flow impounded by the jam surges downstream in the river channel and floodplain area leaving behind high shear walls and large ice pieces in the right overbank area. Figure 3 shows the aftermath of such an event which occurred in March of 1912.

This process of ice formation, breakup and subsequent ice run was modeled using HEC-RAS and the resulting water surface and ice jam profiles used to evaluate ice-structure interaction. For concrete structures such as weirs, design ice forces and heights of ice structure interaction are estimated based on established bridge design codes such as AASHTO (1998) and ice loading guidance found in the Ice Engineering Manual (US Army, 1999). In this project, the main type of ice interaction will be with riprap structures where the lack of theoretical guidance relating ice forces to rock stability necessitates a more empirical approach such increasing the riprap layer thickness.

The design approach for the riprap structures followed an approach similar to the one used in the design of the rock ramp (USACE, 2011a). The rule of thumb taken from lab tests by Sodhi et al. (1996, 1997, and 1999) recommends the D_{50} of the riprap should be 2-3 times the maximum ice thickness. This was not used in the design of the bypass channel for reasons as explained in the previous ice analysis (USACE, 2011a) . These included cost, difficulty of finding and placing rock that large and the fact that the Yellowstone situation is different from the ice ride-up tests upon which the guidance was based. The approach taken was to design the riprap structures based on hydraulic conditions of the 100-year open water flood and add 1.0 ft the layer thickness *T*, scaling up the rock size distribution proportionally.

4. Ice Processes Related to Chutes and Bypass Channels

The literature review of ice processes related to chutes and bypass channels is not yet complete. Based on experience with large ice-affected rivers, ice processes play a major role in terms of overbank flooding and the flow to and from the floodplain. A major difference between fluvial and ice-affected processes is that ice jams may cause flow in overbank areas at much lower discharges than in open water conditions. The HEC-RAS analysis done in this study proved this out. On the lower Yellowstone River, breakup typically progresses downstream from warmer to colder climate in a series ice jams and releases. Jams in the main channel often push flow and ice into side channels and chutes, leaving behind high shear walls and ice pieces in the overbank areas when the jam releases as shown in Figure. 3. As the hydrograph increases to the breakup level, one would expect flow in overbank chutes to increase, floating up the freezeup ice cover and possibly forming small jams. The main breakup ice action would be expected to occur in the main channel however due to the higher velocities and depths and much greater ice supply. When these jams form as they have historically at many locations between Glendive and Sidney, the wide floodplains and side channels serve as relief mechanism accepting and storing flow and ice. Under these conditions, the flow area is large and overbank water velocities relatively low (≤ ~2 ft/s by HEC-RAS calculations at 40 Kcfs) which turns out to be a mitigation factor in terms of the design of bypass channel structures.

5. Ice-Hydraulic Processes Related to ice Loads on the Project

The ice analyses for previous design efforts, diversion found the lower Yellowstone River to be subject to heavy ice formation, dynamic ice breakups and ice jams. Because the Yellowstone flows northeastward from warmer to colder climate, the ice breakup progresses downstream in a series of jams and releases, and ice jam severity tends to increase in the downstream direction as the breaking front encounters stronger thicker ice. These events force flow and ice out of bank, either in side channels and chutes or over the entire floodplain width. Numerous ice jams and ice jam floods have occurred upstream of Intake at Glendive and downstream at Sidney (Haehnel and Tuthill, 2006). Jams have also been reported at Intake in the vicinity of the Richland County Line, Elk Island and Savage. All this suggests that the project reach is subject to the dynamic formation and release of ice jams. The most recent severe ice jam event on the Yellowstone occurred in February 7-13, 1996. Figure 2 shows the Yellowstone River discharge and AFDD for that winter at Miles City and Sidney.

On faster flowing rivers such as the Yellowstone, the predominant ice type is frazil which forms as small particles in super-cooled open water reaches. The frazil crystals stick together (flocculate) to form floes that tend to increase in size with distance traveled. The floes may accumulate along the channel sides to form border ice or stall in slack areas or channel obstructions to build an ice cover in the upstream direction. Only where water currents are slow (≤ 1 ft/s) can in situ thermal ice growth be expected. In the 1 to 1-1/4 ft/s velocity range, the frazil floes will accumulate edge-to-edge in a process known as juxtaposition. At higher water velocities, the floes will stack or “shove” into a thicker ice accumulation. The HEC-RAS model contains an ice routine that calculates ice accumulation thickness by these processes for both the freezeup and breakup cases.

Average December-January discharge at Sidney gage is 5800 cfs with a standard deviation of 1680 cfs for the 1910-2009 period. A higher freezeup discharge will cause a thicker freezeup ice accumulation, since the water velocities and shear forces on the ice underside will be greater. For the purposes of this study, an extreme case freezeup discharge is defined as the long term December-January average flow plus two standard deviations or 9160 cfs. Figures 4 and 5 show HEC-RAS simulated freezeup ice covers in the main river and bypass channel respectively for this flow level. Upstream of the bypass inlet, the shoved frazil ice accumulation in the main river is a much as 8 ft thick while in the bypass channel the simulated freezeup ice cover is hydraulically thickened to about 3 ft thick.

From review of past ice jam events, is estimated that a late-season ice cover such will release in the project reach at a discharge of about 20 Kcfs[2]. Figures 6 and 7 show this

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[2] Review of the early project reports indicates that the ice could release once depth at the dam crest exceeded 3 ft at river flows as low as 9,000 cfs.

pre-release condition. Also, it is assumed that a breakup ice jam in the project area will release at a discharge of about 40 Kcfs[3]. This is based on the Sidney Gage data that give the annual peak on 3/14/1996 of 19.48 ft (instantaneous peak Q = 30 Kcfs) as ice-affected while the 3/6/1994 peak of 24.03 ft (peak Q=75 Kcfs) is listed as open water. In 1994 ice jams were reported at many locations on the lower Yellowstone, but the river may have been clear of ice by the time of the instantaneous peak on 3/6. HEC-RAS was used to calculate breakup ice jam profiles in the vicinity of the project at discharges of 40 Kcfs (Figures 8 and 9 respectively).

Once the ice cover releases, it is assumed that the floes and thicker frazil ice masses travel downstream and impact the project at approximately open water surface elevations (WSE). Open water surface and velocity profiles were calculated for discharges of 20, 40, 60, 80 and 100 Kcfs (Figures 10 and 11). These elevations are used to estimate the height range that the ice floes and ice masses could impact bypass channel structural elements, as discussed in the next section.

6. Ice Forces and Design of Riprap

Most of the structural components affected by ice consist of riprap. The two concrete structures are the sill at the inlet to the bypass channel and the flow augmentation weir near the downstream end. The structures and their ice design issues are discussed below. Hydraulic and riprap design information is summarized in Table 1.

The 100-year event riprap size was calculated by the Isbash Equation which relies on water velocity, rock density and a stability coefficient (0.86 used in this case). The riprap was also sized by methods from USACE (2011a) which uses water velocity, flow depth and a number of empirical coefficients. This EM is one of the few design documents that considers ice, stating that in cases of heavy ice or debris loadings, the layer thickness should be increased 0.5 to 1.0 ft. Since conditions of heavy ice are expected in the bypass channel area, the open water design layer thickness T was increased by 1.0 ft and the rock size scaled up proportionally. Finally the riprap designs by these two methods, factored for ice were compared to preliminary riprap designs provided by the Omaha District (USACE, 2011b and Table 1).

a. Upstream Control Structure at Bypass Inlet

The plans for the upstream control structure call for a 15-ft long by 60-ft wide concrete sill surrounded by riprap. This is probably the most critical structure in terms of vulnerability to ice as its upstream approach lies on the outside of a bend and will be exposed to the full impact of ice runs on the main river. The Omaha District (NWO) design calls for Type C riprap (D_{50} = 12 in) and a layer thickness T of 3.5 ft for the 3.5:1 upstream and downstream slopes and 5:1 side slopes. The ice-factored Isbash and Corps EM methods give rock sizes and bed thicknesses quite similar to the NWO design. In terms of ice action, for the 20 Kcfs and greater flow range where breakup ice movement

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[3] These ice cover and breakup ice jam release discharges are very approximate and will vary greatly depending on ice thickness and ice strength.

would be expected, the water depth and ice clearance over the 1990.3 ft elevation sill and riprap blankets would be sufficient to avoid major ice impacts (Figures. 7a and 9a). Possible areas of vulnerability in terms of ice are 1.) The left hand side slope where the Yellowstone River transitions into the bypass, and 2.) The upstream interface between the concrete sill and the riprap bed. For the first case, one might consider increasing the average rock size to 16-24 in and the bed thickness to at least 4 ft. For the second case, should some of the riprap get scoured away exposing the front edge of the sill, the sill should be designed to withstand a horizontal ice loading of 10 kips/lineal ft.

b. Channel Plug

The channel plug being located off the alignment of the diversion channel will likely not experience many breakup ice impacts. By the time the assumed breakup flow of 20 Kcfs is reached, the bottom of the bypass ice cover would still be below the 2000 ft elevation of the plug crest so ice would not be expected to pass the structure (Figure 7a). At the 40 Kcfs assumed ice jam release discharge, the bottom of the bypass ice cover would be well above the crest of the adjacent channel plug (Figure 9a). Also, with overbank flow velocities on the order of 1 ft/s (Figure 9b), one would not expect rapid downstream movement of ice from the bypass channel to the location of the channel plug.

The preliminary riprap design proposed by the Omaha District is more than adequate to withstand conditions of severe ice based on the ice-factored Ishbash and EM 1110-2-1601 approaches (Table 1).

c. Riprap at Bends for Lateral Stability

The preliminary Omaha District plan calls for armoring the bypass channel bends with riprap with a D_{100} of 16 inches and a layer thickness of 24 inches. This is based on a velocity of 8.75 ft/s. Assuming a rock unit weight of 165 pcf and an Ishbash coefficient of 0.86, the calculated D_{50} would be about 12 in. In this case, the ice-factored Ishbash and EM 1110-2-1601 rock sizes and thicknesses are slightly greater than those calculated by NWO (Table 1).

The bend riprap protection is planned to extend up to the 10-year open water elevation. In the case of the assumed 20 Kcfs breakup discharge the top of the riprap would be at the mid-jam elevation (Figure 7a). For the assumed release discharge of 40 Kcfs, the bottom of an ice jam on the bypass channel , if it were still in place would be about 5 ft above the top of the riprap. Depending on how the ice jam release occurs, this process could result in ice impacts to the riprap.

d. Vertical Control Structures in Bypass Channel and at Outlet

The preliminary riprap design by the District gives comparable results to the ice-factored Ishbash and EM 1110-2-1601 approaches (Table 1). The tops of these vertical control structures will be 1-2 ft below the channel invert as indicated in the HEC-RAS water surface and ice jam profiles. In the 20-40K breakup ice jam flow range, the channel invert and these structures will be well submerged with under ice clearances in the 12-20 ft range (Figures 7a and 9a). It is not expected that the bypass channel bed or vertical control structures will experience significant ice impacts.

f. Downstream Lateral Stability Structure

In the event of a large ice run or an ice jam and release sequence, this embankment will experience severe ice action comparable to existing conditions below the intake dam. The preliminary riprap design by the District is comparable to the results of the ice-factored Ishbash and EM 1110-2-1601 approaches (Table 1).

g. New Dam Crest

It is assumed that the new dam crest will be a horizontal weir with a crest elevation of about 1990.2 ft. In the ramp fish passage alternative, the dam crest was mildly trapezoidal with the invert at 1987 ft and the edges at 1991 ft. It is expected that ice will impact the level-crested dam in a similar way to the trapezoidal crest. In the previous 30 % design of the dam crest, it was anticipated that large ice floes could impact the dam crest over an elevation range of 1985 to 2000 ft. In terms of direct ice impacts to the upstream face of the dam, the design called for an ice loading of 15 kips/ lineal ft. For a thick frazil ice mass sliding horizontally over the top surface of the crest, the ice shear force was estimated to be 2 kips /ft^2. These ice loadings would apply to the revised level-crested dam design. . The 15 kips/ lineal ft loading on the dam face is conservative representing the high end found in the design literature. Although this design loading is applied to vertical concrete structures in rivers subject to heavy ice loadings, a sloped upstream face would be preferable since the ice would tend to ride up over the crest reducing the potential for damage to the concrete. Because the 15 kips/ft ice loading on the dam face is conservative, it would not need to be added to the 2 kips/ft^2 estimate for foe frazil ice masses ice shearing horizontally along the top surface of the dam. *h. Flow Augmentation Weir*

A flow augmentation weir parallel to the Yellowstone River right bank immediately upstream of the diversion dam will add flow to the bypass channel fish entrance downstream of the dam during high flow events. The weir will be constructed of roller compacted concrete with compacted backfill along its upstream side.

The crest of the weir will be at the 7000 cfs water surface elevation of about 1991.0 ft based on HEC-RAS. This is only 0.8 ft higher than the dam crest 1990.2 ft shown in the current HEC-RAS model. Figure 6a shows a worst case ice cover profile at 20,000 cfs, the breakup discharge. These results indicate that the upstream ice will be sufficiently thick to impact the weir when it passes over. With increasing discharge under ice clearance increases and major ice impacts to the weir would be less likely (Figure 8a). Like the dam, the top surface of the flow augmentation weir will need to withstand horizontal forces due to ice sliding along its crest of 2 kips/ft^2. The upstream face of the weir will be vulnerable to severe ice action from ice runs in the main river. It is questionable whether the compacted backfill along the weir face shown in the preliminary plans will be adequate to withstand this type of ice action. A possibility is to eliminate the backfill and extend the concrete to the upstream face of the weir. This flow augmentation weir is a critical component of the main dam serving as the dam's right embankment.

The concrete wall on the upstream side of weir will experience heavy ice impacts and should be designed for an ice loading of 10 kips/lineal ft. This ice loading is conservative and need not be added to the estimated ice shear force of 2 kips/ft^2 on the top surface of the weir. The riprap on the where the concrete wall ties into the bank will also experience heavy ice action. Here, an average stone in the 1.5 -2.0 ft range and a layer thickness of about 4 ft is suggested.

7. Summary and Conclusions

1. This study analyzed ice-related design aspects of a proposed fish bypass channel at the Intake Diversion Dam on the Yellowstone River in Montana. Past ice related design efforts were reviewed and a HEC-RAS model used to develop a worst case ice formation, breakup and release scenario. HEC-RAS calculated results of depth, water velocity and ice thickness were used gage how ice will interact with the various structures making up the proposed bypass channel and size riprap which is the primary component of the these structures. Exceptions include two concrete weirs, one at the inlet and the other at the outlet of the bypass channel. The design ice forces for the concrete structures were estimated by conventional means as outlined in AASHTO (1998) the Ice Engineering Manual US Army (2008).

2. For the upstream concrete sill under a worst case scenario, an ice force of 5 kips/ft could act horizontally along the front edge. For the surface of the upstream sill and the downstream flow augmentation weir crests, a maximum horizontal ice force of 2 kips/ft^2 due to sliding ice is estimated. The concrete wall along the upstream edge of the flow augmentation weir is expected to experience high ice impacts. Here, an ice design load of 10 kips/ft is recommended.

3. Design of riprap to resist ice damage followed the approach taken in the earlier ice analysis of the riprap ramp (USACE 2011a). First an average riprap D^{50} and D^{30} were calculated by the Isbash and EM 1110-2-1601 methods respectively with velocity and depth inputs from a HEC-RAS simulated 100-year open water event. Following the guidance of the EM 1110-2-1601, the layer thickness was increased by 1.0 ft for heavy ice conditions and the rock size fractions scaled up proportionally. This approach produced riprap designs very similar to those provided in the Omaha District preliminary designs (USACE 2012 and Table 1).

4. Several areas where the preliminary riprap designs by the District could be scaled up are the left hand side of the transition from the Yellowstone River into the upstream control structure, and the right bank of the Yellowstone River immediately upstream of

the flow augmentation weir. Here the rock size could be increased to 1.5-2.0 ft and the layer thickness to 4.0 ft.

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Table 1. Hydraulic Conditions for 100-year Open Water Event and Riprap Design for Sturctrual Components

									D$_{50}$ (inches)			D$_{100}$ (inches)			Layer Thickness (inches)		
Structure	HEC-RAS River Station (ft)	Hydraulic Depth (ft)	Average Velocity (ft/s)	Water Surface Slope	Channel Width (ft)	Bed Shear (lb/ft^2)	Bend Radius (ft)	Side Slope (H:V)	Omaha District	Factored Isbash	Factored EM	Omaha District	Factored Isbash	Factored EM	Omaha District	Factored Isbash	Factored EM
Bypass Inlet Weir	15,530	13.0	5.0	0.00026	185	0.21	500	5:1	Type C 12	10	12		20	24	27-40	30	36
Channel Plug	9,586	11.6	6.2	0.00053	230	0.38			20	12	8	30	24	16	45	36	24
Bypass Bends	6300 & 2900	13.0	7.0	0.00032	230	0.26	400-1400	7:1		12	10	16	24	18	24-36	36	28
Vertical Grade Control	9300 & 4800	13.0	6.0	0.0003	230	0.24		5:1	Type C 12	10	12		20	24	27-40	30	36
Bypass Outlet Weir	136	13.0	5.2	0.00075	240	0.61		5:1	Type C 12	10	12		20	24	27-40	30	36
Downstream Lateral Stability Structure	27,575	17.8	6.5	0.00032	800	0.36		3:1	12	10	7	24	20	12	36	30	34
Flow Augmentation Weir	28,203	16.8	6.8	0.0006	150	0.63			Recommend 1.5-2.0-ft riprap where concrete wall ties into bank.								

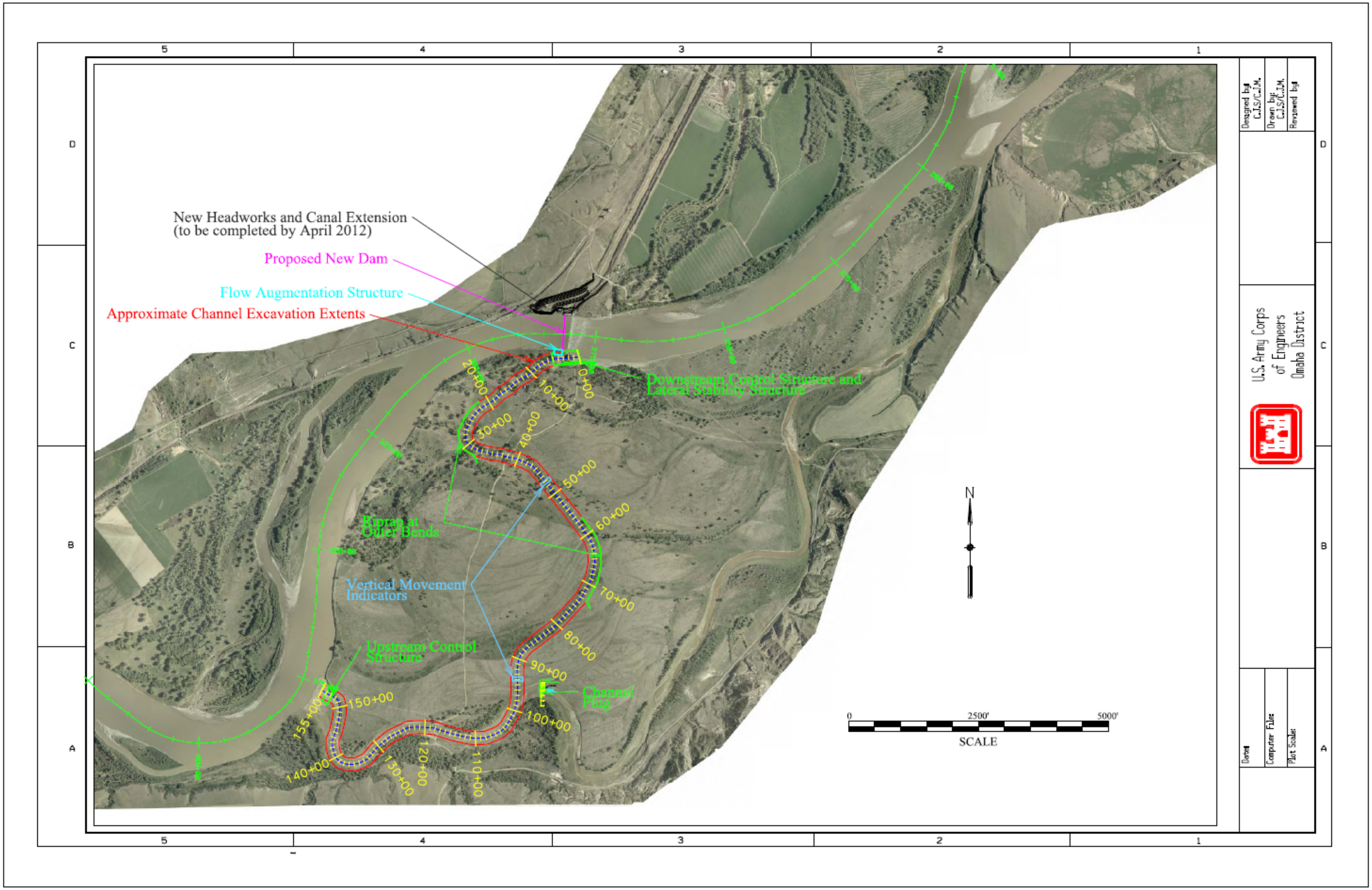


Figure 1. Map of preferred Intake Dam bypass plan as of Jan. 5, 2012 showing structural components.

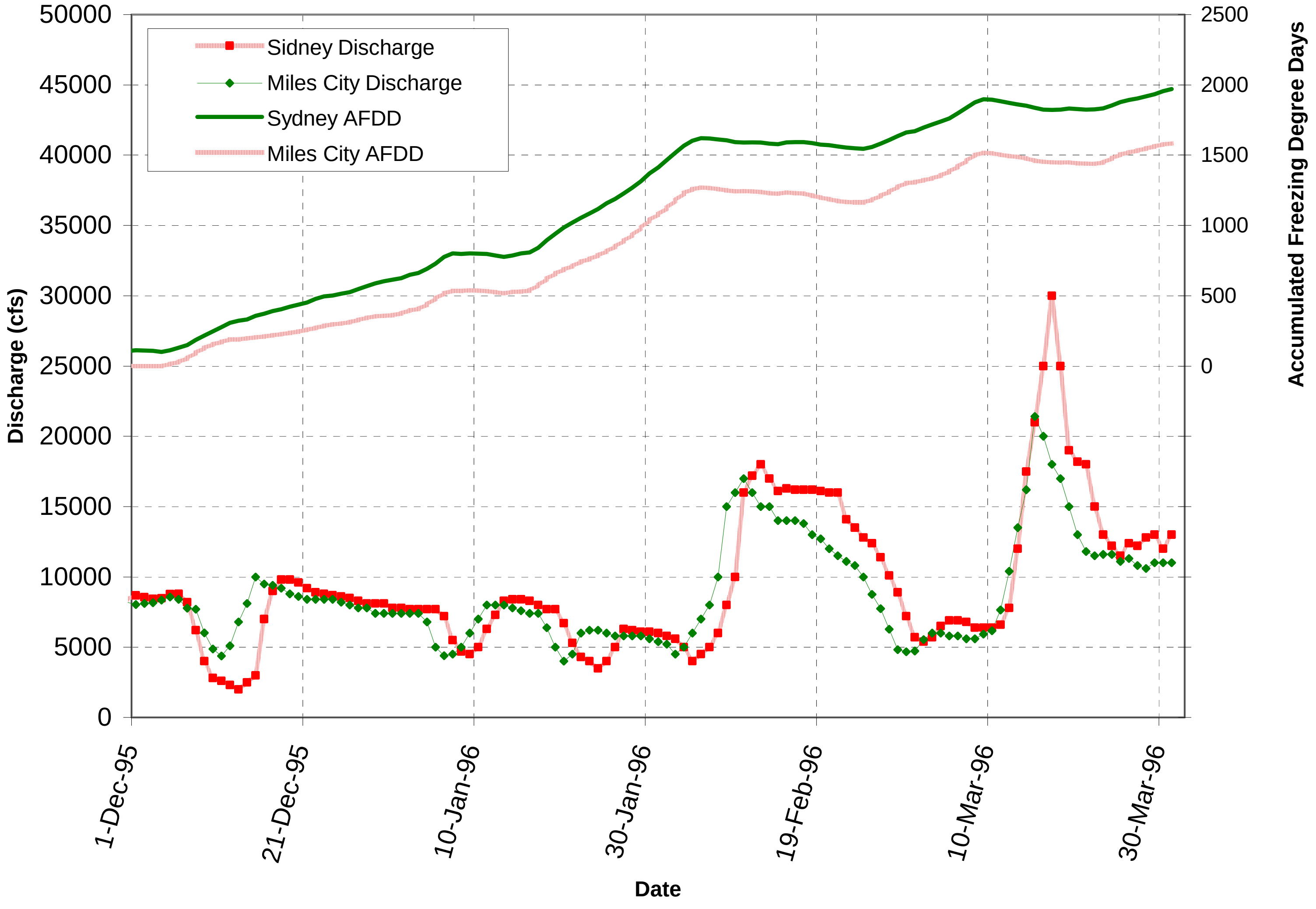


Fig. 2. Yellowstone River discharge and AFDD for the winter of 1996

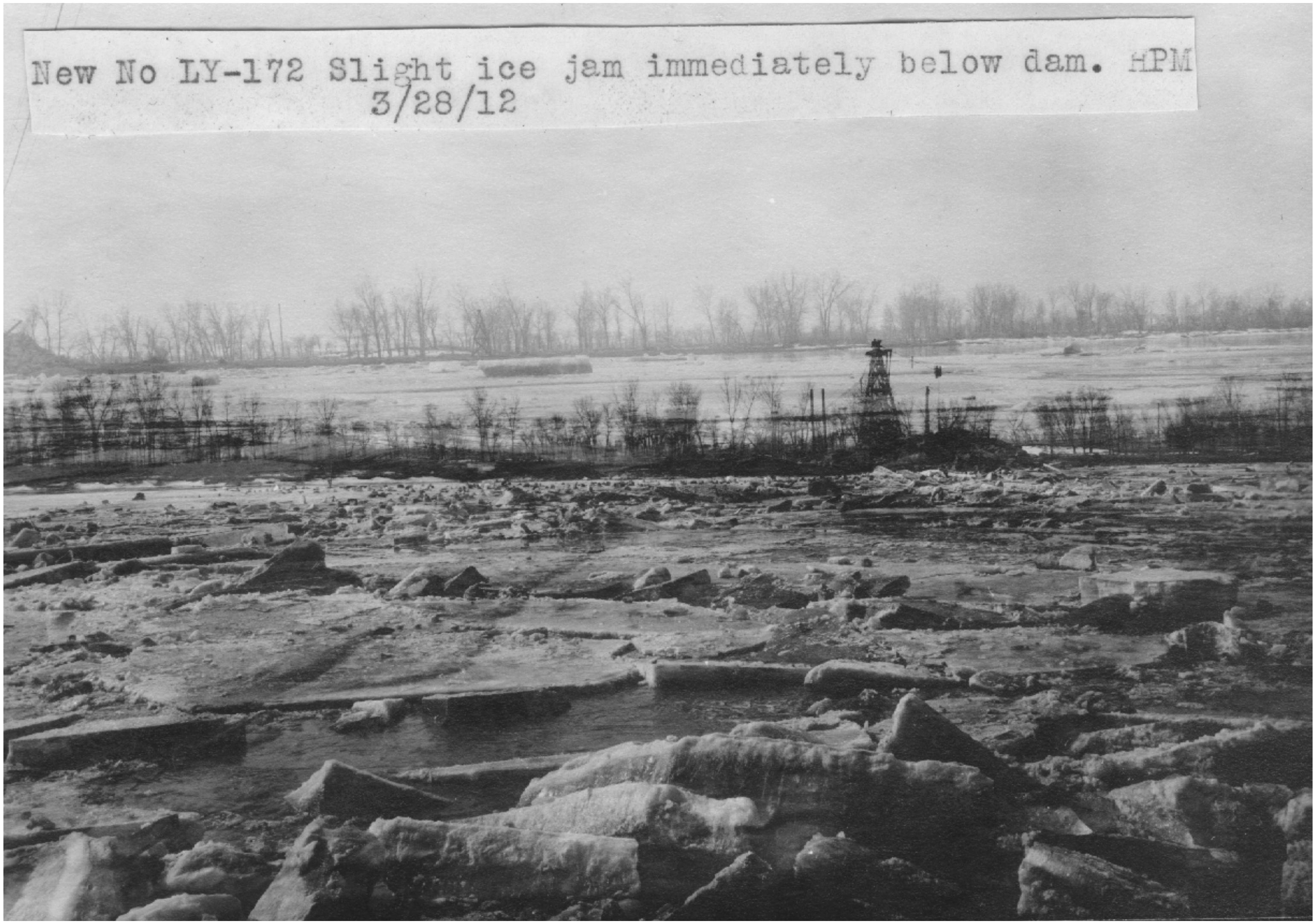


Fig. 3. Ice jam on the Yellowstone River at the Intake in 1912 forcing flow and ice into the right overbank area.

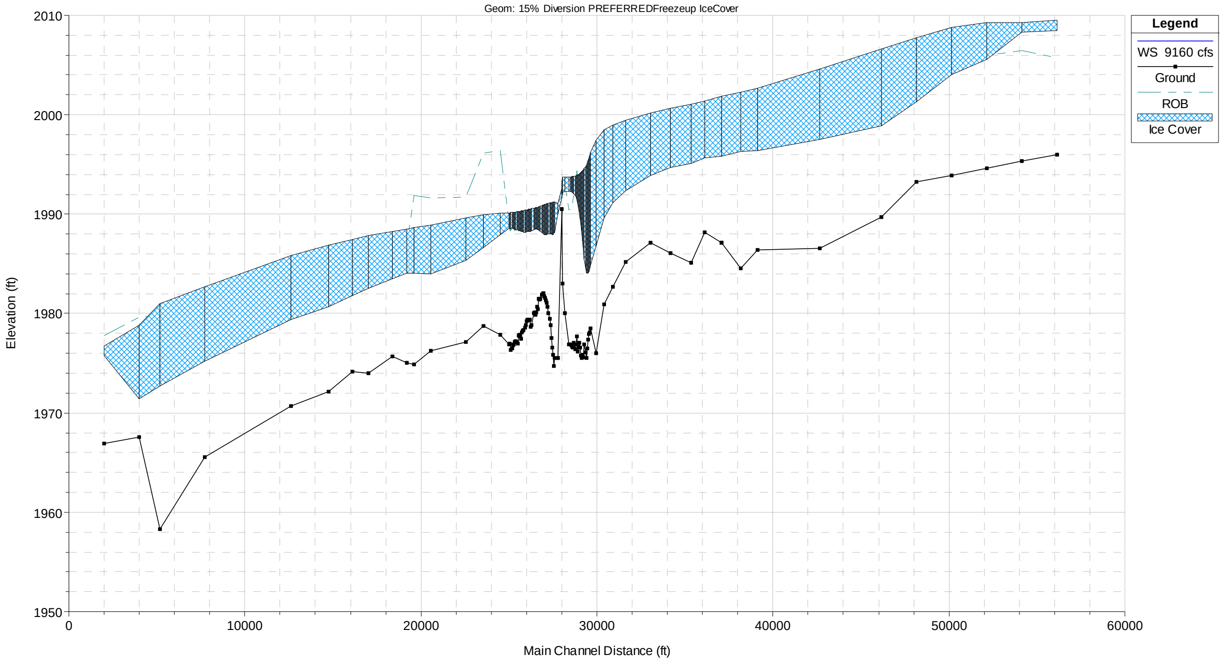


Fig. 4a. Freezeup ice accumulation on main river. Q_{river} = 9160 cfs with 15% passing the bypass channel. n_{ice} = 0.04, porosity = 0.4, V_{eros} = 5 ft/s.

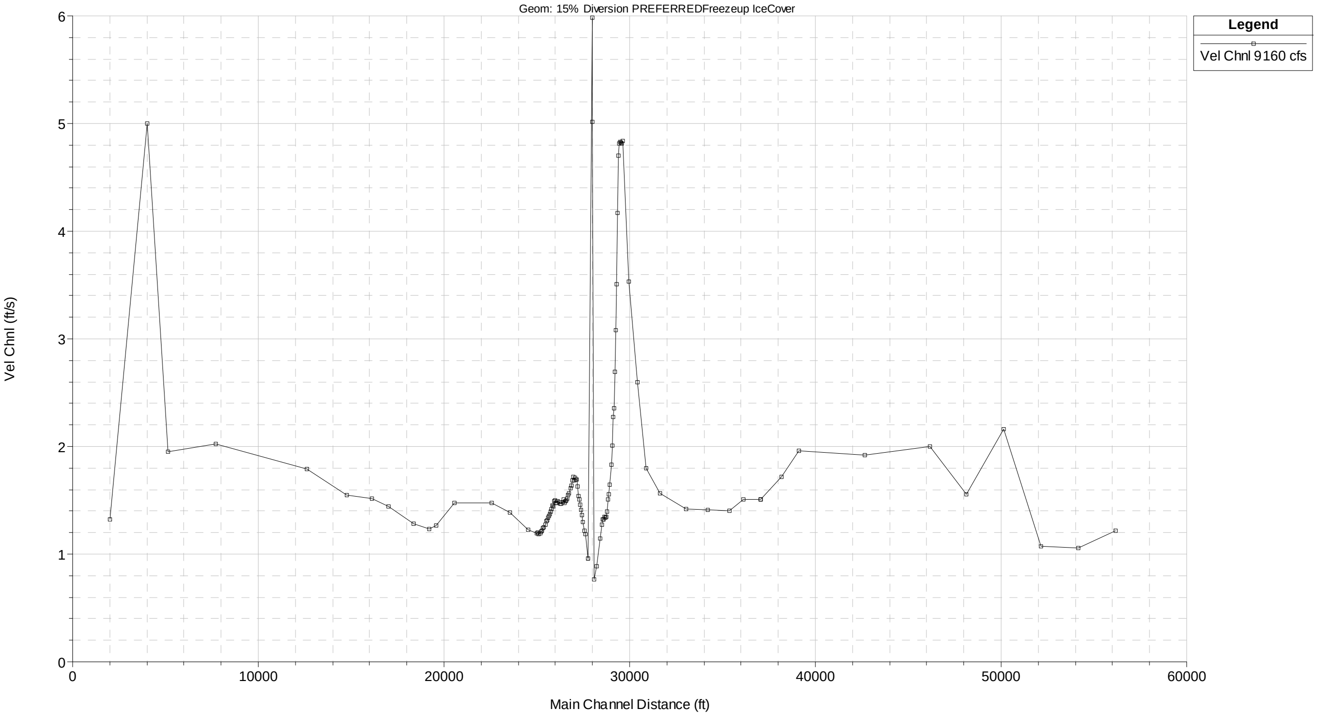


Fig. 4b. Average channel velocity in main river with freezeup ice accumulation. Q_{river} = 9160 cfs with 15% in the bypass channel

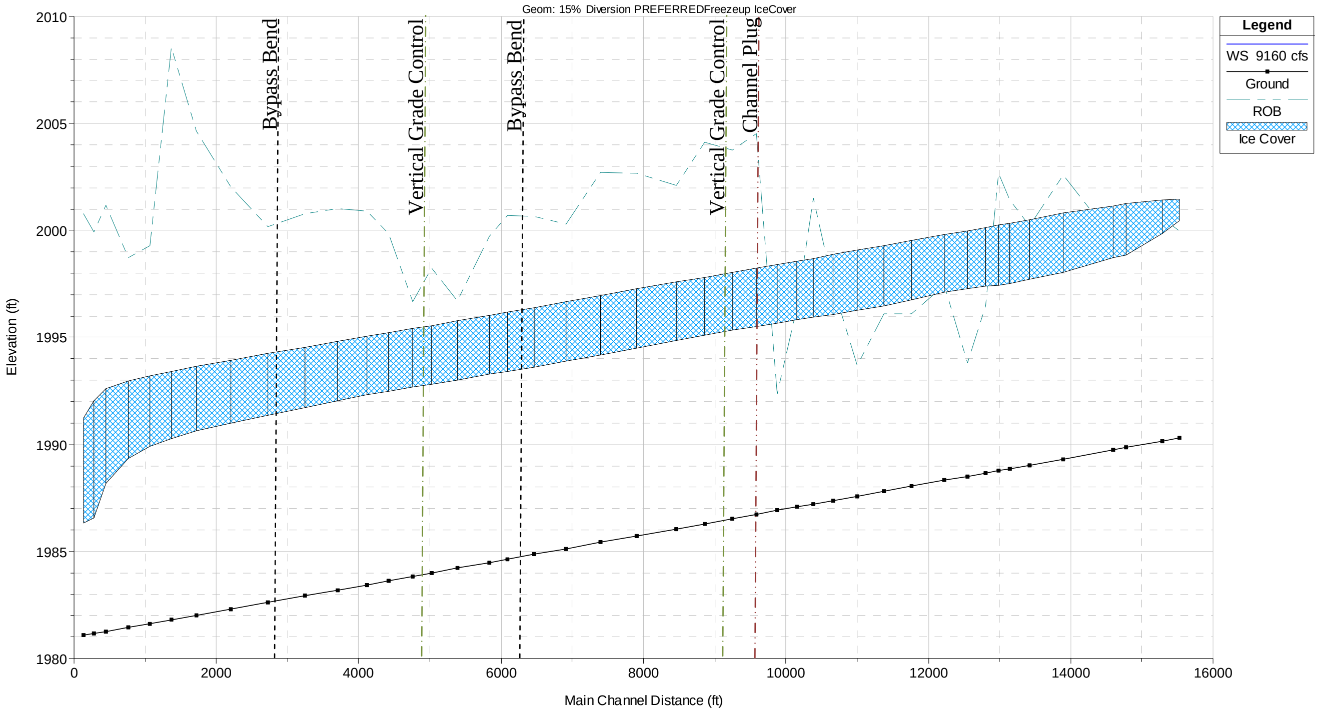


Fig. 5a. Freezeup ice accumulation on bypass channel with 15% diversion. Q_{river} = 9160 cfs with 15% passing the bypass channel.

n_{ice} = 0.04, porosity = 0.4, V_{eros} = 5 ft/s

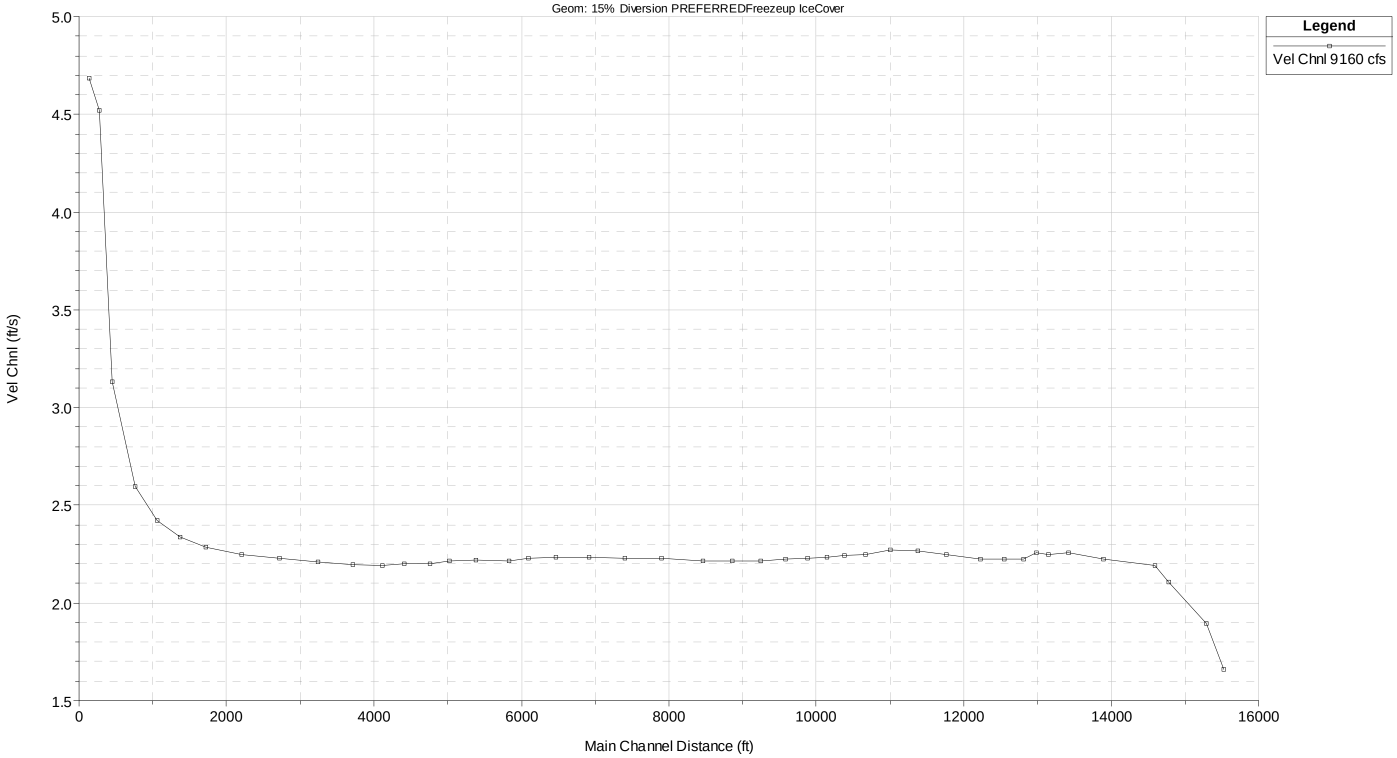


Fig. 5b. Average channel velocity in bypass channel freezeup with ice accumulation. Q_{river} = 9160 cfs with 15% passing the bypass channel.

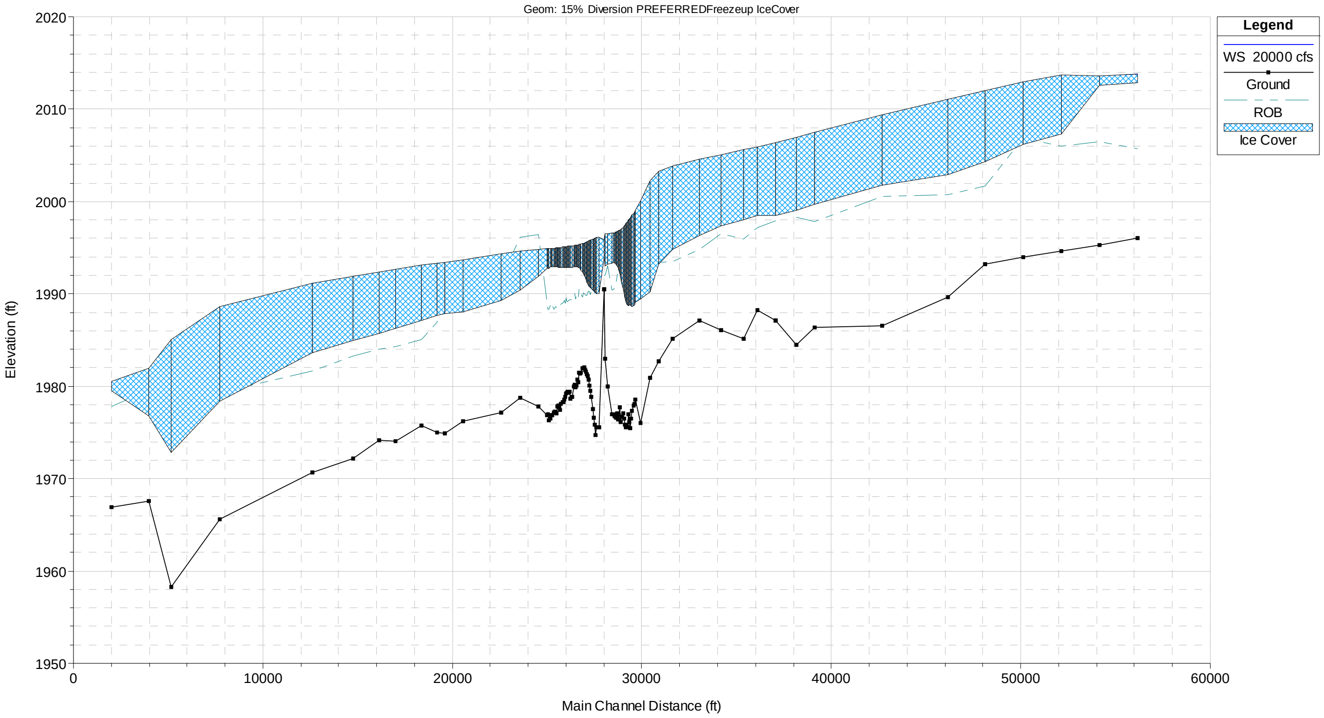


Fig. 6a.. Pre-breakup ice accumulation on main river. Q_{river} = 20,000 cfs with 15% diversion (Q_{bypass}=2600 cfs). n_{ice} = 0.04, porosity = 0.4, V_{eros} = 5 ft/s.

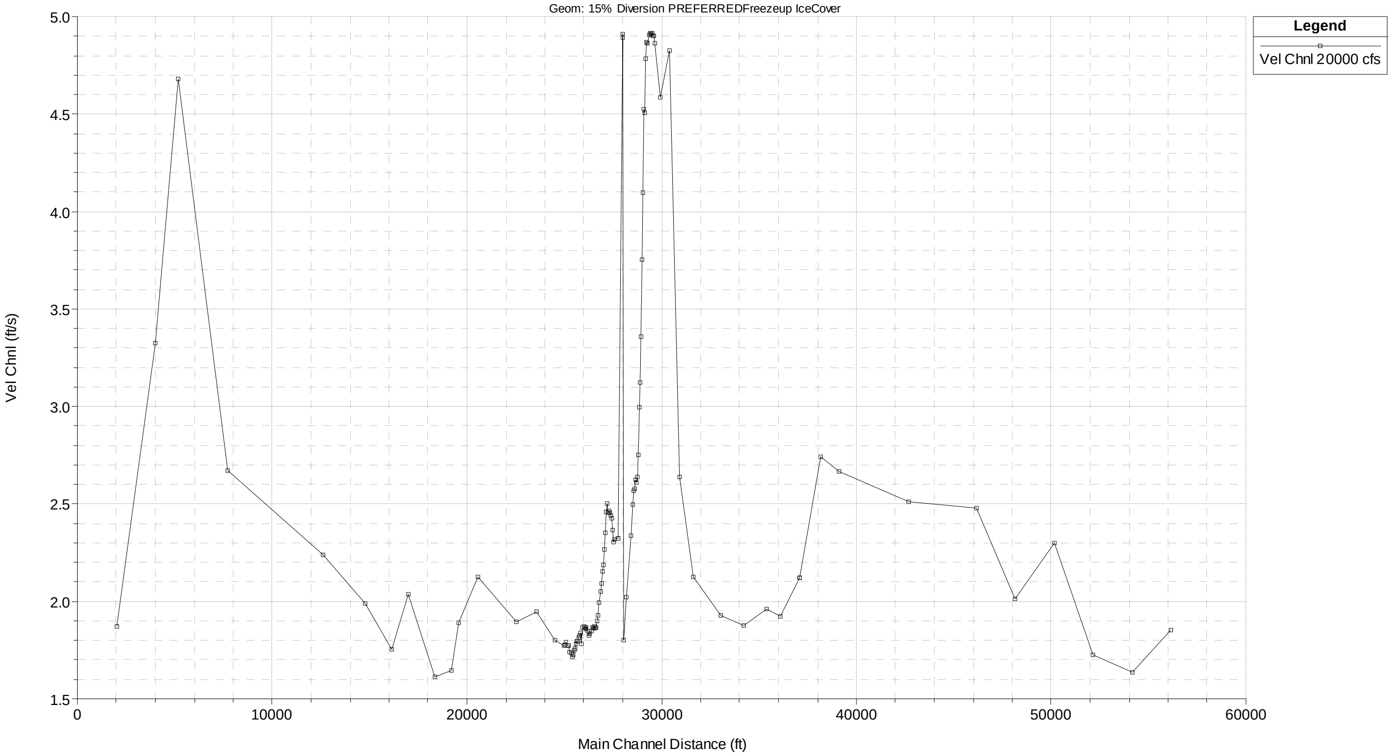


Fig. 6b. Average channel velocity in main river with pre-breakup ice accumulation. Q_{river} = 20,000 cfs with 15% diversion (Q_{bypass}=2600 cfs).

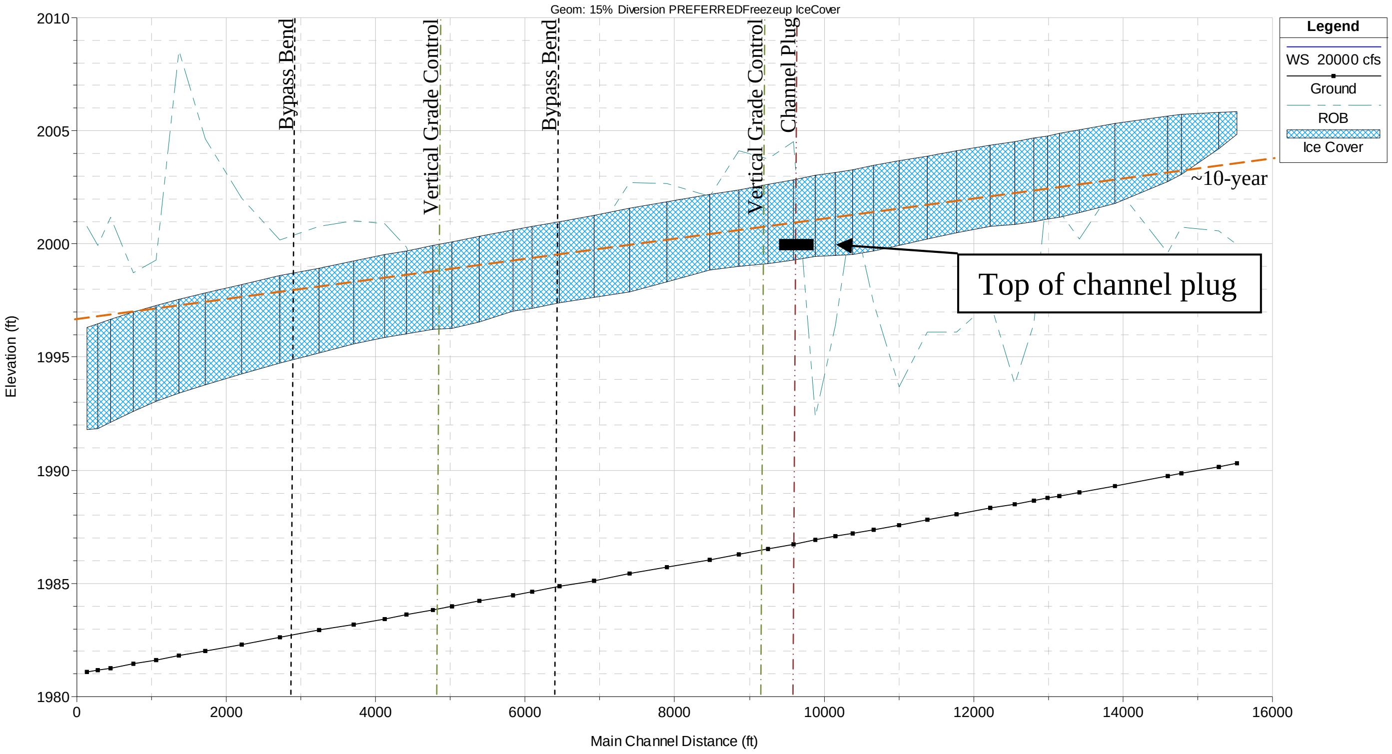


Fig. 7a. Pre-breakup ice accumulation on bypass channel. Q_{river} = 20,000 cfs with 15% diversion (Q_{bypass}=2600 cfs) n_{ice} = 0.04, porosity = 0.4, V_{eros} = 5 ft/s. 10-year elevation indicated by orange dashed line.

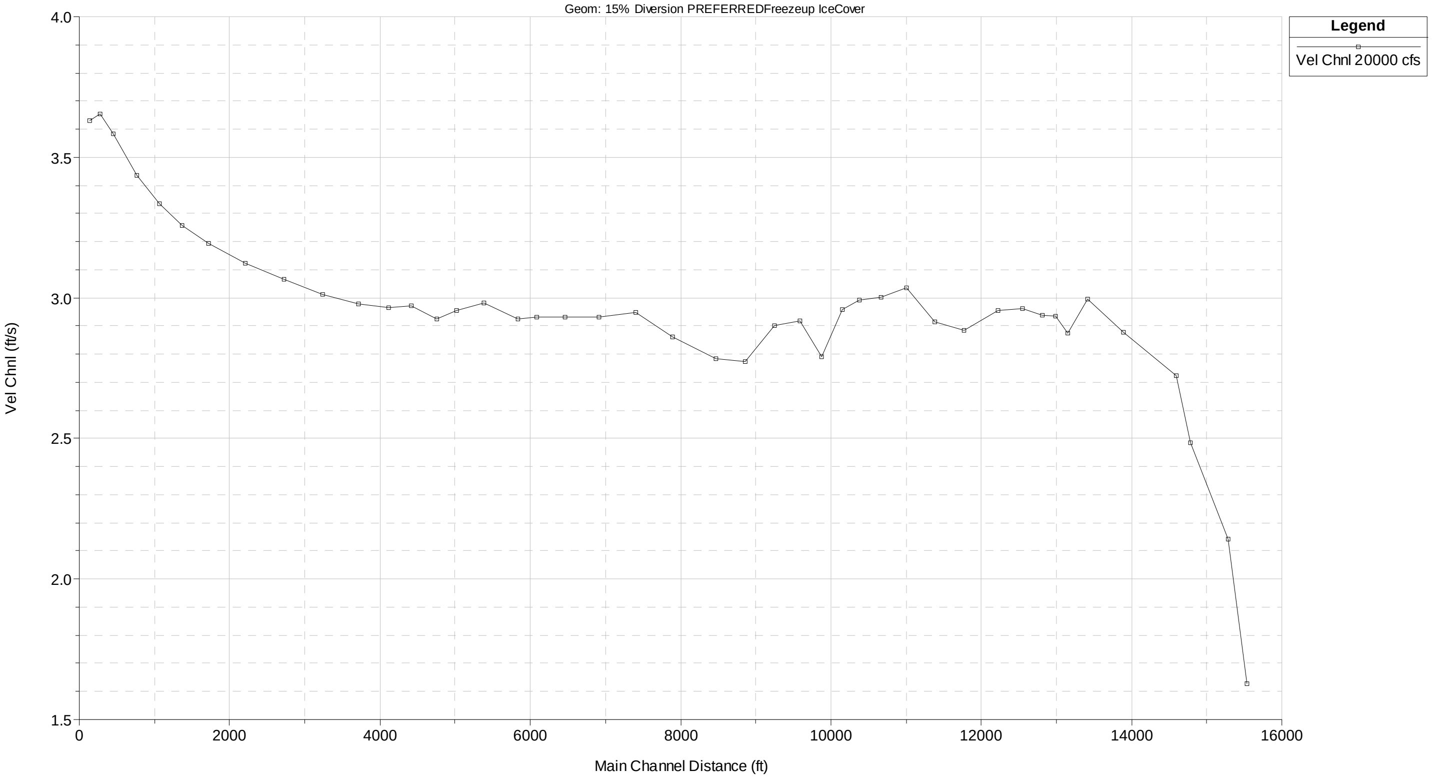


Fig. 7b. Average channel velocity in bypass channel with pre-breakup ice accumulation. Q_{river} = 20,000 cfs with 15% diversion (Q_{bypass}=2600 cfs).

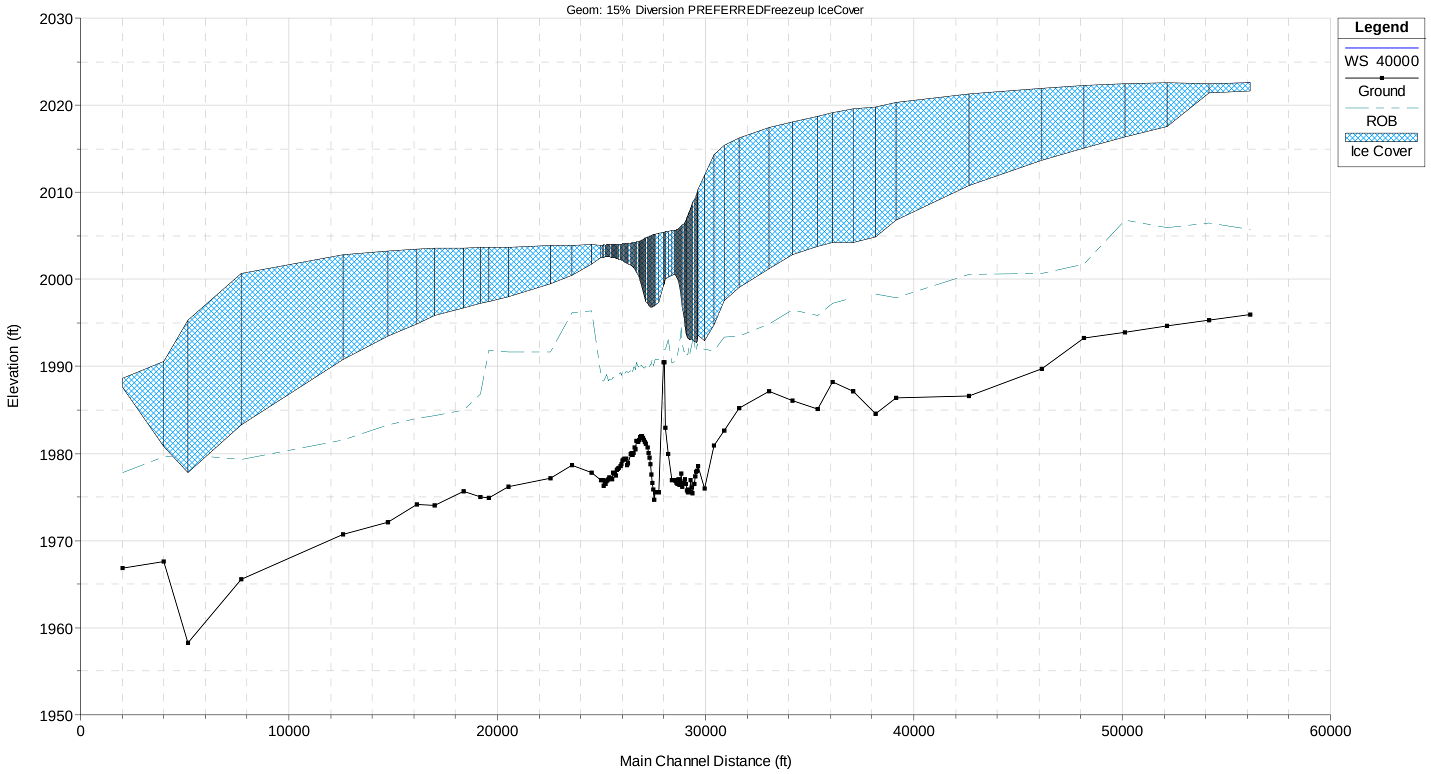


Fig. 8a.. Breakup ice jam on main river. Q_{river} = 40,000 cfs with 15% diversion (Q_{bypass}=5200 cfs). n_{ice} = 0.08, porosity = 0.4, V_{eros} = 5 ft/s.

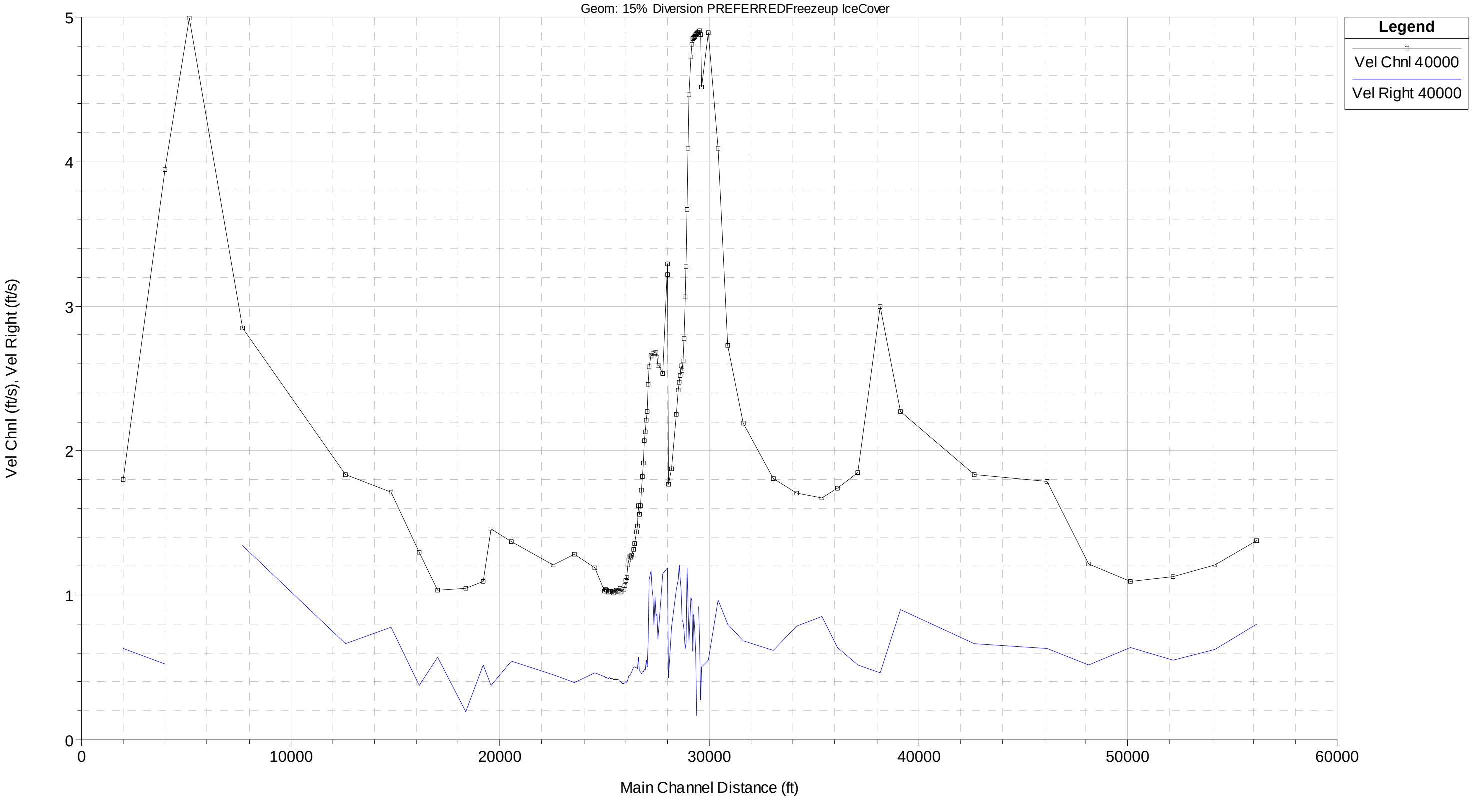


Fig. 8b. Average channel velocity in main river and right overbank with breakup ice jam. Q_{river} = 40,000 cfs with 15% diversion (Q_{bypass}=5200 cfs).

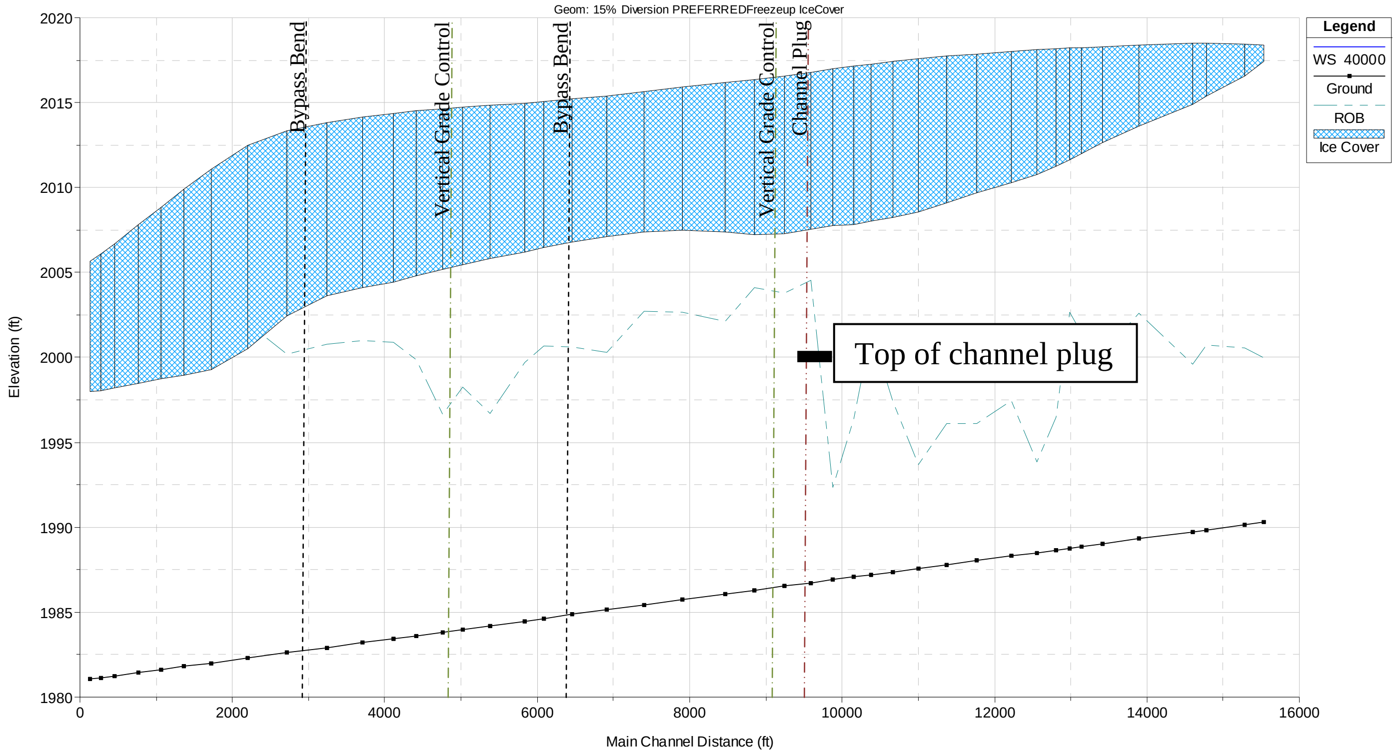


Fig. 9a. Breakup ice jam on bypass channel. Q_{river} = 40,000 cfs with 15% diversion (Q_{bypass}=5200 cfs). n_{ice} = 0.08, porosity = 0.4, V_{eros} = 5 ft/s.

Fig. 9b. Average channel velocity bypass channel and overbanks with breakup ice jam. Q_{river} = 40,000 cfs with 15% diversion (Q_{bypass}=5200 cfs).

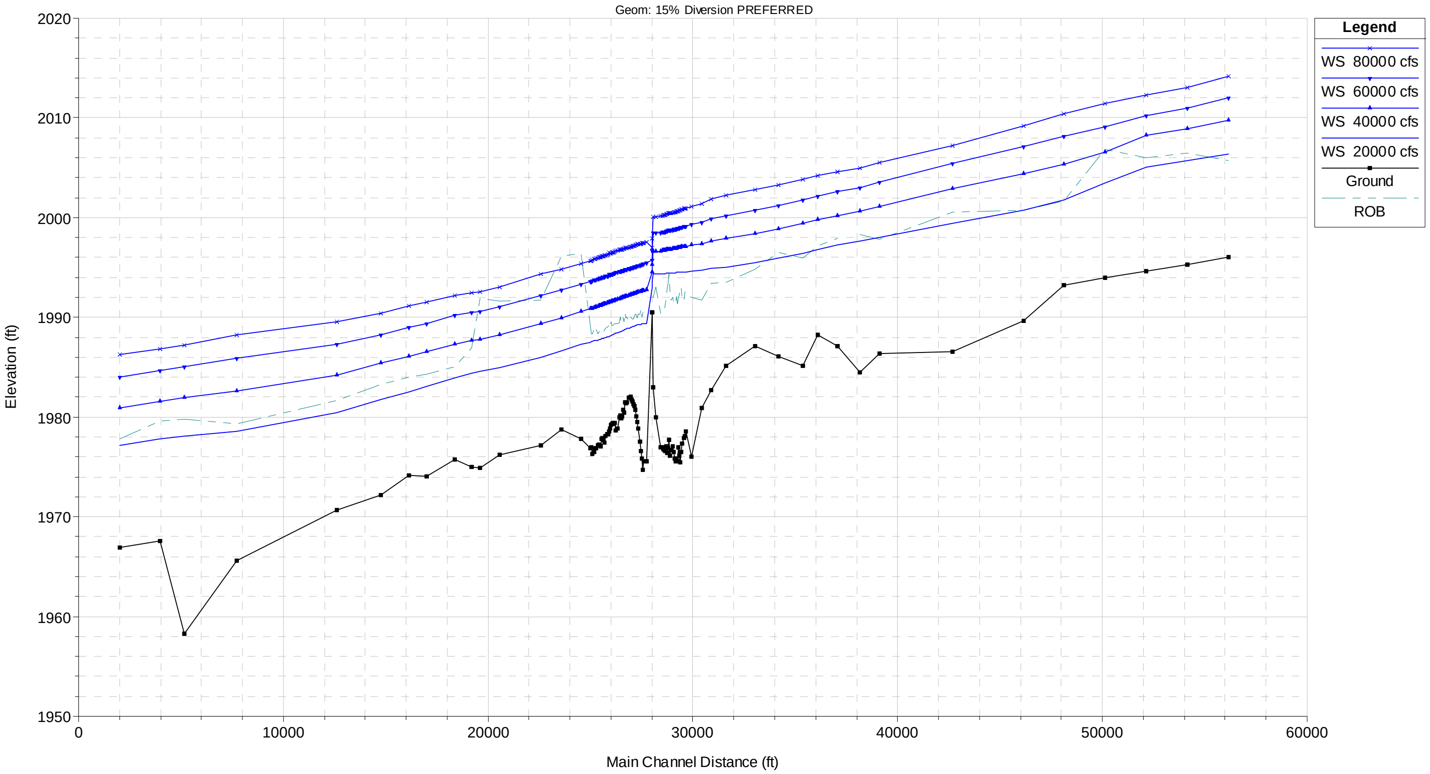


Fig. 10a. Open water surface profiles for river flows of 20, 40, 60 and 80 Kcfs with 15 % diversions.

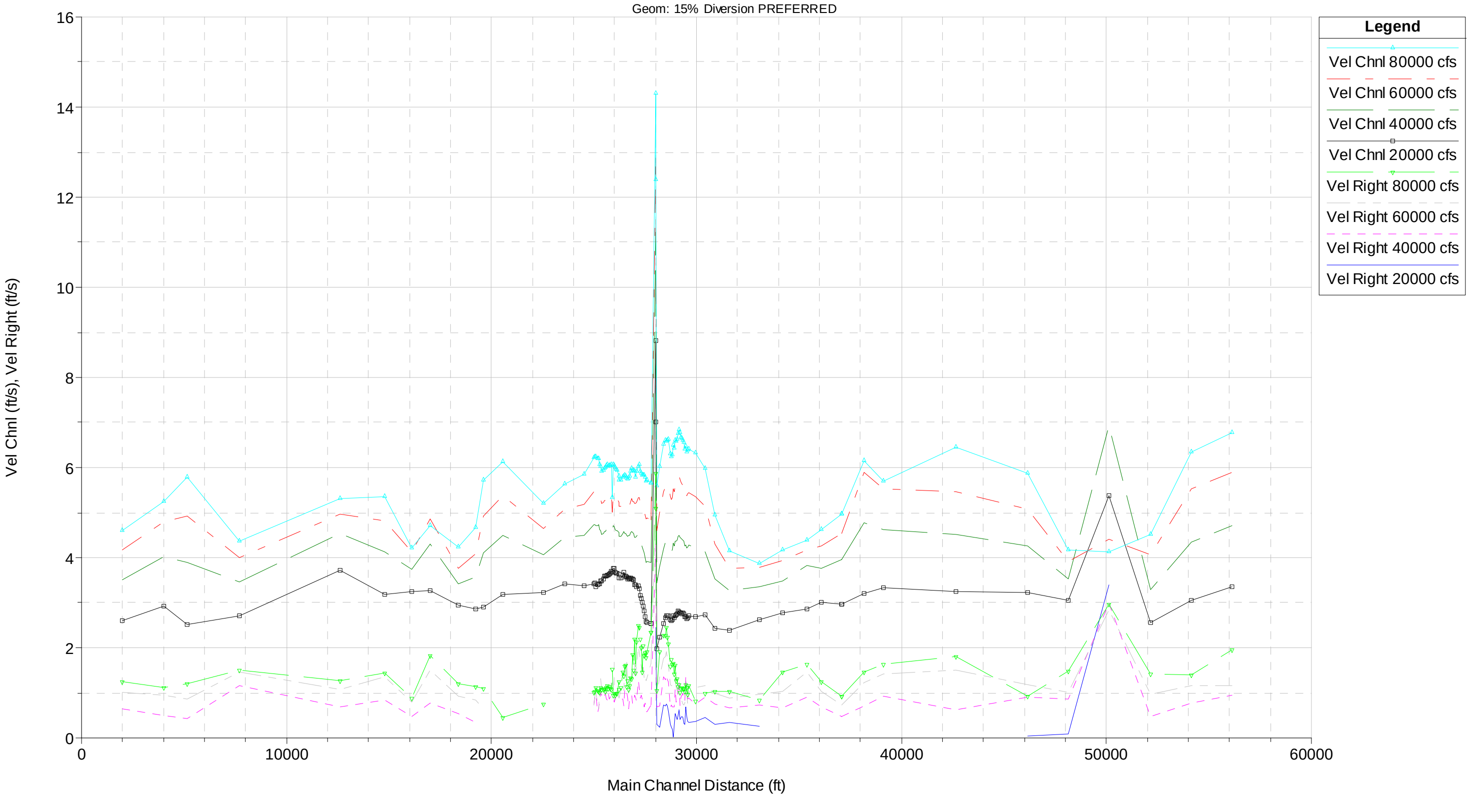


Fig. 10b. Average water velocity in the river channel and right overbank for river flows of 20, 40, 60 and 80 Kcfs with 15 % diversions.

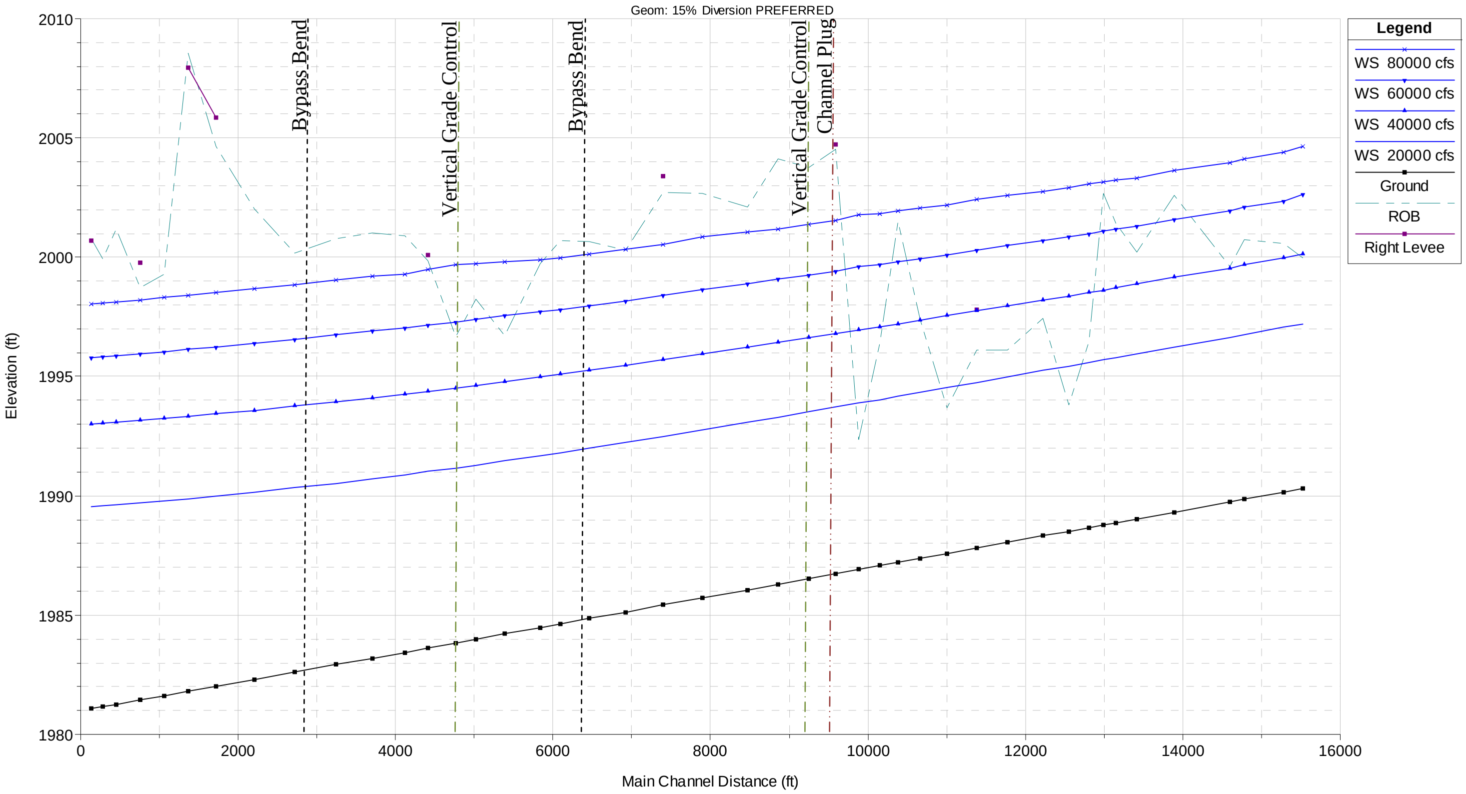


Fig. 111a. Bypass water surface profiles for river flows of 20, 40, 60 and 80 Kcfs with 15 % diversions.

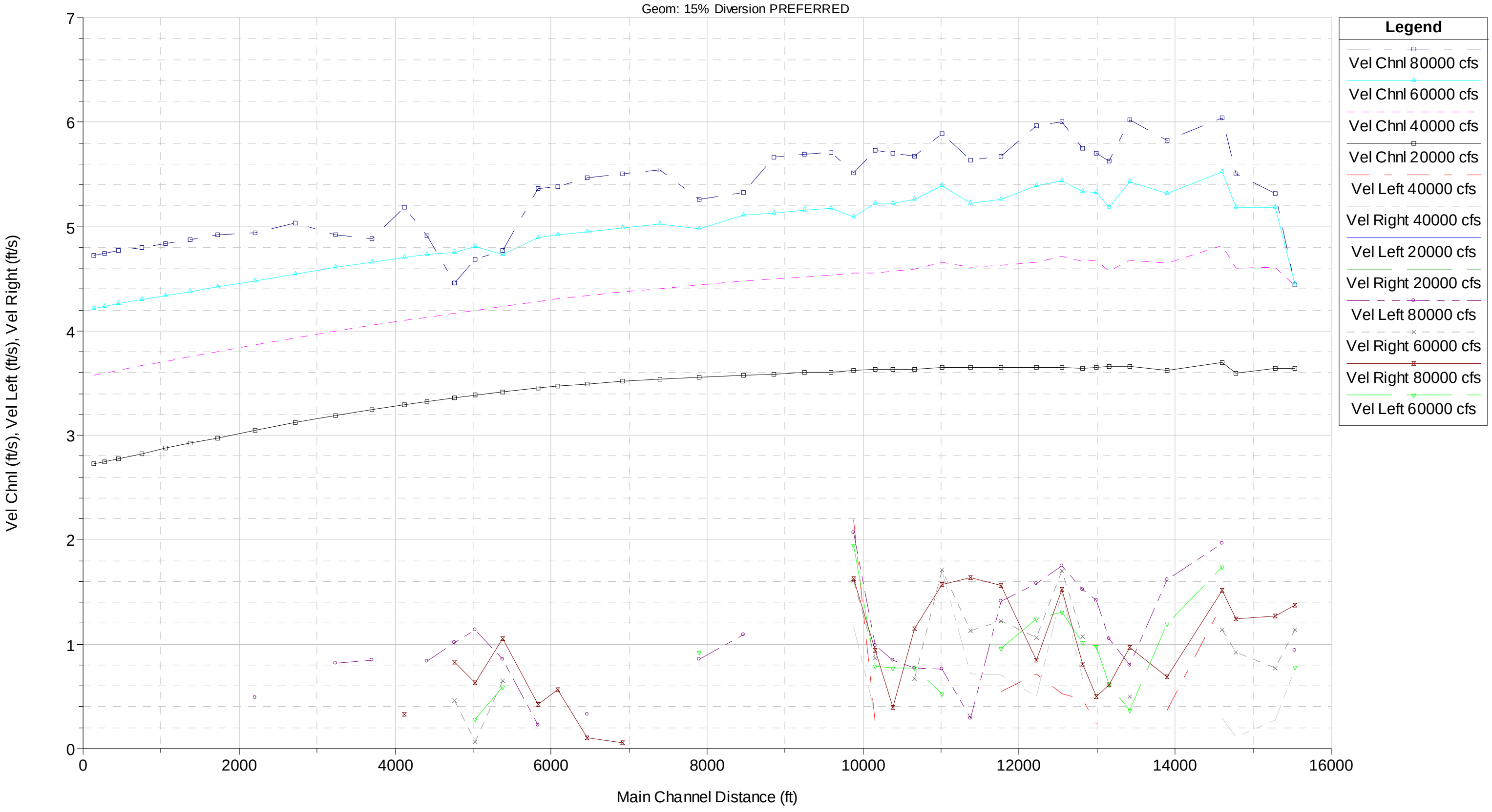


Fig. 11b. Average water velocity in the bypass and overbanks for river flows of 20, 40, 60 and 80 Kcfs with 15 % diversions.

December 2008 (flows fixed)

Glendive, Montana Winter Flow Frequency Update

The purpose of this analysis is to update the discharge probability relationships at Glendive, Montana during the periods that are prone to ice jam flooding on the Yellowstone River. This updated analysis will focus on flows occurring on the Yellowstone River after the construction of Yellowtail Dam on the Bighorn River in 1965.

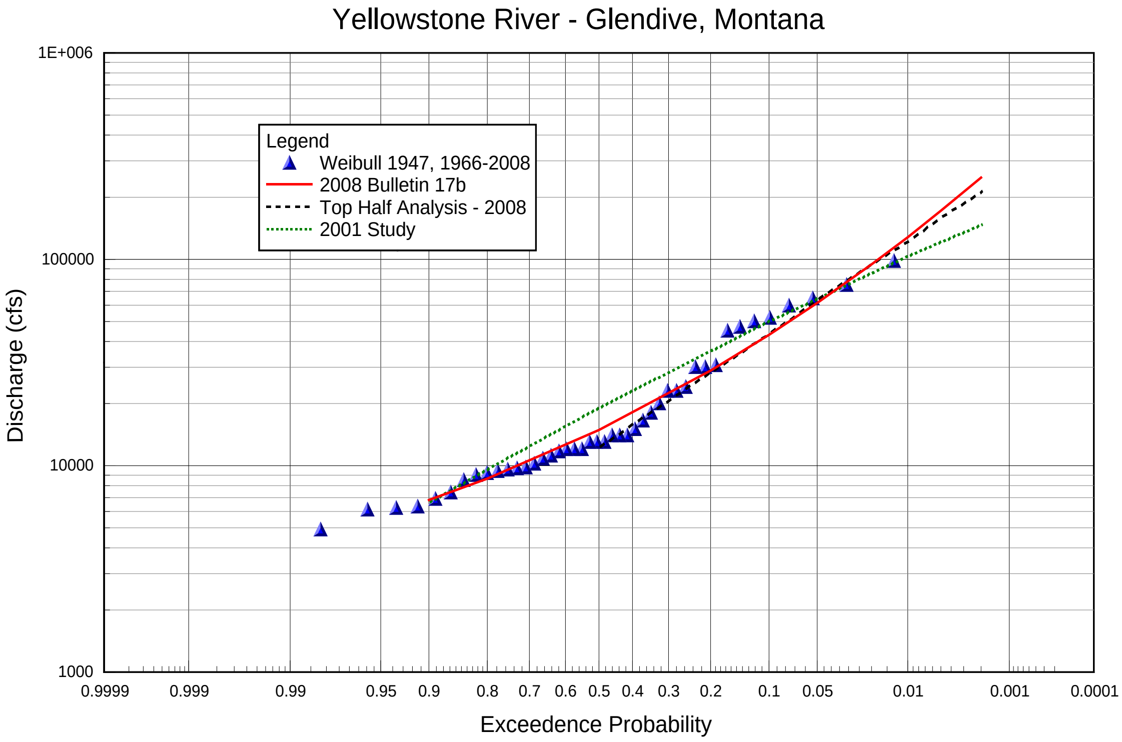
For this updated analysis, the plan was to employ the methodology used in the original 2001 Initial Feasibility Study (COE,2001), truncate the data to 1966 when Yellowtail Dam was operational and to add additional streamflow records through 2008. The 2001 Study used a period of record from 1934 through 1999. While in the process of updating the study, a concern arose about the methodology used in that original analysis. In the 2001 study, an effort was made to separate out the years when there was plains snowmelt runoff. Based on the 66 year period of record, it was determined that only 38 years had a plains snowmelt runoff event. A discharge probability relationship was developed utilizing the methodology presented in Bulletin 17b (WRC,1981) based on the 38 events and a conditional probability was applied to that frequency curve to account for the fact there were only 38 events in the 66 year period of record. Based on Bulletin 17b, the conditional probability is not applicable if there are more than 25 percent of the events are zero over the period of record. In the case of the 2001 study it was 42 percent. This negates using this methodology on this study.

For this update, it was decided not to separate the plains snowmelt runoff years from the years when there is only Yellowstone River baseflow and instead a peak winter flow was determined for each year. Like the 2001 study, daily flows for the Sidney gage were used in the analysis. However, to account for the affects on flows due to the operation of Yellowtail Dam on the Bighorn River only the period of record after Yellowtail Dam was in place was used. In addition, the 2001 study used peak flows through 1999. Therefore, the period record used in the updated analysis was from 1966 through 2008.

The January 1st to April 15th time frame was again used. Flows were factored by 0.98 to account for the difference in drainage areas between the Sidney and Glendive gages and multiplied by 1.05 to convert from a daily flow value to an instantaneous peak value. The methodology presented in Bulletin 17B utilizing the log-Pearson type III distribution was used. The Hydrologic Engineering Center's (HEC) flood frequency analysis program, HEC-FFA (HEC,1992) was used to derive the frequency relationships. The mean logarithm and standard deviation for the analysis were 4.1996 and 0.3082, respectively. The station skew of 0.7000 was used and was not weighted with a regional skew. The discharge probability curve (with computed probability) is shown on Figure 1.

Peak flows for the different return periods are listed in Tables 1 and 2 for computed and expected probability, respectively.

A second statistical method was used to assist in the verification of the flow probability relationships. It appears that the lower peak flows have a large influence on the skew of the probability curve. A second method was utilized called a Top-half analysis where only the highest 50 percent of the values are used in that analysis. Since there were a total of 43 peak discharge values for Glendive, the top 21 values were utilized. The methodology presented in Statistical Methods in Hydrology (HEC,1962) was used. The adjusted mean logarithm and standard deviation for the analysis were 4.0910 and 0.4298, respectively. A skew of 0.0 was used. The discharge probability relationship (with computed probability) is shown on Figure 1. Peak flows for the different return periods are listed in Tables 1 and 2 for computed and expected probability, respectively.



Note: Period of Record 1947, 1966 thru 2008. Peak flows between January 1st to April 15th. Values shown are for computed probability.

Figure 1 – Discharge Probability Relationships

Table 1
Yellowstone River at Glendive, MT
Winter Discharge Probabilities - Computed

	Peak Discharge (cfs)		
	2001	2008 Restudy	
Return Period	Study	Bulletin 17b	Top Half
2-Year	19,000	14,900	12,300
10-Year	49,800	43,100	43,800
20-Year	64,400	61,500	62,800
50-Year	85,500	94,600	94,100
100-Year	103,000	128,000	123,000
500-Year	147,000	249,000	213,000

Note: Values given are for **computed** probability. Discharges listed under Bulletin 17b are the adopted values for this study

Table 2
Yellowstone River at Glendive, MT
Winter Discharge Probabilities - Expected

	Peak Discharge (cfs)		
	2001	2008 Restudy	
Return Period	Study	Bulletin 17b	Top Half
2-Year	19,000	14,900	12,300
10-Year	51,200	44,600	45,400
20-Year	67,400	65,200	66,400
50-Year	91,600	105,400	103,000
100-Year	113,000	148,000	139,000
500-Year	171,000	323,000	260,000

Note: Values given are for **expected** probability. Discharges listed under Bulletin 17b are the adopted values for this study

Results.

A comparison of the 2001 study with the updated discharge probability relationships are listed in Table 1. The updated analyses showed an increase in the 100-year discharge ranging from 19.4 percent to 23.0 percent. The major increase in the 100-year flow can mostly be accounted for by the changing of the methodology used in developing the flow probability relationships. However, the original methodology used in the 2001 study does not follow the rationale set forth in Bulletin 17b. The discharge probability relationship developed from Bulletin 17b was adopted for this restudy as it fit the observed data the best and was verified by the Top-half analysis.

References.

Guidelines for Determining Flood Flow Frequency – Bulletin 17B. Interagency Advisory Committee on Water Data. U.S. Department of the Interior, Geological Survey, Reston, Virginia, September 1981.

HEC-FFA, Flood Frequency Analysis User’s Manual. U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), Davis, California, May 1992.

Statistical Methods in Hydrology. Technical Document 4 (TD-4). U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), Davis, California, January 1962.

Existing Levee Analysis and Plan Formulation, Glendive, Montana. Section 205 Initial Feasibility Report. United States Army Corps of Engineers, Omaha District, January 2001

Intake Diversion Dam Modification
Lower Yellowstone Project, Montana

Appendix C

Geotechnical

APPENDIX C – GEOTECHNICAL/CIVIL

1. Foundation Exploration. Borings for the weir crest and fish bypass channel were conducted during 2009, 2010 and 2011. The 2009 borings were mainly for new headworks phase of this project on the left bank of the Lower Yellowstone River, however several boring were performed on the right bank area on Joe's Island (IMT09-16 through IMT09-21, and IMT09-24). The 2010 borings (IMT10-28, IMT10-30, IMT10-31, IMT10-35, IMT10-39, IMT10-43, IMT10-47, IMT10-51) were performed within the river by barge and were needed for determination of subsoil conditions for the weir crest (the study was suspended after project cost increases). The 2011 borings were performed on or near the bypass channel alignment. Also in 2011 prior to the borings, test pits were excavated near the alignment. See the Geology Appendix for description of the field investigation using borings. Additional borings were performed for the channel, quarry and waste area during late 2012. The waste soil piles will be graded to approximately 25+ feet above natural ground and subsurface conditions were needed to assess settlement and stability. The local irrigation district used an existing undeveloped quarry to mine rock for placement on the existing weir crest, discussions were in-progress to develop the quarry for this project. The borings were to get an understanding of the lateral and subsurface extent of the rock formation in that area. The bypass channel borings of the 2012 investigation yielded similar stratigraphy as the earlier borings. The bypass channel alignment has changed since the 30%, so additional investigation may be required. The new channel alignment is shown on Sheet C-002 in Attachment 3.

1.1. Test Pits Lithology. The following is a description of the test pit excavations per the Project Manager/Geologist logging and observing during the work.

The upper 3-8+ ft thick zone is comprised of silt to silt with very fine sand to very fine sand. This layer was not present in TP-1. Occasionally stringers or thin beds of coarser sands would be observed in the side wall but the 1.5 CY bucket sampling doesn't capture nuance. Some clay both in the matrix and is accessional as blobs in the bucket, it could be lens or thin layers. Walls stood up until undermined at which time they collapsed fairly rapidly. Essentially no cohesion and overbank flood deposits.

Underlying the silty layer was a unit of very rounded river gravel and cobbles (1-5 inches diameter with 2-3 inches being predominant). Usually the matrix was silt to very fine sand, usually mostly silt. Bimodal distribution of the very coarse and very fine was evident. Other zones had a well graded matrix with silt to very coarse sand and the gravels. Gravel was anywhere from about 40% of the unit to greater than 80%. All could be generalized as channel gravel with a fine grained non-cohesive matrix.

TP-5 was dry until the 25 ft depth. In the units with higher percentages of gravel the material was usually saturated and basically flowed when dumped from the bucket resulting in pure gravel. In most places the water poured in, in a few (TP-7is one) it came flowed in slower. In TP-1 head was sufficient to cause boils during excavation and the backfilled excavation was in a quick condition. When the water poured in, the matrix washed out, the gravel collapsed, and the sink hole grew. Usually after 2-3 ft below the water table additional excavation was just an exercise in keeping up with caving, so most holes terminated around 12-15 ft

The entrance to the channel adjacent to the Yellowstone is armored with imbricate cobbles in the 3-5 inch range with smaller clasts infilling the voids. The same material was found throughout the TP-1 section but with matrix material included. Probably a case of the river bed load being the very coarse material deposited during flood and with the finer material being contributed over the years during lower flow or lesser flood stages. More information and analysis of the test pits/boring data is presented in the Hydraulics Appendix.

2. Design Criteria.

Department of Army Corps of Engineers Publications

EM 1110-1-1804	Geotechnical Investigations
EM 1110-1-1905	Bearing Capacity of Soils
EM 1110-2-1901	Seepage Analysis and Control for Dams CH 1
EM 1110-2-1906	Laboratory Soils Testing
TM 5-818-5	Dewatering and Groundwater Control

3. Laboratory Testing. Laboratory tests were performed on representative disturbed and undisturbed samples. These tests consisted of the following: (1) mechanical analyses, Atterberg limits, and moisture determinations on disturbed samples; (2) consolidation tests on undisturbed samples; and (3) unconsolidated undrained (Q) and consolidated undrained (R) triaxial compression tests on undisturbed samples. Only mechanical analysis tests were performed on the test pit samples. Test result sheets have not been included but can be provided when requested (308 plus pages).

3.1. Mechanical Analyses, Atterberg Limits and Moisture Determinations.
Laboratory soil classifications based on mechanical analysis and Atterberg limits were performed on disturbed samples in accordance with the Unified Soil Classification System. The tests were performed in accordance with ASTM D 422, ASTM D 4318, and ASTM D 2216. Similar samples were visually grouped and representative samples from each group were tested and classified by mechanical analyses and Atterberg limits. The liquid limits (LL) for the crest weir borings varied from 61 to 149 and the plasticity indices (PI) from 43 to 124, and in the channel borings the LL varied from 21 to 80 and the PI from 8 to 61. Moisture contents for the weir crest borings varied from 9.2 to 49.3, and 1.9 to 38.7 for the channel borings, being generally in the higher range for the deeper samples. The 2012 borings were tested for moisture content (153 tests), Atterberg limits (23 tests), and mechanical analyses (47 tests).

3.2. Consolidation Tests. A total of 9 consolidation tests were performed on undisturbed samples of weir crest borings. The tests were performed according to ASTM D 2435. The tests resulted in pre-consolidation pressures ranging from approximately 2 to 9 tsf with most of the values in 3-6 tsf range.

3.3. Triaxial Compression Tests. Eight single circle triaxial compression tests, "Q" (UU) were performed on undisturbed samples of foundation material in the Lower Yellowstone River from eight crest weir borings. The UU tests were performed in accordance with ASTM D 2850 and were loaded using a confining pressure of 27.8 psi; this confining pressure was used to correlate with the overburden pressure at the weir crest sheetpile tip. The tests resulted in cohesion values from14.85 to 24.35 psi (1.07 to 1.75 tsf), with a single low value of 3.1 psi (0.22 tsf). The low value may have been due to sample disturbance. Phi angle determinations provided to the structural engineer were determined using the SPT counts and chart correlations.

3.4. Chemistry Tests. Sixteen sets of conductivity (ASTM D5334), resistivity (ASTM G187), sulfate ion (EPA 9056), and pH (ASTM D5464) tests were performed on samples from the weir crest borings. The conductivities ranged from 1.37 to 2.49 mS/cm, the resistivities from 490 to 730 ohms-cm, the sulfate from 12 to 752 mg/kg, and the pH from 7.2 to 9.7. At this time, these values are not of a magnitude that would affect the project cost with design adjustments.

4. Foundation Conditions and Geologic Features. See the Geology Appendix. Soil boring locations are shown in Attachment 1 on sheets C-002 and GI101, boring and test pit logs are shown on sheets GI102 through GI114. In general, the investigation found much of the island to be covered with 6–10 feet of Silts (ML), Clays (CL), and Sands (SM). Below this layer, often encountered was a layer of Silty Sandy Gravel (GW) composed of fine to coarse sands and gravel. Though not analyzed for gradation, soils found in this layer would likely contain material appropriate for the formation of an armor layer in the proposed channel and would likely intersect with the proposed excavation invert.

The river borings discovered overburden materials that are primarily silty or sandy clays (CL), sands (SC, SM, SP) and gravels (GM and GP) with occasional fat clays (CH). The Fort Union Formation was encountered between 6 and 27 feet below river bottom depending on the amount of river scour. Fort Union materials logged within the river borings included very-soft-to-soft and highly-to-unweathered siltstones and shales. SPT blow counts in the siltstones and shales were in the low-20's to low-50's range. Refinement of the sheet pile tip locations will be performed in the next phase of design.

5. Design. The following paragraphs discuss areas of analysis relevant to the project. Further analysis will be conducted in future design submittals.

5.1. Settlement. A settlement calculation was not performed for the 30% design of the weir crest. It should be noted that the added loading pressure is less than or near the pre-consolidation pressures of 3-6 tsf range (visual approximation from curves), so consolidation is not expected in the deeper part of the foundation. The upper part of the foundation (based on SPT counts) may experience some immediate settlement but may be limited due to the sheetpile confining the upper foundation and the inability for water to escape.

The 2012 borings at the waste area indicated the foundation to be composed generally of dense sands and gravels and little or no settlement would occur. Any settlement would occur shortly after or during construction of the waste piles.

5.2. Dewatering. TM 5-818-5 was used for determining the channel excavation dewatering requirements. The method in Figure D-2, open excavation; deep wells, gravity flow, was used which utilized equation (6) on page 4-15 and equation (3) on page 4-18 (see Attachment 2). Equation (6) transforms the rectangular excavation to an equivalent large diameter well. Equation (3) uses the calculated diameter value and results in a total flow into the rectangular excavation.

$A_e = \frac{4}{\pi}\sqrt{(b_1\ b_2)}$ equation (6)

A_e = radius of an equivalent large diameter well
b_1 = one half of one side of excavation rectangle = 150'
b_2 = one half of the other side of excavation rectangle = 50'

$Q_W = \frac{\pi k\ (H^2 - h^2)}{\ln(2L/r_w)}$ equation (3)

Q_w = estimated total flow
k = permeability of substratum = 0.23 ft/min
H = height of water table from impermeable substratum = 40'
h = height of water for drawdown required from impermeable stratum = 25'
L = distance to water source = 1500' average
r_w = radius of well = A_e

5.2.1. Calculated Results. The calculations were performed in spreadsheet format and are attached at the end of this appendix. The total flow was calculated based on the values listed above next to the definitions. The excavation would be a rectangle shape 300' x 100'. The permeability of 0.23 ft/min was based on the mechanical analysis D_{10} size. The resulting total flow was ~1600 gpm for an average source distance of 1500'. The number of wells and the well design were not performed, only the total flow calculated and used in the cost estimate. The L value of 100' was used for upstream control structure location and the resulting flow was ~9000 gpm; sheetpile was included to enclose the excavation and assumed driven into the claystone/shale (20-25'), this would greatly reduce the pumping quantity.

The dewatering associated with the weir crest is anticipated to be minimal, only the initial dewater pumping after creation of the cells is required. The sheet pile will be driven into the claystone/shale foundation material for a distance of ~20' and this material is of a low permeability.

5.2.2. Additional Analyses. Further analyses were performed between the 30% and 60% design. The analyses reviewed the TM 5-818-5 30% design, and also performed a computer analysis using GeoStudios SEEP/W software. The SEEP/W analysis resulted in very similar results as the Technical Manual. The analyses are presented in detail in Attachment 3 and included appendices.

5.3. Bearing Capacity. The tests cohesion values were presented in a previous paragraph. For a continuous footings, at surface and vertical load, for $\phi = 0$: $N_c = 5.14$, $N_q = 1$, $N_\gamma = 0$, and the bearing capacity equation reduces to $q_{ult} = 5.14c$. Ignoring the low cohesion value of 0.22 tsf presented earlier, the range of cohesion values would yield a bearing capacity of approximately 5.5 to 9 tsf unfactored. For the structural design it was determined to use a reduced and conservative value of 3 tsf unfactored after reviewing the relatively lower SPT values in the upper sampling depths of the borings. This reduced design value with a factor of safety of 2 would result in an allowable bearing pressure of 1.5 tsf or 3000 psf.

5.4. Slope Stability. The stability of the bypass channel cross section is more dependent on the water flow forces (erosional) versus the soil structure. A slope stability analysis was not performed due to the flat side slopes and an overall average of 1V on 6.5H, and the coarse granular material. The internal strength angle would have to be less than 9 degrees for the slopes to reach instability.

The soil foundation stability of the new weir crest should not be a major concern. The tests results cohesion values from 1.07 to 1.75 tsf are high and if coupled with a small friction angle, and the depth of sheetpile, it is unlikely rotational stability would be an issue.

Global stability of the waste piles should not be an issue based on the subsurface conditions found in the 2012 borings. Shallow slides could be an issue but should be mitigated in the project specifications, since the area is large any excessive moisture contents of the channel excavated material should be distributed by locating placements and working the material.

5.4.1. Embankment Stability. The only structure deemed to require a stability analysis is the downstream cofferdam. This structure includes a soil zone where the upstream cofferdam, and the channel block are rock fill structures.

The downstream coffer dam will be constructed of clayey sands, sand-silt mixtures (SC). It will be 10-ft high with 1V on 2H slopes and 20-ft wide crest set at Elev. 1994. The full height of The Yellowstone River side slope is protected with 2-ft thick layer of riprap for the full height and extent from the tie-in near the existing crest weir to xxx' along the cofferdam.

Borings IMT 09-17 and IMT 09-18 were used to establish local soil stratigraphy showing mainly poorly-graded sands and gravels intermixed with clays and silts (SP-SM, SP-SC, GP-GM, GP, SC, GM).

GeoStudio 2007 SLOPE/W software was used to analyze slope stability of downstream cofferdam. The soils properties in Table 1 were used for modeling. See Figure 1 for soil layering used in the model. Phi angles were lowered to make the analysis more conservative.

Table 1 – Cofferdam Stability Soil Parameters				
Soil Type	**Location**	**Unit Weight (pcf)**	**Cohesion (psf)**	**Phi (degrees)**
SC	Embankment	95	400	18
Riprap	Embankment D/S Slope	120	0	19
SP-SM	Foundation 1	125	150	23
GP-GM	Foundation 2	120	50	13
GP	Foundation 3	115	0	17
SP	Foundation 4	125	0	19

The cofferdam was fully loaded from upstream side (channel dewatering side) with 1-ft depth of water on the downstream side (Lower Yellowstone River side).

Other modeling inputs used were: Morgenstern-Price analysis type, steady seepage conditions, optimized slip surface, and pore water pressure conditions established from an arbitrary piezometric line drawn through embankment (not SEEP/W).

Factor of Safety of 1.78 was calculated for the given conditions. Increasing phi factors of sands and gravels to more realistic values, raises FS to approximately 2.5. Figure 2 presents the resulting critical failure surface for the 1.78 FS.

Calculated FS values show that the embankment should not encounter slope failure during normal, even extended, loading conditions.

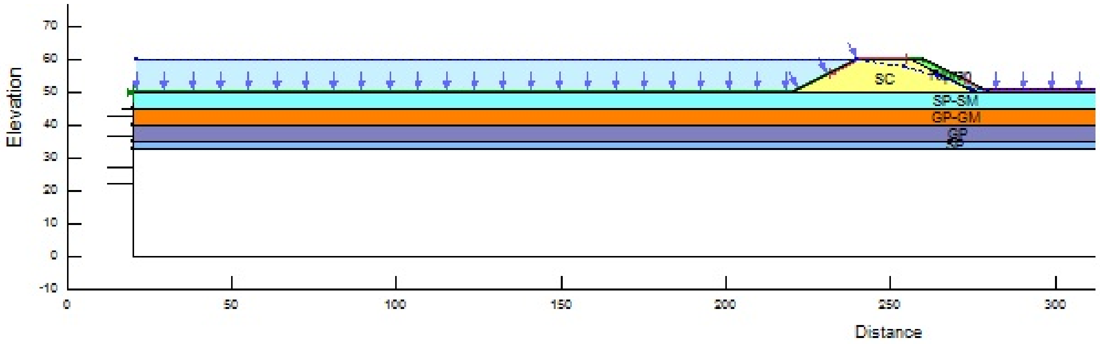


Figure 1. Downstream Coffer Dam – Intake Channel, Yellowstone River, Montana
Slope Stability Analysis – Steady Seepage Conditions – Fully Loaded Conditions
(Soil stratigraphy and phreatic surface shown)

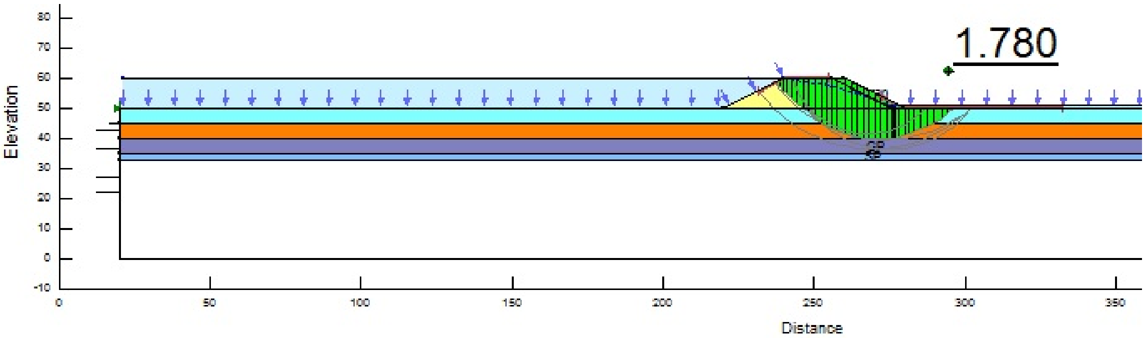


Figure 2. Downstream Coffer Dam – Intake Channel, Yellowstone River, Montana
Slope Stability Analysis – Steady Seepage Conditions – Fully Loaded Conditions
(Failure slip surface with minimum Factor of Safety shown)

6. Construction. The following paragraphs discuss some areas of construction and related construction procedures.

6.1. Foundation Preparation. This will consist of clearing and grubbing trees, bushes, and other excessive vegetation as well as stripping the required embankment base area and spillway and borrow areas of objectionable grass and cultivated crop remains and roots.

6.2. Cofferdams. The work within the new channel will be protected by a cofferdam at the upstream entrance and the downstream exit. These two cofferdams will be constructed early in the construction. The upstream cofferdam will consist of sheet pile driven below grade into the large alluvial material to prevent underseepage. The zone of the cofferdam will be large riprap on both the upstream and downstream with a 20’ wide crest and 1V on 2H side slopes (help resist ice forces). The cofferdam at the downstream exit will be lower in height because it will be below the existing diversion dam, it will be a similar cross section but most of the cross section will be cohesive material. Some of the rock placement on the new channel side slopes will be placed after the cofferdam removal.

The high flow channel block will be zoned similar to the upstream cofferdam with large riprap on both the upstream (river side) and downstream (high flow channel side). The with a 15’ wide crest and 1V on 3H upstream side slope and 1V on 6H downstream side slope, and steel sheet pile at the crest centerline. The specified rock layer thickness and height of the structure dictated in entirety of the cross section being rock.

6.3. Dewatering. The area of open excavations requiring pumping should be kept to a minimum. The Vertical Grade Control Structures are the main excavations requiring the permanent placement of large rock, these areas should be kept to minimum surface area so the amount of water entering the excavation is minimized (see Attachment 3 for inflow amounts). A small perched trench at the new bypass channel centerline should be utilized to pass water to the downstream. The upstream (highest in elevation) structure should be excavated first and proceeding to the downstream, and water pumped from the excavation into the trench. The upstream portion of the trench would no longer be needed as the work progresses downstream. The pumped water flowing in the trench would pond against the downstream cofferdam and be pumped over the cofferdam into the Lower Yellowstone River. The upper (above water table) part of the channel should be excavated with scrapers, the lower granular material can be excavated with backhoes and in-the-wet.

6.4. Rock for Structures. The rock for the entrance, exit, vertical grade control, weir crest structure, and horizontal control structures would come from either commercial sources in Wyoming or South Dakota, or development of a quarry near the site, or a combination of both. The quarry near the site is used by the irrigation district to fortify the existing diversion dam. The site appears to consist mainly of a layer of cap stone on the top of a butte. The overburden would be removed, stockpiled, and used later for site reclamation. The rock would be blasted and rock pushed down the butte from north to south. It is unlikely the on-site quarry would be used due to the unknown extent and limited quality information of the site material, and associated quarry development environmental issues. The 2012 borings provided information that the top of rock sloped rapidly to the south and was covered by considerable overburden soils. The thickness of the rock formation was not confirmed but it is felt it would require a large amount of soil excavation and drilling and blasting at a considerable depth to manufacture the graded rock. The terrain in the area, along with the borings, would indicate the lateral extent would be large to arrive at the quantity of rock needed.

6.5. Existing Tramway. The alignment of the fish bypass channel exit near the existing diversion dam will require the tramway tower to the demolished and the cable removed. Existing rock piles near the existing diversion dam abutment area will be utilized in the project. The tramway is shown in plan view on Sheet CG207 of the plans separate from the Appendix.

6.6. Barge Inlet. A barge inlet is planned to be excavated on the south bank upstream of the diversion dam. The inlet will be used to launch the barge(s) and to dock and load the barges during the construction duration of the new weir crest. *This feature was removed as the concept after the Value Engineering Study was to use a trestle bridge to construct the new crest weir.*

Intake Diversion Dam Modification
Lower Yellowstone Project, Montana
60% Geotechnical Design Documentation Report

Attachment 1

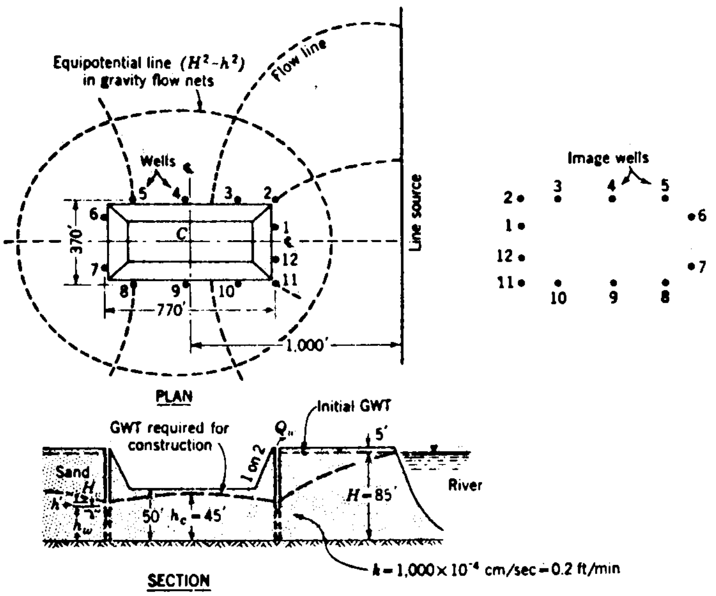
<u>PROBLEM</u>: Design a system of 16-in. slotted screen wells, pumped by deep-well turbine pumps, for lowering the groundwater level 5 ft below the bottom of the excavation. Assume maximum allowable Q_w = 1,200 gpm, wells located 5 ft from top of slope, well radius $r_w = 1$ ft, and D_{10} of gravel filter = 0.25 mm.

<u>SOLUTION</u>: Estimate total flow required from eq 3(fig. 4-17) using, radius A_e of an equivalent large-diameter well computed from eq 6 (fig. 4-14).

$$A_e = \frac{4}{\pi}\sqrt{770/2 \times 370/2} = 340 \text{ ft}$$

$$Q_T = \frac{\pi(0.2)(85^2 - 45^2)}{\ln[(2 \times 1{,}000)/340]} = 1{,}840 \text{ cfm} = 13{,}800 \text{ gpm}$$

Use 12 wells with Q_w = 1,150 gpm. Locate wells as shown in plan so as to intercept equal quantity of flow as indicated by flow net and to obtain approximate level drawdown beneath excavation. Compute head h_e at center of excavation and head h_w at a well from eq 3 and 4 (fig. 4-18) to check adequacy of system.



<u>Head at Point C and Well 4 Computed by Method of Images for</u>
<u>Q_w = 1,150 gpm = 153 cfm</u>

	Head at Point C			Head at Well 4		
Well	S_i ft	r_i ft	$\ln \frac{S_i}{r_i}$	$S_{i,4}$ ft	$r_{i,4}$ ft	$\ln \frac{S_{i,4}}{r_{i,4}}$
1	1,620	390	1.42	1,650	410	1.39
2	1,630	420	1.36	1,640	400	1.41
3	1,800	290	1.82	1,800	240	2.02
4	2,040	180	2.42	2,050	1	7.63
5	2,280	330	1.93	2,300	250	2.22
6	2,400	390	1.82	2,420	370	1.88
7	2,400	390	1.82	2,435	460	1.67
8	2,280	330	1.93	2,330	440	1.67
9	2,040	180	2.42	2,090	370	1.73
10	1,800	290	1.82	1,840	435	1.44
11	1,630	420	1.36	1,675	540	1.13
12	1,620	390	1.42	1,650	480	1.24

$F'_c = 21.54 \times 154 = 3320$ $\qquad$ $F'_w = 25.44 \times 154 = 3920$

From eq 2 and 3 (fig. 4-18), $H^2 - h_c^2 = \frac{3320}{\pi(0.2)} = 5280$. From eq 3 and 4 (fig. 4-18), $H^2 - h_w^2 = \frac{3920}{\pi(0.2)} = 6240$

$$h_c = \sqrt{85^2 - 5280} = 44.1 \text{ ft} \qquad h_w = \sqrt{85^2 - 6240} = 31.4 \text{ ft}$$

The corresponding flow per foot of well screen is 1,150/32, or 36 gpm per ft. Compute head loss in well H_w from fig. 4-24.

$H_e = 1.80$ ft (from fig. 4-24a) $\qquad$ $H_v = 0.06$ ft (from fig. 4-24c)

$H_r + H_v = 0.15\left(\frac{32}{100} \times \frac{1}{2}\right) = 0.02$ (from fig. 4-24b and using the flow through one-half the length of screen)

$H_w = 1.88$ ft, say 2.0 ft

Thus $h_w - H_w = 32.0 - 2.0 = 30.0$ ft. Bowls of pump should be set about 2 ft below this level, and the pump provided with a 10-ft suction pipe. With such a suction pipe, $H_r + H_s$ will be slightly less than the value computed above. Had the approximate method in fig. 4-19: (array 4) been used, the following values of F'_c and F'_w would have been obtained:

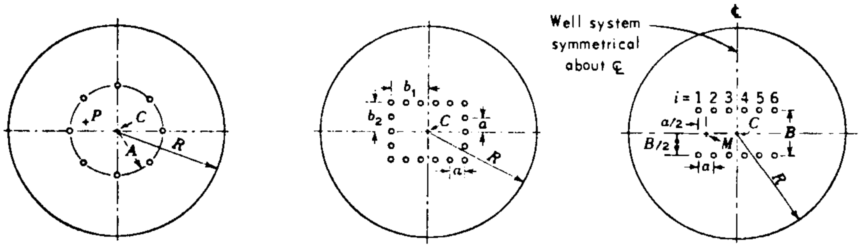
$$F'_c = 154 \times 12 \ln \frac{2 \times 1{,}000}{340} = 3270$$

$$F'_w = 154 \times \left[12 \ln\left(\frac{2 \times 1{,}025}{340}\right) + \ln \frac{340}{12 \times 1}\right] = 3840$$

These values agree closely with those computed by the exact method.

(Modified from "Foundation Engineering, " G. A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw- Hill Book Company.)

Figure D-2. Open excavation; deep wells; gravity flow.



ARRAY 1 ARRAY 2 ARRAY 3

ALL WELLS ARE FULLY PENETRATING WITH A CIRCULAR SOURCE. THE FLOW, Q_w, FROM ALL WELLS IS EQUAL.

F_w = DRAWDOWN FACTOR FOR ANY WELL IN THE ARRAY. F_c = DRAWDOWN FACTOR FOR CENTER OF THE ARRAY.
F_m = DRAWDOWN FACTOR AT POINT M IN ARRAY 3. $n, R, Q_w, h_p, h_w, r_w, r_i, r_{wj}, r_{ij}$, ARE DEFINED IN FIG 4-13.

ARRAY 1. CIRCULAR ARRAY OF EQUALLY SPACED WELLS

$$F_w = Q_w \ln \frac{R^n}{n r_w A^{(n-1)}} \qquad (1)$$

$$F_c = nQ_w \ln R/A \qquad (2)$$

WHERE A = DIMENSION SHOWN IN ARRAY 1 ABOVE.

DRAWDOWN AT POINTS P AND C FOR ARTESIAN FLOW CAN BE COMPUTED FROM

$$\text{DRAWDOWN} = (H - h_p) = \frac{(H - h_w)\left(n \ln R \quad \sum_{i=1}^{i=n} \ln r_i\right)}{\ln \dfrac{R^n}{n r_w A^{(n-1)}}} \qquad (3)$$

$$\text{DRAWDOWN} = (H - h_c) = \frac{(H - h_w) n \ln (R/A)}{\ln \dfrac{R^n}{n r_w A^{(n-1)}}} \qquad (4)$$

DRAWDOWN AT C FOR GRAVITY FLOW CAN BE COMPUTED FROM

$$(H - h_c) = H - \sqrt{H^2 - \frac{n(H^2 - h_w^2) \ln (R/A)}{\ln \dfrac{R^n}{n r_w A^{(n-1)}}}} \qquad (5)$$

ARRAY 2. RECTANGULAR ARRAY OF EQUALLY SPACED WELLS

F_w AND F_c MAY BE APPROXIMATED FROM EQ 1 AND 2, RESPECTIVELY, IF A_e IS SUBSTITUTED FOR A AND

$$A_e = \frac{4}{\pi}\sqrt{b_1 b_2} \qquad (6)$$

F_w AND F_c CAN BE COMPUTED MORE EXACTLY FROM

$$F_w = Q_w \ln \frac{R}{r_{wj}} + \sum_{i=1}^{i=n-1} Q_w \ln \frac{R}{r_{ij}} \qquad (7)$$

$$F_c = \sum_{i=1}^{i=n} Q_w \ln \frac{R}{r_i} \qquad (8)$$

ARRAY 3. TWO PARALLEL LINES OF EQUALLY SPACED WELLS

$$F_c = 4Q_w \sum_{i=1}^{i=n/4} \ln \frac{R}{1/2\sqrt{a^2(2i-1)^2 + B^2}} \qquad (9)$$

$$F_m = 2Q_w \sum_{i=1}^{i=n/2} \ln \frac{R}{1/2\sqrt{a^2(2i-3)^2 + B^2}} \qquad (10)$$

WHERE i = WELL NUMBER AS SHOWN IN THE ARRAY ABOVE.

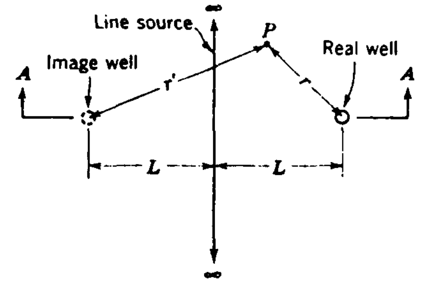
NOTE THAT THE LOCATION OF M IS MIDWAY BETWEEN THE TWO LINES OF WELLS AND CENTERED BETWEEN THE END TWO WELLS OF THE LINE. THIS POINT CORRESPONDS TO THE LOCATION OF THE MINIMUM DRAWDOWN WITHIN THE ARRAY.

VALUES DETERMINED FOR F_w, F_c, AND F_m ARE SUBSTITUTED FOR F IN EQ 1 AND 3 (FIG. 4-13) TO COMPUTE DRAWDOWN AT THE RESPECTIVE POINTS.

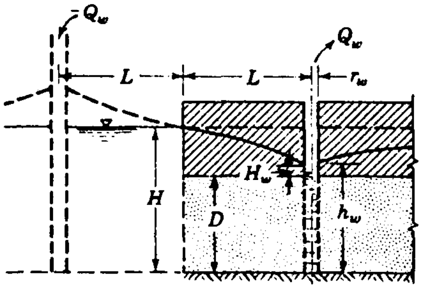
(Modified from "Foundation Engineering, "G. A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

Figure 4-14. Drawdown factors for fully penetrating circular, rectangular, and two-line well arrays; circular source; artesian and gravity flows.

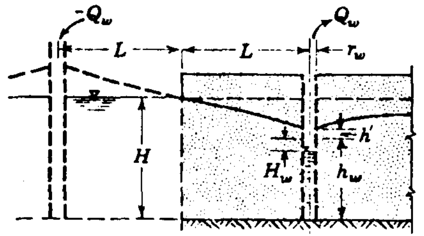
EQUATIONS FOR FLOW AND DRAWDOWN FOR A FULLY PENETRATING WELL WITH A LINE SOURCE OF INFINITE LENGTH WERE DEVELOPED UTILIZING THE METHOD OF IMAGE WELLS. THE IMAGE WELL IS CONSTRUCTED AS SHOWN IN (a) BELOW.



(a)



(b) ARTESIAN FLOW



H_w IS OBTAINED FROM FIG. 4-24.

(c) GRAVITY FLOW

ARTESIAN FLOW

FLOW, Q_w

$$Q_w = \frac{2\pi k D(H - h_w)}{\ln(2L/r_w)} \tag{1}$$

DRAWDOWN AT ANY POINT, P, LOCATED A DISTANCE, r, FROM THE WELL.

$$H - h = \frac{Q_w}{2\pi k D} \ln\left(\frac{r'}{r}\right) \tag{2}$$

GRAVITY FLOW

FLOW, Q_w

$$Q_w = \frac{\pi k\left(H^2 - h_w^2\right)}{\ln(2L/r_w)} \tag{3}$$

DRAWDOWN AT ANY POINT, P, LOCATED A DISTANCE, r, FROM THE WELL.

$$H^2 - h^2 = \frac{Q_w}{\pi k} \ln\frac{r'}{r} \tag{4}$$

IN THE EQUATIONS ABOVE, THE DISTANCE TO THE LINE SOURCE MUST BE COMPARED TO THE CIRCULAR RADIUS OF INFLUENCE, R, FOR THE WELL. IF 2L IS GREATER THAN R, THE WELL WILL PERFORM AS IF SUPPLIED BY A CIRCULAR SOURCE OF SEEPAGE, AND SOLUTIONS FOR A LINE SOURCE OF SEEPAGE ARE NOT APPLICABLE.

SEE FIG. 4-23 FOR DETERMINING THE VALUE OF R.

SEE FIG. 4-24 FOR DETERMINING THE VALUE OF H_w.

(Modified from "Foundation Engineering," G. A, Leonards, ed., 1962. McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

Figure 4-17. Flow and drawdown for fully penetrating single well; line source; artesian and gravity flows.

Excavation length = 300 ft.

Excavation width = 100 ft.

L = 1500 ft.

H = 40 ft.

h_w = 25 ft.

k = 0.23 ft./min.

A_e = 110.27 ft.

Q_T = 213.26 cfm

1595.30 gpm

Intake Diversion Dam Modification
Lower Yellowstone Project, Montana
60% Geotechnical Design Documentation Report

Attachment 2

DIVERSION DAM FISH BYPASS CHANNEL DEWATERING STUDY

SUMMARY

Seepage into the Intake Dam fish bypass channel is calculated so that dewatering measures can be prepared. The permeability of the subsurface is estimated using lab and field tests. The seepage is predicted using analytical and numerical (SEEP/W) models. Recharge of the channel following end of dewatering is also modeled.

CONTENTS

1 DETERMINATION OF PERMEABILITY

From the 30%DDR Report, Appendix C Paragraph 4, Foundation Conditions and Geologic Features,

> "In general, the investigation found much of the island to be covered with 6-10 feet of Silts (ML), Clays (CL), and Sands (SM). Below this layer, often encountered was a layer of Silty Sandy Gravel (GW) composed of fine to coarse sands and gravel."

The majority of seepage into the channel is likely to be from the gravel layer, for which permeability has been determined. Appendix A shows the profile of the channel with boring logs and inferred stratigraphy. Hazen permeability has been included at elevations corresponding to where lab samples were taken.

1.1 Hazen Equation.

The Hazen equation correlates grain size D10 of a soil to permeability k. Appendix B shows the Terracon lab results for the 2012 soil samples and the correlated Hazen permeability for each soil gradation.

Hazen equation: k [m/s] = (1 / 100) * (D10 [mm])^2

1.2 PZ Pump Tests.

Two piezometers (IMT12-03 and IMT12-06) were installed as temporary piezometers during the 2012 investigation for the purpose of conducting response tests, and were abandoned following the completion of rising head tests. As shown in Appendix C, field permeability has been correlated with the results of the rising head tests using method described in "Soil Mechanics in Engineering Practice 3rd ed." by Terzaghi, Peck, and Mesri. The permeability calculated from the field tests correlate well with the Hazen permeability calculated with samples from nearby boreholes.

1.3 Results.

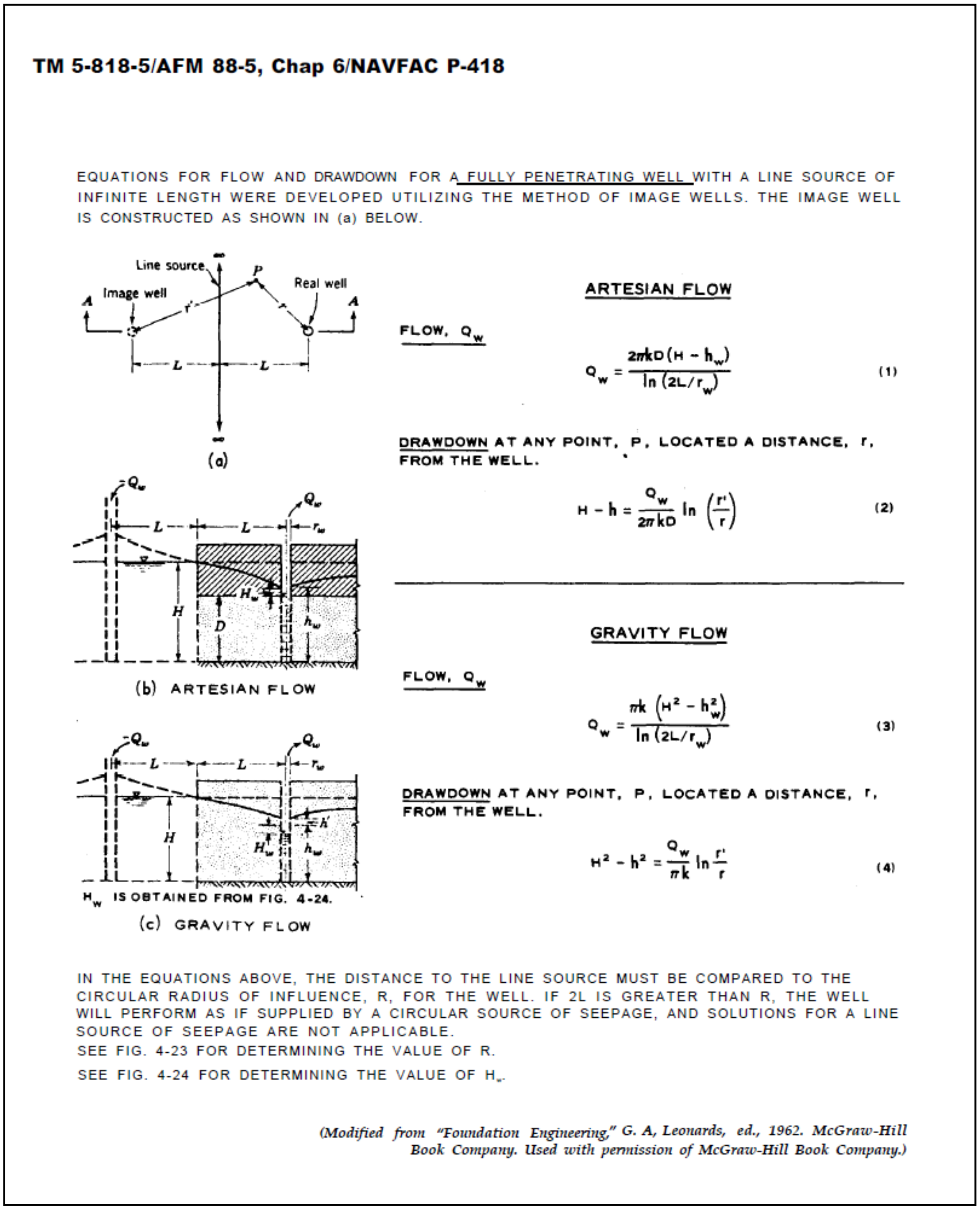
The following table presents the gravel permeability as described by the methods above. A permeability of 0.23 ft/min was used in the 30% DDR report dewatering analysis.

Data Source	Permeability k (ft / min)	k (ft / sec)
Average of 2012 boring samples	0.03	0.00051
Max k of 2012 boring samples	0.14	0.0023
Rising head test IMT12-03	0.16	0.0026
Rising head test IMT12-06	0.24	0.004

2 DEWATERING CALCULATION

The following equations were used to make a dewatering estimate in the 30% DDR report.

2.1 Drawdown Well Equations



TM 5-818-5/AFM 88-5, Chap 6/NAVFAC P-418

EQUATIONS FOR FLOW AND DRAWDOWN FOR A FULLY PENETRATING WELL WITH A LINE SOURCE OF INFINITE LENGTH WERE DEVELOPED UTILIZING THE METHOD OF IMAGE WELLS. THE IMAGE WELL IS CONSTRUCTED AS SHOWN IN (a) BELOW.

(a)

(b) ARTESIAN FLOW

H_w IS OBTAINED FROM FIG. 4-24.

(c) GRAVITY FLOW

ARTESIAN FLOW

FLOW, Q_w

$$Q_w = \frac{2\pi k D (H - h_w)}{\ln(2L/r_w)} \quad (1)$$

DRAWDOWN AT ANY POINT, P, LOCATED A DISTANCE, r, FROM THE WELL.

$$H - h = \frac{Q_w}{2\pi k D} \ln\left(\frac{r'}{r}\right) \quad (2)$$

GRAVITY FLOW

FLOW, Q_w

$$Q_w = \frac{\pi k \left(H^2 - h_w^2\right)}{\ln(2L/r_w)} \quad (3)$$

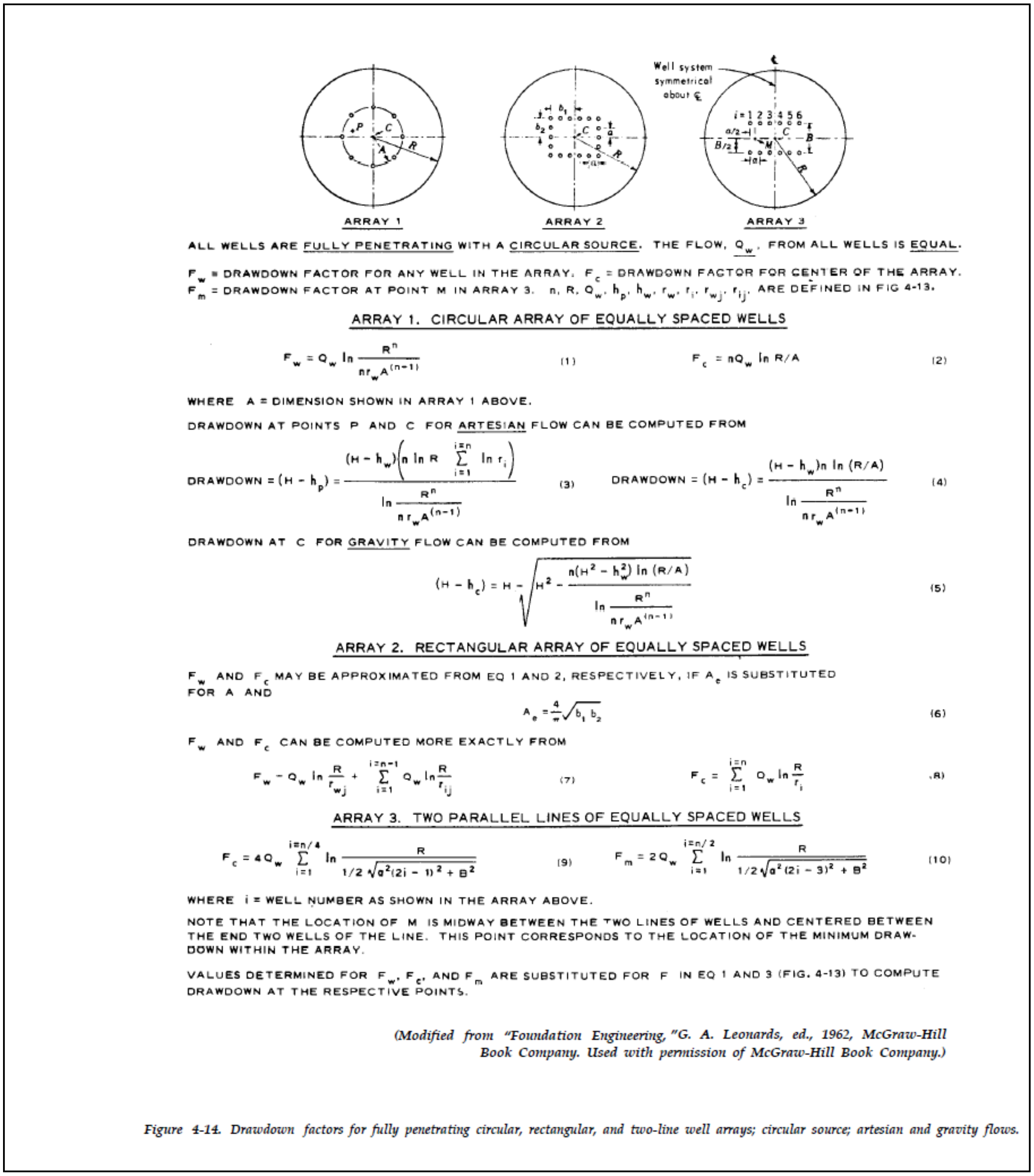
DRAWDOWN AT ANY POINT, P, LOCATED A DISTANCE, r, FROM THE WELL.

$$H^2 - h^2 = \frac{Q_w}{\pi k} \ln\frac{r'}{r} \quad (4)$$

IN THE EQUATIONS ABOVE, THE DISTANCE TO THE LINE SOURCE MUST BE COMPARED TO THE CIRCULAR RADIUS OF INFLUENCE, R, FOR THE WELL. IF 2L IS GREATER THAN R, THE WELL WILL PERFORM AS IF SUPPLIED BY A CIRCULAR SOURCE OF SEEPAGE, AND SOLUTIONS FOR A LINE SOURCE OF SEEPAGE ARE NOT APPLICABLE.
SEE FIG. 4-23 FOR DETERMINING THE VALUE OF R.
SEE FIG. 4-24 FOR DETERMINING THE VALUE OF H_w.

(Modified from "Foundation Engineering," G. A, Leonards, ed., 1962. McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

- Equation used in 30% DDR Dewatering analysis: Gravity flow.
- Well radius rw to be substituted by "Ae", which is a transformation of rectangular excavation into an equivalent well circle (see next page).



ALL WELLS ARE FULLY PENETRATING WITH A CIRCULAR SOURCE. THE FLOW, Q_w, FROM ALL WELLS IS EQUAL.

F_w = DRAWDOWN FACTOR FOR ANY WELL IN THE ARRAY. F_c = DRAWDOWN FACTOR FOR CENTER OF THE ARRAY. F_m = DRAWDOWN FACTOR AT POINT M IN ARRAY 3. $n, R, Q_w, h_p, h_w, r_w, r_i, r_{wj}, r_{ij}$, ARE DEFINED IN FIG 4-13.

ARRAY 1. CIRCULAR ARRAY OF EQUALLY SPACED WELLS

$$F_w = Q_w \ln \frac{R^n}{n r_w A^{(n-1)}} \qquad (1) \qquad\qquad F_c = nQ_w \ln R/A \qquad (2)$$

WHERE A = DIMENSION SHOWN IN ARRAY 1 ABOVE.

DRAWDOWN AT POINTS P AND C FOR ARTESIAN FLOW CAN BE COMPUTED FROM

$$\text{DRAWDOWN} = (H - h_p) = \frac{(H - h_w)\left(n \ln R \quad \sum_{i=1}^{i=n} \ln r_i\right)}{\ln \frac{R^n}{n r_w A^{(n-1)}}} \qquad (3) \qquad \text{DRAWDOWN} = (H - h_c) = \frac{(H - h_w) n \ln (R/A)}{\ln \frac{R^n}{n r_w A^{(n-1)}}} \qquad (4)$$

DRAWDOWN AT C FOR GRAVITY FLOW CAN BE COMPUTED FROM

$$(H - h_c) = H - \sqrt{H^2 - \frac{n(H^2 - h_w^2) \ln (R/A)}{\ln \frac{R^n}{n r_w A^{(n-1)}}}} \qquad (5)$$

ARRAY 2. RECTANGULAR ARRAY OF EQUALLY SPACED WELLS

F_w AND F_c MAY BE APPROXIMATED FROM EQ 1 AND 2, RESPECTIVELY, IF A_e IS SUBSTITUTED FOR A AND

$$A_e = \frac{4}{\pi}\sqrt{b_1 b_2} \qquad (6)$$

F_w AND F_c CAN BE COMPUTED MORE EXACTLY FROM

$$F_w - Q_w \ln \frac{R}{r_{wj}} + \sum_{i=1}^{i=n-1} Q_w \ln \frac{R}{r_{ij}} \qquad (7) \qquad\qquad F_c = \sum_{i=1}^{i=n} Q_w \ln \frac{R}{r_i} \qquad (8)$$

ARRAY 3. TWO PARALLEL LINES OF EQUALLY SPACED WELLS

$$F_c = 4Q_w \sum_{i=1}^{i=n/4} \ln \frac{R}{1/2\sqrt{a^2(2i-1)^2 + B^2}} \qquad (9) \qquad F_m = 2Q_w \sum_{i=1}^{i=n/2} \ln \frac{R}{1/2\sqrt{a^2(2i-3)^2 + B^2}} \qquad (10)$$

WHERE i = WELL NUMBER AS SHOWN IN THE ARRAY ABOVE.

NOTE THAT THE LOCATION OF M IS MIDWAY BETWEEN THE TWO LINES OF WELLS AND CENTERED BETWEEN THE END TWO WELLS OF THE LINE. THIS POINT CORRESPONDS TO THE LOCATION OF THE MINIMUM DRAWDOWN WITHIN THE ARRAY.

VALUES DETERMINED FOR F_w, F_c, AND F_m ARE SUBSTITUTED FOR F IN EQ 1 AND 3 (FIG. 4-13) TO COMPUTE DRAWDOWN AT THE RESPECTIVE POINTS.

(Modified from "Foundation Engineering," G. A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

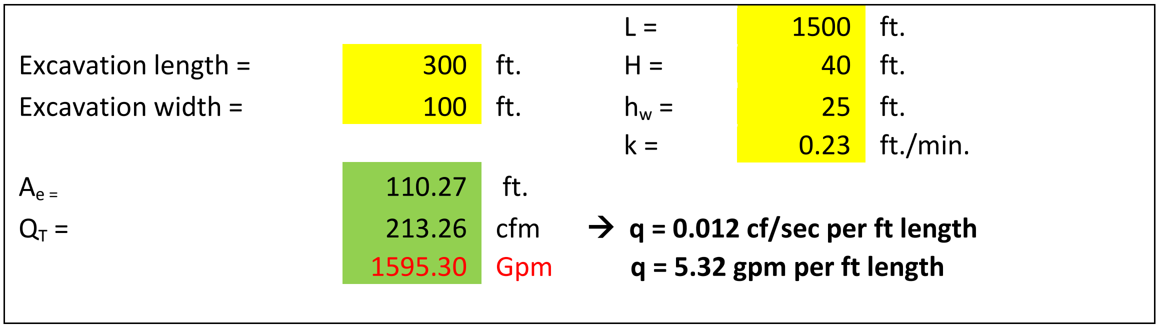
Figure 4-14. Drawdown factors for fully penetrating circular, rectangular, and two-line well arrays; circular source; artesian and gravity flows.

- Well radius "Ae" calculated from width and length of rectangular drawdown array.
- b1 and b2 are width and length of rectangular excavation.

2.2 Average Case

An “average case” model of the channel dewatering was developed in the 30% DDR report to create an estimate for the necessary dewatering along the alignment during excavation. The inputs of this model are reviewed. The results of this model are compared against a SEEP/W model. The channel is assumed to be ~1500ft from the river (L=1500ft), on average.

2.2.1 Average Case – Well Equations (30% DDR)



			L =	1500	ft.
Excavation length =	300	ft.	H =	40	ft.
Excavation width =	100	ft.	h_w =	25	ft.
			k =	0.23	ft./min.
A_e =	110.27	ft.			
Q_T =	213.26	cfm	→ **q = 0.012 cf/sec per ft length**		
	1595.30	Gpm	**q = 5.32 gpm per ft length**		

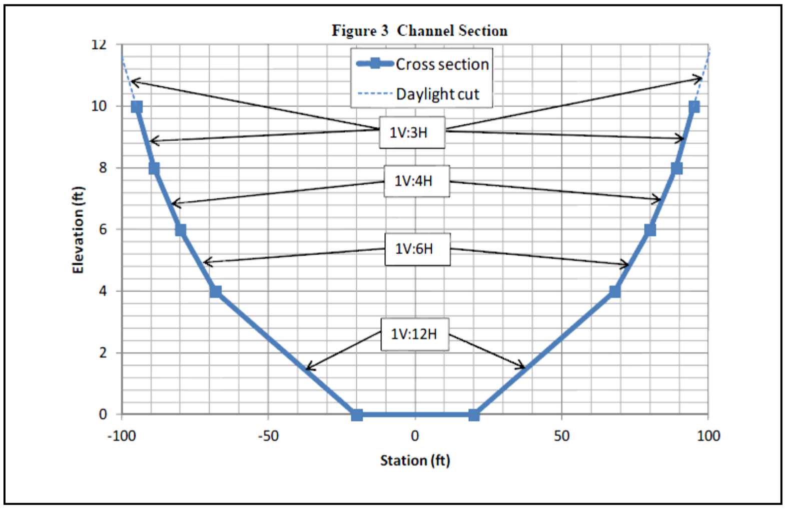
Assumptions.
H = EL difference between River GWT and the top of impermeable clay-shale
Hw = EL difference between drawdown GWT and the top of impermeable clay-shale
L = distance between center of excavation and river GWT
Qt = total flow into rectangular excavation
q= unit flow into excavation per ft length

2.2.2 Average Case – Well Equations (Modified Inputs)

			L =	1500	ft.
Excavation length =	2000	ft.	H =	40	ft.
Excavation width =	200	ft.	h_w =	25	ft.
			k =	0.23	ft./min.
			k=	1.26E-02	m/s
A_{e} =	402.63	ft.			
Q_T =	350.79	cfm	**→ q =**	**0.0029**	**cf /sec per foot length**
	2624.08	gpm	**→ q =**	**1.31**	**gpm per foot length**

Assumptions.

- Channel cross-section (from 30%DDR Appendix A) shows well array width would be ~200ft
- Modeling a long channel, therefore assumed excavation ~infinite, B/H ~ 1/10 → length = 2000ft
- Modified inputs result in a reduced in-flow estimate

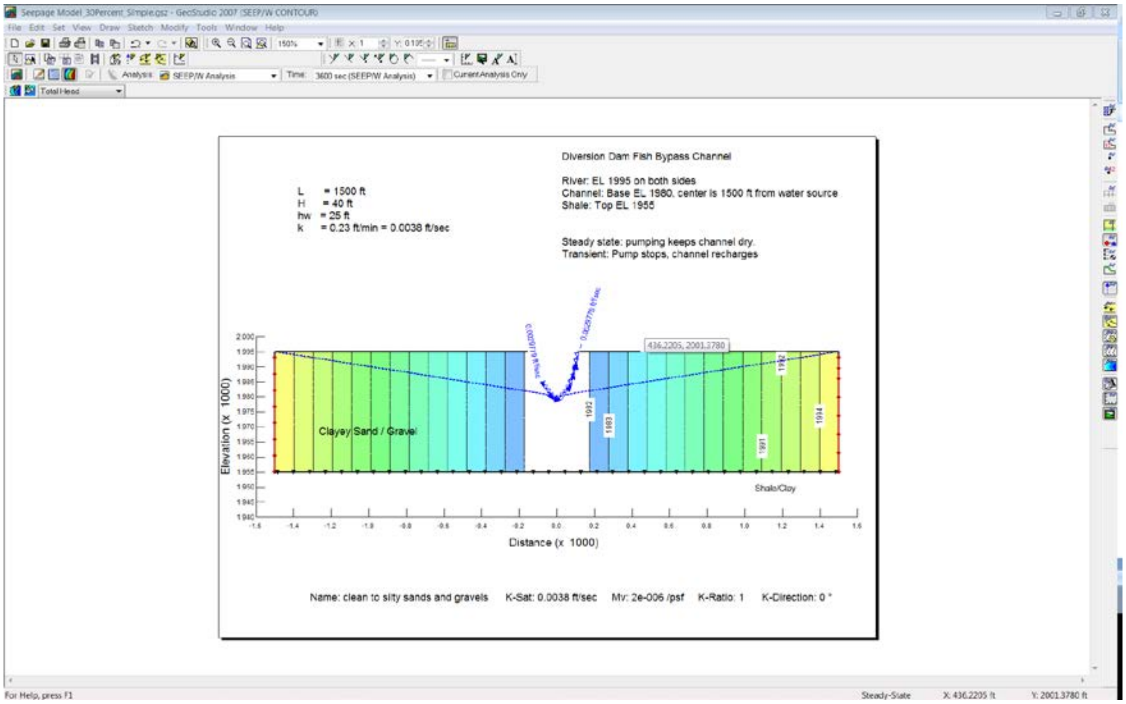


Width ~200ft

Results.

Modeling the excavation as long shape (B/H=10) results in a smaller predicted inflow, per foot.

2.2.3 Average Case – SEEP/W Model



Diversion Dam Fish Bypass Channel

River: EL 1995 on both sides
Channel: Base EL 1980, center is 1500 ft from water source
Shale: Top EL 1955

Steady state: pumping keeps channel dry.
Transient: Pump stops, channel recharges

L = 1500 ft
H = 40 ft
hw = 25 ft
k = 0.23 ft/min = 0.0038 ft/sec

Name: clean to silty sands and gravels K-Sat: 0.0038 ft/sec Mv: 2e-006 /psf K-Ratio: 1 K-Direction: 0 °

➔ **q = 0.0025 ft^3/sec / 1ft length**

➔ **q = 1.13 gpm / 1ft length**

Assumptions.

- L=1500ft
- H = 40ft (EL 1995ft to 1955 ft)
- hw = 25ft (EL 1980ft to 1955ft)
- k=0.23 ft/min (0.0038 ft/sec)
- channel geometry from 30%DDR Appendix A
- Clay/Shale assumed to impermeable layer unaffected by pumping, same as drawdown equations.
- Topsoil/ML layer discounted, to be removed during excavation.

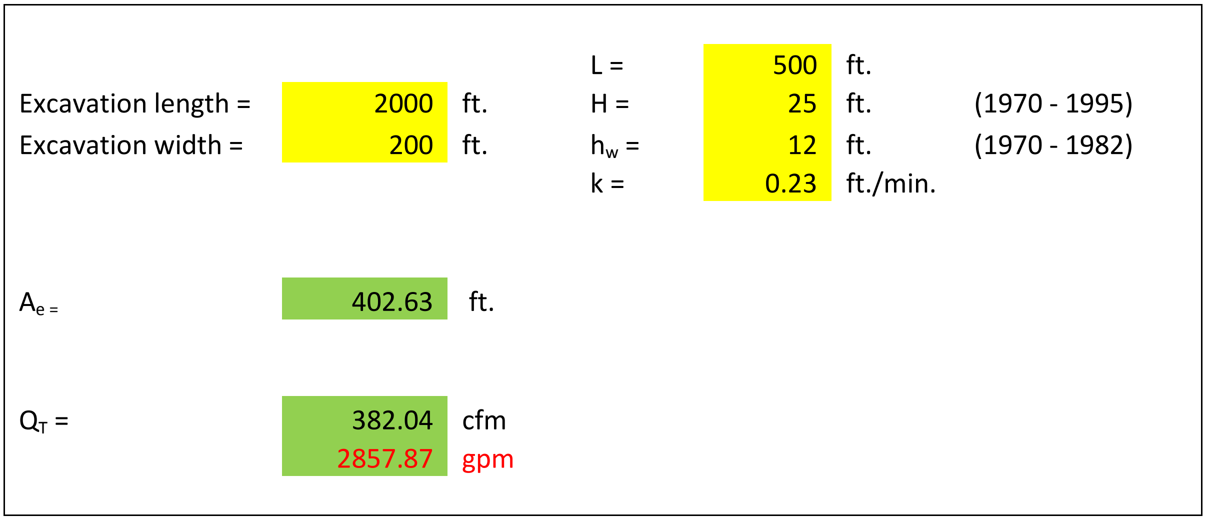
Results.

Results of SEEP/W Model match closely with the results of the "well drawdown equations-modified inputs", likely in part due to the similar assumption of a long, linear channel.

2.3 Sta 14+00 Case

A specific cross-section was modeled to test the sensitivity of the results from the drawdown equations and SEEP/W model. Station 14+00 is near the outlet (fish inlet) of the alignment, where the channel is about 500ft from the river.

2.3.1 Sta 14+00 Case - Well Equations



			L =	500	ft.	
Excavation length =	2000	ft.	H =	25	ft.	(1970 - 1995)
Excavation width =	200	ft.	h_w =	12	ft.	(1970 - 1982)
			k =	0.23	ft./min.	
A_e =	402.63	ft.				
Q_T =	382.04	cfm				
	2857.87	gpm				

→q = 0.0032 cfs / ft

→q = 1.43 gpm / ft

Assumptions.

H = EL difference between River GWT and the top of impermeable clay-shale

Hw = EL difference between drawdown GWT and the top of impermeable clay-shale

L = distance between center of excavation and river GWT

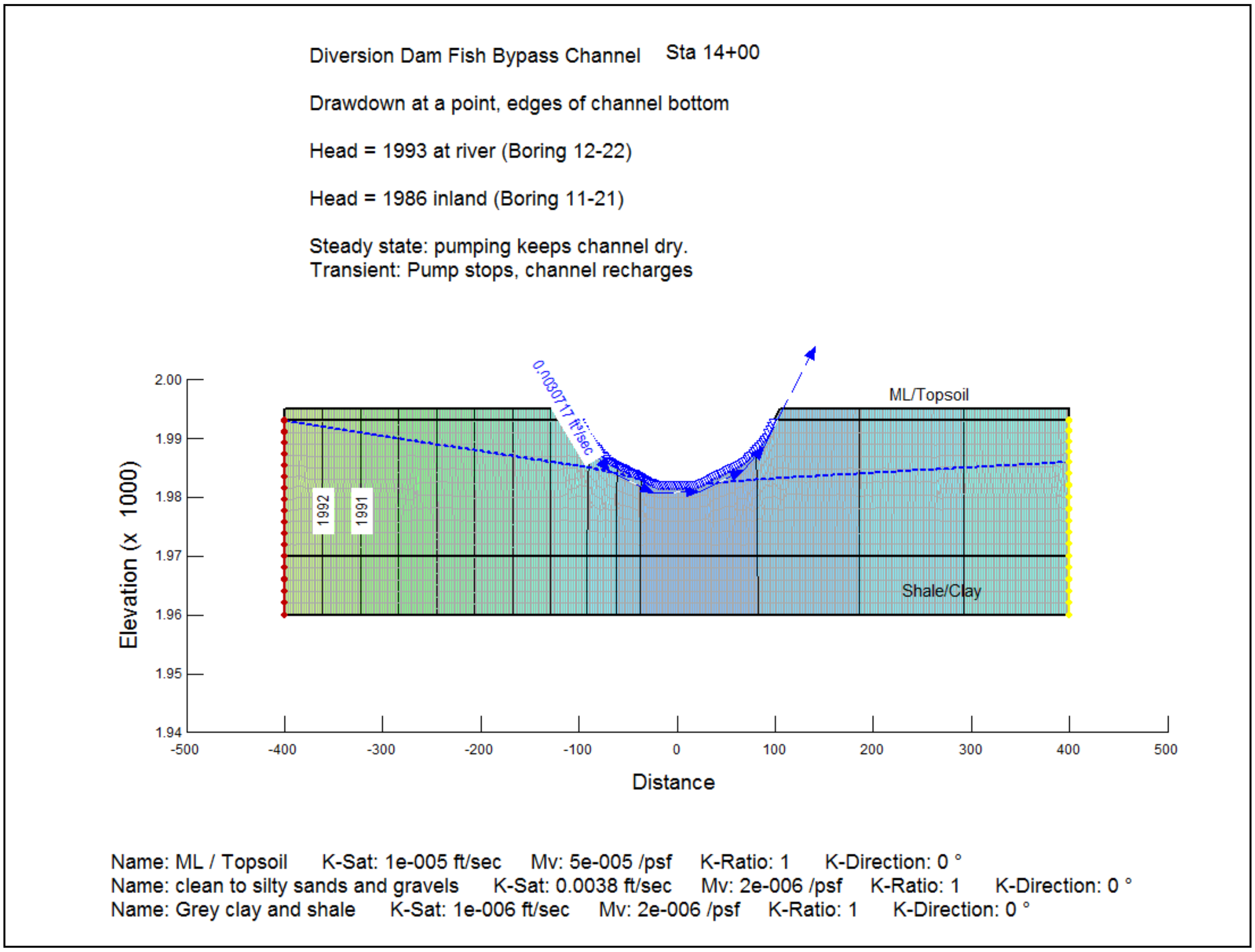
H and Hw determined from borings and channel alignments (see APPENDIX A – Channel Profile with Borings).

L determined from plan view of channel alignment.

Results.

Inflow is not very different from Average case. The water source is nearer (500 ft vs 1500ft average case), but the height of drawdown is smaller and the permeable layer is less thick.

2.3.2 Sta 14+00 Case – SEEP/W Model



q= 0.003 ft^3/sec / 1ft length
q= 1.36 gpm / 1ft length

Assumptions.
Water level is not the same on each side. Water level at river and inland were determined from boring logs.

Borings drilling dates. 2011 borings were drilled in November, 2012 borings were drilled in October. Therefore seasonal variation is not an issue, and the two sets can be used together in determining groundwater levels for analysis.

Results.
Close agreement with the drawdown equations. The SEEP/W model predicts a slightly smaller inflow, which is expected because the GWT is lower inland, while the drawdown equation assumes that the river level is present on both sides of the channel.

2.3.3 Sta 14+00 Case – SEEP/W Model Recharge

Two-step SEEPW Analysis - Assumptions

- Dewatering analysis was a steady state condition. Boundaries were set to keep the channel dry. Provided the steady-state flow quantity into the channel (dewatering requirement).
- Transient analysis begins when the dewatering condition is removed. Provides the length of time it takes for the channel to recharge.

Results

The groundwater surface reached a stable condition within 1 hour, filling the channel.

3 SUMMARY TABLES

Dewatering Variation with Permeability

Station	k = 0.23 ft/min	k = 0.23 ft/min	k = 0.03 ft/min	k = 0.03 ft/min
	Drawdown Eq. Inflow per ft (gpm)	SEEP Inflow per ft (gpm)	Drawdown Eq. Inflow per ft (gpm)	SEEP Inflow per ft (gpm)
Average Case	1.31	1.13	0.17	0.18
Sta 14+00	1.43	1.36	-	-
Sta 28+00	-	-	-	-
Sta 65+00	-	-	-	-

Original estimate: average of 0.012 (ft^3/sec)/ft of channel

Note: inflow quantities not yet estimated for Sta 28+00 and Sta 65+00 cases.

Note: k = 0.23 ft/min is indicated by field PZ rising head tests, and the max value from Hazen permeability based from lab samples.
k = 0.03 ft/min is indicated by the average of Hazen permeability based from lab samples.

Cross-sections Geometry

Channel Info			Boring: Near River			Boring: Along Channel			Boring: Inland			Stratigraphy	
Cross-section	Channel base EL	Channel centerline	Boring	Distance from River	GWT	Boring	Distance from River	GWT	Boring	Distance from River	GWT	Top of clayey gravel/sand	Top of clay/shale
	(ft)	(ft)		(ft)	(ft)		(ft)	(ft)		(ft)	(ft)	(ft)	(ft)
30% DDR Ave.	1980	1500	-	0	1995	-	1500	-	-	3000	1995	1995	1955
Sta 14+00	1982	300	12-22	200	1993	12-10	400	1991	11-21	800	1986	1993	1960
Sta 28+00	1982	500	12-22	200	1993	11-19	750	1990	11-18	1125	1990	1995	1978
Sta 65+00	1985	2375	12-21	200	1993	12-06	2375	1990	11-13	3200	1983	1992	1975

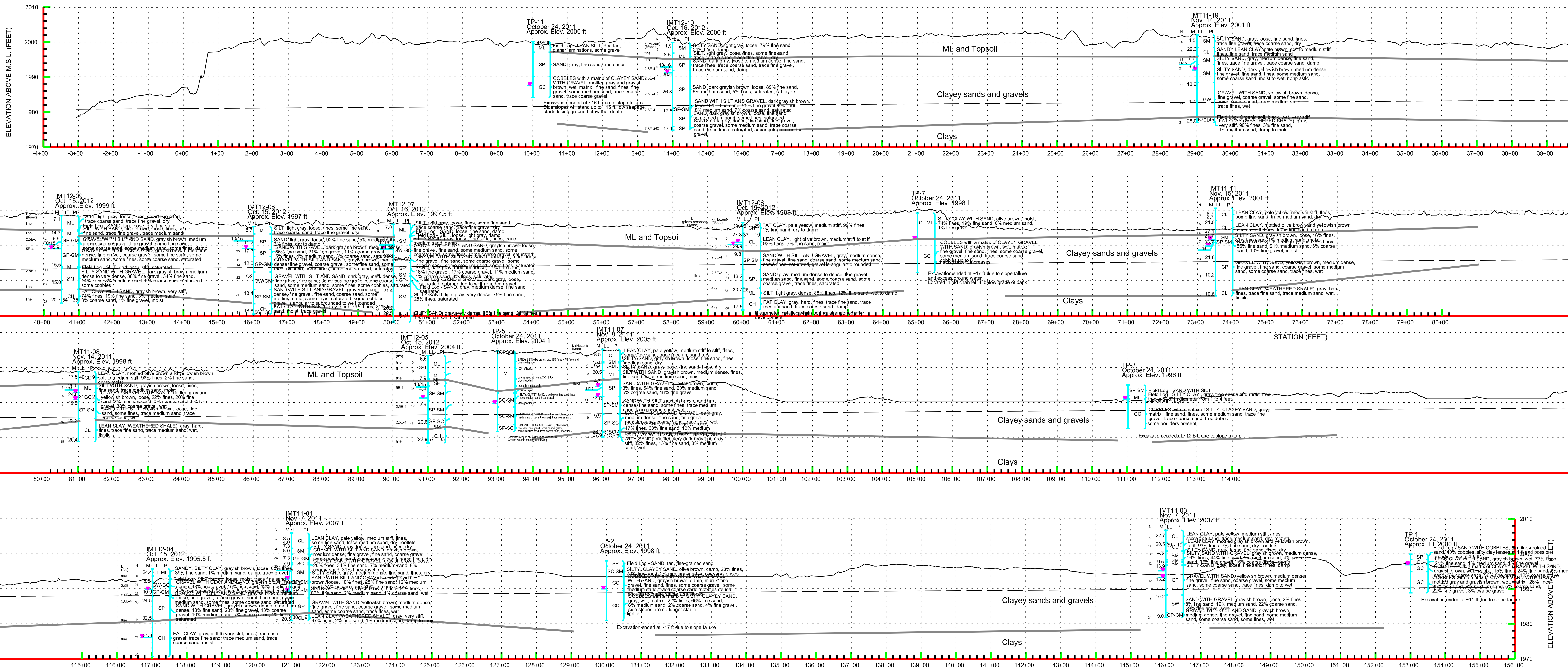
Note: inflow quantities not yet estimated for Sta 28+00 and Sta 65+00 cases.

APPENDIX A – CHANNEL PROFILE WITH BORINGS

APPENDIX B - HAZEN CORRELATION FOR PERMEABILITY

APPENDIX C - DETERMINATION OF PERMEABILITY FROM PZ PUMP TESTS

Appendices attached on the following pages.



LINE	SURFACE	OFFSET
———	surface_b	0.00

Scaled 10.0000 Times Ver.
Scaled 1.0000 Times Hor.

LOWER YELLOWSTONE RIVER FISH BYPASS
RECEIVED NOVEMBER 1, 2012

Terracon Project No. 05126338

Group	Boring and Sample Nos.	Depth (ft)	Description	USCS	Sieve % Passing											Hazen						Atterberg			Moisture Content	Required Tests
															all	k	sample									
												0.42	0.177	0.074		ft/s	USCS	Station	Top EL	Sample	EL					
					3"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200	D10					mid-depth		LL	PL	PI	%	
A	IMT-12-01 D-1	1.0' - 2.5'	10YR 7/3 Very Pale Brown Silt	ML	100.0	100.0	100.0	100.0	98.7	97.9	97.7	97.6	97.0	86.1								25	22	3	3.2	AL/MA
A	D-2	3.5' - 5.0'																							2.9	
A	D-3	6.0' - 7.5'																							11.6	
A	D-4	8.5' - 10.0'																							12.5	
B	D-5	13.5' - 15.0'	2.5Y 4/1 Dark Gray Poorly Graded Sand	SP	100.0	100.0	100.0	100.0	97.8	96.4	96.0	95.2	51.7	4.3	0.086	2.4E-04	SP								21.9	MA
C	D-6	18.5' - 20.0'	2.5Y 6/1 Gray Poorly Graded Sand with Silt and Gravel	SP-SM	100.0	100.0	79.5	72.7	61.4	46.0	39.5	32.7	19.1	9.1	0.083	2.3E-04	SP-SM								11.4	MA
D	D-7	23.5' - 25.0'	2.5Y 6/1 Gray Fat Clay	CH	100.0	100.0	100.0	100.0	96.3	94.9	93.9	92.9	90.8	89.8			CH					64	22	42	28.2	AL/MA
	U-1	25.0' - 27.0'													#N/A		#N/A									
E	IMT-12-02 D-1	1.0' - 2.5'	2.5Y 4/3 Olive Brown Silt with Sand	ML	100.0	100.0	100.0	100.0	97.5	96.6	96.0	95.6	94.6	83.4			ML					28	25	3	26.4	AL/MA
F	D-2	3.5' - 5.0'	10YR 5/2 Grayish Brown Poorly Graded Gravel with Silt and Sand	GP-GM	100.0	68.4	53.4	45.5	32.7	25.8	22.8	19.5	15.3	8.2	0.100	3.3E-04	GP-GM								4.5	MA
C	D-3	6.0' - 7.5'													0.083	2.3E-04	SP-SM								13.9	
C	D-4	8.5' - 10.0'													0.083	2.3E-04	SP-SM								14.5	
C	D-5	13.5' - 15.0'													0.083	2.3E-04	SP-SM								14.5	
G	IMT-12-02 (Cont') D-6	18.5' - 20.0'	10YR 5/2 Grayish Brown Fat Clay	CH	100.0	100.0	100.0	100.0	99.0	98.4	97.3	96.8	96.0	95.3			CH					90	25	65	33.8	AL/MA
	D-7	23.5' - 25.0'	Not delivered												#N/A		#N/A									
	U-1	20.0' - 22.0'													#N/A		#N/A									
H	IMT-12-03 D-1	1.0' - 2.5'	10YR 5/2 Grayish Brown Sandy Lean Clay	CL	100.0	100.0	100.0	100.0	100.0	100.0	99.7	99.1	87.0	50.7			CL	126.00				NP	NP	NP	17.7	AL/MA
H	D-2	3.5' - 5.0'															CL	126.00							20.5	
I	D-3	6.0' - 7.5'	10YR 4/1 Dark Gray Poorly Graded Gravel with Silt and Sand	GP-GM	100.0	85.1	46.0	42.6	31.8	26.3	21.8	17.0	12.4	7.1	0.130	5.6E-04	GP-GM	126.00							8.4	MA
J	D-4	8.5' - 10.0'	10YR 4/1 Dark Gray Well Graded Gravel with Silt and Sand	GW-GM	100.0	86.9	68.4	59.6	43.0	30.8	25.6	21.0	10.4	5.3	0.169	9.4E-04	GW-GM	126.00							9.7	MA
K	D-5	13.5' - 15.0'	10YR 5/1 Gray Poorly Graded Sand with Gravel	SP	100.0	92.6	78.4	71.4	58.0	47.0	37.2	21.4	3.8	0.6	0.263	2.3E-03	SP	126.00							13.9	MA
L	D-6	18.5' - 20.0'	10YR 5/1 Gray Fat Clay	CH	100.0	100.0	100.0	100.0	99.7	98.7	97.6	97.0	95.6	93.8			CH	126.00				50	21	29	25.2	AL/MA
	U-1	20.0' - 22.0'													#N/A		#N/A	126.00								
M	IMT-12-04 D-1	1.0' - 2.5'	10YR 5/2 Grayish Brown Sandy Silty Clay	CL-ML	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.3	90.9	60.1			CL-ML	117.00	1995.5	2.0	1993.5	NP	NP	NP	24.4	AL/MA
N	D-2	3.5' - 5.0'	10YR 5/12 Grayish Brown Well Graded Gravel with Clay and Sand	GW-GC	100.0	95.3	70.7	62.9	47.3	35.6	28.8	23.8	14.5	9.1	0.091	2.7E-04	GW-GC	117.00	1995.5	4.0	1991.5	NP	NP	NP	8.5	AL/MA
I	IMT-12-04 (Cont') D-3	6.0' - 7.5'													0.130	5.6E-04	GP-GM	117.00	1995.5	7.0	1988.5				10.9	
O	D-4	8.5' - 10.0'	10YR 5/2 Grayish Brown Poorly Graded Sand with Gravel	SP	100.0	86.6	82.8	75.5	64.3	57.4	53.7	47.0	17.1	4.4	0.119	4.7E-04	SP	117.00	1995.5	9.0	1986.5				13.7	MA
D	D-5	13.5' - 15.0'															CH	117.00	1995.5	14.0	1981.5				24.5	
D	D-6	18.5' - 20.0'															CH	117.00	1995.5	19.0	1976.5				32.6	
D	D-7	23.5' - 25.0'															CH	117.00	1995.5	24.0	1971.5				31.3	
A	IMT-12-05 D-1	1.0' - 2.5'															ML	91.00	2004.0	2.0	2002.0				6.6	
A	D-2	3.5' - 5.0'															ML	91.00	2004.0	4.0	2000.0				3.0	
P	D-3	6.0' - 7.5'	10YR 6/2 Light Brownish Gray Sandy Silt	ML	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.6	93.3	53.6			ML	91.00	2004.0	7.0	1997.0				7.9	MA
Q	D-4	8.5' - 10.0'	10YR 4/2 Dark Grayish Brown Poorly Graded Sand with Silt and Gravel	SP-SM	100.0	100.0	87.1	80.4	61.8	52.5	48.9	41.8	16.2	5.7	0.116	4.4E-04	SP-SM	91.00	2004.0	9.0	1995.0				4.4	MA
C	D-5	13.5' - 15.0'													0.083	2.3E-04	SP-SM	91.00	2004.0	14.0	1990.0				2.9	
R	D-6	18.5' - 20.0'	2.5Y 5/2 Grayish Brown Poorly Graded Sand with Clay and Gravel	SP-SC	100.0	88.5	79.4	70.0	55.4	42.1	34.0	30.3	21.1	10.6	0.074	1.8E-04	SP-SC	91.00	2004.0	19.0	1985.0	NP	NP	NP	20.6	AL/MA
S	D-7	23.5' - 25.0'	2.5Y 5/1 Gray Fat Clay	CH	100.0	100.0	100.0	100.0	100.0	99.9	99.7	99.4	99.0	98.2			CH	91.00	2004.0	24.0	1980.0	57	22	35	23.9	AL/MA
	IMT-12-05 (Cont') U-1	22.0' - 24.0'													#N/A		#N/A	91.00	2004.0	23.0	1981.0					
T	IMT-12-06 D-1	1.0' - 2.5'	2.5Y 8/3 Pale Yellow Fat Clay	CH	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.5	98.5			CH	60.00	1996.0	2.0	1994.0	51	22	29	13.4	AL/MA
U	D-2	3.5' - 5.0'	2.5Y 5/3 Light Olive Brown Lean Clay	CL	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.5	98.5	93.3			CL	60.00	1996.0	4.0	1992.0	37	18	19	27.3	AL/MA

LOWER YELLOWSTONE RIVER FISH BYPASS
RECEIVED NOVEMBER 1, 2012

Terracon Project No. 05126338

Group	Boring and Sample Nos.	Depth (ft)	Description	USCS	Sieve % Passing											Hazen							Atterberg			Moisture Content	Required Tests
															all	k	sample									
												0.42	0.177	0.074		ft/s	USCS	Station	Top EL	Sample	EL					
					3"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200	D10					mid-depth		LL	PL	PI	%	
U	D-3	6.0' - 7.5'															CL	60.00	1996.0	7.0	1989.0				29.9	
C	D-4	8.5' - 10.0'													0.083	2.3E-04	SP-SM	60.00	1996.0	9.0	1987.0				9.8	
K	D-5a	15.0'-16.5'													0.263	2.3E-03	SP	60.00	1996.0	16.0	1980.0				13.2	
V	**D-6**	**18.5' - 20.0'**	**2.5Y 7/1 Light Gray Silt**	**ML**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.9**	**99.9**	**99.7**	**99.1**	**87.8**			ML	60.00	1996.0	19.0	1977.0	**26**	**25**	**1**	**20.7**	**AL/MA**
L	D-7	23.5' - 25.0'															CH	60.00	1996.0	24.0	1972.0				17.5	
A	**IMT-12-07** D-1	1.0' - 2.5'															ML	50.00	1997.5	2.0	1995.5				7.0	
Y	D-2	3.5' - 5.0'															SM	50.00	1997.5	4.0	1993.5				20.5	
N	D-3	6.0' - 7.5'															GW-GC	50.00	1997.5	7.0	1990.5				11.6	
J	D-4	8.5' - 10.0'															GW-GM	50.00	1997.5	9.0	1988.5				13.8	
W	**IMT-12-07 (Cont') D-5**	**13.5' - 15.0'**	**2.5Y 4/1 Dark Gray Poorly Graded Sand with Gravel**	**SP**	**100.0**	**83.1**	**75.2**	**72.6**	**65.0**	**60.8**	**57.9**	**50.2**	**12.6**	**2.7**	0.150	7.4E-04	SP	50.00	1997.5	14.0	1983.5				**15.9**	**MA**
X	**D-6**	**18.5' - 20.0'**	**2.5Y 7/1 Light Gray Silty Sand**	**SM**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.9**	**98.6**	**24.7**			SM	50.00	1997.5	19.0	1978.5	**NP**	**NP**	**NP**	**21.4**	**AL/MA**
X	D-7	23.5' - 25.0'															SM	50.00	1997.5	24.0	1973.5				28.2	
Y	**D-8**	**24.5' - 26.0'**	**2.5Y 6/1 Gray Silty Sand**	**SM**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.7**	**98.7**	**95.3**	**23.5**			SM	50.00	1997.5	25.0	1972.5				**22.5**	**MA**
	U-1	26.0' - 28.0'													#N/A		#N/A	50.00	1997.5	27.0	1970.5					
A	**IMT-12-08** D-1	1.0' - 2.5'															ML	46.00	1997.0	2.0	1995.0				8.7	
AQ	D-2	3.5' - 5.0'															SP	46.00	1997.0	4.0	1993.0				11.2	
Z	**D-3**	**6.0' - 7.5'**	**2.5y 4/2 Dark Grayish Brown Poorly Graded Sand with Gravel**	**SP**	**100.0**	**88.5**	**76.1**	**71.3**	**67.8**	**64.9**	**63.4**	**60.5**	**20.1**	**4.8**	0.109	3.9E-04	SP	46.00	1997.0	7.0	1990.0				**17.3**	**MA**
I	D-4a	10.0'-11.5'													0.130	5.6E-04	GP-GM	46.00	1997.0	11.0	1986.0				12.0	
J	D-5	13.5' - 15.0'													0.169	9.4E-04	GW-GM	46.00	1997.0	14.0	1983.0				7.8	
C	D-6	18.5' - 20.0'													0.083	2.3E-04	SP-SM	46.00	1997.0	19.0	1978.0				13.4	
AA	**D-7**	**23.5' - 25.0'**	**2.5Y 6/1 Gray Fat Clay with Sand**	**CH**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.8**	**98.8**	**79.2**			CH	46.00	1997.0	24.0	1973.0	**56**	**18**	**38**	**18.8**	**AL/MA**
A	**IMT-12-09** D-1	1.0' - 2.5'															ML	40.50	1999.0	2.0	1997.0				7.1	
E	D-2	3.5' - 5.0'															ML	40.50	1999.0	4.0	1995.0				14.7	
F	D-3	6.0' - 7.5'													0.100	3.3E-04	GP-GM	40.50	1999.0	7.0	1992.0				5.9	
I	D-4	8.5' - 10.0'													0.130	5.6E-04	GP-GM	40.50	1999.0	9.0	1990.0				5.9	
AB	**D-5**	**13.5' - 15.0'**	**2.5Y 4/2 Dark Grayish Brown Silty Sand with Gravel**	**SM**	**100.0**	**100.0**	**85.6**	**75.3**	**62.0**	**56.0**	**52.4**	**47.8**	**34.4**	**14.4**	0.074	1.8E-04	SM	40.50	1999.0	14.0	1985.0				**15.5**	**MA**
AB	D-6	18.5' - 20.0'															SM	40.50	1999.0	19.0	1980.0				15.0	
AC	**D-7**	**23.5' - 25.0'**	**2.5Y 5/2 Grayish Brown Fat Clay with Sand**	**CH**	**100.0**	**100.0**	**100.0**	**100.0**	**98.5**	**96.1**	**94.2**	**92.7**	**90.2**	**73.8**			CH	40.50	1999.0	24.0	1975.0	**54**	**19**	**35**	**20.7**	**AL/MA**
AD	**IMT-12-10 D-1**	**1.0' - 2.5'**	**2.5Y 7/2 Light Gray Silty Sand**	**SM**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.8**	**75.5**	**21.2**			SM	14.00	2000.0	2.0	1998.0				**1.9**	**MA**
A	D-2	3.5' - 5.0'															ML	14.00	2000.0	4.0	1996.0				8.5	
B	D-3	6.0' - 7.5'													0.086	2.4E-04	SP	14.00	2000.0	7.0	1993.0				8.4	
AE	**D-4**	**8.5' - 10.0'**	**2.5Y 4/2 Dark Grayish Brown Poorly Graded Sand**	**SP**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.8**	**94.2**	**53.9**	**4.8**	0.085	2.4E-04	SP	14.00	2000.0	9.0	1991.0				**26.5**	**MA**
AE	D-5	13.5' - 15.0'													0.085	2.4E-04	SP	14.00	2000.0	14.0	1986.0				26.8	
AF	**IMT-12-10 (Cont') D-6**	**18.5' - 20.0'**	**2.5Y 4/2 Dark Grayish Brown Poorly Graded Sand with Silt and Gravel**	**SP-SM**	**100.0**	**100.0**	**91.1**	**85.4**	**74.7**	**67.7**	**63.8**	**60.2**	**44.8**	**8.5**	0.078	2.0E-04	SP-SM	14.00	2000.0	19.0	1981.0				**17.5**	**MA**
W	D-7	23.5' - 25.0'													0.150	7.4E-04	SP	14.00	2000.0	24.0	1976.0				17.1	
A	**IMT-12-11** D-1	1.0' - 2.5'																							4.8	
P	D-2	3.5' - 5.0'																							10.8	
I	D-3	6.0' - 7.5'													0.130	5.6E-04	GP-GM								3.9	
F	D-4	8.5' - 10.0'													0.100	3.3E-04	GP-GM								5.9	

LOWER YELLOWSTONE RIVER FISH BYPASS
RECEIVED NOVEMBER 1, 2012

Terracon Project No. 05126338

Group	Boring and Sample Nos.	Depth (ft)	Description	USCS	Sieve % Passing										all	Hazen k ft/s	sample USCS	Station	Top EL	Sample	EL	Atterberg			Moisture Content	Required Tests
												0.42	0.177	0.074												
					3"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200	D10					mid-depth		LL	PL	PI	%	
J	D-5A	15.0' -16.5'																							13.1	
J	D-6	18.5' - 20.0'																							7.3	
AG	**D-7**	**23.5' - 25.0'**	**2.5Y 5/2 Grayish Brown Clayey Sand with Gravel**	**SC**	**100.0**	**100.0**	**95.2**	**83.7**	**62.1**	**50.5**	**45.0**	**40.6**	**31.1**	**26.7**								**33**	**15**	**18**	**12.6**	**AL/MA**
A	**IMT-12-12** D-1	1.0' - 2.5'																							6.0	
A	D-2	3.5' - 5.0'																							4.8	
E	D-3	6.0' - 7.5'															**ML**								17.6	
P	**IMT-12-12 (Cont')** D-4	8.5' - 10.0'																							17.5	
Q	D-5	13.5' - 15.0'																							5.0	
AH	**D-6**	**18.5' - 20.0'**	**2.5Y 5/2 Grayish Brown Well Graded Sand with Gravel**	**SW**	**100.0**	**100.0**	**87.1**	**76.1**	**59.3**	**41.7**	**25.5**	**14.6**	**8.6**	**3.7**	**0.234**	**1.8E-03**									**3.6**	**MA**
AI	**IMT-12-13** **D-1**	**1.0' - 2.5'**	**2.5Y 6/2 Light Brownish Gray Silty Sand**	**SM**	**100.0**	**100.0**	**100.0**	**100.0**	**97.0**	**92.0**	**83.2**	**70.7**	**56.1**	**48.0**								**23**	**21**	**2**	**2.4**	**AL/MA**
AH	D-2	3.5' - 5.0'																							2.8	
I	D-3	6.0' - 7.5'													**0.130**	**5.6E-04**	**GP-GM**								2.6	
AJ	**D-4**	**8.5' - 10.0'**	**10YR 2/1 Black Coal**	**Coal**	**100.0**	**100.0**	**100.0**	**85.0**	**84.2**	**80.4**	**77.5**	**66.9**	**47.5**	**27.5**											**74.4**	**MA**
AK	**D-5**	**13.5' - 15.0'**	**10YR 4/1 Dark Gray Fat Clay with Sand**	**CH**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.9**	**98.9**	**96.7**	**92.0**	**84.8**								**52**	**24**	**28**	**26.2**	**AL/MA**
V	D-6	18.5' - 20.0'																							21.6	
AI	**IMT-12-14** D-1	1.0' - 2.5'																							3.9	
Q	D-2	3.5' - 5.0'																							5.3	
Q	D-3	6.0' - 7.5'																							4.1	
B	**IMT-12-12 (Cont')** D-4	8.5' - 10.0'													**0.086**	**2.4E-04**	**SP**								3.2	
AL	**D-5**	**13.5' - 15.0'**	**7.5YR 3/3 Dark Brown Poorly Graded Sand with Silt and Gravel**	**SP-SM**	**100.0**	**100.0**	**84.8**	**74.0**	**54.0**	**42.0**	**31.4**	**22.1**	**12.6**	**7.0**	**0.129**	**5.5E-04**									**4.0**	**MA**
AL	D-6	18.5' - 20.0'																							5.8	
A	**IMT-12-15** D-1	1.0' - 2.5'																							6.3	
P	D-2	3.5' - 5.0'																							8.6	
P	D-3	6.0' - 7.5'																							12.4	
P	D-4	8.5' - 10.0'																							9.5	
Q	D-5	13.5' - 15.0'																							4.0	
Q	D-6	18.5' - 20.0'																							8.1	
E	**IMT-12-16** D-1	1.0' - 2.5'															**ML**								6.5	
P	D-2	3.5' - 5.0'																							8.3	
U	D-3	6.0' - 7.5'																							12.2	
AM	**IMT-12-16 (Cont')** **D-4**	**8.5' - 10.0'**	**2.5Y 6/2 Light Brownish Gray Poorly Graded Sand with Silt**	**SP-SM**	**100.0**	**100.0**	**100.0**	**96.5**	**88.1**	**76.2**	**67.9**	**59.4**	**44.3**	**11.0**											**2.5**	**MA**
Q	D-5	13.5' - 15.0'																							4.0	
AE	D-6	18.5' - 20.0'																							2.2	
A	**IMT-12-17** D-1	1.0' - 2.5'																							4.3	
A	D-2	3.5' - 5.0'																							3.5	
AI	D-3	6.0' - 7.5'																							5.6	
AN	**D-4**	**8.5' - 10.0'**	**2.5Y 5/3 Light Olive Brown Silty, Clayey Sand**	**SC-SM**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**98.2**	**91.3**	**60.5**	**28.7**								**NP**	**NP**	**NP**	**5.0**	**AL/MA**
AO	**D-5**	**13.5' - 15.0'**	**2.5Y 6/2 Light Brownish Gray Poorly Graded Sand**	**SP**	**100.0**	**100.0**	**100.0**	**93.6**	**85.1**	**72.9**	**55.6**	**35.5**	**9.3**	**2.8**	**0.183**	**1.1E-03**									**2.8**	**MA**
AO	D-6	18.5' - 20.0'																							2.0	

LOWER YELLOWSTONE RIVER FISH BYPASS
RECEIVED NOVEMBER 1, 2012

Terracon Project No. 05126338

Group	Boring and Sample Nos.	Depth (ft)	Description	USCS	Sieve % Passing										all	Hazen k	sample					Atterberg			Moisture Content	Required Tests
												0.42	0.177	0.074		ft/s	USCS	Station	Top EL	Sample	EL					
					3"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200	D10					mid-depth		LL	PL	PI	%	
AP		AP appears out of sequence later in the report																								
U	IMT-12-18 D-1	1.0' - 2.5'																							7.5	
Y	D-2	3.5' - 5.0'																							6.0	
AM	IMT-12-18 (Cont') D-3	6.0' - 7.5'																							13.1	
AE	D-4	8.5' - 10.0'																							3.5	
AQ	**D-5**	**13.5' - 15.0'**	**2.5Y 7/2 Light Gray Poorly Graded Sand**	**SP**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**99.8**	**95.1**	**26.9**	**2.6**	**0.105**	**3.6E-04**									**1.2**	**MA**
AR	**D-6**	**18.5' - 20.0'**	**2.5Y 5/2 Grayish Brown Silty Sand with Gravel**	**SM**	**100.0**	**90.8**	**88.8**	**85.4**	**79.5**	**74.3**	**67.0**	**56.4**	**29.1**	**13.1**											**5.1**	**MA**
A	IMT-12-19 D-1	1.0' - 2.5'																							5.7	
P	D-2	3.5' - 5.0'																							5.5	
AQ	D-3	6.0' - 7.5'																							3.1	
AO	D-4	8.5' - 10.0'																							3.9	
AH	D-5	13.5' - 15.0'																							2.6	
AF	D-6	18.5' - 20.0'																							3.2	
A	IMT-12-20 D-1	1.0' - 2.5'																							4.9	
P	D-2	3.5' - 5.0'																							7.8	
AQ	IMT-12-20 (Cont') D-3	6.0' - 7.5'																							5.8	
F	D-4	8.5' - 10.0'													**0.100**	**3.3E-04**	**GP-GM**								4.6	
AB	D-5	13.5' - 15.0'																							20.1	
N	D-6	18.5' - 20.0'																							8.5	
AP	**D-7**	**23.5'-25.0'**	**2.5Y 2.5/1 Black & 2.5Y 6/2 Light Brownish Gray Poorly Graded Sand with Shale, Trace Coal**	**SP-SC**	**100.0**	**100.0**	**100.0**	**97.5**	**83.3**	**76.7**	**62.9**	**47.9**	**22.6**	**5.8**	**0.100**	**3.3E-04**						**NP**	**NP**	**NP**	**49.8**	**AL/MA**
A	IMT-12-21 D-1	1.0' - 2.5'																							8.7	
M	D-2	3.5' - 5.0'																							12.5	
AG	D-3	6.0' - 7.5'																							1.7	
Q	D-4	8.5' - 10.0'																							4.5	
AS	**IMT-12-21 (Cont') D-5**	**13.5' - 15.0'**	**2.5Y 4/2 Dark Grayish Brown Poorly Graded Sand with Silt and Gravel**	**SP-SM**	**100.0**	**94.3**	**84.3**	**80.9**	**67.8**	**60.8**	**58.2**	**53.6**	**21.0**	**5.4**	**0.104**	**3.6E-04**									**15.3**	**MA**
AO	D-6	18.5' - 20.0'																							24.5	
B	D-7	23.5' - 25.0'													**0.086**	**2.4E-04**	**SP**								20.9	
P	IMT-12-22 D-1	1.0' - 2.5'																							6.9	
P	D-2	3.5' - 5.0'																							18.4	
AN	D-3	6.0' - 7.5'																							24.7	
F	D-4	8.5' - 10.0'													**0.100**	**3.3E-04**	**GP-GM**								5.7	
Z	D-5	13.5' - 15.0'																							24.6	
AO	D-6	18.5' - 20.0'																							26.9	
AT	**D-7**	**23.5' - 25.0'**	**2.5Y 3/1 Very Dark Gray Sandy Fat Clay**	**CH**	**100.0**	**100.0**	**100.0**	**98.7**	**97.9**	**96.2**	**88.9**	**80.7**	**71.3**	**64.1**								**53**	**28**	**25**	**42.3**	**AL/MA**
A	IMT-12-23 D-1	1.0' - 2.5'																							13.9	
Y	D-2	3.5' - 5.0'																							11.4	
AD	D-3	6.0' - 7.5'																							25.0	
AU	**D-4A**	**10.0'-11.5**	**2.5Y 3/1 Very Dark Gray Poorly Graded Gravel with Silt and Sand**	**GP-GM**	**100.0**	**75.6**	**59.3**	**52.6**	**36.5**	**29.7**	**26.8**	**23.4**	**15.2**	**10.3**								**21**	**19**	**2**	**9.8**	**AL/MA**
AU	D-5A	15.0'-16.5'																							10.9	

LOWER YELLOWSTONE RIVER FISH BYPASS
RECEIVED NOVEMBER 1, 2012

Terracon Project No. 05126338

Group	Boring and Sample Nos.	Depth (ft)	Description	USCS	Sieve % Passing										all	Hazen k	sample					Atterberg			Moisture Content	Required Tests
												0.42	0.177	0.074		ft/s	USCS	Station	Top EL	Sample	EL					
					3"	3/4"	1/2"	3/8"	#4	#10	#20	#40	#80	#200	D10					mid-depth		LL	PL	PI	%	
C	**IMT-12-23 (Cont')** D-6	18.5' - 20.0'													**0.083**	**2.3E-04**	**SP-SM**								16.4	
C	D-7	23.5' - 25.0'													**0.083**	**2.3E-04**	**SP-SM**								9.2	
	IMT-12-27 HQ-1	14.1' - 16.3'													**#N/A**		**#N/A**									
	HQ-2	19.15' - 21.3'													**#N/A**		**#N/A**									
A	**IMT-12-28** D-1	8.5' - 10.0'																							5.2	

average k	5.1E-04	ft/s	average k	0.031	ft/min
max k	2.3E-03	ft/s	max k	1.4E-01	ft/min

Eq 14.11
Terzaghi Peck Mesri
Soil Mechanics in Engineering Practice 3rd ed

PZ: IMT12-03

Purpose of equation: define the order of magnitude of the in-situ permeability.

step

2 **k = (1/C) * A(dh/dt) / (r'h')**
where
2a k = hydraulic conductivity
2b C = coeff from fig 14.13

2c A=cross-section of casing
PI*(r^2) ID casing =2in Acasing = .35ft^2

2d dh = change in water level during test
ho test = 18.1
h end test (8min) = 9.31
dh =8.79 ft

2e dt=change in time over which water level changes
most change happened over dt= 8min

2f r' = radius of uncased cylindrical section of hole (sand filter?)
boring diameter = 8in , borehole radius r'=4in

2g h' = mean distance between steady gwt and the water level in the casing (during dt)
ho (9.38 TOC) = equilibrium
median test time h (4min) = (10.12ft)
h'=.74ft

Step
1 **C = f(L, Ho, r')** **(figure 14.13)**
where

1a L=depth of borehole bgs
L=22ft

1b Ho= depth from surface to impermeable bedrock
Borings ?11/04 nearby, shale @ 23.5 ft.
Assuming shale near bottom of 12-03
Ho slightly >L

1c L/Ho maxes at 0.85 (figure 14.13)
use L/Ho = 0.85

1d L/r' and L/Ho --> L'/r' (fig 14.13a) --> C (fig 14.13c)

	STEP 1	units	inputs
	L	ft	22
	r'	ft	0.33
	L/r'	-	792
	Ho	ft	~25
	L/Ho	-	0.85
fig 14.13 a)	L'/r'	-	2
fig 14.13 c)	C	-	10

STEP 2	units	inputs	
A_{casing}	ft^2	0.35	
dh	ft	8.79	
dt	min	8	
r'	ft	0.33	
h'	ft	0.74	
C	-	10	
k	ft/min	0.1555	in GW
k	ft/sec	0.0026	in GW
k	**m/sec**	**0.0008**	**in GW**

filterpack between 6.4ft and 22ft bgs between SW, GW, and MH, screen in GW Unit
Assuming response test gives indication of GW Unit's permeability.

Reference: Lower Yellowstone River
Fish Bypass Project
Intake, Montana
Field Investigation Report
19-Mar-13

Sieve data: 05126338 MA 12-18-12

TPM3rd ed table 43.1
Missouri River deposits typical k= 2E-4 to 2E-3
This test at Yellowstone River, but is consistent with table of typical values

	depth	Sample	boring unit	sample USCS	D10 (mm)	Hazen eq k (m/s)
	~2	D1	SM, SC	CL	-	
	4	D2	SC, SW	CL	-	
in	7	D3	SW, GW	GP-GM	0.12	**0.0001**
response	9	D4	GW	GW-GM	0.19	**0.0004**
testing	14	D5	GW	SP	0.24	**0.0006**
range	19	D6	GW, MH	CH	-	
	21	D7	MH	#N/A	-	

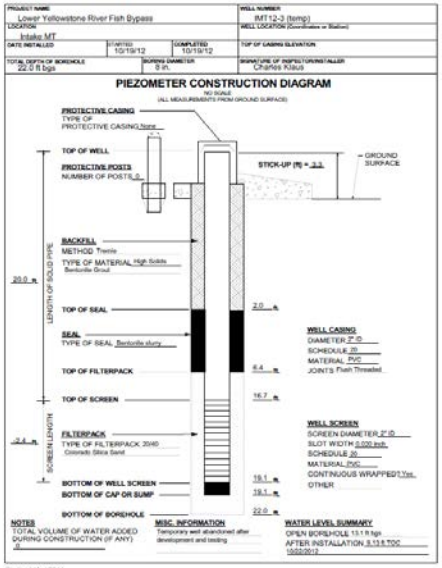
RESULTS
Response test gave k 1.4x greater than the Hazen equation.

A larger permeability is expected of the larger scale test

Hazen eq: k (m/s) = 1 /100 (D10^2)
D10 in mm

RESULTS: Piezo response test and Hazen eq give consistent permeability in the gravel

k(well)/k(sample)
1.37


PROJECT NAME: Lower Yellowstone River Fish Bypass
WELL NUMBER: IMT12-3 (temp)
LOCATION: Intake MT
WELL LOCATION (Coordinates or Station):
DATE INSTALLED: STARTED 10/19/12 COMPLETED 10/19/12
TOP OF CASING ELEVATION:
TOTAL DEPTH OF BOREHOLE: 22.0 ft bgs
BORING DIAMETER: 8 in.
SIGNATURE OF INSPECTOR/INSTALLER: Charles Klaus

PIEZOMETER CONSTRUCTION DIAGRAM
NO SCALE
(ALL MEASUREMENTS FROM GROUND SURFACE)

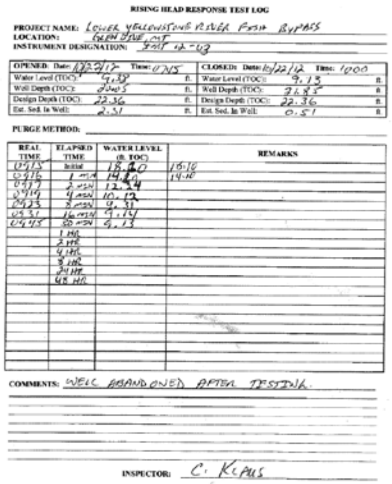
PROTECTIVE CASING
TYPE OF PROTECTIVE CASING None
PROTECTIVE POSTS
NUMBER OF POSTS 0
STICK-UP (ft) = 3.3
BACKFILL
METHOD Tremie
TYPE OF MATERIAL High Solids Bentonite Grout
SEAL
TYPE OF SEAL Bentonite slurry
FILTERPACK
TYPE OF FILTERPACK 20/40 Colorado Silica Sand
WELL CASING
DIAMETER 2" ID
SCHEDULE 20
MATERIAL PVC
JOINTS Flush Threaded
WELL SCREEN
SCREEN DIAMETER 2" ID
SLOT WIDTH 0.020 inch
SCHEDULE 20
MATERIAL PVC
CONTINUOUS WRAPPED? Yes
OTHER

NOTES
TOTAL VOLUME OF WATER ADDED DURING CONSTRUCTION (IF ANY) 0

MISC. INFORMATION
Temporary well abandoned after development and testing

WATER LEVEL SUMMARY
OPEN BOREHOLE 13.1 ft bgs
AFTER INSTALLATION 9.13 ft TOC 10/22/2012

Revised Mar 2011


RISING HEAD RESPONSE TEST LOG

PROJECT NAME: LOWER YELLOWSTONE RIVER FISH BYPASS
LOCATION: GLENDIVE, MT
INSTRUMENT DESIGNATION: IMT 12-03

OPENED: Date: 10/22/12	Time: 0915	CLOSED: Date: 10/22/12	Time: 1000
Water Level (TOC):	9.38 ft.	Water Level (TOC):	9.13 ft.
Well Depth (TOC):	20.05 ft.	Well Depth (TOC):	21.85 ft.
Design Depth (TOC):	22.36 ft.	Design Depth (TOC):	22.36 ft.
Est. Sed. In Well:	2.31 ft.	Est. Sed. In Well:	0.51 ft.

PURGE METHOD:

REAL TIME	ELAPSED TIME	WATER LEVEL (ft. TOC)	REMARKS
0915	Initial	18.10	18.10
0916	1 MIN	14.10	14.10
0917	2 MIN	12.54	
0919	4 MIN	10.12	
0923	8 MIN	9.31	
0931	16 MIN	9.14	
0945	30 MIN	9.13	
	1 HR		
	2 HR		
	4 HR		
	8 HR		
	24 HR		
	48 HR		

COMMENTS: WELL ABANDONED AFTER TESTING.

INSPECTOR: C. KLAUS

Eq 14.11
Terzaghi Peck Mesri
Soil Mechanics in Engineering Practice 3rd ed

PZ: IMT12-06

Purpose of equation: define the in-situ permeability within an order of magnitude.

step

2 **k = (1/C) * A(dh/dt) / (r'h')**
where
2a k = hydraulic conductivity
2b C = coeff from fig 14.13

2c A=cross-section of casing
PI*(r^2) ID casing =2in Acasing = .35ft^2

2d dh = change in water level during test
ho test = 17.93ft TOC
h end test (8min) = 9.21 TOC
dh = 8.72 ft

2e dt=change in time over which water level changes
most change happened over 8min

2f r' = radius of uncased cylindrical section of hole (sand filter?)
boring diameter = 8in , borehole radius r'=4in

2g h' = mean distance between steady gwt and the water level in the casing (during dt)
ho (8.81 TOCo) = equilibrium
median test time h (4min) = (9.58 -0.3ft TOCo)
h'=0.47ft

Step

1 **C = f(L, Ho, r')** **(figure 14.13)**
where

1a L=depth of borehole bgs
L=25ft

1b Ho= depth from surface to impermeable bedrock
Borings 11-10 and 11 nearby, shale @ 23.5 ft.
Assuming shale near bottom of 12-06
Ho slightly >L

1c L/Ho maxes at 0.85 (figure 14.13)
use L/Ho = 0.85

1d L/r' and L/Ho --> L'/r' (fig 14.13a) --> C (fig 14.13c)

	STEP 1	units	inputs
	L	ft	25
	$r'_{borehole}$	ft	0.33
	L/r'	-	900
	Ho	ft	~25
	L/Ho	-	0.85
fig 14.13 a)	L'/r'	-	2
fig 14.13 c)	C	-	10

STEP 2	units	inputs	
A_{casing}	ft^2	0.35	
dh	ft	8.72	
dt	min	8	
$r'_{borehole}$	in	0.33	
h'	ft	0.47	
C	-	10	
k	**ft/min**	**0.2429**	**in SP**
k	**ft/sec**	**0.0040**	**in SP**
k	**m/sec**	**0.0012**	**in SP**

filterpack between 7ft and 25ft bgs between CL, SP-SM, SP, ML, and CH, screen only in SP.
Assuming response test gives indication of SP permeability.

Reference: Lower Yellowstone River
Fish Bypass Project
Intake, Montana
Field Investigation Report
19-Mar-13

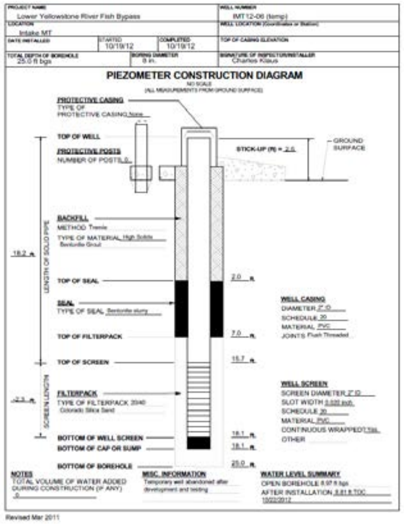
RESULTS
Response test gave k 1.8x greater than the Hazen equation.
Results are within 2x, which is very consistent
Also, a larger permeability is expected of the larger scale test

TPM3rd ed table 43.1
Missouri River deposits typical k= 2E-4 to 2E-3
This test at Yellowstone River, but is consistent with table of typical values

	depth	**Sample**	**sample USCS**	**D10 (mm)**	**Hazen eq k (m/s)**
	1-2.5	D1	CH	very fine	
	3.5-5	D2	CL	very fine	
in	6-7.5	D3	CL	very fine	
response	8.5-10	D4	SP-SM	0.083	**0.00007**
testing	15-16.5	D5	SP-SM	0.263	**0.0007**
range	18.5-20	D6	ML	very fine	
	23.5-25	D7	CH	very fine	

Hazen eq: k (m/s) = 1 /100 (D10^2)
D10 in mm

k(well) / k(sample)
1.79



PROJECT NAME Lower Yellowstone River Fish Bypass	WELL NUMBER IMT12-06 (temp)
LOCATION Intake MT	WELL LOCATION (Coordinates or Station)
DATE INSTALLED STARTED 10/19/12 COMPLETED 10/19/12	TOP OF CASING ELEVATION
TOTAL DEPTH OF BOREHOLE 25.0 ft bgs BORING DIAMETER 8 in.	SIGNATURE OF INSPECTOR/INSTALLER Charles Klaus

PIEZOMETER CONSTRUCTION DIAGRAM
NO SCALE
(ALL MEASUREMENTS FROM GROUND SURFACE)

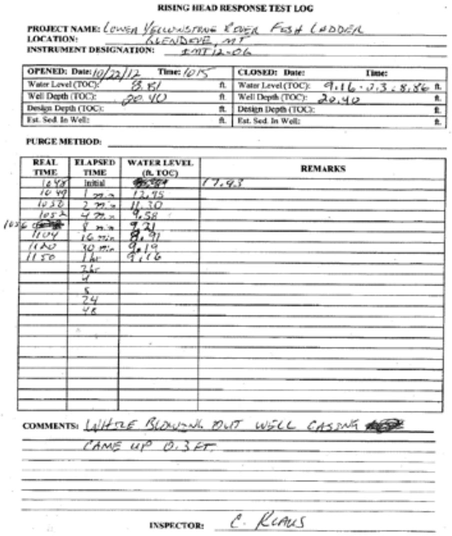
PROTECTIVE CASING
TYPE OF PROTECTIVE CASING None
PROTECTIVE POSTS
NUMBER OF POSTS 0
BACKFILL
METHOD Tremie
TYPE OF MATERIAL High Solids Bentonite Grout
SEAL
TYPE OF SEAL Bentonite slurry
FILTERPACK
TYPE OF FILTERPACK 20/40 Colorado Silica Sand
STICK-UP (ft) = 2.6
WELL CASING
DIAMETER 2" ID
SCHEDULE 20
MATERIAL PVC
JOINTS Flush Threaded
WELL SCREEN
SCREEN DIAMETER 2" ID
SLOT WIDTH 0.020 inch
SCHEDULE 20
MATERIAL PVC
CONTINUOUS WRAPPED? Yes
OTHER

NOTES
TOTAL VOLUME OF WATER ADDED DURING CONSTRUCTION (IF ANY)
0

MISC. INFORMATION
Temporary well abandoned after development and testing

WATER LEVEL SUMMARY
OPEN BOREHOLE 8.97 ft bgs
AFTER INSTALLATION 8.81 ft TOC
10/22/2012

Revised Mar 2011



RISING HEAD RESPONSE TEST LOG

PROJECT NAME: Lower Yellowstone River Fish Ladder
LOCATION: Glendive, MT
INSTRUMENT DESIGNATION: IMT12-06

OPENED: Date: 10/22/12 Time: 1015	CLOSED: Date: Time:
Water Level (TOC): 8.81 ft.	Water Level (TOC): 9.16 - 0.3 = 8.86 ft.
Well Depth (TOC): 20.40 ft.	Well Depth (TOC): 20.40 ft.
Design Depth (TOC): ft.	Design Depth (TOC): ft.
Est. Sed. In Well: ft.	Est. Sed. In Well: ft.

PURGE METHOD:

REAL TIME	ELAPSED TIME	WATER LEVEL (ft. TOC)	REMARKS
1048	Initial	[illegible]	17.93
1049	1 min	12.95	
1050	2 min	11.30	
1052	4 min	9.58	
1056 [illegible]	8 min	9.21	
1104	16 min	8.91	
1120	30 min	9.19	
1150	1 hr	9.16	
	2 hr		
	4		
	8		
	24		
	48		

COMMENTS: WHILE BLOWING OUT WELL CASING [illegible]
CAME UP 0.3 FT.

INSPECTOR: C. Klaus

ability tests are carried out during the secondary compression stage (Article 16.7). Permeability measurements at several void ratios are used to define the e vs log k relationship. Another reliable method for determining the permeability of soft clays uses the results of excess pore-water pressure measurements during constant rate of strain oedometer tests (Article 16.9). The permeability of clays can also be computed by analyzing the deformation vs time data from an incrementally loaded oedometer test, together with a theory of consolidation. The necessary equations and procedures are presented in Article 25.

14.7 In Situ Permeability Tests

Preliminary information about the order of magnitude and variability of the coefficient of permeability of a natural pervious stratum can be obtained by permeability tests in exploratory borings while drilling proceeds. The observations during drilling should also furnish information concerning the presence or absence of free communication between pervious strata encountered in the holes.

Most of the common procedures used in connection with drill holes are based on the principle of the falling-head permeability test. The hole is cased from the ground surface to the top of the zone to be tested and extends without support for a suitable depth below the casing. Usually the uncased part of the hole has a roughly cylindrical shape. If the pervious stratum is not too thick, the hole is preferably extended through the full thickness; otherwise the hole penetrates only part of the pervious material.

If the pervious zone is below the water table, the test may be carried out by adding water to raise the water level in the casing and then allowing the water level to descend toward its equilibrium position. The elevation is measured as a function of time, and the coefficient of permeability is calculated by means of the expression

$$k = \frac{1}{C} \frac{A(\Delta h/\Delta t)}{r_0' h_m'} \qquad (14.11)$$

where Δh is the drop in water level in the casing during an interval of time Δt, A is the inside cross-sectional area of the casing, h_m' is the mean distance during the interval Δt from the water level in the casing to the equilibrium water level in the pervious zone, and r_o' is the mean radius of the roughly cylindrical hole below the casing. The coefficient C is a dimensionless quantity that depends on the shape of the cylindrical hole and the depth of penetration into the pervious layer. Values of C for various conditions are given in Fig. 14.13 (Zangar 1953).

In a falling-head test in a drill hole it is likely that fines suspended in the water may form a filter skin over the walls and bottom of the hole in the pervious material; consequently, the observed permeability may be too small. The error may be avoided by bailing the water from the casing until the water level is below that of the pervious stratum and by measuring the elevation of the water level at various times as it rises toward its equilibrium position. The value of k can be calculated by Eq. 14.11 as before. However, if the permeable stratum is cohesionless the water level cannot be lowered too far or the hole will collapse and the cohesionless material may rise into the casing.

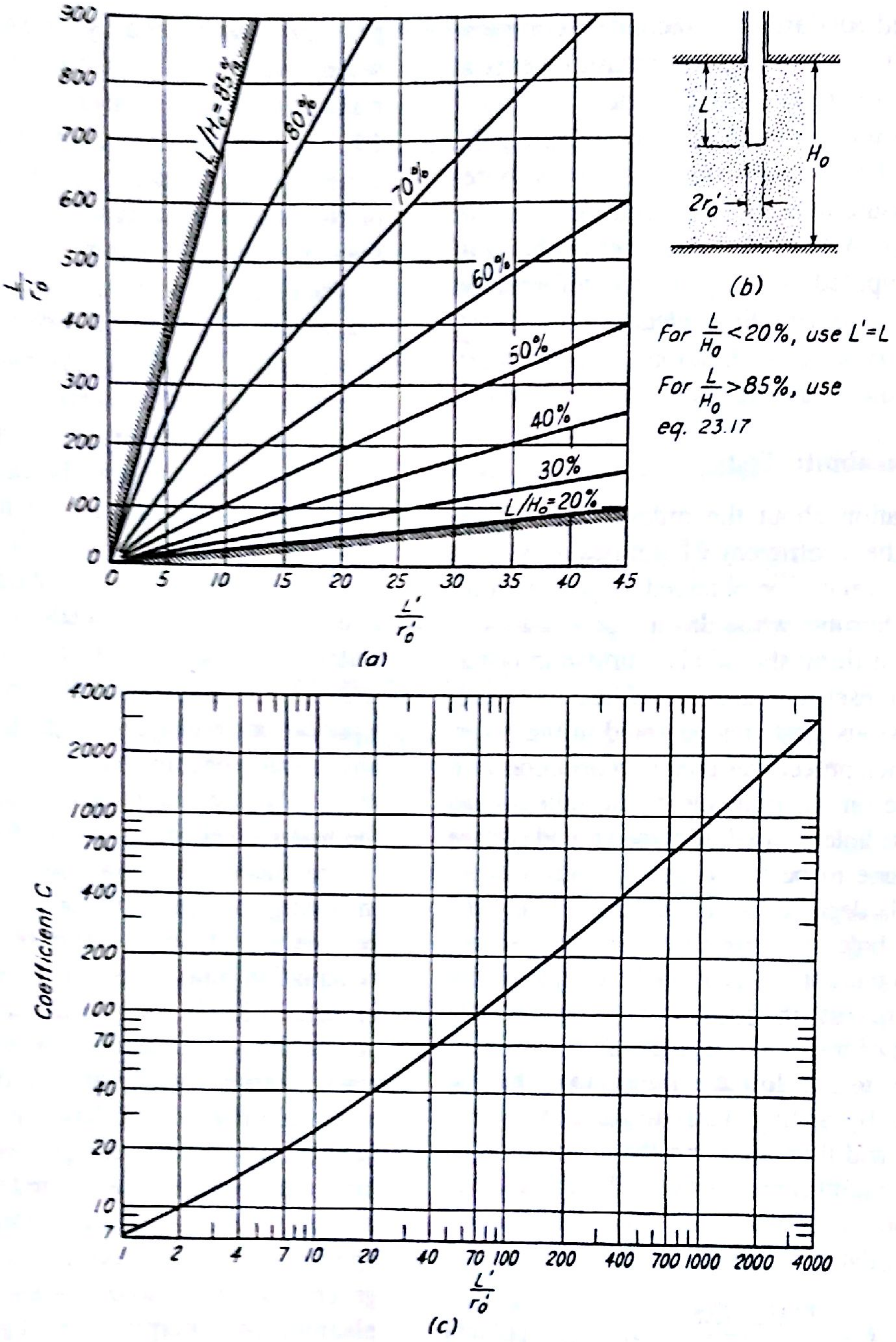
The results of such tests are little more than an indication of the order of magnitude of the coefficient of permeability. More reliable information is obtained from pumping tests on test wells.

The usual diameter of a pumping-test well is about 300 mm. Observation wells should be established in two lines, one in the direction of normal groundwater flow and the other perpendicular to it. At least two, and preferably four, observation wells should be established in each line. The observation wells should permit entrance of water over most of the thickness of the aquifer. The initial groundwater level should be observed in all the wells for a period long enough to establish the amount and nature of any fluctuations that normally occur at the site. Pumping should then be started at a constant rate of discharge and the water levels measured in the observation wells.

The theory of radial flow toward a pumping well, including the equations for calculating the coefficient of permeability from the results of measurements in the observation wells when equilibrium is reached, is outlined in Article 23. In most practical problems, however, the permeability is evaluated on the basis of measurements made before equilibrium in the observation wells is achieved (Theis 1935, Jacob 1950). The nonequilibrium methods also provide insight regarding the existence and influence of sources of groundwater infiltration, barriers to flow, and other characteristics of the aquifer. Their application has developed into a specialty practiced by groundwater hydrologists whose expertise is useful in the planning and interpretation of pumping tests.

The permeability of soft clays has been measured *in situ* by falling-head tests in piezometers that are driven in place or installed in boreholes. Field investigations by Tavenas et al. (1986) show that piezometers fitted with porous bronze elements and installed by driving into position are subject to clogging and cause remolding of the soil and a reduction in void ratio and permeability. Such *in situ* measurements may grossly underestimate horizontal permeability of soft clays. However, the permeability measured by falling head tests in soft clay deposits, using a nonclogging, self-boring permeameter (Tavenas et al. 1986) was found to be in good agreement with laboratory measurements on undisturbed specimens. Because *in situ* tests measure only horizontal permeability at the *in situ* void ratio, do not provide any information on the change in permeability with change in void ratio, and even when reliable are rather expensive and time consuming, laboratory permeability tests on undis-

Ref: "Soil Mechanics in Engineering Practice, 3rd ed" by Terzaghi, Peck, Mesri 1996



For $\frac{L}{H_o} < 20\%$, use $L' = L$

For $\frac{L}{H_o} > 85\%$, use eq. 23.17

Figure 14.13 Permeability test in open drill hole into pervious stratum. (*a*) Chart for determining ratio L'/r'_o for various penetrations L/H_o shown in (*b*). (*c*) Chart for determining coefficient *C* for use in Eq. 14.11 (after Zangar 1953).

turbed specimens are preferable for determining the permeability of uniform soft clay and silt deposits.

14.8 Permeability of Stratified Masses of Soil

Natural transported soils commonly consist of layers that have different permeability. To determine the average coefficient of permeability of such deposits, representative samples are secured from each of the layers and are tested. Once the values of *k* are known for the individual strata, the averages can be computed by using the following method. Let

$k_1, k_2 \cdots k_n$ = coefficients of permeability of the individual strfata

$H_1, H_2 \cdots H_n$ = thicknesses of corresponding strata

$H = H_1 + H_2 + \cdots H_n$ = total thickness

k_I = average coefficient of permeability parallel to bedding planes (usually horizontal)

k_{II} = average coefficient of permeability perpendicular to bedding planes (usually vertical)

Ref: "Soil Mechanics in Engineering Practice, 3rd ed" by Terzaghi, Peck, Mesri 1996

Intake Diversion Dam Modification
Lower Yellowstone Project, Montana
60% Geotechnical Design Documentation Report

Attachment 3

MATCHLINE: SEE SHEET CG104

H:\Intake 60% Design\MM04-C002.dgn

g6edxtjm

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK
DESCRIPTION
DATE
APPR.

MARK
DESCRIPTION
DATE
APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY:
TJM

DWN BY:
BMG

CKD BY:
TJM

SUBMITTED BY:
BNJ

FILE NAME:
MM04-C002.dgn

SIZE:
33.1X22

PLOT SCALE:
0.0833 ft / in.

DATE:
JAN. 2008

SOLICITATION NO.:
W9128F-0X-X-00XX

CONTRACT NO.:
W9128F-0X-C-00XX

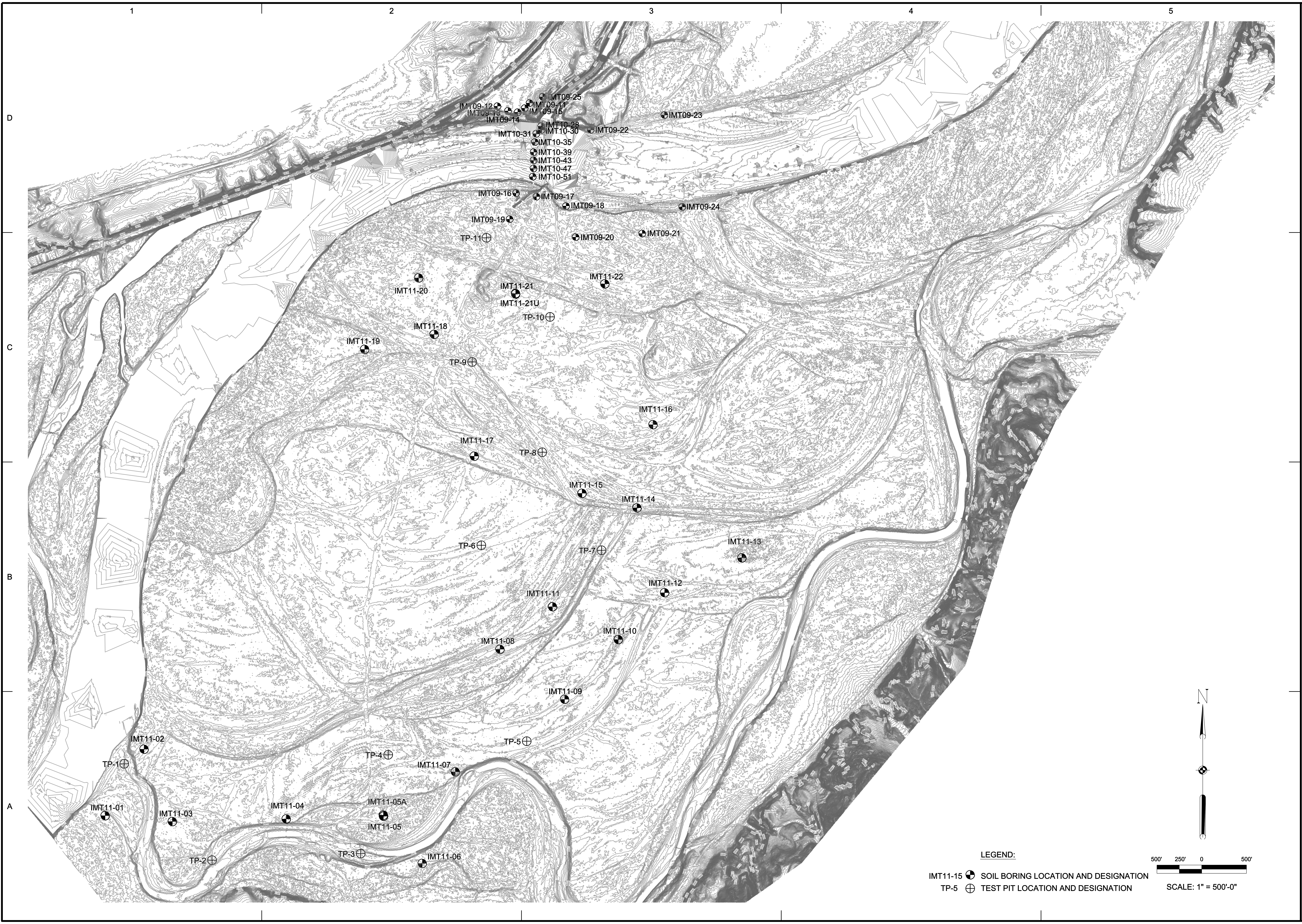
FILE NUMBER:
X

PLOT DATE:
8/26/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

QUARRY AND WASTE LOCATION PLAN

SHEET
IDENTIFICATION
NUMBER
C-002



LEGEND:

IMT11-15 ◉ SOIL BORING LOCATION AND DESIGNATION

TP-5 ⊕ TEST PIT LOCATION AND DESIGNATION

SCALE: 1" = 500'-0"

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY:
T.J.M.

DATE:
JAN. 2008

DWN BY:
T.J.M.

CKD BY:
B.N.J.

SOLICITATION NO.:
W9128F-0X-X-00XX

SUBMITTED BY:
B.N.J.

CONTRACT NO.:
W9128F-0X-C-00XX

FILE NAME:
MM04GI101.dgn

FILE NUMBER:

SIZE:
33.1X22

PLOT SCALE:
0.08 ' / in.

PLOT DATE:
3/1/2012

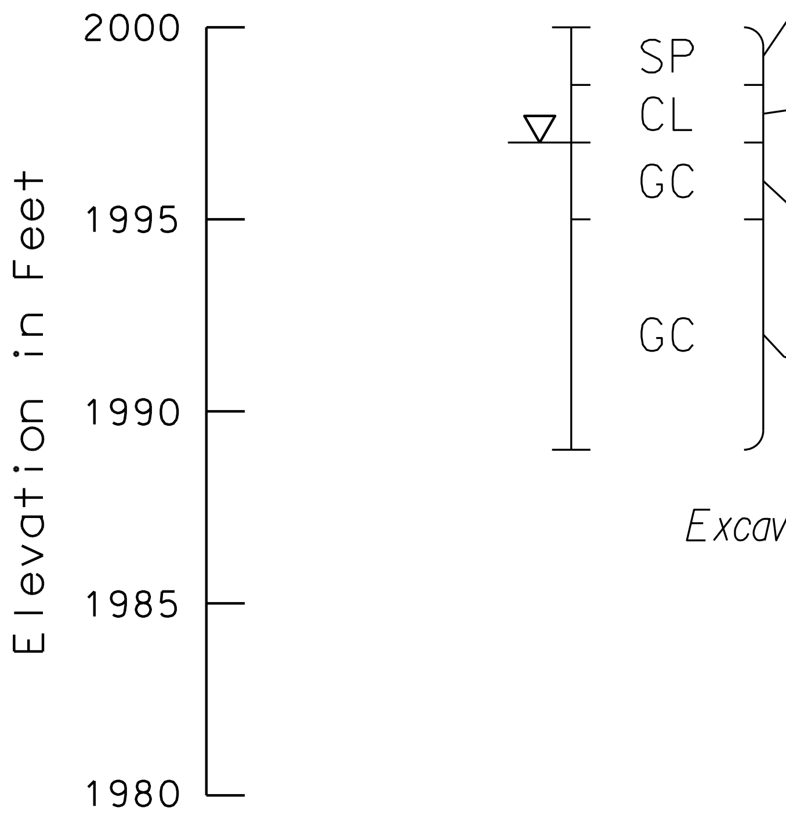
LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT
SOIL BORING AND TEST PIT LOCATION PLAN

SHEET
IDENTIFICATION
NUMBER
GI101

I:\dwgs\geotech\MM04GI101.dgn

g6edxcas

TP-1
October 24, 2011
Approx. El. 2000 ft



Field Log - SAND WITH COBBLES,tan,fine-grained sand,40% cobbles,silty clay lenses at 1 ft and possible organic lense at 1.5 ft

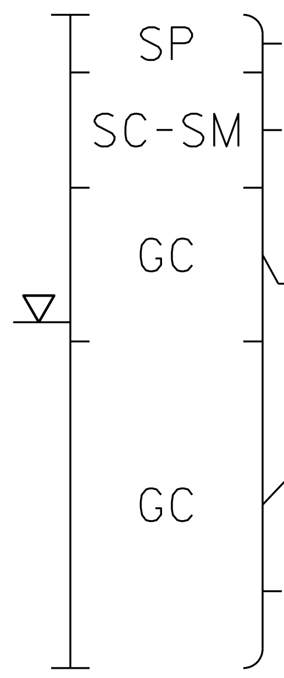
LEAN CLAY WITH SAND,grayish brown,wet,77% fines, 21% fine sand,1% medium sand,1% fine gravel

COBBLES with a matrix of CLAYEY GRAVEL WITH SAND, grayish brown,wet,matrix: 15% fines,24% fine sand,8% medium sand,5% coarse sand,36% fine gravel,12% coarse gravel

COBBLES with a matrix of CLAYEY SAND WITH GRAVEL, mottled gray and grayish brown,wet,matrix: 26% fines, 35% fine sand,9% medium sand,5% coarse sand, 22% fine gravel,3% coarse gravel

Excavation ended at ~11 ft due to slope failure

TP-2
October 24, 2011
Approx. Elev. 1998 ft



Field Log - SAND,tan,fine-grained sand

SILTY,CLAYEY SAND,olive brown,damp,28% fines, 70% fine sand,2% medium sand,minor sand lenses

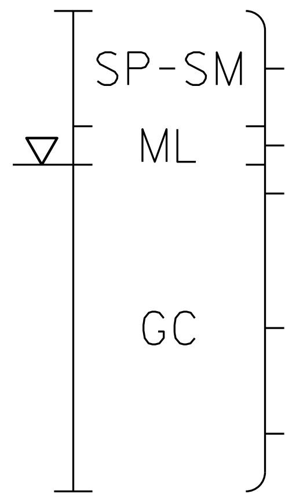
COBBLES with a matrix of CLAYEY GRAVEL WITH SAND,grayish brown,damp,matrix:fine gravel,fine sand,fines,some coarse gravel,some medium sand,trace coarse sand,cobbles dense enough to create stable side slopes

COBBLES with a matrix of SILTY,CLAYEY SAND, gray,wet,matrix: 22% fines,66% fine sand, 6% medium sand,2% coarse sand,4% fine gravel, side slopes are no longer stable

lignite

Excavation ended at ~17 ft due to slope failure

TP-3
October 24, 2011
Approx. Elev. 1996 ft



Field Log - SAND WITH SILT

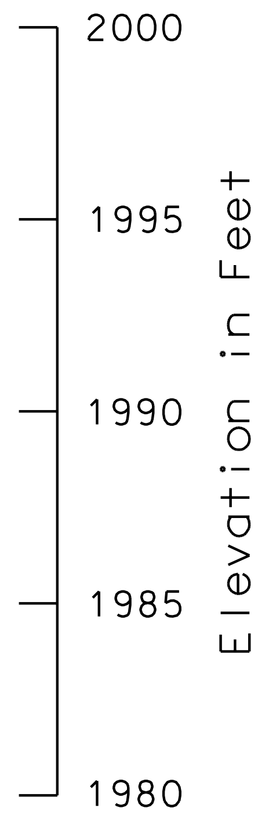
Field Log - SILTY CLAY ,gray,tree debris and roots,tree trunks 6"-8" in diameter from 1 to 4 feet

LEAN SILT layer

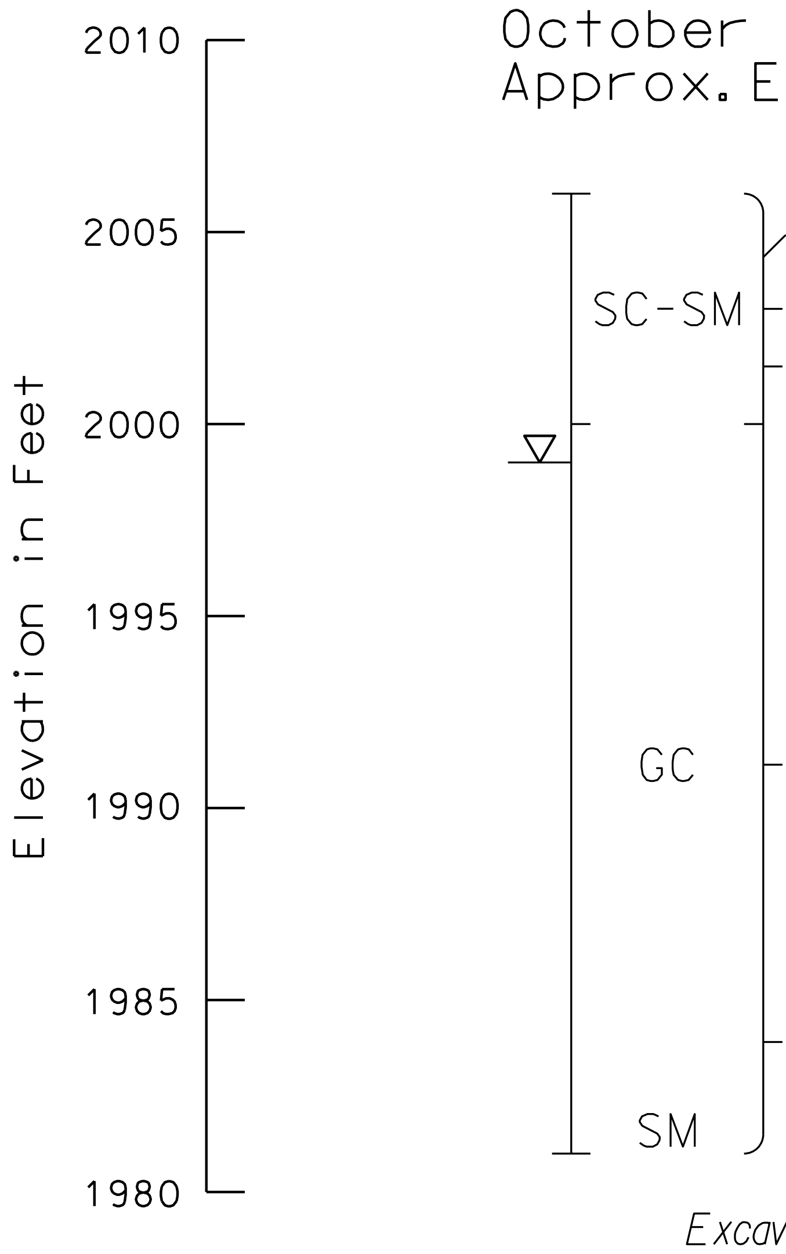
COBBLES with a matrix of SILTY,CLAYEY SAND,gray, matrix: fine sand,fines,some medium sand,trace fine gravel,trace coarse sand,tree debris

some boulders present

Excavation ended at ~12.5 ft due to slope failure



TP-4
October 24, 2011
Approx. Elev. 2006 ft



SILTY,CLAYEY SAND,olive brown,fine sand,fines trace medium sand,dry,with sand stringers

becomes gray and less cohesive

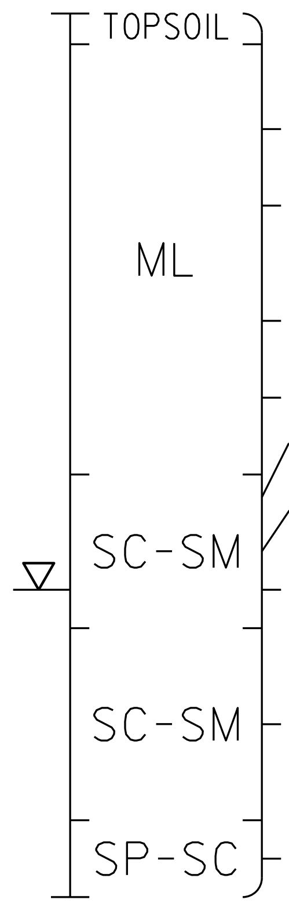
gravel layer

COBBLES with a matrix of SAND WITH CLAY AND GRAVEL,olive brown,moist to wet, matrix: 5% fines,40% fine sand,9% medium sand,5% coarse sand,27% fine gravel, 14% coarse gravel

cobble content increases with depth slopes become unstable as seepage increases

Excavation ended at ~25 ft due to slope failure

TP-5
October 24, 2011
Approx. Elev. 2004 ft



SANDY SILT,olive brown,dry,53% fines,47% fine sand scattered gravel

root horizons

coarse sand stringers,2"-3" thick cross bedding

unstable vertical walls

gravel layer

SILTY,CLAYEY SAND,olive brown,fine sand,fines trace medium sand,trace gravel

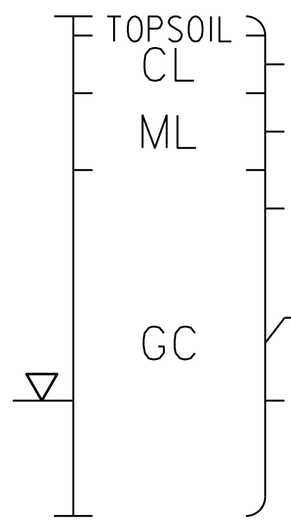
20% gravel layer

SILTY,CLAYEY SAND,gray,fine sand,fines,some medium sand,trace fine gravel,trace coarse sand

SAND WITH CLAY AND GRAVEL,olive brown, fine sand,fine gravel,some coarse gravel, some medium sand,trace coarse sand,trace fines

Excavation ended at ~23 ft due to slope failure
Ground water is seeping,not flowing

TP-6
October 24, 2011
Approx. Elev. 2000 ft



Field Log - LEAN CLAY,dry,discontinuous laminations

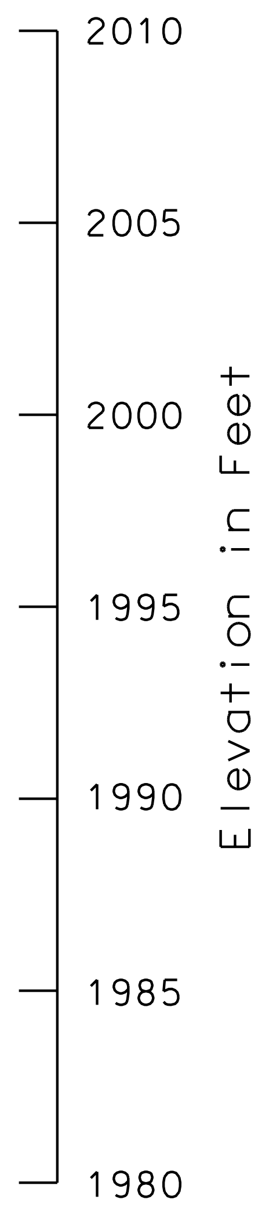
Field Log - LEAN SILT,dry,tan,~2" thick beds

LEAN SILT layer

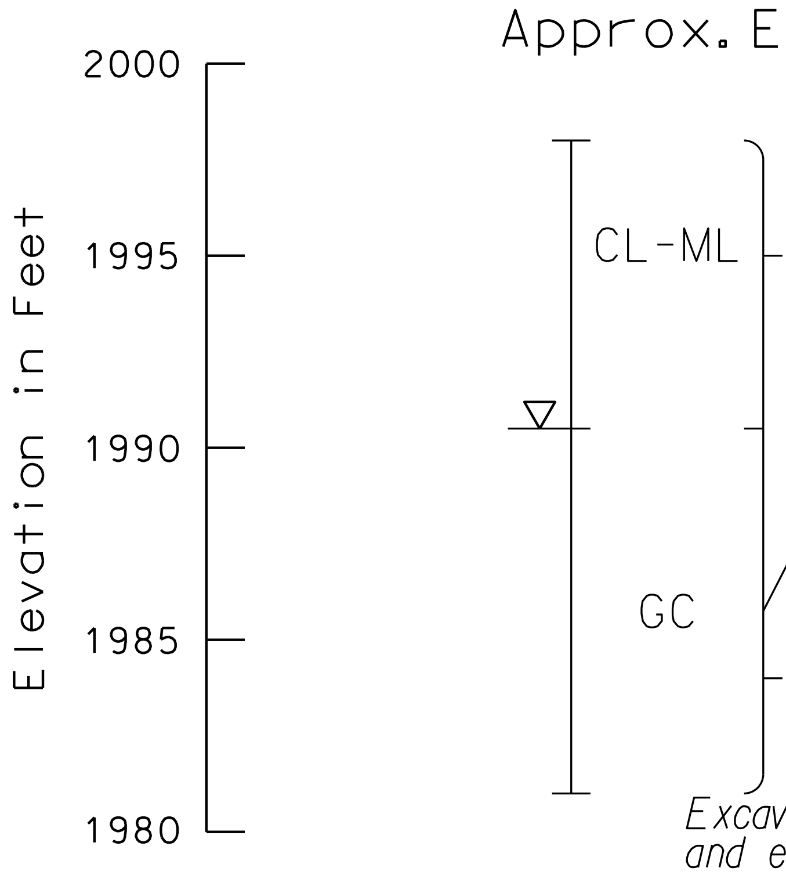
COBBLES with a matrix of SAND WITH CLAY AND GRAVEL, olive brown,matrix: fine sand,fine gravel,some coarse gravel, some medium sand,trace coarse sand,trace fines

finer-grained bed

Excavation ended at ~13 ft due to slope failure



TP-7
October 24, 2011
Approx. Elev. 1998 ft



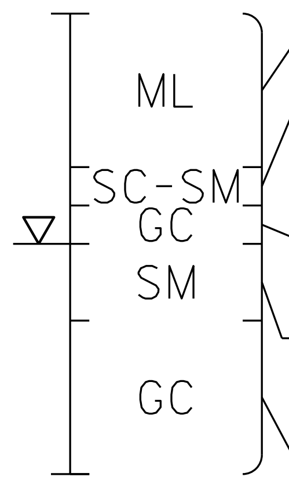
SILTY CLAY WITH SAND,olive brown,moist, 74% fines,19% fine sand,6% medium sand, 1% fine gravel

COBBLES with a matrix of CLAYEY GRAVEL WITH SAND,grayish brown,wet,matrix: fine gravel,fine sand,fines,some coarse gravel, some medium sand,trace coarse sand cobbles up to 5"

matrix content increases

Excavation ended at ~17 ft due to slope failure and excess ground water
Located in old channel,4' below grade of bank

TP-8
October 24, 2011
Approx. Elev. 1996 ft



Field Log - LEAN SILT,very fine-grained sand,fine laminations

SILTY,CLAYEY SAND,olive brown,fine sand,fines trace medium sand

COBBLES with a matrix of SAND WITH CLAY AND GRAVEL,olive brown,matrix: fine sand,fine gravel, some coarse gravel,some medium sand,trace coarse sand,trace fines

Field Log - SILTY SAND,fine-grained sand

COBBLES with a matrix of SAND WITH CLAY AND GRAVEL,olive brown,matrix: fine sand,fine gravel, some coarse gravel,some medium sand,trace coarse sand,trace fines

Excavation ended at ~12 ft due to slope failure and excess ground water
Located in channel depression

TEST PIT LEGEND

TP-1	Test pit number
Approx. El. 2000 ft	Elevation of top of test pit (approximate)
October 24, 2011	Date test pit completed
▽	Ground water level encountered during trenching
% fines	Percent of soil by dry weight passing the No.200 sieve

TEST PIT NOTES

1. The descriptive data at the right of the logs are the results of field and laboratory data. The terms "dry, moist, wet, etc." are field descriptions made by the inspector in the field at the time of drilling.

2. The logs furnished represent the types of soil encountered at their respective locations and the water level encountered at that time. The logs are considered representative of the soils which were encountered; however, the water level recorded can fluctuate appreciably at different seasons of the year or from year to year depending largely on climatic conditions. The contractor should satisfy himself as to the ground water conditions he will encounter at the time of construction.

3. Field logs, laboratory classification data, test results of trenches, are on file in the Omaha District Office and are available for examination by any interested contractor at said office.

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

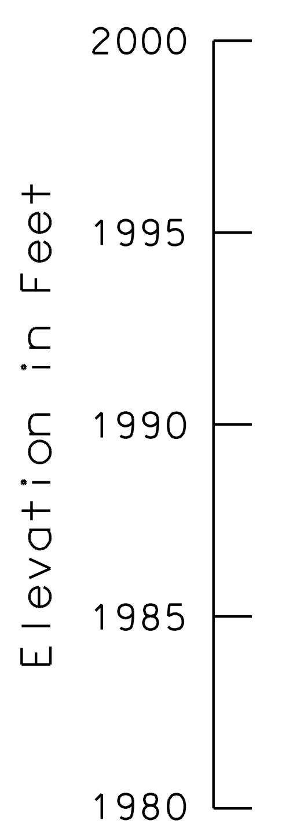
DESIGNED BY: C.A.F.
DATE: JAN. 2008
DWN BY: C.A.F.
CKD BY: T.J.M.
SOLICITATION NO.: W9128F-0X-X-00XX
SUBMITTED BY: B.N.J.
CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: MM04GI102.dgn
FILE NUMBER:
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
PLOT DATE: 3/7/2012

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

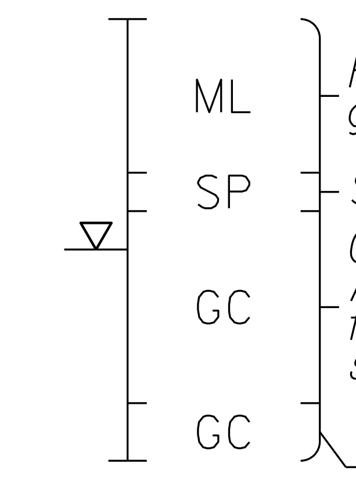
LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT

TEST PIT LOGS
TP-1 THROUGH TP-8

SHEET
IDENTIFICATION
NUMBER
GI102



TP-9
October 24, 2011
Approx. Elev. 1996 ft



Field Log - LEAN SILT, tan, very fine grained sand, roots

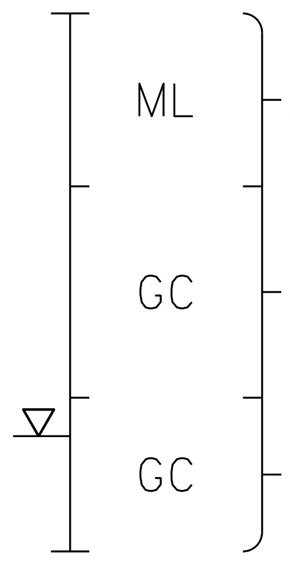
SAND, gray, damp, 4% fines, 96% fine sand

COBBLES with a matrix of SAND WITH CLAY AND GRAVEL, olive brown, wet, matrix: fine sand, fine gravel, some coarse gravel, some medium sand, trace coarse sand, trace fines

COBBLES with a matrix of SAND WITH SILTY CLAY AND GRAVEL, grayish brown, wet, matrix: 6% fines, 45% fine sand, 4% medium sand, 3% coarse sand, 21% fine gravel, 21% coarse gravel

Excavation ended at ~11.5 ft due to slope failure

TP-10
October 24, 2011
Approx. Elev. 2000 ft



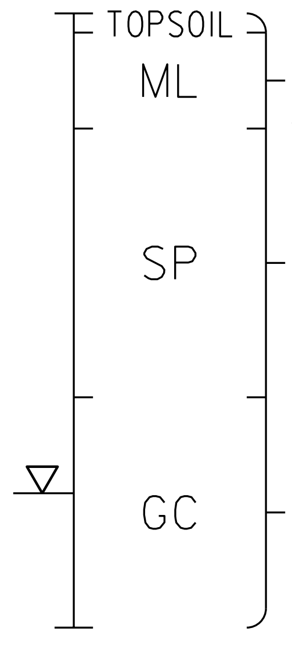
Field Log - LEAN SILT, dry, tan

COBBLES with a matrix of CLAYEY SAND WITH GRAVEL, mottled gray and grayish brown, moist, matrix: fine sand, fines, fine gravel, some medium sand, trace coarse sand, trace coarse gravel

COBBLES with a matrix of CLAYEY GRAVEL WITH SAND, grayish brown, wet, matrix: 12% fines, 24% fine sand, 6% medium sand, 6% coarse sand, 27% fine gravel, 25% coarse gravel

Excavation ended at ~14 ft due to slope failure

TP-11
October 24, 2011
Approx. Elev. 2000 ft

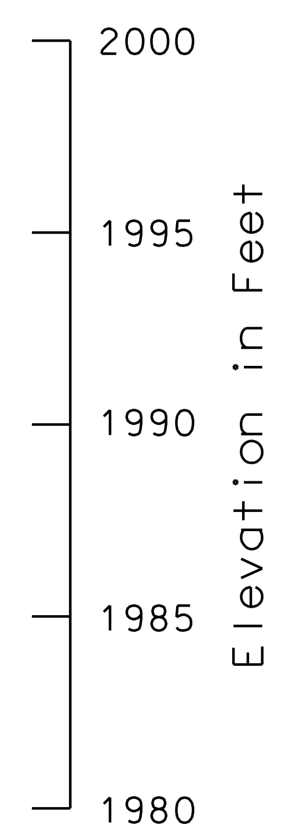


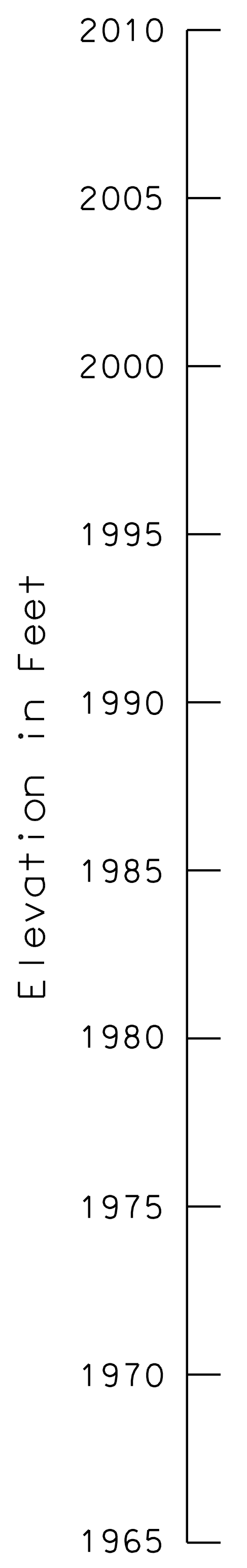
Field Log - LEAN SILT, dry, tan, planar laminations, some gravel

SAND, gray, fine sand, trace fines

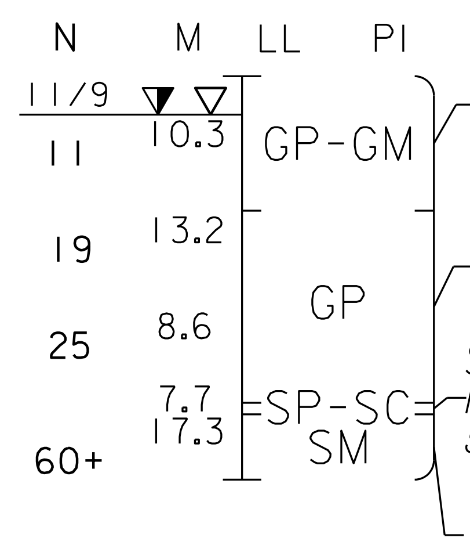
COBBLES with a matrix of CLAYEY SAND WITH GRAVEL, mottled gray and grayish brown, wet, matrix: fine sand, fines, fine gravel, some medium sand, trace coarse sand, trace coarse gravel

Excavation ended at ~16 ft due to slope failure
Side slopes will stand up to ~15 ft, low seepage starts losing ground below that depth





IMT11-01
Nov. 8, 2011
Approx. Elev. 2004 ft



GRAVEL WITH SILT AND SAND, grayish brown, medium dense, 8% fines, 18% fine sand, 10% medium sand, 9% coarse sand, 55% fine gravel, wet, occasional cobbles

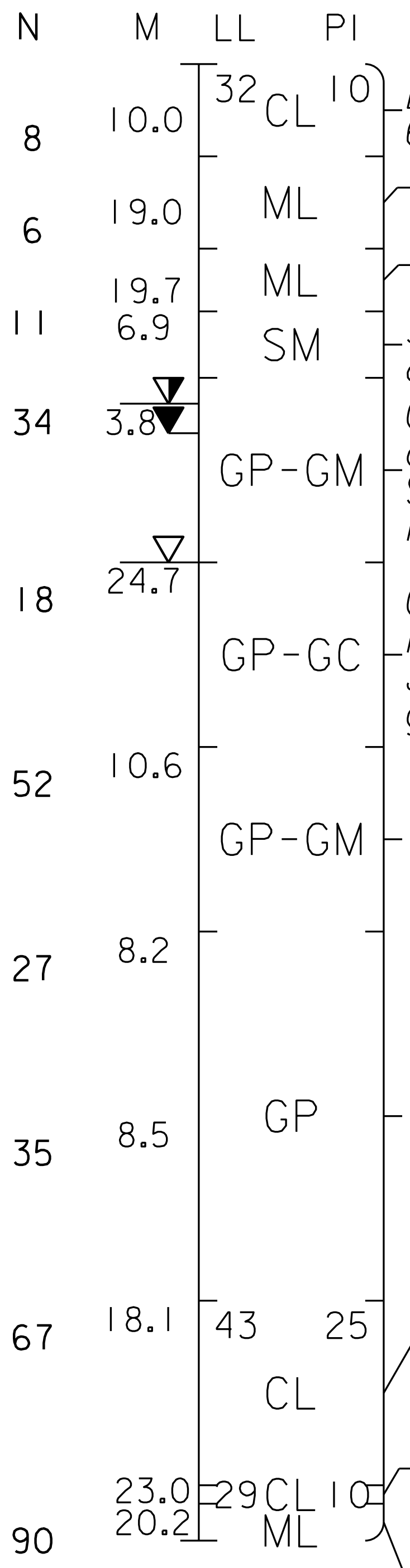
GRAVEL WITH SAND, yellowish brown, medium dense, 3% fines, 19% fine sand, 11% medium sand, 10% coarse sand, 42% fine gravel, 15% coarse gravel, wet, occasional cobbles

SAND WITH CLAY AND GRAVEL, grayish brown, medium dense, 11% fines, 24% fine sand, 14% medium sand, 19% coarse sand, 32% fine gravel, wet

SILTY SAND (WEATHERED SILTSTONE), light olive brown, 47% fines, 26% fine sand, 16% medium sand, 7% coarse sand, 4% fine gravel, wet, hard, decomposed, nonplastic

Auger refusal at 10.5 ft (Boulder?)

IMT11-02
Nov. 8, 2011
Approx. Elev. 2006 ft



LEAN CLAY, pale yellow, stiff, 93% fines, 6% fine sand, 1% medium sand, dry, rootlets

SILT, mottled olive brown and grayish brown, loose, 88% fines, 12% fine sand, moist, nonplastic

SILT WITH SAND, mottled dark gray and olive brown, medium dense, 80% fines, 20% fine sand, moist, nonplastic

SILTY SAND, gray, medium dense, 15% fines, 85% fine sand

GRAVEL WITH SILT AND SAND, grayish brown, dense, 6% fines, 26% fine sand, 11% medium sand, 9% coarse sand, 32% fine gravel, 16% coarse gravel, moist

GRAVEL WITH CLAY AND SAND, dark grayish brown, medium dense, 5% fines, 23% fine sand, 14% medium sand, 9% coarse sand, 19% fine gravel, 30% coarse gravel, moist

GRAVEL WITH SILT AND SAND, grayish brown, very dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, wet

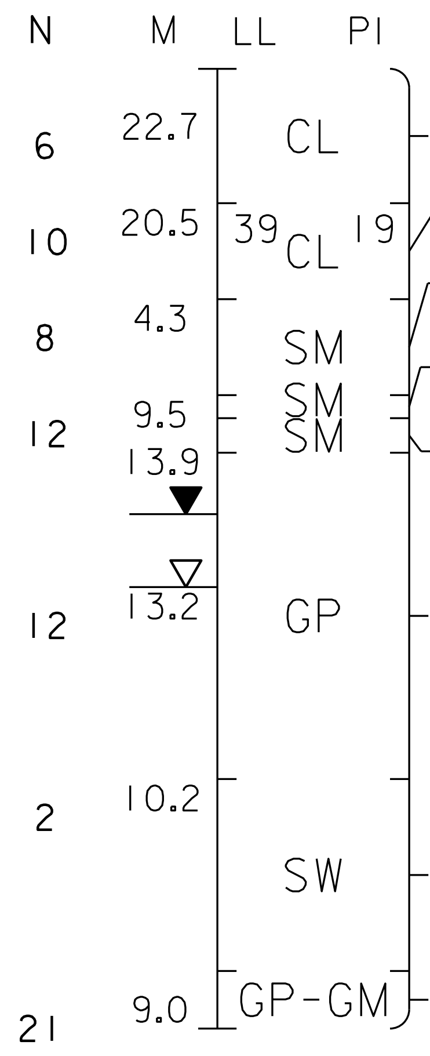
GRAVEL WITH SAND, yellowish brown, medium dense to dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, wet

LEAN CLAY (SHALE), mottled gray and dark gray, hard, 91% fines, 4% fine sand, 1% medium sand, 1% coarse sand, 3% fine gravel, dry, wet

LEAN CLAY (SANDY SHALE), pale brown, hard, 69% fines, 8% fine sand, 18% medium sand, 4% coarse sand, 1% fine gravel, fissile, wet

SANDY SILT (SILTSTONE), pale brown, hard, 57% fines, 42% fine sand, 1% medium sand, wet, unconsolidated, nonplastic

IMT11-03
Nov. 7, 2011
Approx. Elev. 2007 ft



LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry, rootlets

LEAN CLAY, mottled grayish brown and yellowish brown, stiff, 93% fines, 7% fine sand, dry, rootlets

SILTY SAND, gray, loose, fine sand, fines, dry

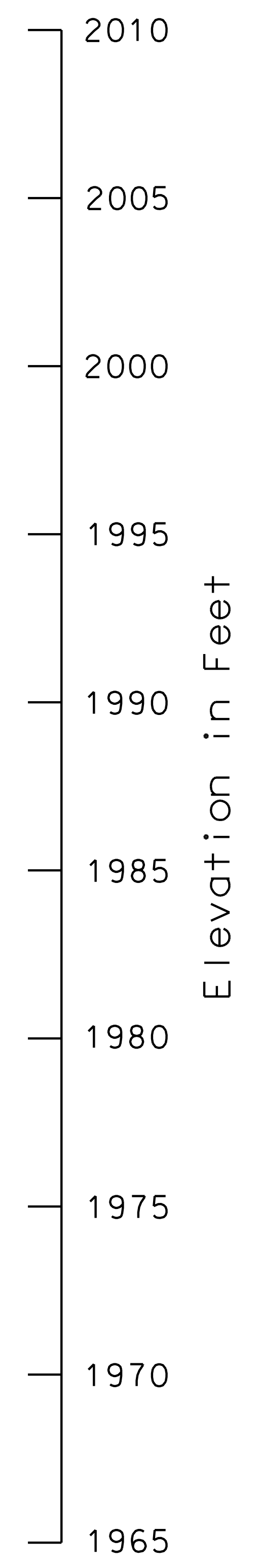
SILTY SAND WITH GRAVEL, grayish brown, medium dense, 16% fines, 44% fine sand, 5% medium sand, 4% coarse sand, 16% fine gravel, 16% coarse gravel, damp

SILTY SAND, gray, loose, fine sand, fines, damp

GRAVEL WITH SAND, yellowish brown, medium dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, damp to wet

SAND WITH GRAVEL, grayish brown, loose, 2% fines, 8% fine sand, 19% medium sand, 22% coarse sand, 49% fine gravel, wet

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, wet



BORING LEGEND

IMT11-01	Drill hole number
Approx. Elev. 2004 ft	Approximate elevation of top of boring
Nov. 8, 2011	Date boring completed
M	Natural moisture content in percent
LL	Liquid limit
PI	Plasticity index
N	Standard penetration blow count. Number of blows for a 140-pound weight dropping 30 inches, to drive a 2-inch outside diameter sampler, 1 foot.
SO_4	Sulfate ion content in soil, mg/L
% fines	Percent of soil by dry weight passing the No.200 sieve
D.D.	Dry density, p.c.f.
▽	Ground water level encountered during drilling
▼	Ground water level encountered at end of drilling
▼	Ground water level encountered after 24 hours
11/9	Hole cave-in depth and date

BORING NOTES

1. The descriptive data at the right of the logs are the results of field and laboratory data. The terms "dry, moist, wet, etc." are field descriptions made by the inspector in the field at the time of drilling. See "M" on the condensed log of borings for laboratory determination of moisture contents for the soil. Laboratory classifications are in accordance with the Unified Soils Classification System.

2. The logs furnished represent the types of soil encountered at their respective locations and the water level encountered at that time. The boring logs are considered representative of the soils which were encountered; however, the water level recorded can fluctuate appreciably at different seasons of the year or from year to year depending largely on climatic conditions. The contractor should satisfy himself as to the ground water conditions he will encounter at the time of construction.

3. Field logs, laboratory classification data, and test results of borings are on file on file in the Omaha District Office and are available for examination by any interested contractor at said office.

NOTE: SEE SHEET GI102 FOR TEST PIT LEGEND AND NOTES

I:\dwgs\geotech\MM04GI103.dgn
g6edxcas

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

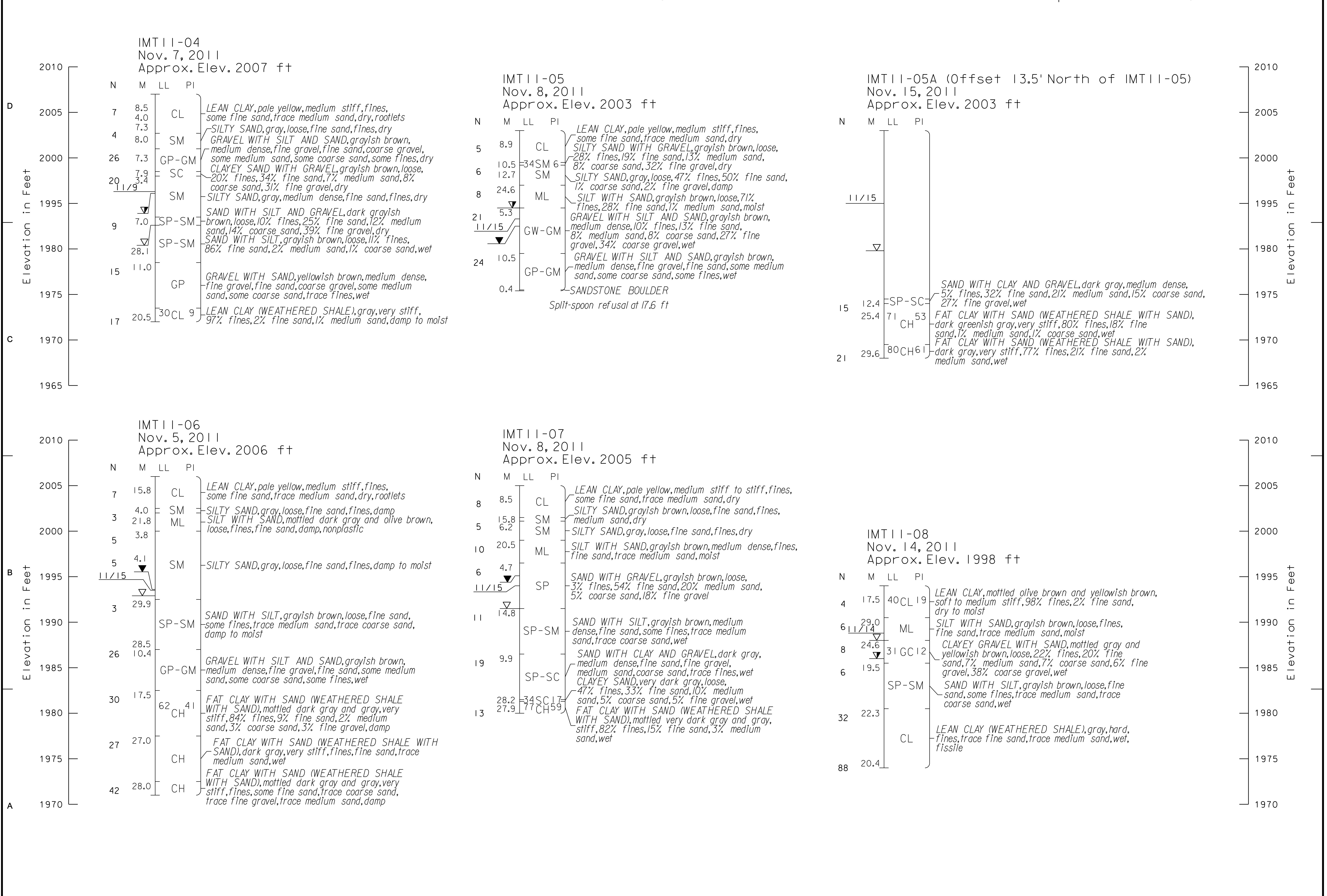
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.		DATE: JAN. 2008
DWN BY: C.A.F.	CKD BY: T.J.M.	SOLICITATION NO.: W9128F-0X-X-00XX
SUBMITTED BY: B.N.J.		CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: MM04GI103.dgn		FILE NUMBER:
SIZE: 33.1X22	PLOT SCALE: 0.0833 ft / in.	PLOT DATE: 3/7/2012

LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT

TEST PIT AND SOIL BORING LOGS
TEST PITS TP-9 THROUGH TP-11 &
DRILL HOLES IMT11-01 THROUGH IMT11-03

SHEET
IDENTIFICATION
NUMBER
GI103



IMT11-04
Nov. 7, 2011
Approx. Elev. 2007 ft

N	M	LL	PI		
7	8.5 4.0			CL	LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry, rootlets
4	7.3 8.0			SM	SILTY SAND, gray, loose, fine sand, fines, dry
26	7.3			GP-GM	GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, some fines, dry
20	7.9 3.4			SC	CLAYEY SAND WITH GRAVEL, grayish brown, loose, 20% fines, 34% fine sand, 7% medium sand, 8% coarse sand, 31% fine gravel, dry
				SM	SILTY SAND, gray, medium dense, fine sand, fines, dry
9	7.0			SP-SM	SAND WITH SILT AND GRAVEL, dark grayish brown, loose, 10% fines, 25% fine sand, 12% medium sand, 14% coarse sand, 39% fine gravel, dry
	28.1			SP-SM	SAND WITH SILT, grayish brown, loose, 11% fines, 86% fine sand, 2% medium sand, 1% coarse sand, wet
15	11.0			GP	GRAVEL WITH SAND, yellowish brown, medium dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, wet
17	20.5	30	9	CL	LEAN CLAY (WEATHERED SHALE), gray, very stiff, 97% fines, 2% fine sand, 1% medium sand, damp to moist

IMT11-05
Nov. 8, 2011
Approx. Elev. 2003 ft

N	M	LL	PI		
5	8.9			CL	LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry
6	10.5	34	6	SM	SILTY SAND WITH GRAVEL, grayish brown, loose, 28% fines, 19% fine sand, 13% medium sand, 8% coarse sand, 32% fine gravel, dry
	12.7			SM	SILTY SAND, gray, loose, 47% fines, 50% fine sand, 1% coarse sand, 2% fine gravel, damp
8	24.6			ML	SILT WITH SAND, grayish brown, loose, 71% fines, 28% fine sand, 1% medium sand, moist
21	5.3			GW-GM	GRAVEL WITH SILT AND SAND, grayish brown, medium dense, 10% fines, 13% fine sand, 8% medium sand, 8% coarse sand, 27% fine gravel, 34% coarse gravel, wet
24	10.5			GP-GM	GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, wet
	0.4				SANDSTONE BOULDER

Split-spoon refusal at 17.6 ft

IMT11-05A (Offset 13.5' North of IMT11-05)
Nov. 15, 2011
Approx. Elev. 2003 ft

N	M	LL	PI		
15	12.4			SP-SC	SAND WITH CLAY AND GRAVEL, dark gray, medium dense, 5% fines, 32% fine sand, 21% medium sand, 15% coarse sand, 27% fine gravel, wet
	25.4	71	53	CH	FAT CLAY WITH SAND (WEATHERED SHALE WITH SAND), dark greenish gray, very stiff, 80% fines, 18% fine sand, 1% medium sand, 1% coarse sand, wet
21	29.6	80	61	CH	FAT CLAY WITH SAND (WEATHERED SHALE WITH SAND), dark gray, very stiff, 77% fines, 21% fine sand, 2% medium sand, wet

IMT11-06
Nov. 5, 2011
Approx. Elev. 2006 ft

N	M	LL	PI		
7	15.8			CL	LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry, rootlets
	4.0			SM	SILTY SAND, gray, loose, fine sand, fines, damp
3	21.8			ML	SILT WITH SAND, mottled dark gray and olive brown, loose, fines, fine sand, damp, nonplastic
5 5	3.8 4.1			SM	SILTY SAND, gray, loose, fine sand, fines, damp to moist
3	29.9 28.5			SP-SM	SAND WITH SILT, grayish brown, loose, fine sand, some fines, trace medium sand, trace coarse sand, damp to moist
26	10.4			GP-GM	GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, wet
30	17.5	62	41	CH	FAT CLAY WITH SAND (WEATHERED SHALE WITH SAND), mottled dark gray and gray, very stiff, 84% fines, 9% fine sand, 2% medium sand, 3% coarse sand, 3% fine gravel, damp
27	27.0			CH	FAT CLAY WITH SAND (WEATHERED SHALE WITH SAND), dark gray, very stiff, fines, fine sand, trace medium sand, wet
42	28.0			CH	FAT CLAY WITH SAND (WEATHERED SHALE WITH SAND), mottled dark gray and gray, very stiff, fines, some fine sand, trace coarse sand, trace fine gravel, trace medium sand, damp

IMT11-07
Nov. 8, 2011
Approx. Elev. 2005 ft

N	M	LL	PI		
8	8.5			CL	LEAN CLAY, pale yellow, medium stiff to stiff, fines, some fine sand, trace medium sand, dry
	15.8			SM	SILTY SAND, grayish brown, loose, fine sand, fines, medium sand, dry
5	6.2			SM	SILTY SAND, gray, loose, fine sand, fines, dry
10	20.5			ML	SILT WITH SAND, grayish brown, medium dense, fines, fine sand, trace medium sand, moist
6	4.7			SP	SAND WITH GRAVEL, grayish brown, loose, 3% fines, 54% fine sand, 20% medium sand, 5% coarse sand, 18% fine gravel
11	14.8			SP-SM	SAND WITH SILT, grayish brown, medium dense, fine sand, some fines, trace medium sand, trace coarse sand, wet
19	9.9			SP-SC	SAND WITH CLAY AND GRAVEL, dark gray, medium dense, fine sand, fine gravel, medium sand, coarse sand, trace fines, wet
	28.2	34	17	SC	CLAYEY SAND, very dark gray, loose, 47% fines, 33% fine sand, 10% medium sand, 5% coarse sand, 5% fine gravel, wet
13	27.9	77	59	CH	FAT CLAY WITH SAND (WEATHERED SHALE WITH SAND), mottled very dark gray and gray, stiff, 82% fines, 15% fine sand, 3% medium sand, wet

IMT11-08
Nov. 14, 2011
Approx. Elev. 1998 ft

N	M	LL	PI		
4	17.5	40	19	CL	LEAN CLAY, mottled olive brown and yellowish brown, soft to medium stiff, 98% fines, 2% fine sand, dry to moist
6	29.0			ML	SILT WITH SAND, grayish brown, loose, fines, fine sand, trace medium sand, moist
8	24.6	31	12	GC	CLAYEY GRAVEL WITH SAND, mottled gray and yellowish brown, loose, 22% fines, 20% fine sand, 7% medium sand, 7% coarse sand, 6% fine gravel, 38% coarse gravel, wet
6	19.5			SP-SM	SAND WITH SILT, grayish brown, loose, fine sand, some fines, trace medium sand, trace coarse sand, wet
32 88	22.3 20.4			CL	LEAN CLAY (WEATHERED SHALE), gray, hard, fines, trace fine sand, trace medium sand, wet, fissile

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

I:\dwgs\geotech\MM04GI104.dgn

g6edxcas

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

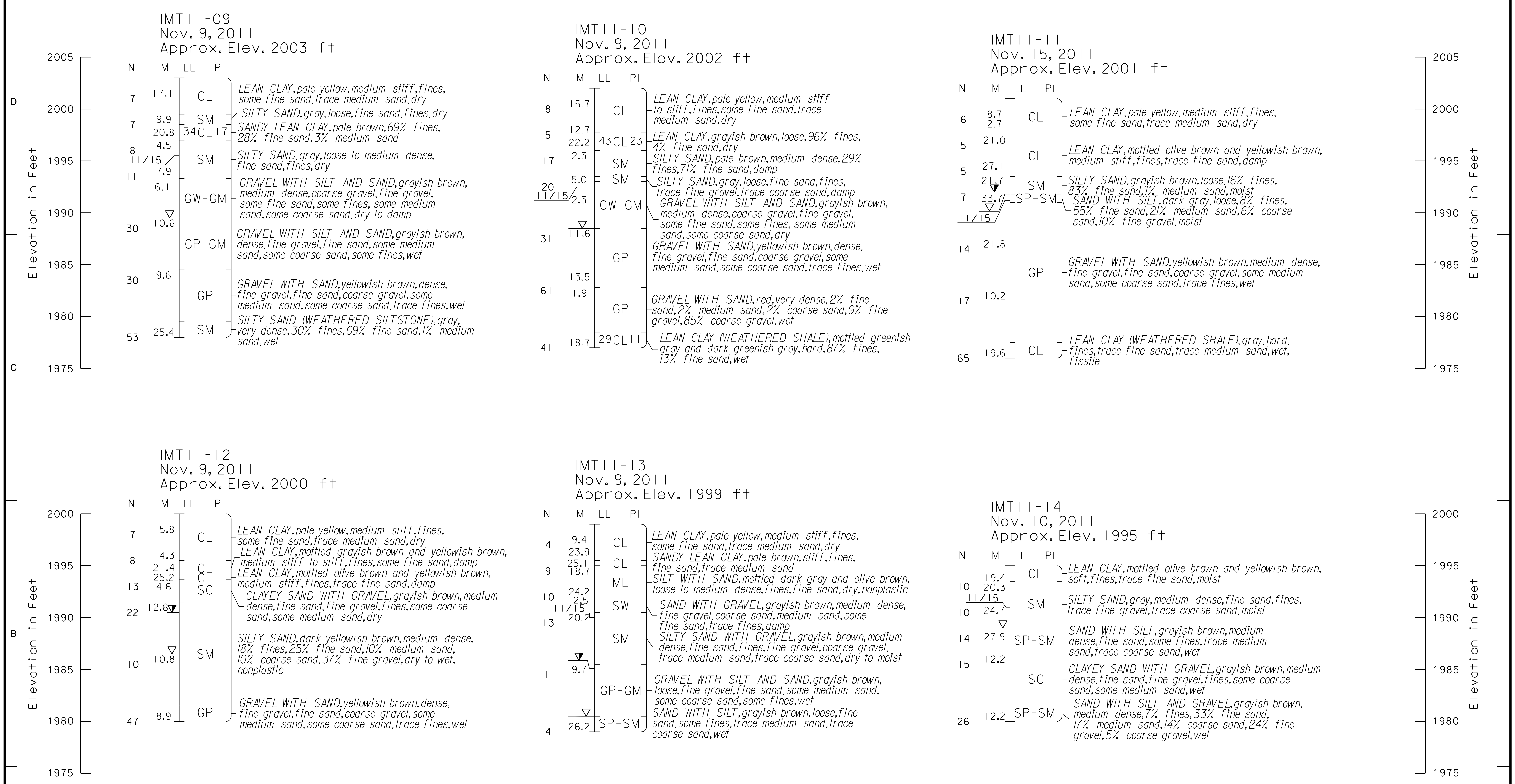
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI104.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 3/6/2012

LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT

SOIL BORING LOGS
DRILL HOLES IMT11-04 THROUGH IMT11-08

SHEET
IDENTIFICATION
NUMBER
GI104



IMT11-09
Nov. 9, 2011
Approx. Elev. 2003 ft

N	M	LL		PI	
7	17.1		CL		LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry
7	9.9		SM		SILTY SAND, gray, loose, fine sand, fines, dry
	20.8	34	CL	17	SANDY LEAN CLAY, pale brown, 69% fines, 28% fine sand, 3% medium sand
8 11/15	4.5 7.9		SM		SILTY SAND, gray, loose to medium dense, fine sand, fines, dry
11	6.1		GW-GM		GRAVEL WITH SILT AND SAND, grayish brown, medium dense, coarse gravel, fine gravel, some fine sand, some fines, some medium sand, some coarse sand, dry to damp
30	▽ 10.6		GP-GM		GRAVEL WITH SILT AND SAND, grayish brown, dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, wet
30	9.6		GP		GRAVEL WITH SAND, yellowish brown, dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, wet
53	25.4		SM		SILTY SAND (WEATHERED SILTSTONE), gray, very dense, 30% fines, 69% fine sand, 1% medium sand, wet

IMT11-10
Nov. 9, 2011
Approx. Elev. 2002 ft

N	M	LL		PI	
8	15.7 12.7		CL		LEAN CLAY, pale yellow, medium stiff to stiff, fines, some fine sand, trace medium sand, dry
5	22.2	43	CL	23	LEAN CLAY, grayish brown, loose, 96% fines, 4% fine sand, dry
17	2.3		SM		SILTY SAND, pale brown, medium dense, 29% fines, 71% fine sand, damp
20	5.0		SM		SILTY SAND, gray, loose, fine sand, fines, trace fine gravel, trace coarse sand, damp
11/15	2.3		GW-GM		GRAVEL WITH SILT AND SAND, grayish brown, medium dense, coarse gravel, fine gravel, some fine sand, some fines, some medium sand, some coarse sand, dry
31	▽ 11.6 13.5		GP		GRAVEL WITH SAND, yellowish brown, dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, wet
61	1.9		GP		GRAVEL WITH SAND, red, very dense, 2% fine sand, 2% medium sand, 2% coarse sand, 9% fine gravel, 85% coarse gravel, wet
41	18.7	29	CL	11	LEAN CLAY (WEATHERED SHALE), mottled greenish gray and dark greenish gray, hard, 87% fines, 13% fine sand, wet

IMT11-11
Nov. 15, 2011
Approx. Elev. 2001 ft

N	M	LL		PI	
6	8.7 2.7		CL		LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry
5 5	21.0 27.1		CL		LEAN CLAY, mottled olive brown and yellowish brown, medium stiff, fines, trace fine sand, damp
	21.7 ▼		SM		SILTY SAND, grayish brown, loose, 16% fines, 83% fine sand, 1% medium sand, moist
7 11/15	33.7 ▽		SP-SM		SAND WITH SILT, dark gray, loose, 8% fines, 55% fine sand, 21% medium sand, 6% coarse sand, 10% fine gravel, moist
14 17	21.8 10.2		GP		GRAVEL WITH SAND, yellowish brown, medium dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, wet
65	19.6		CL		LEAN CLAY (WEATHERED SHALE), gray, hard, fines, trace fine sand, trace medium sand, wet, fissile

IMT11-12
Nov. 9, 2011
Approx. Elev. 2000 ft

N	M	LL		PI	
7	15.8 14.3		CL		LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry
8	21.4		CL		LEAN CLAY, mottled grayish brown and yellowish brown, medium stiff to stiff, fines, some fine sand, damp
	25.2		CL		LEAN CLAY, mottled olive brown and yellowish brown, medium stiff, fines, trace fine sand, damp
13	4.6		SC		CLAYEY SAND WITH GRAVEL, grayish brown, medium dense, fine sand, fine gravel, fines, some coarse sand, some medium sand, dry
22 10	12.6 ▼ ▽ 10.8		SM		SILTY SAND, dark yellowish brown, medium dense, 18% fines, 25% fine sand, 10% medium sand, 10% coarse sand, 37% fine gravel, dry to wet, nonplastic
47	8.9		GP		GRAVEL WITH SAND, yellowish brown, dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, wet

IMT11-13
Nov. 9, 2011
Approx. Elev. 1999 ft

N	M	LL		PI	
4	9.4 23.9		CL		LEAN CLAY, pale yellow, medium stiff, fines, some fine sand, trace medium sand, dry
	25.1		CL		SANDY LEAN CLAY, pale brown, stiff, fines, fine sand, trace medium sand
9 10	18.7 24.2		ML		SILT WITH SAND, mottled dark gray and olive brown, loose to medium dense, fines, fine sand, dry, nonplastic
11/15	2.5		SW		SAND WITH GRAVEL, grayish brown, medium dense, fine gravel, coarse sand, medium sand, some fine sand, trace fines, damp
13	20.2 ▼		SM		SILTY SAND WITH GRAVEL, grayish brown, medium dense, fine sand, fines, fine gravel, coarse gravel, trace medium sand, trace coarse sand, dry to moist
1	9.7 ▽		GP-GM		GRAVEL WITH SILT AND SAND, grayish brown, loose, fine gravel, fine sand, some medium sand, some coarse sand, some fines, wet
4	26.2		SP-SM		SAND WITH SILT, grayish brown, loose, fine sand, some fines, trace medium sand, trace coarse sand, wet

IMT11-14
Nov. 10, 2011
Approx. Elev. 1995 ft

N	M	LL		PI	
	19.4		CL		LEAN CLAY, mottled olive brown and yellowish brown, soft, fines, trace fine sand, moist
10 11/15 10	20.3 24.7 ▽		SM		SILTY SAND, gray, medium dense, fine sand, fines, trace fine gravel, trace coarse sand, moist
14	27.9		SP-SM		SAND WITH SILT, grayish brown, medium dense, fine sand, some fines, trace medium sand, trace coarse sand, wet
15	12.2		SC		CLAYEY SAND WITH GRAVEL, grayish brown, medium dense, fine sand, fine gravel, fines, some coarse sand, some medium sand, wet
26	12.2		SP-SM		SAND WITH SILT AND GRAVEL, grayish brown, medium dense, 7% fines, 33% fine sand, 17% medium sand, 14% coarse sand, 24% fine gravel, 5% coarse gravel, wet

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI105.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 3/6/2012

LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT

SOIL BORING LOGS
IMT11-09 THROUGH IMT11-14

SHEET
IDENTIFICATION
NUMBER
GI105

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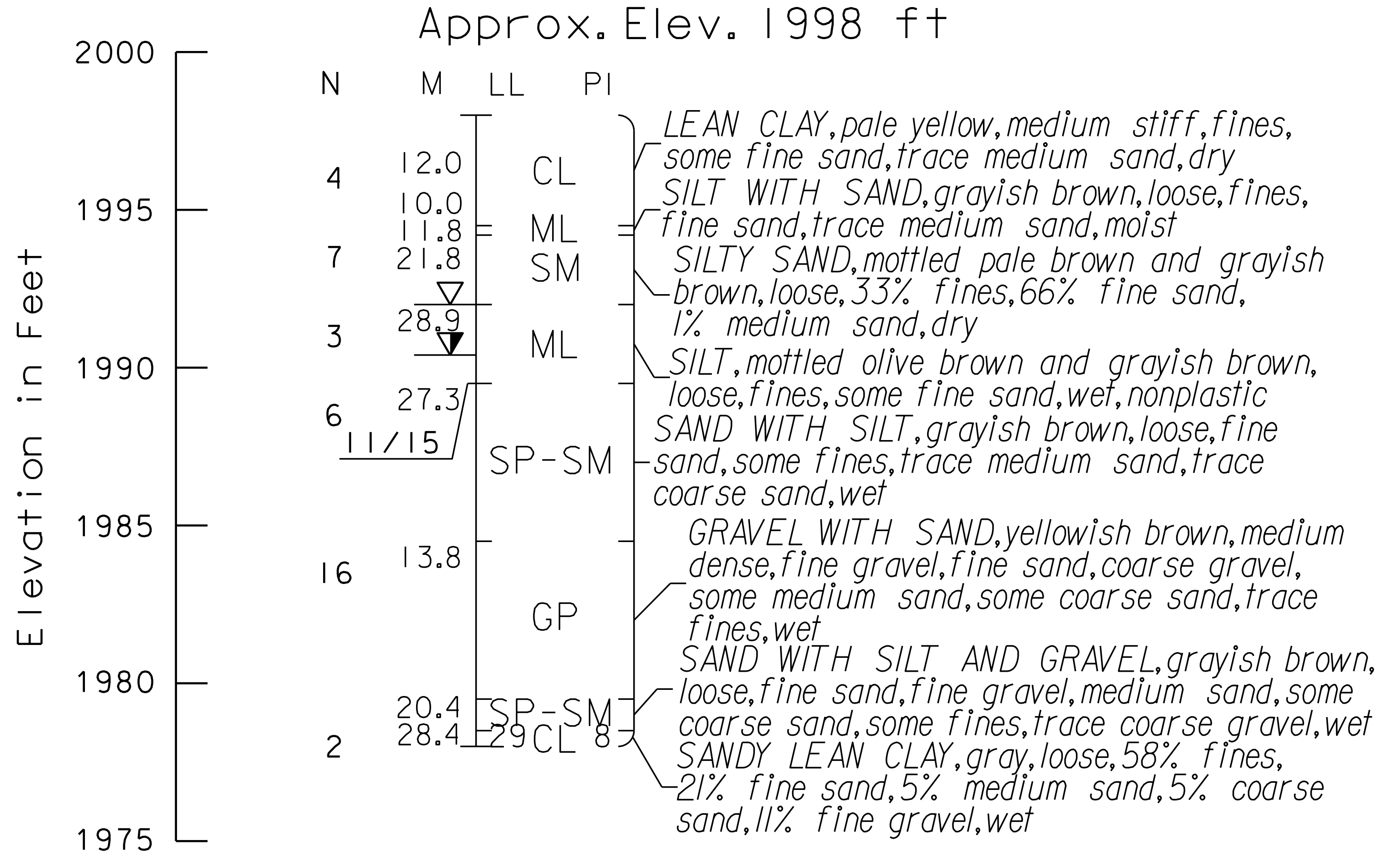
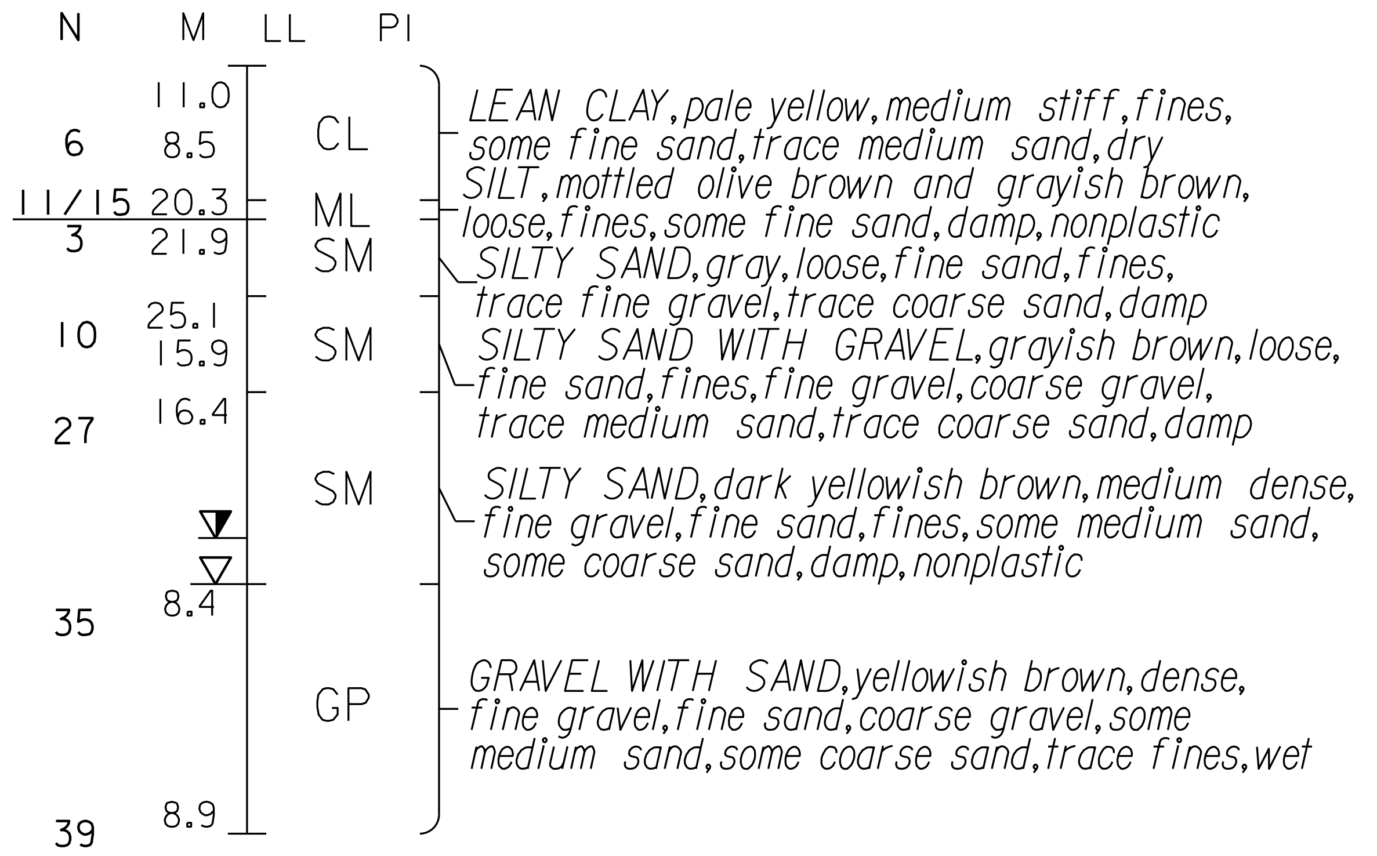
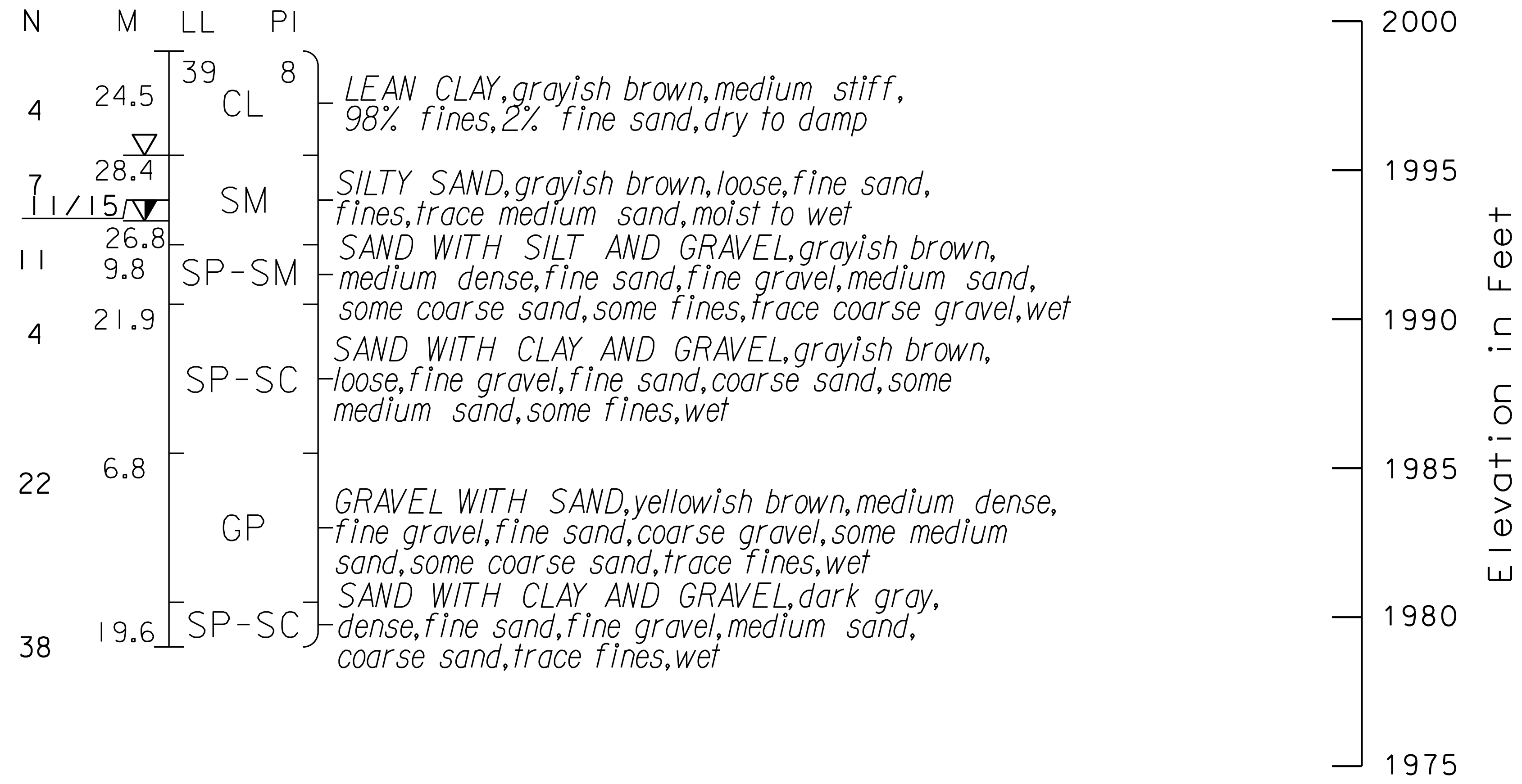
IMT11-15
Nov. 10, 2011
Approx. Elev. 1998 ft



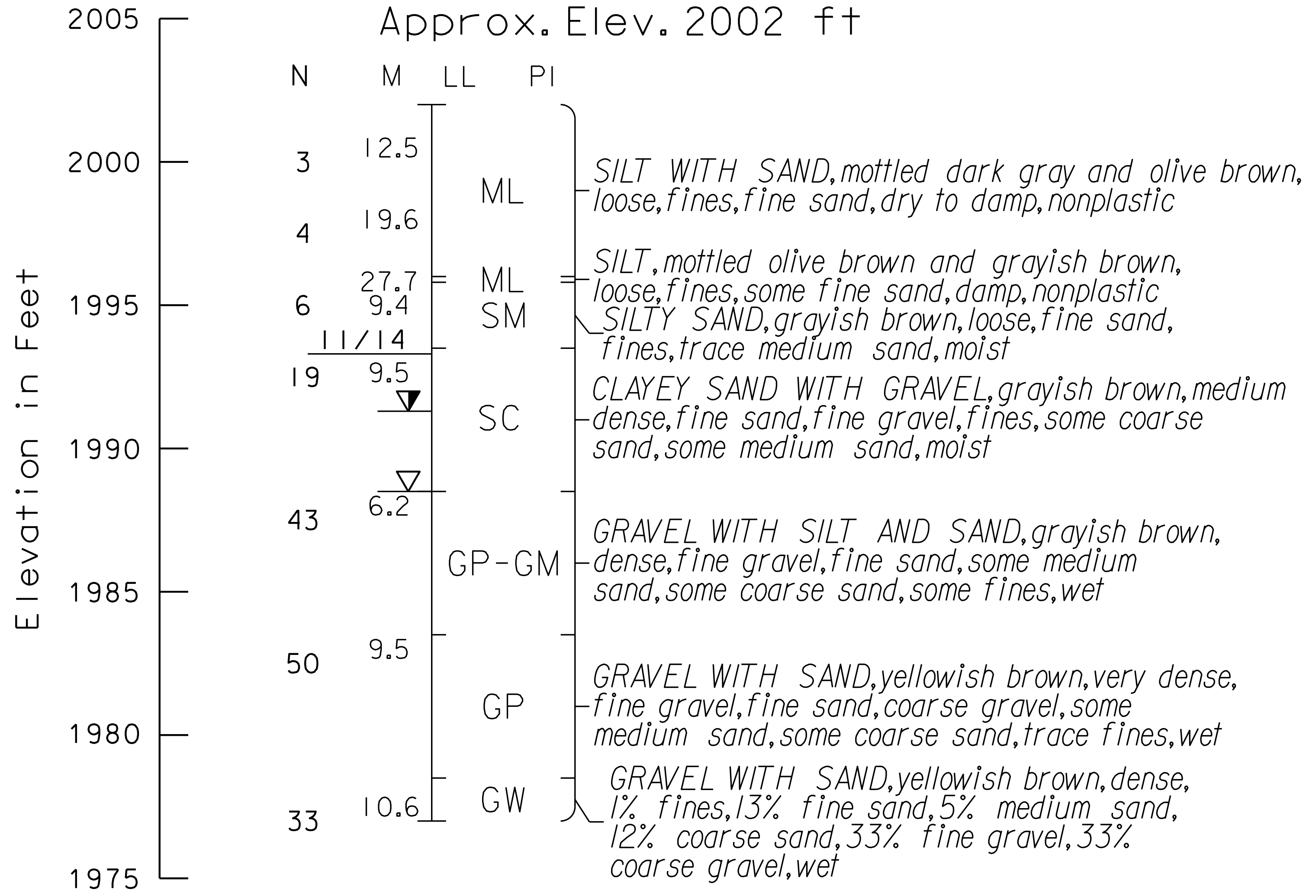
IMT11-16
Nov. 10, 2011
Approx. Elev. 1999 ft



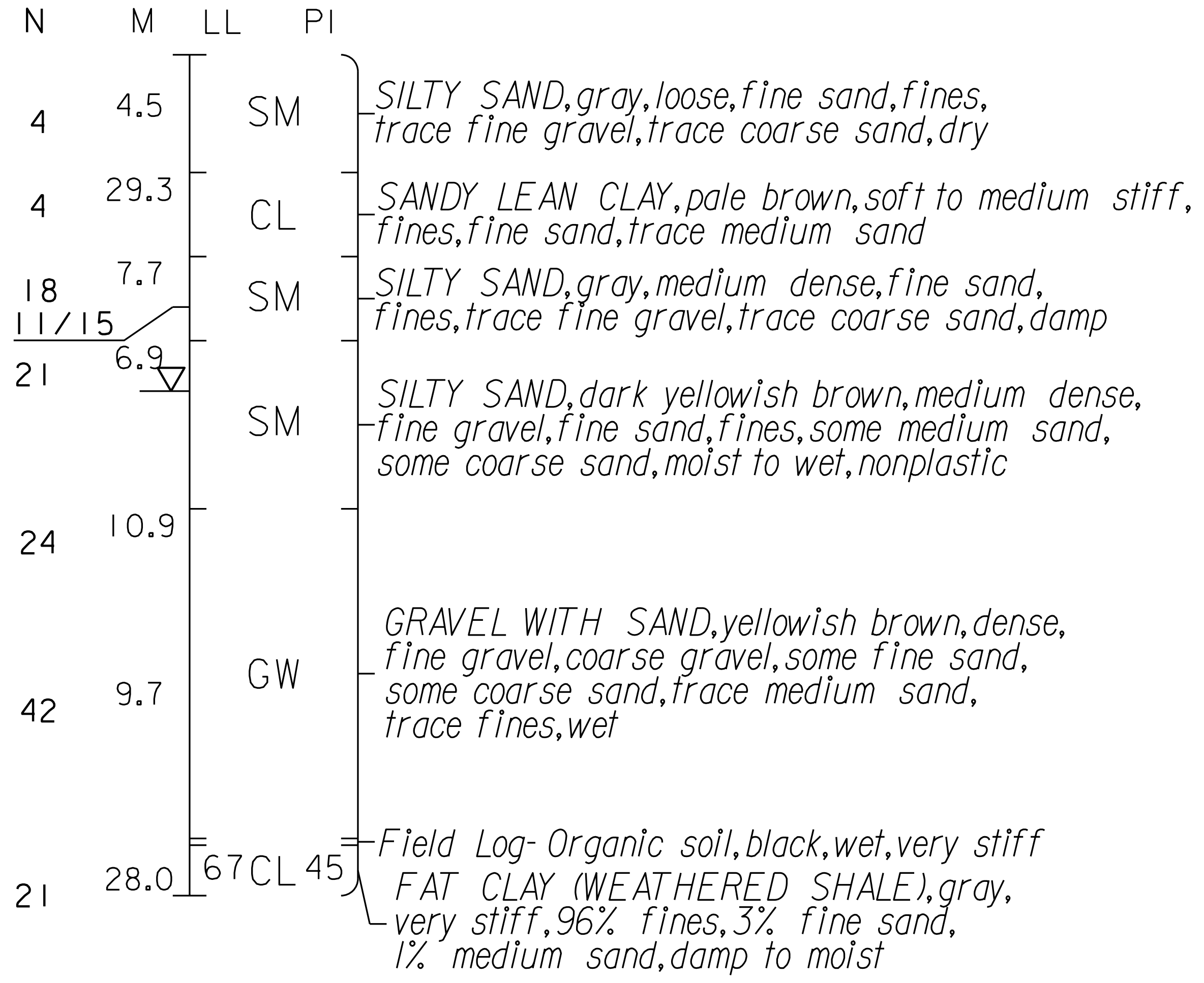
IMT11-17
Nov. 14, 2011
Approx. Elev. 1999 ft



IMT11-18
Nov. 14, 2011
Approx. Elev. 2002 ft



IMT11-19
Nov. 14, 2011
Approx. Elev. 2001 ft



IMT11-20
Nov. 11, 2011
Approx. Elev. 2001 ft

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

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US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

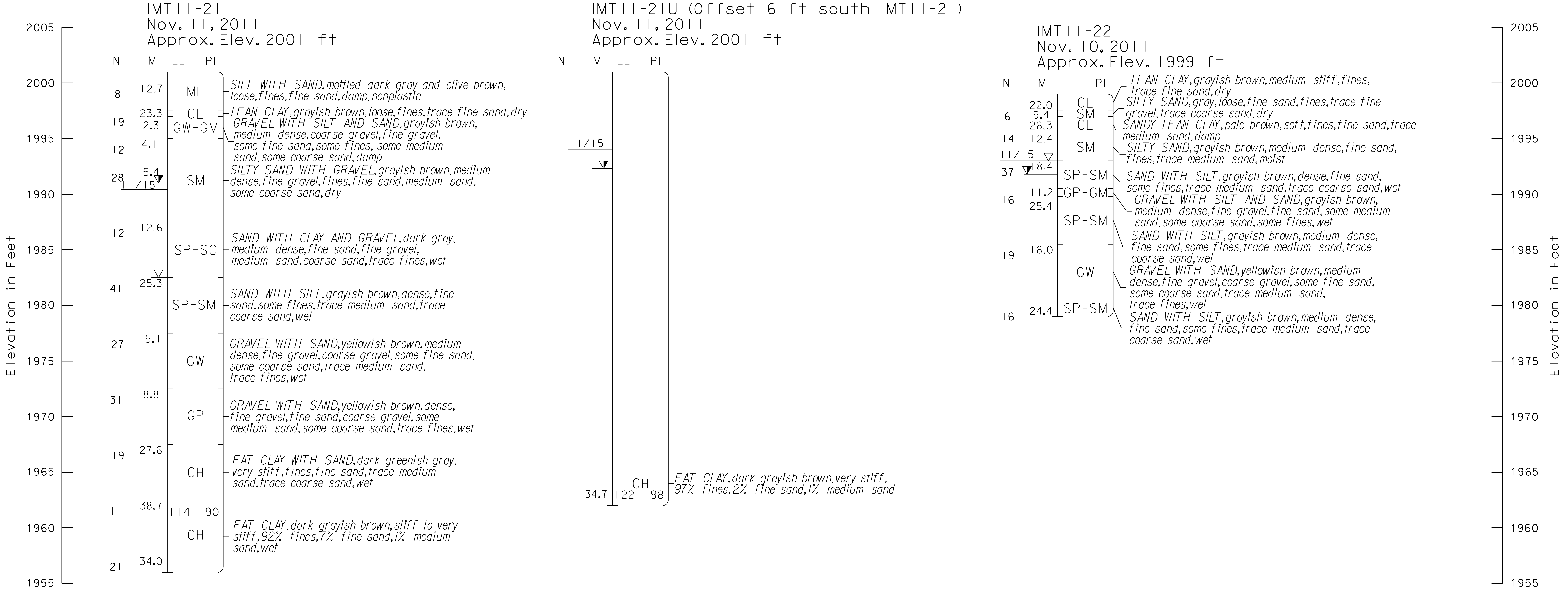
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI106.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 3/6/2012

LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT

SOIL BORING LOGS
IMT11-15 THROUGH IMT11-20

SHEET
IDENTIFICATION
NUMBER
GI106



IMT11-21
Nov. 11, 2011
Approx. Elev. 2001 ft

SILT WITH SAND, mottled dark gray and olive brown, loose, fines, fine sand, damp, nonplastic

LEAN CLAY, grayish brown, loose, fines, trace fine sand, dry

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, coarse gravel, fine gravel, some fine sand, some fines, some medium sand, some coarse sand, damp

SILTY SAND WITH GRAVEL, grayish brown, medium dense, fine gravel, fines, fine sand, medium sand, some coarse sand, dry

SAND WITH CLAY AND GRAVEL, dark gray, medium dense, fine sand, fine gravel, medium sand, coarse sand, trace fines, wet

SAND WITH SILT, grayish brown, dense, fine sand, some fines, trace medium sand, trace coarse sand, wet

GRAVEL WITH SAND, yellowish brown, medium dense, fine gravel, coarse gravel, some fine sand, some coarse sand, trace medium sand, trace fines, wet

GRAVEL WITH SAND, yellowish brown, dense, fine gravel, fine sand, coarse gravel, some medium sand, some coarse sand, trace fines, wet

FAT CLAY WITH SAND, dark greenish gray, very stiff, fines, fine sand, trace medium sand, trace coarse sand, wet

FAT CLAY, dark grayish brown, stiff to very stiff, 92% fines, 7% fine sand, 1% medium sand, wet

IMT11-21U (Offset 6 ft south IMT11-21)
Nov. 11, 2011
Approx. Elev. 2001 ft

FAT CLAY, dark grayish brown, very stiff, 97% fines, 2% fine sand, 1% medium sand

IMT11-22
Nov. 10, 2011
Approx. Elev. 1999 ft

LEAN CLAY, grayish brown, medium stiff, fines, trace fine sand, dry

SILTY SAND, gray, loose, fine sand, fines, trace fine gravel, trace coarse sand, dry

SANDY LEAN CLAY, pale brown, soft, fines, fine sand, trace medium sand, damp

SILTY SAND, grayish brown, medium dense, fine sand, fines, trace medium sand, moist

SAND WITH SILT, grayish brown, dense, fine sand, some fines, trace medium sand, trace coarse sand, wet

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, wet

SAND WITH SILT, grayish brown, medium dense, fine sand, some fines, trace medium sand, trace coarse sand, wet

GRAVEL WITH SAND, yellowish brown, medium dense, fine gravel, coarse gravel, some fine sand, some coarse sand, trace medium sand, trace fines, wet

SAND WITH SILT, grayish brown, medium dense, fine sand, some fines, trace medium sand, trace coarse sand, wet

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI107.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 3/6/2012

LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT

SOIL BORING LOGS
DRILL HOLES IMT11-21, IMT11-21U & IMT11-22

SHEET
IDENTIFICATION
NUMBER
GI107

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g6edxcas

IMT10-28
Nov. 18, 2010
Approx. Elev. 1985 ft

Field Log - River Substrate
SANDY LEAN CLAY, mottled gray, yellowish brown & grayish brown, soft, 68% fines, 20% fine sand, 8% medium sand, 3% coarse sand, 1% fine gravel, wet
FAT CLAY WITH SAND, mottled gray and grayish brown, very stiff, 78% fines, 21% fine sand, 2% medium sand, wet, trace organics
FAT CLAY, gray, stiff to very stiff, interbedded with sandy clay, moist
pH=8.7, resistivity=490 ohms-cm, $SO_4 < 0.1\%$
Field Log - coal seam, less than 0.1' thick
pH=9.2, resistivity=552 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY (SLIGHTLY WEATHERED SILTSTONE) WITH SAND, mottled gray and grayish brown, hard, fines and fine sand, moist, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and grayish brown, hard, moist, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and olive brown, hard, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled dark gray and grayish brown, hard, 100% fines, massive, uncemented
D.D. = 97.7 p.c.f.

Boring located in Yellowstone River
Water levels not recorded

IMT10-30
Nov. 19, 2010
Approx. Elev. 1983 ft

Field Log - River Substrate
Field Log - CLAYEY SAND, gray, loose, fine sand, wet
Field Log - coal seam, black, organic
SILTY, CLAYEY SAND WITH GRAVEL, yellowish brown, medium dense to dense, 20% fines, 22% fine sand, 26% medium sand, 13% coarse sand, 19% fine gravel, wet
pH=9.4, resistivity=685 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY (SLIGHTLY WEATHERED SILTSTONE) WITH SAND, mottled gray and grayish brown, hard, fines and fine sand, moist, uncemented, massive
pH=9.4, resistivity=649 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY WITH SAND (SLIGHTLY WEATHERED SHALE/SILTSTONE), mottled gray and grayish brown, hard, fines and fine sand, trace medium sand
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and grayish brown, hard, moist, massive, uncemented
trace shell fragments
FAT CLAY (SLIGHTLY WEATHERED SHALE), dark grayish brown, hard, moist, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), black, hard, moist, massive, uncemented
D.D. = 89.3 p.c.f.
FAT CLAY (SLIGHTLY WEATHERED SHALE), dark grayish brown, 92% fines, 3% fine sand, 2% medium sand, hard, moist, massive, uncemented

Boring located in Yellowstone River
Water levels not recorded

IMT10-31
Nov. 17, 2010
Approx. Elev. 1980 ft

Field Log - River Substrate
SILTY SAND WITH GRAVEL, dark yellowish brown, loose, 13% fines, 39% fine sand, 14% medium sand, 6% coarse sand, 28% fine gravel
GRAVEL WITH SILT AND SAND, dark grayish brown, dense, 7% fines, 16% fine sand, 15% medium sand, 15% coarse sand, 42% fine gravel, 5% coarse gravel
FAT CLAY (SLIGHTLY WEATHERED SILTSTONE) WITH SAND, mottled gray and grayish brown, very stiff, fines and fine sand, massive, uncemented
pH=9.7, resistivity=629 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY WITH SAND (SLIGHTLY WEATHERED SILTSTONE), mottled gray and grayish brown, very stiff, fines and fine sand, massive, uncemented
pH=9.3, resistivity=565 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and grayish brown, very stiff to hard, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), dark grayish brown, very stiff, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), black, hard, trace shell fragments, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), dark grayish brown, hard, massive, uncemented
D.D. = 91.1 p.c.f.
FAT CLAY (SLIGHTLY WEATHERED SHALE), olive gray, hard, 96% fines, 2% fine sand, 2% medium sand, massive, uncemented, trace coal

Boring located in Yellowstone River
Water levels not recorded

IMT10-35
Nov. 17, 2010
Approx. Elev. 1981 ft

Field Log - River Substrate
Field Log - SAND, medium dense, medium sand
Field-SANDY GRAVEL, gray, wet, fine gravel, med. to coarse sand
SAND, gray, med. dense, fine sand, trace fines & med. sand, wet
SAND WITH SILT AND GRAVEL, gray, med. dense, fine sand, fine gravel, med. sand, some coarse sand, trace fines, wet
SILTY SAND WITH GRAVEL, dark yellowish brown, med. dense, fine sand, fine gravel, some med. sand, some fines, some coarse sand, wet
SILTY, CLAYEY SAND WITH GRAVEL (WEATHERED SHALE), grayish brown, very dense, 32% fines, 19% fine sand, 25% med. sand, 9% coarse sand, 15% fine gravel, wet
pH=9.7, resistivity=599 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY (WEATHERED SILTSTONE) WITH SAND, mottled gray & grayish brown, hard, fines & fine sand, wet
pH=9.2, resistivity=550 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and grayish brown, very stiff, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), dark grayish brown, very stiff, trace shell fragments
FAT CLAY (SLIGHTLY WEATHERED SHALE), black, hard, massive, uncemented, wet, trace organics
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray, and grayish brown, hard, 98% fines, 1% fine sand, 1% medium sand, massive, uncemented, wet
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled olive gray and gray, hard, 98% fines, 1% fine sand, 1% medium sand, massive, uncemented, wet
D.D. = 103.1 p.c.f.

Boring located in Yellowstone River
Water levels not recorded

IMT10-39
Nov. 16, 2010
Approx. Elev. 1982 ft

Field Log - River Substrate
Field Log - SAND, gray, medium dense, wet, medium sand
Field Log - GRAVEL WITH SAND, gray, medium dense, wet, fine gravel, medium to coarse sand, trace coarse gravel
SAND, gray, medium dense, fine sand, trace fines and medium sand, wet
GRAVEL WITH SAND, grayish brown, medium dense to dense, 3% fines, 17% fine sand, 10% medium sand, 10% coarse sand, 44% fine gravel, 16% coarse gravel, wet
Field Log - SAND, gray, medium dense, wet, medium sand
SAND WITH CLAY AND GRAVEL, yellowish brown, medium dense, 5% fines, 12% fine sand, 27% medium sand, 28% coarse sand, 24% fine gravel, 4% coarse gravel
pH=9.3, resistivity=680 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY, grayish brown, very stiff, moist, trace sand
FAT CLAY (WEATHERED SHALE), grayish brown, stiff, moist
pH=9.7, resistivity=694 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and grayish brown, very stiff, massive, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), black, very stiff, massive, uncemented, trace shell fragments
coal seams
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and black, stiff, massive, uncemented, trace shell fragments
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled dark gray and dark grayish brown, hard, 98% fines, 2% fine sand, massive, uncemented, fissile
D.D. = 94.2 p.c.f.

Boring located in Yellowstone River
Water levels not recorded

IMT10-43
Nov. 15, 2010
Approx. Elev. 1983 ft

Field Log - River Substrate
Field Log - SANDY GRAVEL, brownish gray, loose, wet, fine gravel, coarse and medium sand
SAND, gray, med. dense, fine sand, trace fines and med. sand, wet
SAND WITH GRAVEL, gray, medium dense, fine gravel, fine sand, some medium sand, trace coarse sand, wet
SAND, gray, loose, fine sand, trace fines and medium sand, wet
Field Log - SANDY GRAVEL, brownish gray, loose, wet, fine gravel, coarse and medium sand
SAND, gray, loose, fine sand, trace fines and medium sand, wet
SAND WITH GRAVEL, gray, dense, fine gravel, fine sand, some medium sand, trace coarse sand, wet
pH=9.3, resistivity=680 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY (SLIGHTLY WEATHERED SILTSTONE) WITH SAND, mottled gray and grayish brown, hard, fines and fine sand, wet, uncemented
pH=9.7, resistivity=694 ohms-cm, $SO_4 < 0.1\%$
FAT CLAY WITH SAND (SLIGHTLY WEATHERED SILTSTONE), mottled gray and grayish brown, very stiff to hard, uncemented
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and grayish brown, very stiff to hard, massive, uncemented
D.D. = 75.9 p.c.f.
FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled dark grayish brown and very dark grayish brown, hard, 93% fines, 4% fine sand, 3% medium sand, massive, uncemented

Boring located in Yellowstone River
Water levels not recorded

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

I:\dwgs\geotech\MM04GI108.dgn

g6edxcos

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

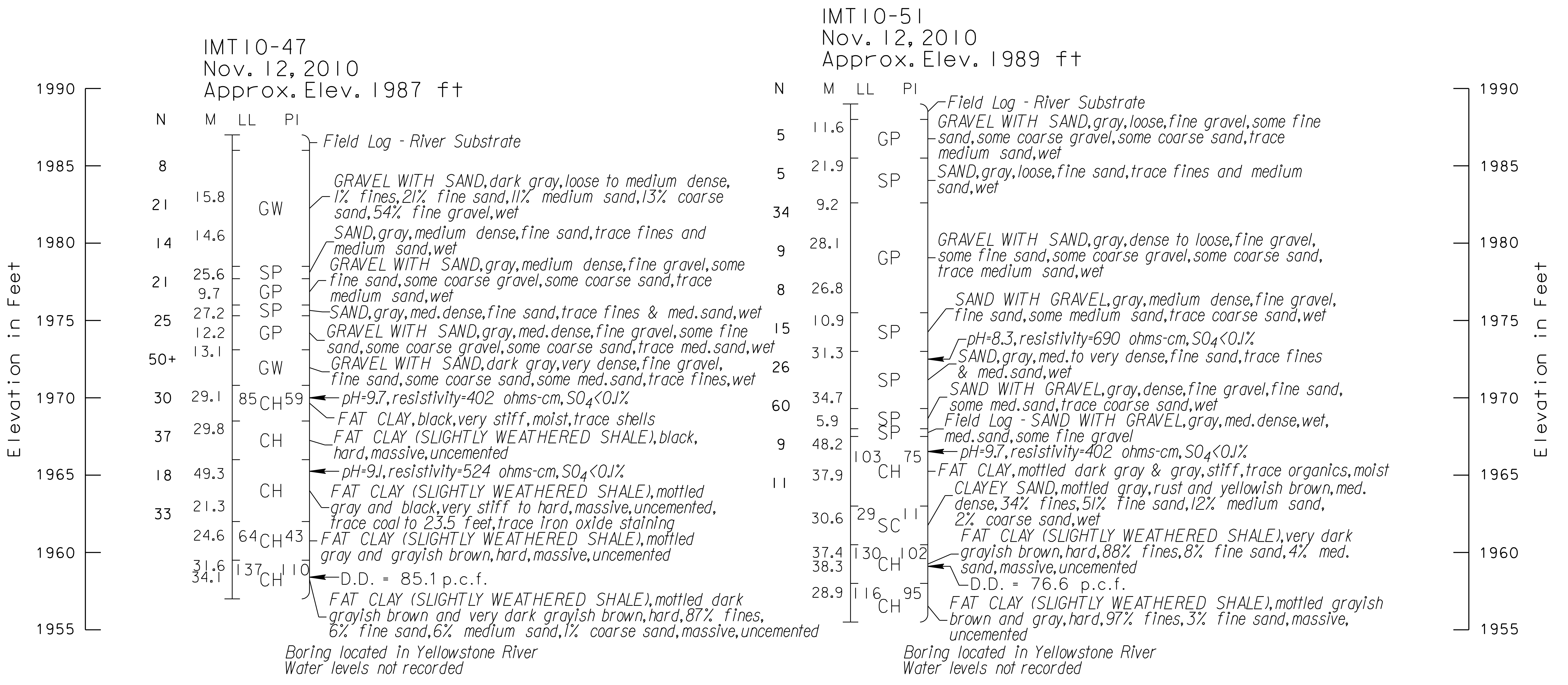
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI108.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 3/6/2012

LOWER YELLOWSTONE RIVER
INTAKE DAM FISH SCREEN AND SLUICING
INTAKE, MONTANA
PRELIMINARY DESIGN REPORT

SOIL BORING LOGS
DRILL HOLES IMT10-28, IMT10-30, IMT10-31,
IMT10-35, IMT10-39, & IMT10-43

SHEET
IDENTIFICATION
NUMBER
GI108



IMT10-47
Nov. 12, 2010
Approx. Elev. 1987 ft

N	M	LL		PI
8				
21	15.8		GW	
14	14.6			
21	25.6		SP	
	9.7		GP	
25	27.2		SP	
	12.2		GP	
50+	13.1		GW	
30	29.1	85	CH	59
37	29.8		CH	
18	49.3		CH	
33	21.3			
	24.6	64	CH	43
	31.6			
	34.1	137	CH	110

Field Log - River Substrate

GRAVEL WITH SAND, dark gray, loose to medium dense, 1% fines, 21% fine sand, 11% medium sand, 13% coarse sand, 54% fine gravel, wet

SAND, gray, medium dense, fine sand, trace fines and medium sand, wet

GRAVEL WITH SAND, gray, medium dense, fine gravel, some fine sand, some coarse gravel, some coarse sand, trace medium sand, wet

SAND, gray, med. dense, fine sand, trace fines & med. sand, wet

GRAVEL WITH SAND, gray, med. dense, fine gravel, some fine sand, some coarse gravel, some coarse sand, trace med. sand, wet

GRAVEL WITH SAND, dark gray, very dense, fine gravel, fine sand, some coarse sand, some med. sand, trace fines, wet

pH=9.7, resistivity=402 ohms-cm, SO_4<0.1%

FAT CLAY, black, very stiff, moist, trace shells

FAT CLAY (SLIGHTLY WEATHERED SHALE), black, hard, massive, uncemented

pH=9.1, resistivity=524 ohms-cm, SO_4<0.1%

FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and black, very stiff to hard, massive, uncemented, trace coal to 23.5 feet, trace iron oxide staining

FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled gray and grayish brown, hard, massive, uncemented

D.D. = 85.1 p.c.f.

FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled dark grayish brown and very dark grayish brown, hard, 87% fines, 6% fine sand, 6% medium sand, 1% coarse sand, massive, uncemented

Boring located in Yellowstone River
Water levels not recorded

IMT10-51
Nov. 12, 2010
Approx. Elev. 1989 ft

N	M	LL		PI
5	11.6		GP	
5	21.9		SP	
34	9.2			
9	28.1		GP	
8	26.8			
15	10.9		SP	
26	31.3		SP	
60	34.7			
	5.9		SP	
			SP	
9	48.2	103	CH	75
11	37.9			
	30.6	29	SC	11
	37.4	130	CH	102
	38.3			
	28.9	116	CH	95

Field Log - River Substrate

GRAVEL WITH SAND, gray, loose, fine gravel, some fine sand, some coarse gravel, some coarse sand, trace medium sand, wet

SAND, gray, loose, fine sand, trace fines and medium sand, wet

GRAVEL WITH SAND, gray, dense to loose, fine gravel, some fine sand, some coarse gravel, some coarse sand, trace medium sand, wet

SAND WITH GRAVEL, gray, medium dense, fine gravel, fine sand, some medium sand, trace coarse sand, wet

pH=8.3, resistivity=690 ohms-cm, SO_4<0.1%

SAND, gray, med. to very dense, fine sand, trace fines & med. sand, wet

SAND WITH GRAVEL, gray, dense, fine gravel, fine sand, some med. sand, trace coarse sand, wet

Field Log - SAND WITH GRAVEL, gray, med. dense, wet, med. sand, some fine gravel

pH=9.7, resistivity=402 ohms-cm, SO_4<0.1%

FAT CLAY, mottled dark gray & gray, stiff, trace organics, moist

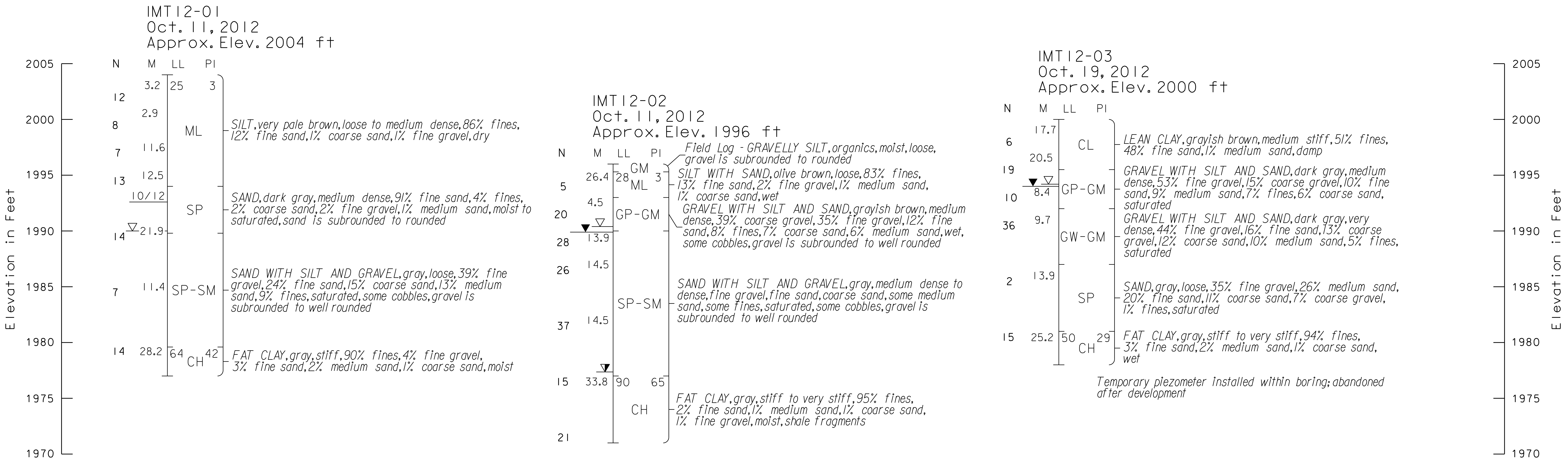
CLAYEY SAND, mottled gray, rust and yellowish brown, med. dense, 34% fines, 51% fine sand, 12% medium sand, 2% coarse sand, wet

FAT CLAY (SLIGHTLY WEATHERED SHALE), very dark grayish brown, hard, 88% fines, 8% fine sand, 4% med. sand, massive, uncemented

D.D. = 76.6 p.c.f.

FAT CLAY (SLIGHTLY WEATHERED SHALE), mottled grayish brown and gray, hard, 97% fines, 3% fine sand, massive, uncemented

Boring located in Yellowstone River
Water levels not recorded



IMT12-01
Oct. 11, 2012
Approx. Elev. 2004 ft

N	M	LL		PI
	3.2	25		3
12				
8	2.9		ML	
7	11.6			
13	12.5			
	10/12		SP	
14	21.9			
7	11.4		SP-SM	
14	28.2	64	CH	42

SILT, very pale brown, loose to medium dense, 86% fines, 12% fine sand, 1% coarse sand, 1% fine gravel, dry

SAND, dark gray, medium dense, 91% fine sand, 4% fines, 2% coarse sand, 2% fine gravel, 1% medium sand, moist to saturated, sand is subrounded to rounded

SAND WITH SILT AND GRAVEL, gray, loose, 39% fine gravel, 24% fine sand, 15% coarse sand, 13% medium sand, 9% fines, saturated, some cobbles, gravel is subrounded to well rounded

FAT CLAY, gray, stiff, 90% fines, 4% fine gravel, 3% fine sand, 2% medium sand, 1% coarse sand, moist

IMT12-02
Oct. 11, 2012
Approx. Elev. 1996 ft

N	M	LL		PI
			GM	
5	26.4	28	ML	3
20	4.5		GP-GM	
28	13.9			
26	14.5		SP-SM	
37	14.5			
15	33.8	90	CH	65
21				

Field Log - GRAVELLY SILT, organics, moist, loose, gravel is subrounded to rounded

SILT WITH SAND, olive brown, loose, 83% fines, 13% fine sand, 2% fine gravel, 1% medium sand, 1% coarse sand, wet

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, 39% coarse gravel, 35% fine gravel, 12% fine sand, 8% fines, 7% coarse sand, 6% medium sand, wet, some cobbles, gravel is subrounded to well rounded

SAND WITH SILT AND GRAVEL, gray, medium dense to dense, fine gravel, fine sand, coarse sand, some medium sand, some fines, saturated, some cobbles, gravel is subrounded to well rounded

FAT CLAY, gray, stiff to very stiff, 95% fines, 2% fine sand, 1% medium sand, 1% coarse sand, 1% fine gravel, moist, shale fragments

IMT12-03
Oct. 19, 2012
Approx. Elev. 2000 ft

N	M	LL		PI
	17.7			
6			CL	
	20.5			
19				
10	8.4		GP-GM	
36	9.7		GW-GM	
2	13.9		SP	
15	25.2	50	CH	29

LEAN CLAY, grayish brown, medium stiff, 51% fines, 48% fine sand, 1% medium sand, damp

GRAVEL WITH SILT AND SAND, dark gray, medium dense, 53% fine gravel, 15% coarse gravel, 10% fine sand, 9% medium sand, 7% fines, 6% coarse sand, saturated

GRAVEL WITH SILT AND SAND, dark gray, very dense, 44% fine gravel, 16% fine sand, 13% coarse gravel, 12% coarse sand, 10% medium sand, 5% fines, saturated

SAND, gray, loose, 35% fine gravel, 26% medium sand, 20% fine sand, 11% coarse sand, 7% coarse gravel, 1% fines, saturated

FAT CLAY, gray, stiff to very stiff, 94% fines, 3% fine sand, 2% medium sand, 1% coarse sand, wet

Temporary piezometer installed within boring; abandoned after development

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.		DATE: JAN. 2008
DWN BY: C.A.F.	CKD BY: T.J.M.	SOLICITATION NO.: W9128F-0X-X-00XX
SUBMITTED BY: B.N.J.		CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: MM04GI109		FILE NUMBER:
SIZE: 33.1X22	PLOT SCALE: 0.0833 ft / in.	PLOT DATE: 8/11/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

SOIL BORING LOGS
DRILL HOLES IMT10-47, IMT10-51, &
IMT12-01 THROUGH IMT12-03

SHEET
IDENTIFICATION
NUMBER
GI109

pw:\\NWO-APOMA.nwo.ds.usace.army.mil:CENWO - Omaha District\Documents\Civil Works\United States of America\Missouri River Basin\Yellowstone River\Intake, MT\30500 - Construction E&D\MM04 - Intake Fish Passage\30DAO - Plans & Specs\dwgs\geotech\MM04GI109

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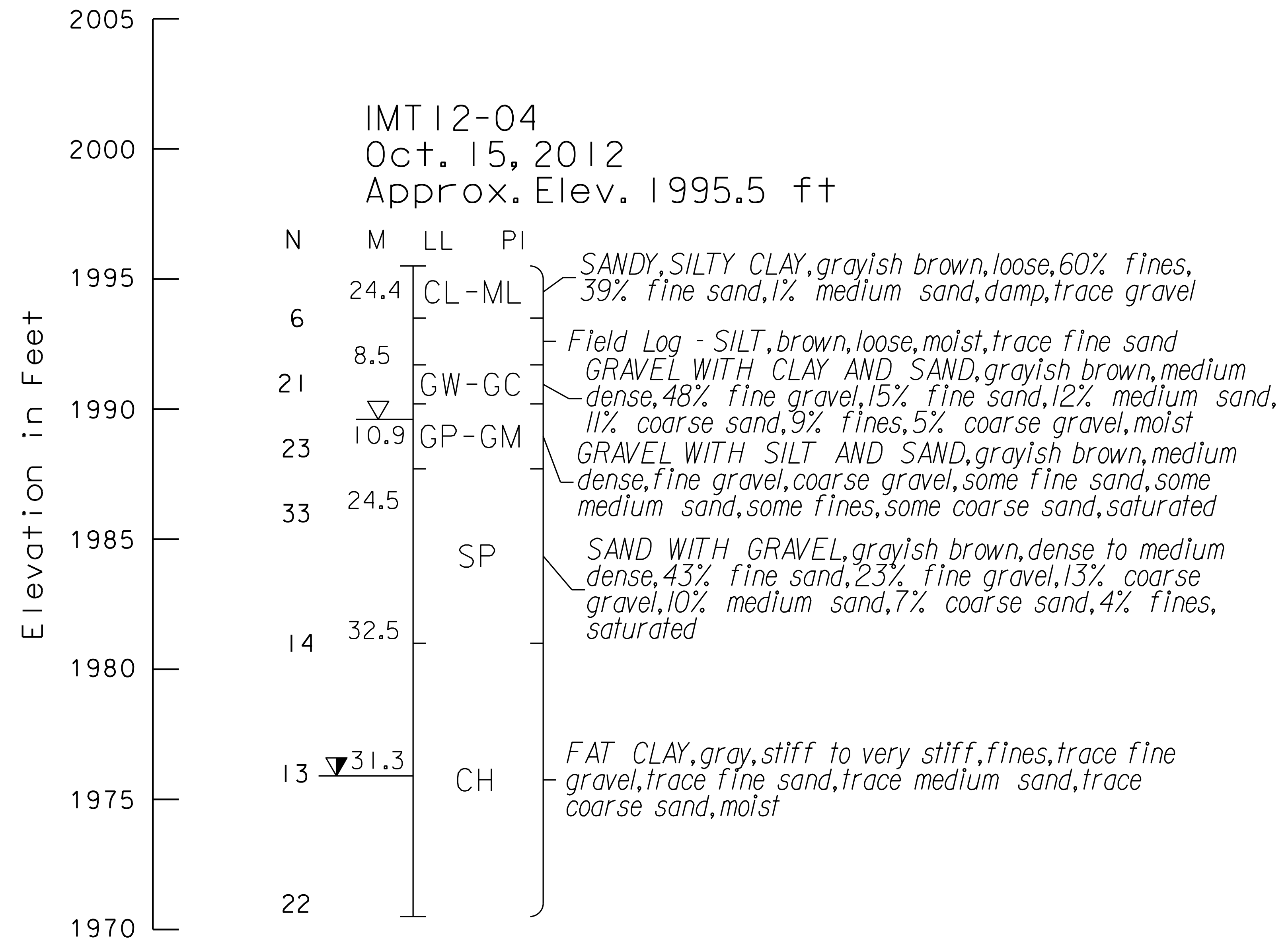


IMT12-04
Oct. 15, 2012
Approx. Elev. 1995.5 ft

SANDY, SILTY CLAY, grayish brown, loose, 60% fines, 39% fine sand, 1% medium sand, damp, trace gravel

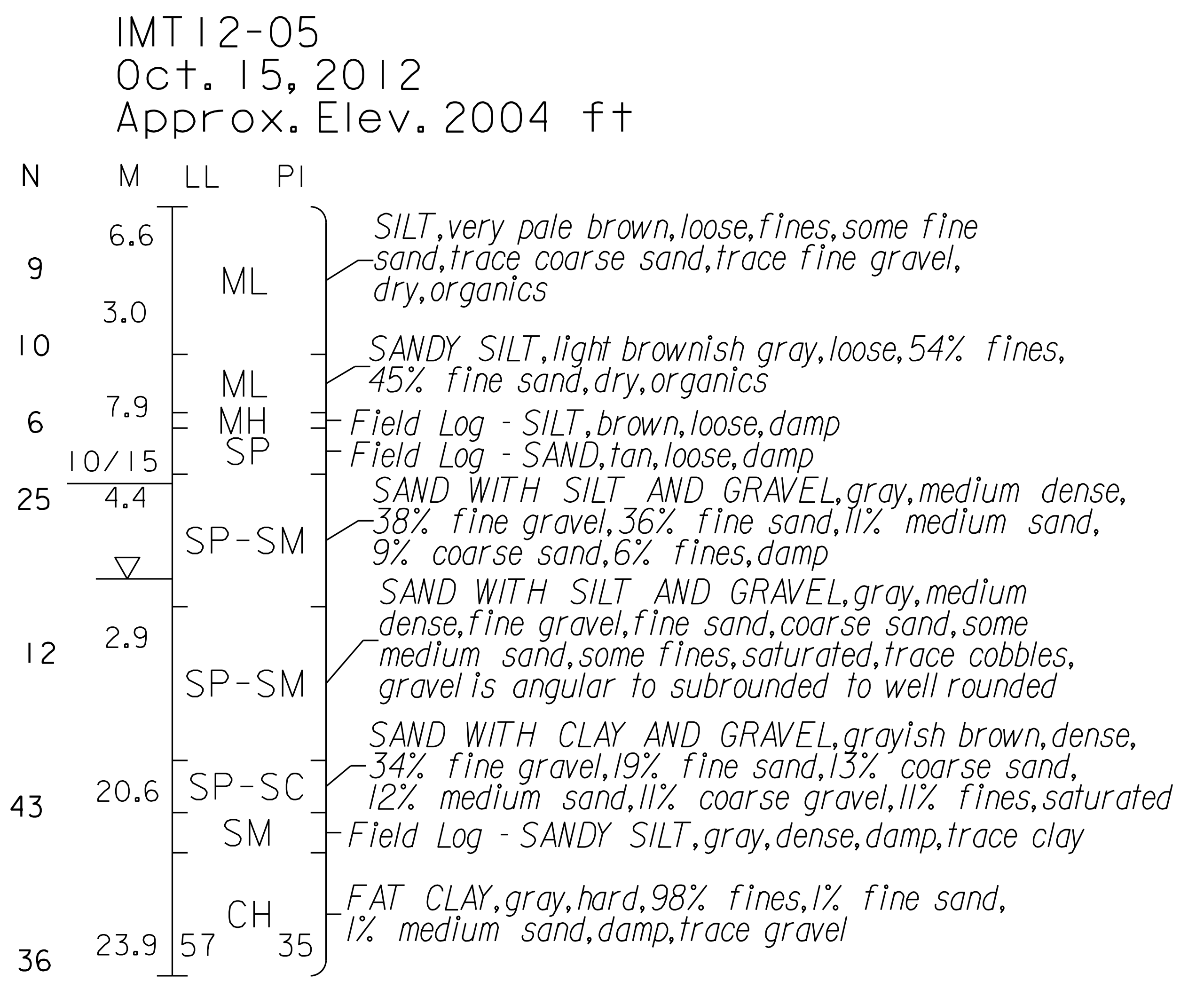
Field Log - SILT, brown, loose, moist, trace fine sand

GRAVEL WITH CLAY AND SAND, grayish brown, medium dense, 48% fine gravel, 15% fine sand, 12% medium sand, 11% coarse sand, 9% fines, 5% coarse gravel, moist

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, coarse gravel, some fine sand, some medium sand, some fines, some coarse sand, saturated

SAND WITH GRAVEL, grayish brown, dense to medium dense, 43% fine sand, 23% fine gravel, 13% coarse gravel, 10% medium sand, 7% coarse sand, 4% fines, saturated

FAT CLAY, gray, stiff to very stiff, fines, trace fine gravel, trace fine sand, trace medium sand, trace coarse sand, moist



IMT12-05
Oct. 15, 2012
Approx. Elev. 2004 ft

SILT, very pale brown, loose, fines, some fine sand, trace coarse sand, trace fine gravel, dry, organics

SANDY SILT, light brownish gray, loose, 54% fines, 45% fine sand, dry, organics

Field Log - SILT, brown, loose, damp

Field Log - SAND, tan, loose, damp

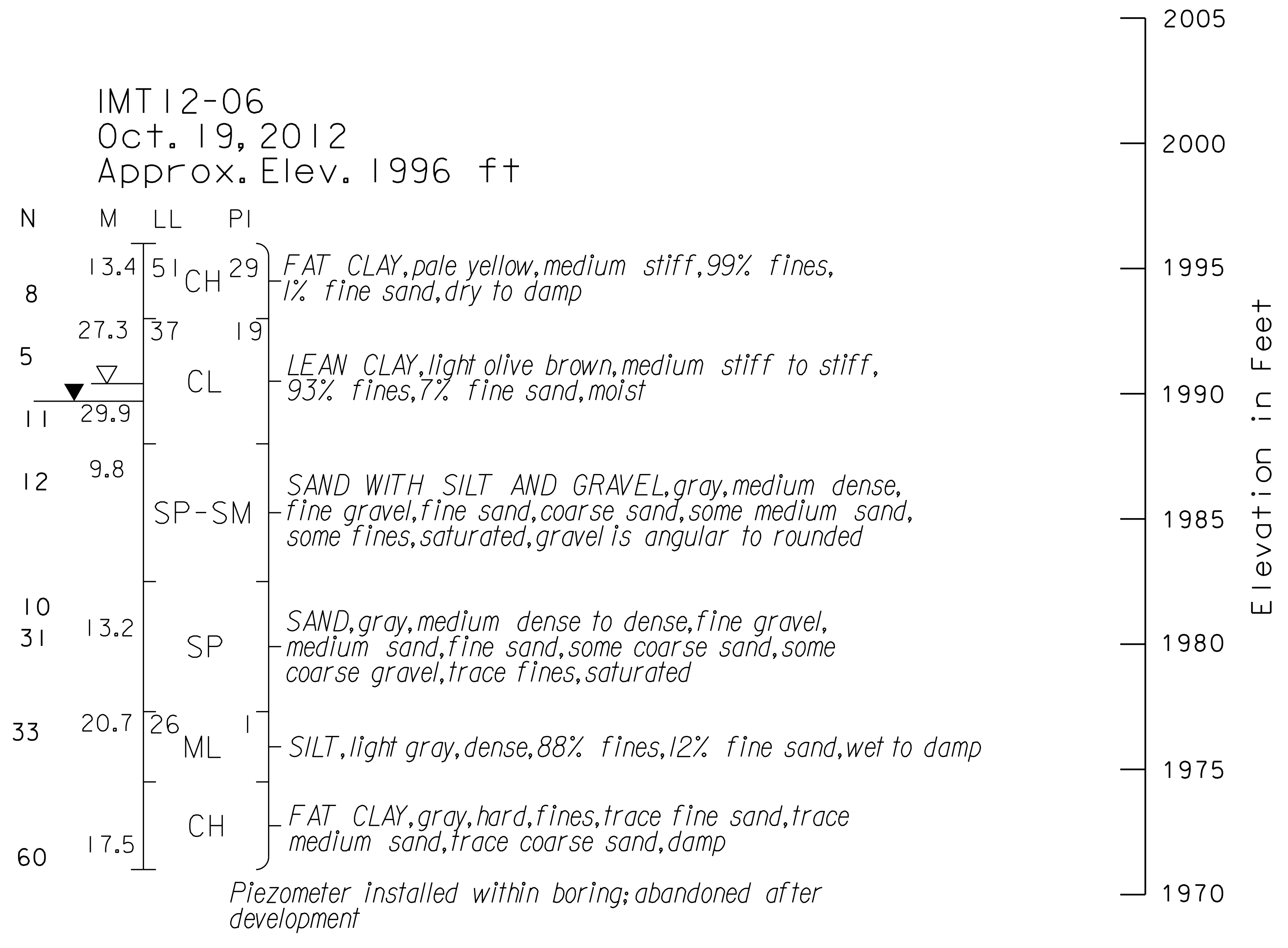
SAND WITH SILT AND GRAVEL, gray, medium dense, 38% fine gravel, 36% fine sand, 11% medium sand, 9% coarse sand, 6% fines, damp

SAND WITH SILT AND GRAVEL, gray, medium dense, fine gravel, fine sand, coarse sand, some medium sand, some fines, saturated, trace cobbles, gravel is angular to subrounded to well rounded

SAND WITH CLAY AND GRAVEL, grayish brown, dense, 34% fine gravel, 19% fine sand, 13% coarse sand, 12% medium sand, 11% coarse gravel, 11% fines, saturated

Field Log - SANDY SILT, gray, dense, damp, trace clay

FAT CLAY, gray, hard, 98% fines, 1% fine sand, 1% medium sand, damp, trace gravel



IMT12-06
Oct. 19, 2012
Approx. Elev. 1996 ft

FAT CLAY, pale yellow, medium stiff, 99% fines, 1% fine sand, dry to damp

LEAN CLAY, light olive brown, medium stiff to stiff, 93% fines, 7% fine sand, moist

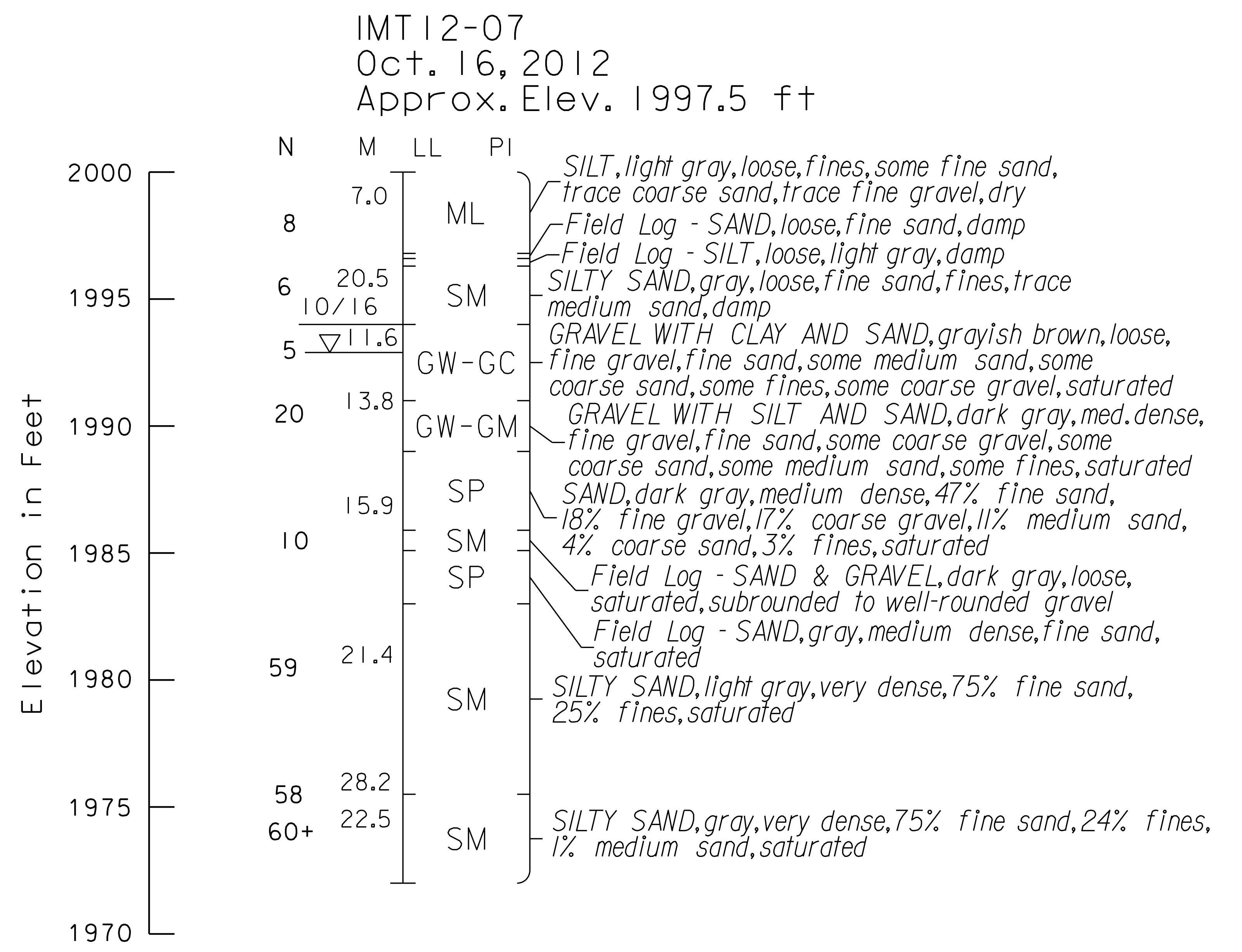
SAND WITH SILT AND GRAVEL, gray, medium dense, fine gravel, fine sand, coarse sand, some medium sand, some fines, saturated, gravel is angular to rounded

SAND, gray, medium dense to dense, fine gravel, medium sand, fine sand, some coarse sand, some coarse gravel, trace fines, saturated

SILT, light gray, dense, 88% fines, 12% fine sand, wet to damp

FAT CLAY, gray, hard, fines, trace fine sand, trace medium sand, trace coarse sand, damp

Piezometer installed within boring; abandoned after development



IMT12-07
Oct. 16, 2012
Approx. Elev. 1997.5 ft

SILT, light gray, loose, fines, some fine sand, trace coarse sand, trace fine gravel, dry

Field Log - SAND, loose, fine sand, damp

Field Log - SILT, loose, light gray, damp

SILTY SAND, gray, loose, fine sand, fines, trace medium sand, damp

GRAVEL WITH CLAY AND SAND, grayish brown, loose, fine gravel, fine sand, some medium sand, some coarse sand, some fines, some coarse gravel, saturated

GRAVEL WITH SILT AND SAND, dark gray, med. dense, fine gravel, fine sand, some coarse gravel, some coarse sand, some medium sand, some fines, saturated

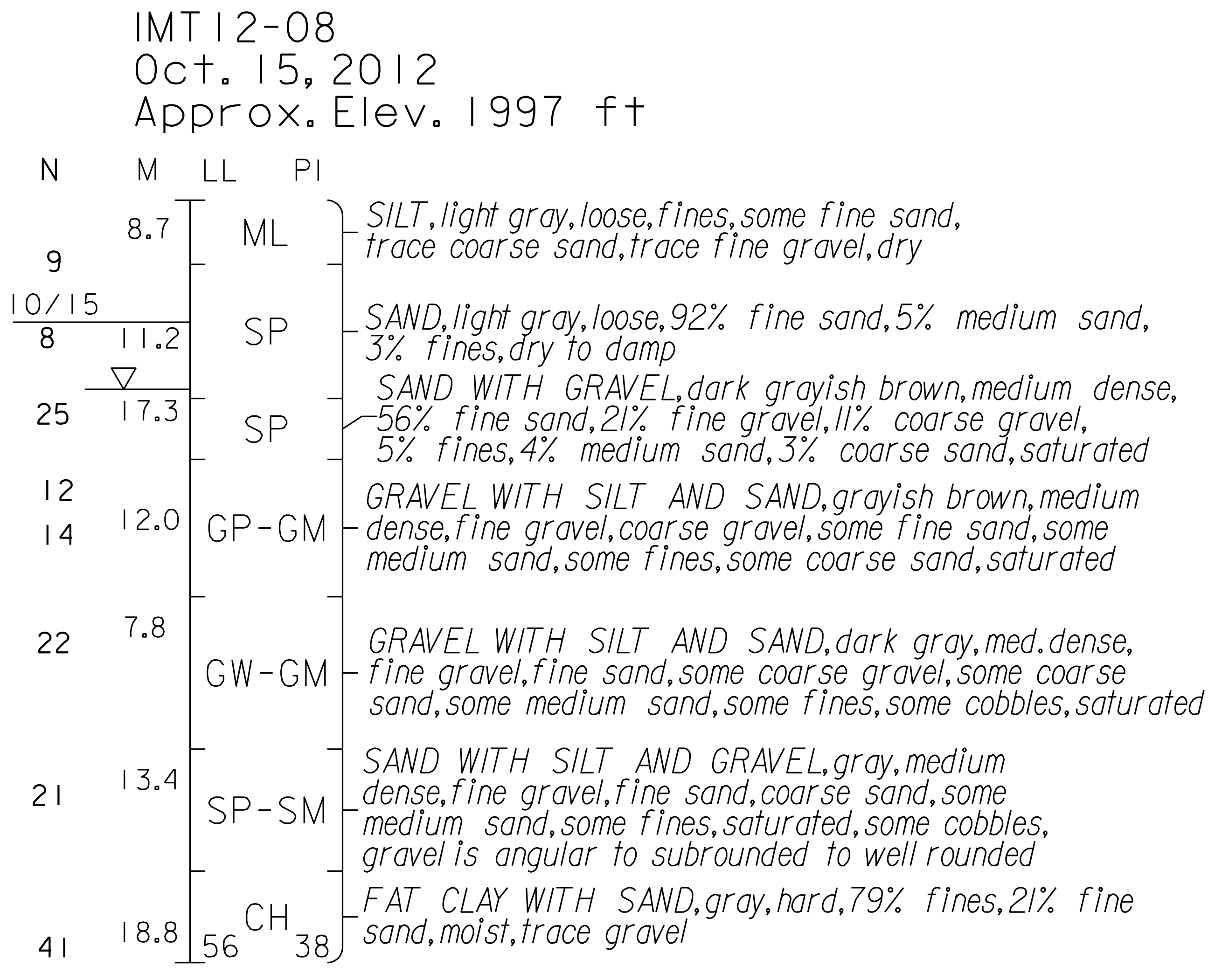
SAND, dark gray, medium dense, 47% fine sand, 18% fine gravel, 17% coarse gravel, 11% medium sand, 4% coarse sand, 3% fines, saturated

Field Log - SAND & GRAVEL, dark gray, loose, saturated, subrounded to well-rounded gravel

Field Log - SAND, gray, medium dense, fine sand, saturated

SILTY SAND, light gray, very dense, 75% fine sand, 25% fines, saturated

SILTY SAND, gray, very dense, 75% fine sand, 24% fines, 1% medium sand, saturated



IMT12-08
Oct. 15, 2012
Approx. Elev. 1997 ft

SILT, light gray, loose, fines, some fine sand, trace coarse sand, trace fine gravel, dry

SAND, light gray, loose, 92% fine sand, 5% medium sand, 3% fines, dry to damp

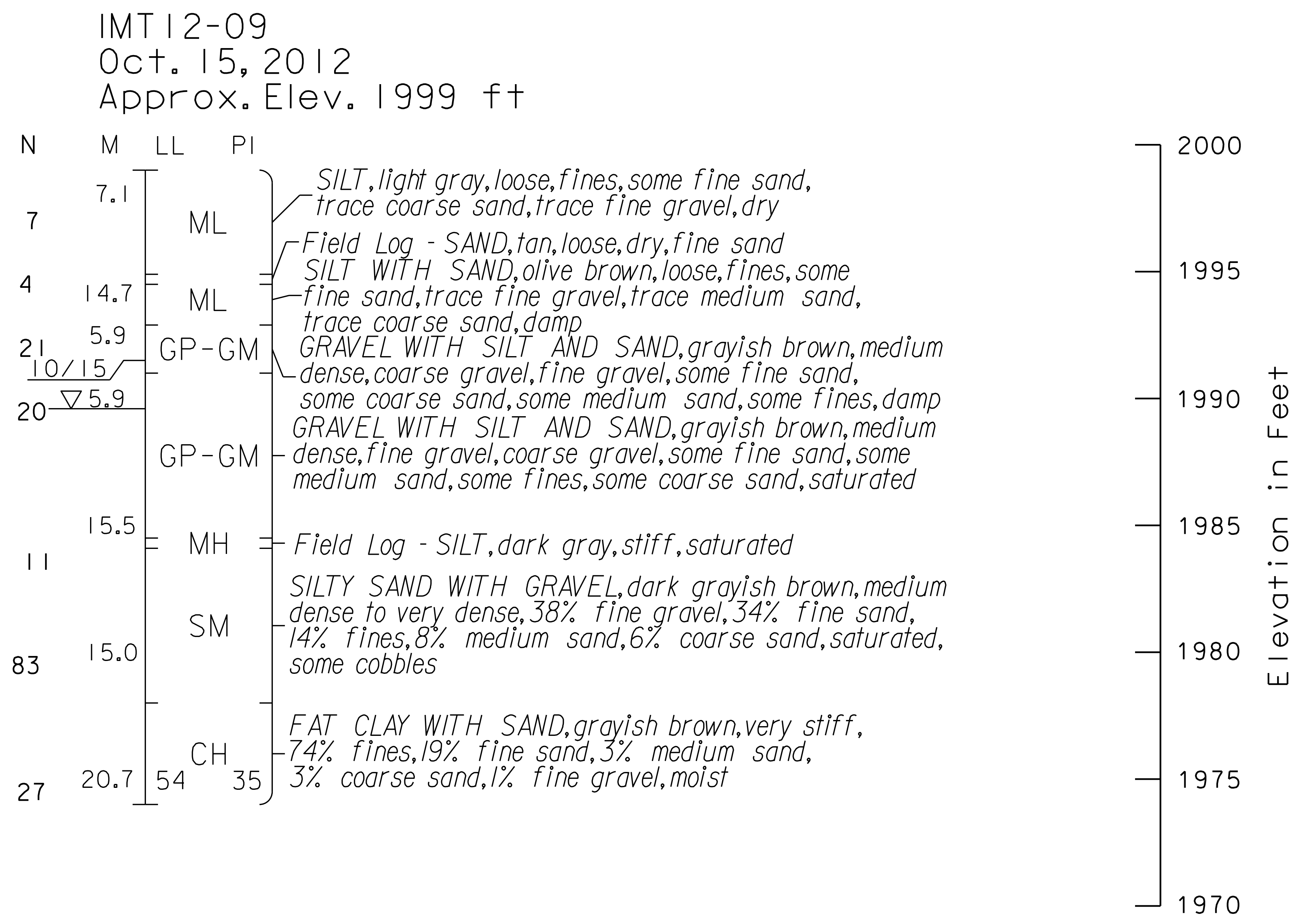
SAND WITH GRAVEL, dark grayish brown, medium dense, 56% fine sand, 21% fine gravel, 11% coarse gravel, 5% fines, 4% medium sand, 3% coarse sand, saturated

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, coarse gravel, some fine sand, some medium sand, some fines, some coarse sand, saturated

GRAVEL WITH SILT AND SAND, dark gray, med. dense, fine gravel, fine sand, some coarse gravel, some coarse sand, some medium sand, some fines, some cobbles, saturated

SAND WITH SILT AND GRAVEL, gray, medium dense, fine gravel, fine sand, coarse sand, some medium sand, some fines, saturated, some cobbles, gravel is angular to subrounded to well rounded

FAT CLAY WITH SAND, gray, hard, 79% fines, 21% fine sand, moist, trace gravel



IMT12-09
Oct. 15, 2012
Approx. Elev. 1999 ft

SILT, light gray, loose, fines, some fine sand, trace coarse sand, trace fine gravel, dry

Field Log - SAND, tan, loose, dry, fine sand

SILT WITH SAND, olive brown, loose, fines, some fine sand, trace fine gravel, trace medium sand, trace coarse sand, damp

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, coarse gravel, fine gravel, some fine sand, some coarse sand, some medium sand, some fines, damp

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, fine gravel, coarse gravel, some fine sand, some medium sand, some fines, some coarse sand, saturated

Field Log - SILT, dark gray, stiff, saturated

SILTY SAND WITH GRAVEL, dark grayish brown, medium dense to very dense, 38% fine gravel, 34% fine sand, 14% fines, 8% medium sand, 6% coarse sand, saturated, some cobbles

FAT CLAY WITH SAND, grayish brown, very stiff, 74% fines, 19% fine sand, 3% medium sand, 3% coarse sand, 1% fine gravel, moist

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

pw:\\NWO-APO1OMA.nwo.ds.usace.army.mil:CENWO - Omaha District\Documents\Civil Works\United States of America\Missouri River Basin\Yellowstone River\Intake, MT\30500 - Construction E&D\MM04 - Intake Fish Passage\30DA0 - Plans & Specs\dwgs\geotech\MM04GI110

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US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

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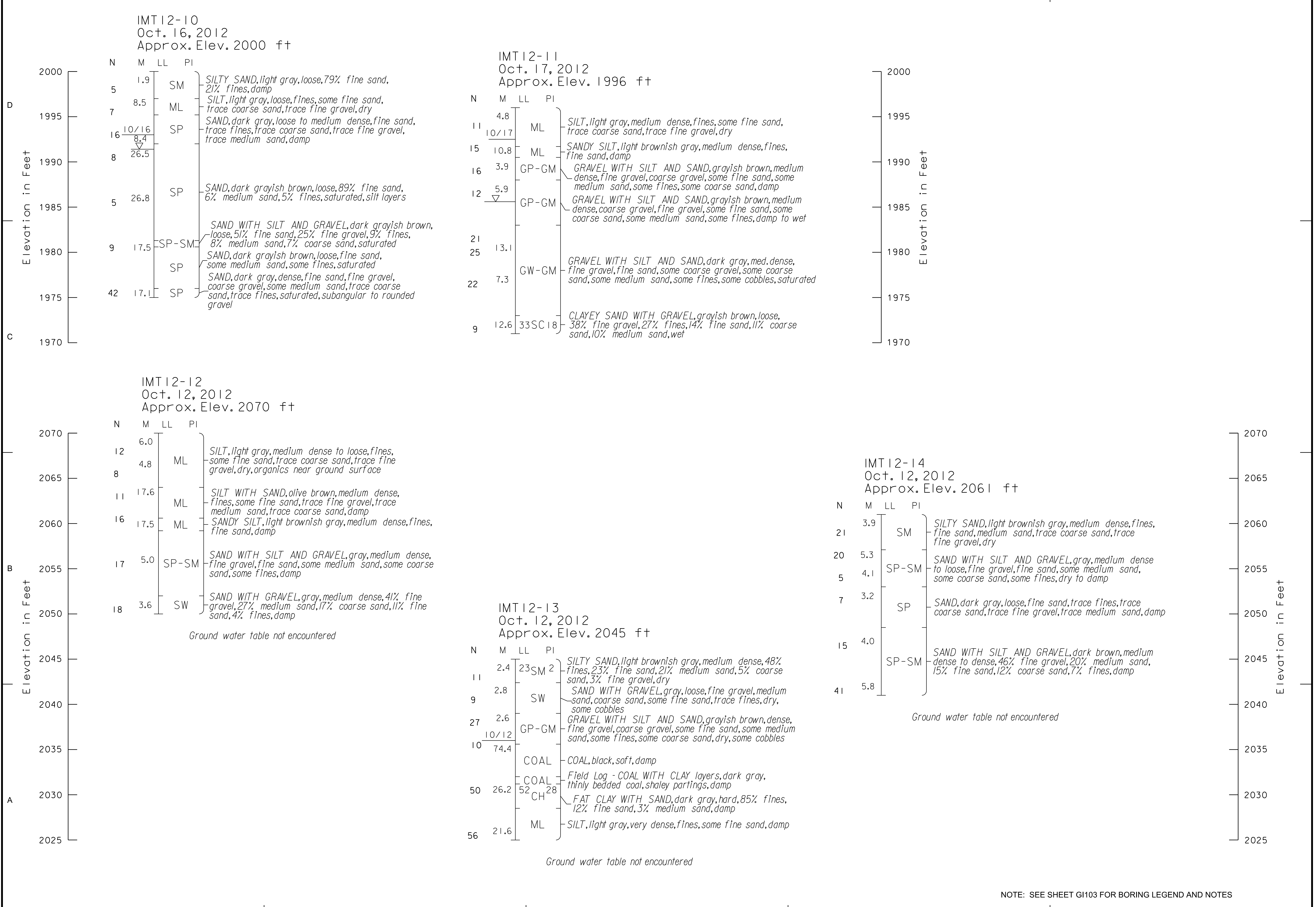
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.
DATE: JAN. 2008
DWN BY: C.A.F.
CKD BY: T.J.M.
SOLICITATION NO.: W9128F-0X-X-00XX
SUBMITTED BY: B.N.J.
CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: MM04GI110
FILE NUMBER:
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
PLOT DATE: 8/11/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

SOIL BORING LOGS
DRILL HOLES IMT12-04 THROUGH IMT12-09

SHEET
IDENTIFICATION
NUMBER
GI110



IMT12-10
Oct. 16, 2012
Approx. Elev. 2000 ft

SILTY SAND,light gray,loose,79% fine sand, 21% fines,damp

SILT,light gray,loose,fines,some fine sand, trace coarse sand,trace fine gravel,dry

SAND,dark gray,loose to medium dense,fine sand, trace fines,trace coarse sand,trace fine gravel, trace medium sand,damp

SAND,dark grayish brown,loose,89% fine sand, 6% medium sand,5% fines,saturated,silt layers

SAND WITH SILT AND GRAVEL,dark grayish brown, loose,51% fine sand,25% fine gravel,9% fines, 8% medium sand,7% coarse sand,saturated

SAND,dark grayish brown,loose,fine sand, some medium sand,some fines,saturated

SAND,dark gray,dense,fine sand,fine gravel, coarse gravel,some medium sand,trace coarse sand,trace fines,saturated,subangular to rounded gravel

IMT12-11
Oct. 17, 2012
Approx. Elev. 1996 ft

SILT,light gray,medium dense,fines,some fine sand, trace coarse sand,trace fine gravel,dry

SANDY SILT,light brownish gray,medium dense,fines, fine sand,damp

GRAVEL WITH SILT AND SAND,grayish brown,medium dense,fine gravel,coarse gravel,some fine sand,some medium sand,some fines,some coarse sand,damp

GRAVEL WITH SILT AND SAND,grayish brown,medium dense,coarse gravel,fine gravel,some fine sand,some coarse sand,some medium sand,some fines,damp to wet

GRAVEL WITH SILT AND SAND,dark gray,med.dense, fine gravel,fine sand,some coarse gravel,some coarse sand,some medium sand,some fines,some cobbles,saturated

CLAYEY SAND WITH GRAVEL,grayish brown,loose, 38% fine gravel,27% fines,14% fine sand,11% coarse sand,10% medium sand,wet

IMT12-12
Oct. 12, 2012
Approx. Elev. 2070 ft

SILT,light gray,medium dense to loose,fines, some fine sand,trace coarse sand,trace fine gravel,dry,organics near ground surface

SILT WITH SAND,olive brown,medium dense, fines,some fine sand,trace fine gravel,trace medium sand,trace coarse sand,damp

SANDY SILT,light brownish gray,medium dense,fines, fine sand,damp

SAND WITH SILT AND GRAVEL,gray,medium dense, fine gravel,fine sand,some medium sand,some coarse sand,some fines,damp

SAND WITH GRAVEL,gray,medium dense,41% fine gravel,27% medium sand,17% coarse sand,11% fine sand,4% fines,damp

Ground water table not encountered

IMT12-13
Oct. 12, 2012
Approx. Elev. 2045 ft

SILTY SAND,light brownish gray,medium dense,48% fines,23% fine sand,21% medium sand,5% coarse sand,3% fine gravel,dry

SAND WITH GRAVEL,gray,loose,fine gravel,medium sand,coarse sand,some fine sand,trace fines,dry, some cobbles

GRAVEL WITH SILT AND SAND,grayish brown,dense, fine gravel,coarse gravel,some fine sand,some medium sand,some fines,some coarse sand,dry,some cobbles

COAL,black,soft,damp

Field Log - COAL WITH CLAY layers,dark gray, thinly bedded coal,shaley partings,damp

FAT CLAY WITH SAND,dark gray,hard,85% fines, 12% fine sand,3% medium sand,damp

SILT,light gray,very dense,fines,some fine sand,damp

Ground water table not encountered

IMT12-14
Oct. 12, 2012
Approx. Elev. 2061 ft

SILTY SAND,light brownish gray,medium dense,fines, fine sand,medium sand,trace coarse sand,trace fine gravel,dry

SAND WITH SILT AND GRAVEL,gray,medium dense to loose,fine gravel,fine sand,some medium sand, some coarse sand,some fines,dry to damp

SAND,dark gray,loose,fine sand,trace fines,trace coarse sand,trace fine gravel,trace medium sand,damp

SAND WITH SILT AND GRAVEL,dark brown,medium dense to dense,46% fine gravel,20% medium sand, 15% fine sand,12% coarse sand,7% fines,damp

Ground water table not encountered

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI111
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 8/11/2014

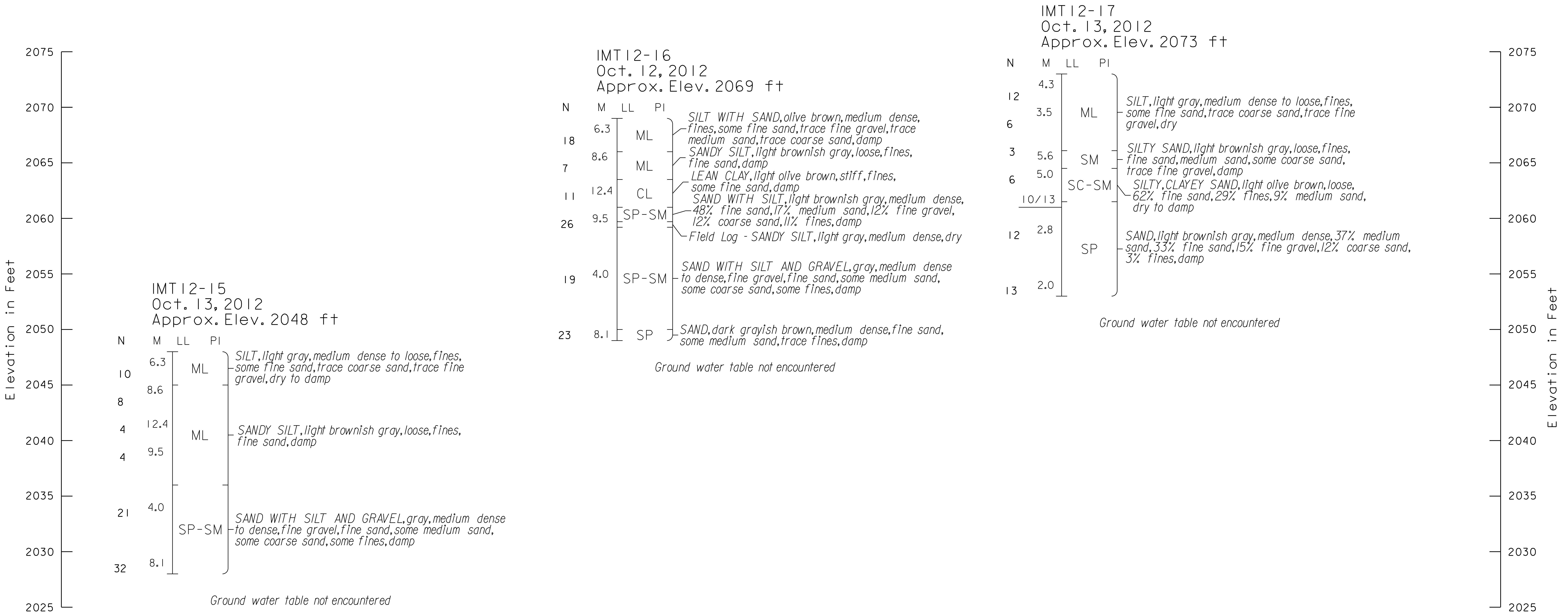
LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

SOIL BORING LOGS
DRILL HOLES IMT12-10 THROUGH IMT12-14

SHEET
IDENTIFICATION
NUMBER
GI111

pw:\\NWO-AP01OMA.nwo.ds.usace.army.mil:CENWO - Omaha District\Documents\Civil Works\United States of America\Missouri River Basin\Yellowstone River\Intake, MT\30500 - Construction E&D\MM04 - Intake Fish Passage\30DA0 - Plans & Specs\dwgs\geotech\MM04GI111

g6edxcas



IMT12-15
Oct. 13, 2012
Approx. Elev. 2048 ft

SILT, light gray, medium dense to loose, fines, some fine sand, trace coarse sand, trace fine gravel, dry to damp

SANDY SILT, light brownish gray, loose, fines, fine sand, damp

SAND WITH SILT AND GRAVEL, gray, medium dense to dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, damp

Ground water table not encountered

IMT12-16
Oct. 12, 2012
Approx. Elev. 2069 ft

SILT WITH SAND, olive brown, medium dense, fines, some fine sand, trace fine gravel, trace medium sand, trace coarse sand, damp

SANDY SILT, light brownish gray, loose, fines, fine sand, damp

LEAN CLAY, light olive brown, stiff, fines, some fine sand, damp

SAND WITH SILT, light brownish gray, medium dense, 48% fine sand, 17% medium sand, 12% fine gravel, 12% coarse sand, 11% fines, damp

Field Log - SANDY SILT, light gray, medium dense, dry

SAND WITH SILT AND GRAVEL, gray, medium dense to dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, damp

SAND, dark grayish brown, medium dense, fine sand, some medium sand, trace fines, damp

Ground water table not encountered

IMT12-17
Oct. 13, 2012
Approx. Elev. 2073 ft

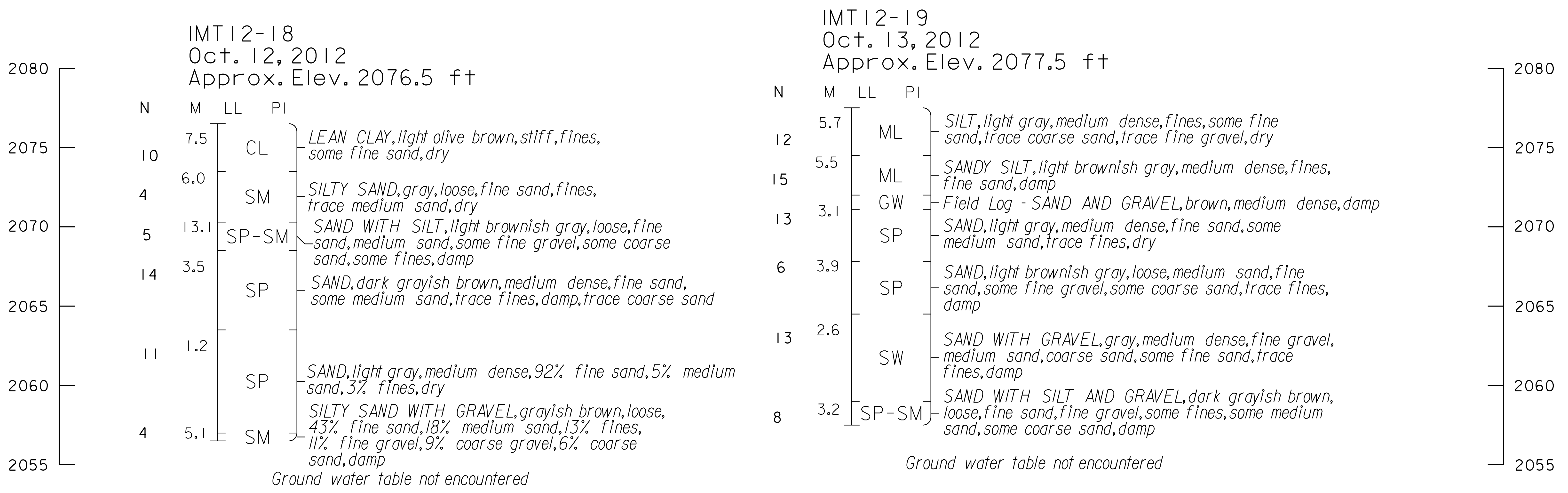
SILT, light gray, medium dense to loose, fines, some fine sand, trace coarse sand, trace fine gravel, dry

SILTY SAND, light brownish gray, loose, fines, fine sand, medium sand, some coarse sand, trace fine gravel, damp

SILTY, CLAYEY SAND, light olive brown, loose, 62% fine sand, 29% fines, 9% medium sand, dry to damp

SAND, light brownish gray, medium dense, 37% medium sand, 33% fine sand, 15% fine gravel, 12% coarse sand, 3% fines, damp

Ground water table not encountered



IMT12-18
Oct. 12, 2012
Approx. Elev. 2076.5 ft

LEAN CLAY, light olive brown, stiff, fines, some fine sand, dry

SILTY SAND, gray, loose, fine sand, fines, trace medium sand, dry

SAND WITH SILT, light brownish gray, loose, fine sand, medium sand, some fine gravel, some coarse sand, some fines, damp

SAND, dark grayish brown, medium dense, fine sand, some medium sand, trace fines, damp, trace coarse sand

SAND, light gray, medium dense, 92% fine sand, 5% medium sand, 3% fines, dry

SILTY SAND WITH GRAVEL, grayish brown, loose, 43% fine sand, 18% medium sand, 13% fines, 11% fine gravel, 9% coarse gravel, 6% coarse sand, damp

Ground water table not encountered

IMT12-19
Oct. 13, 2012
Approx. Elev. 2077.5 ft

SILT, light gray, medium dense, fines, some fine sand, trace coarse sand, trace fine gravel, dry

SANDY SILT, light brownish gray, medium dense, fines, fine sand, damp

Field Log - SAND AND GRAVEL, brown, medium dense, damp

SAND, light gray, medium dense, fine sand, some medium sand, trace fines, dry

SAND, light brownish gray, loose, medium sand, fine sand, some fine gravel, some coarse sand, trace fines, damp

SAND WITH GRAVEL, gray, medium dense, fine gravel, medium sand, coarse sand, some fine sand, trace fines, damp

SAND WITH SILT AND GRAVEL, dark grayish brown, loose, fine sand, fine gravel, some fines, some medium sand, some coarse sand, damp

Ground water table not encountered

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI112
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 8/11/2014

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

SOIL BORING LOGS
DRILL HOLES IMT12-15 THROUGH IMT12-19

SHEET
IDENTIFICATION
NUMBER
GI112

pw:\\NWO-APOIOMA.nwo.ds.usace.army.mil:CENWO - Omaha District\Documents\Civil Works\United States of America\Missouri River Basin\Yellowstone River\Intake, MT\30500 - Construction E&D\MM04 - Intake Fish Passage\300A0 - Plans & Specs\dwgs\geotech\MM04GI113

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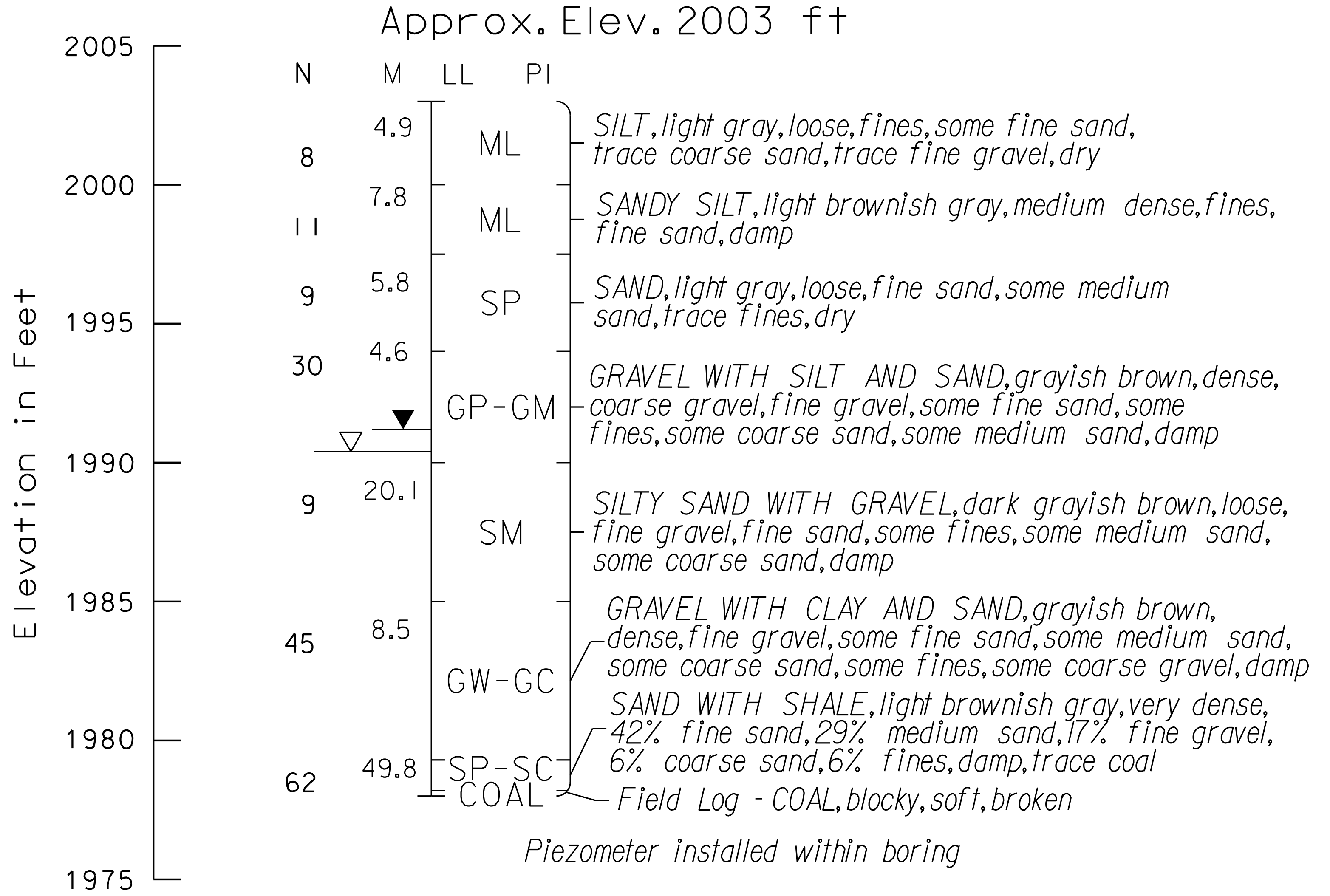
IMT12-20
Oct. 18, 2012
Approx. Elev. 2003 ft



SILT, light gray, loose, fines, some fine sand, trace coarse sand, trace fine gravel, dry

SANDY SILT, light brownish gray, medium dense, fines, fine sand, damp

SAND, light gray, loose, fine sand, some medium sand, trace fines, dry

GRAVEL WITH SILT AND SAND, grayish brown, dense, coarse gravel, fine gravel, some fine sand, some fines, some coarse sand, some medium sand, damp

SILTY SAND WITH GRAVEL, dark grayish brown, loose, fine gravel, fine sand, some fines, some medium sand, some coarse sand, damp

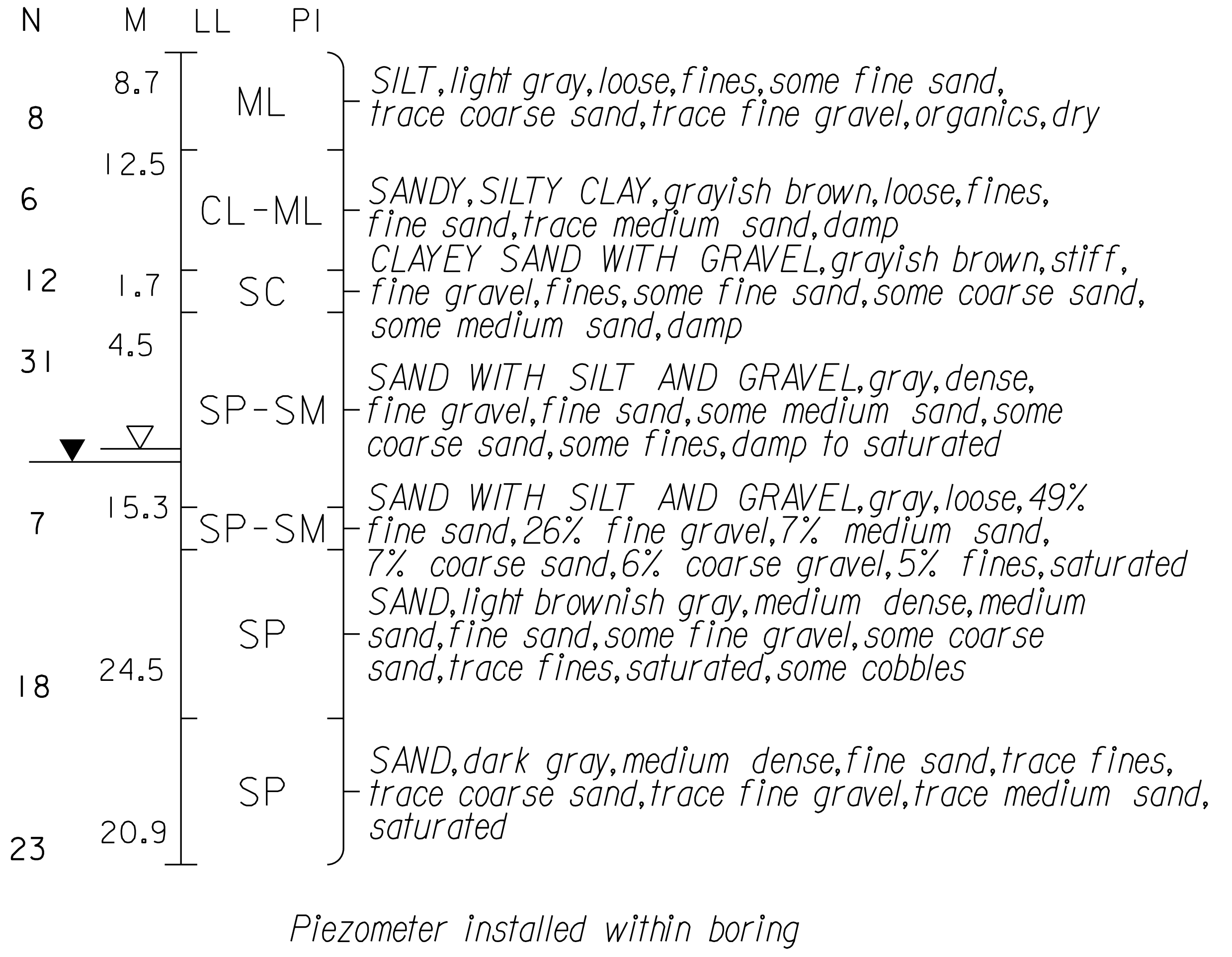
GRAVEL WITH CLAY AND SAND, grayish brown, dense, fine gravel, some fine sand, some medium sand, some coarse sand, some fines, some coarse gravel, damp

SAND WITH SHALE, light brownish gray, very dense, 42% fine sand, 29% medium sand, 17% fine gravel, 6% coarse sand, 6% fines, damp, trace coal

Field Log - COAL, blocky, soft, broken

Piezometer installed within boring

IMT12-21
Oct. 18, 2012
Approx. Elev. 2005 ft



SILT, light gray, loose, fines, some fine sand, trace coarse sand, trace fine gravel, organics, dry

SANDY, SILTY CLAY, grayish brown, loose, fines, fine sand, trace medium sand, damp

CLAYEY SAND WITH GRAVEL, grayish brown, stiff, fine gravel, fines, some fine sand, some coarse sand, some medium sand, damp

SAND WITH SILT AND GRAVEL, gray, dense, fine gravel, fine sand, some medium sand, some coarse sand, some fines, damp to saturated

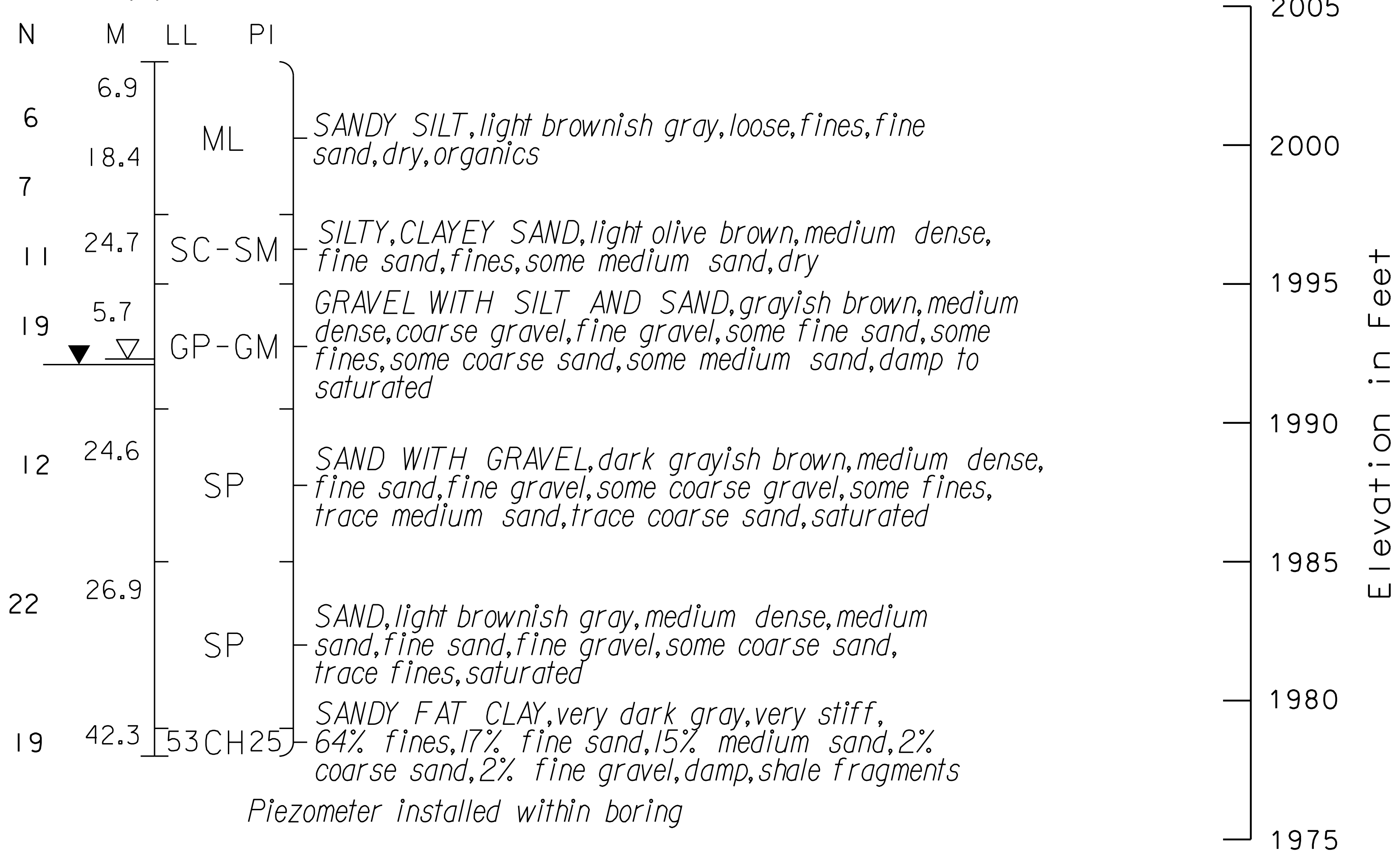
SAND WITH SILT AND GRAVEL, gray, loose, 49% fine sand, 26% fine gravel, 7% medium sand, 7% coarse sand, 6% coarse gravel, 5% fines, saturated

SAND, light brownish gray, medium dense, medium sand, fine sand, some fine gravel, some coarse sand, trace fines, saturated, some cobbles

SAND, dark gray, medium dense, fine sand, trace fines, trace coarse sand, trace fine gravel, trace medium sand, saturated

Piezometer installed within boring

IMT12-22
Oct. 17, 2012
Approx. Elev. 2003 ft



SANDY SILT, light brownish gray, loose, fines, fine sand, dry, organics

SILTY, CLAYEY SAND, light olive brown, medium dense, fine sand, fines, some medium sand, dry

GRAVEL WITH SILT AND SAND, grayish brown, medium dense, coarse gravel, fine gravel, some fine sand, some fines, some coarse sand, some medium sand, damp to saturated

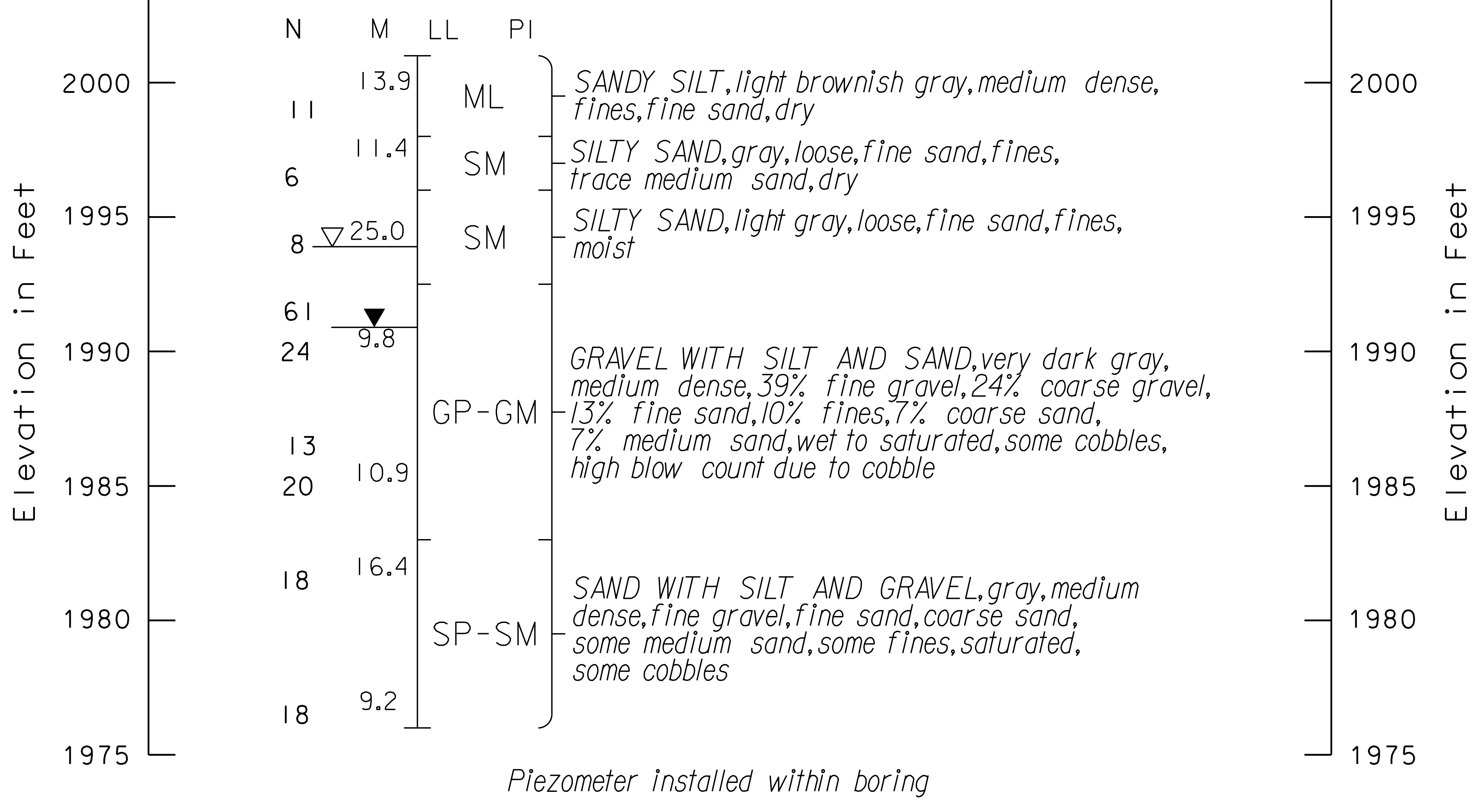
SAND WITH GRAVEL, dark grayish brown, medium dense, fine sand, fine gravel, some coarse gravel, some fines, trace medium sand, trace coarse sand, saturated

SAND, light brownish gray, medium dense, medium sand, fine sand, fine gravel, some coarse sand, trace fines, saturated

SANDY FAT CLAY, very dark gray, very stiff, 64% fines, 17% fine sand, 15% medium sand, 2% coarse sand, 2% fine gravel, damp, shale fragments

Piezometer installed within boring

IMT12-23
Oct. 18, 2012
Approx. Elev. 2001 ft



SANDY SILT, light brownish gray, medium dense, fines, fine sand, dry

SILTY SAND, gray, loose, fine sand, fines, trace medium sand, dry

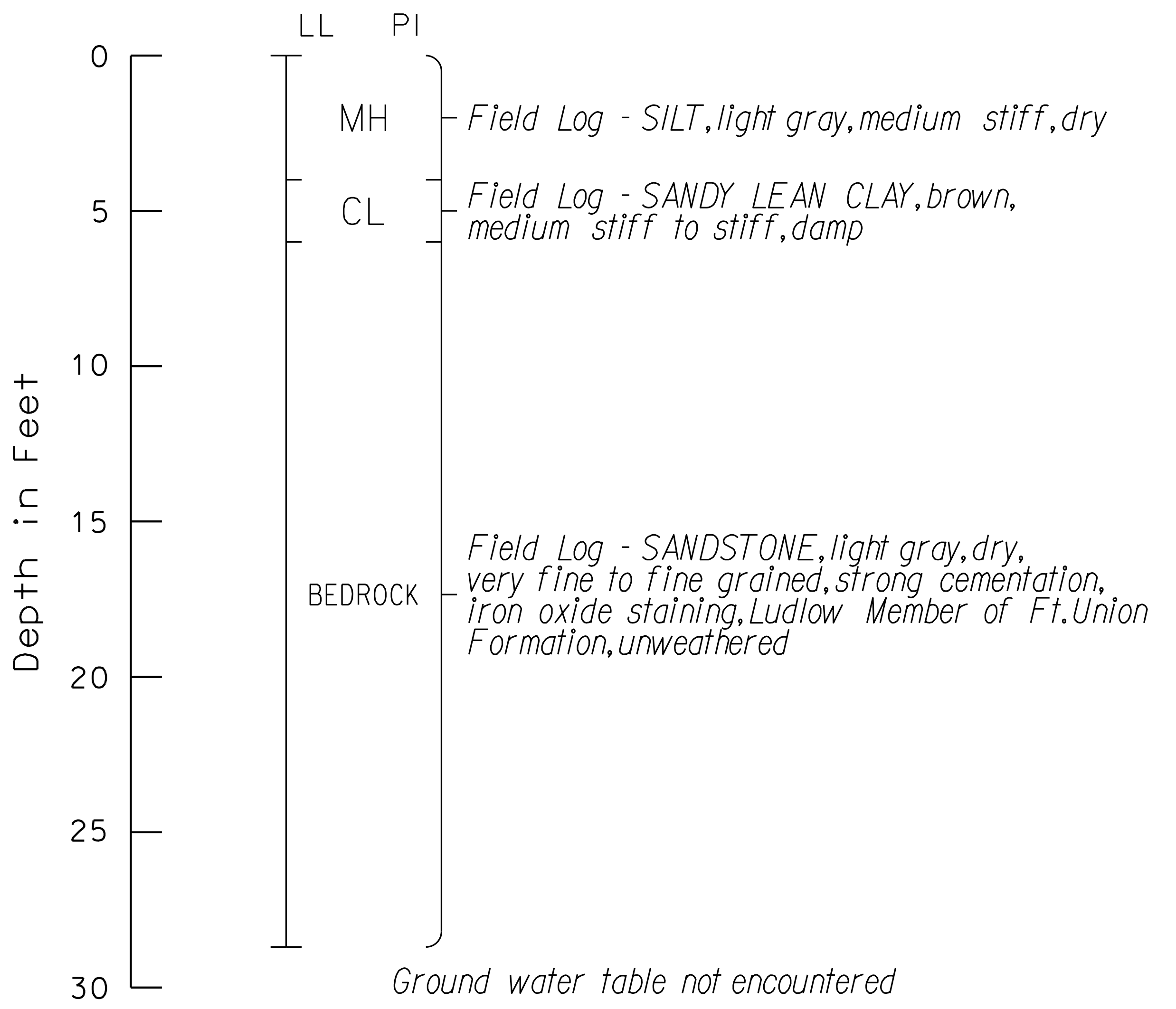
SILTY SAND, light gray, loose, fine sand, fines, moist

GRAVEL WITH SILT AND SAND, very dark gray, medium dense, 39% fine gravel, 24% coarse gravel, 13% fine sand, 10% fines, 7% coarse sand, 7% medium sand, wet to saturated, some cobbles, high blow count due to cobble

SAND WITH SILT AND GRAVEL, gray, medium dense, fine gravel, fine sand, coarse sand, some medium sand, some fines, saturated, some cobbles

Piezometer installed within boring

IMT12-24
Oct. 24, 2012



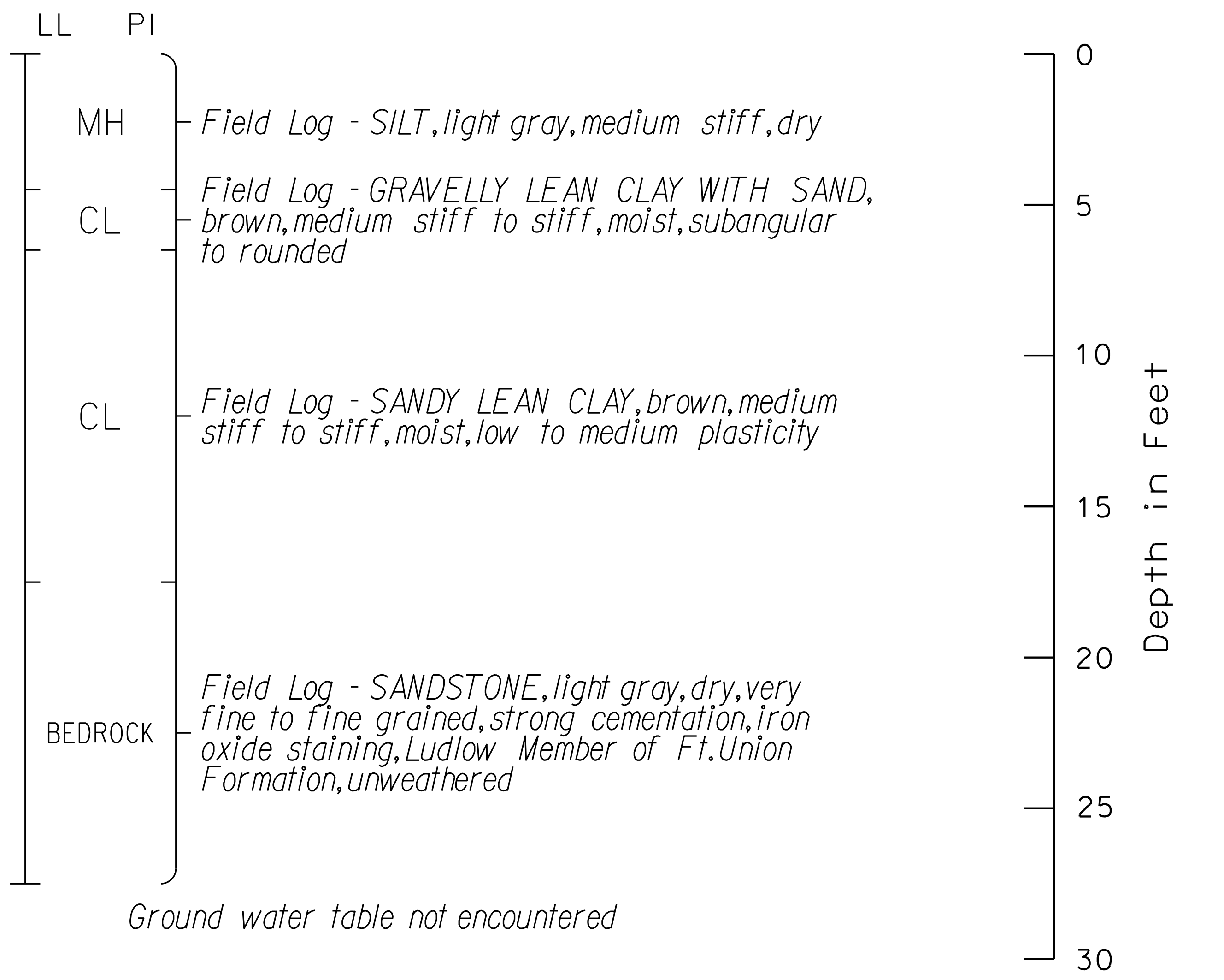
Field Log - SILT, light gray, medium stiff, dry

Field Log - SANDY LEAN CLAY, brown, medium stiff to stiff, damp

Field Log - SANDSTONE, light gray, dry, very fine to fine grained, strong cementation, iron oxide staining, Ludlow Member of Ft. Union Formation, unweathered

Ground water table not encountered

IMT12-25
Oct. 24, 2012



Field Log - SILT, light gray, medium stiff, dry

Field Log - GRAVELLY LEAN CLAY WITH SAND, brown, medium stiff to stiff, moist, subangular to rounded

Field Log - SANDY LEAN CLAY, brown, medium stiff to stiff, moist, low to medium plasticity

Field Log - SANDSTONE, light gray, dry, very fine to fine grained, strong cementation, iron oxide staining, Ludlow Member of Ft. Union Formation, unweathered

Ground water table not encountered

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

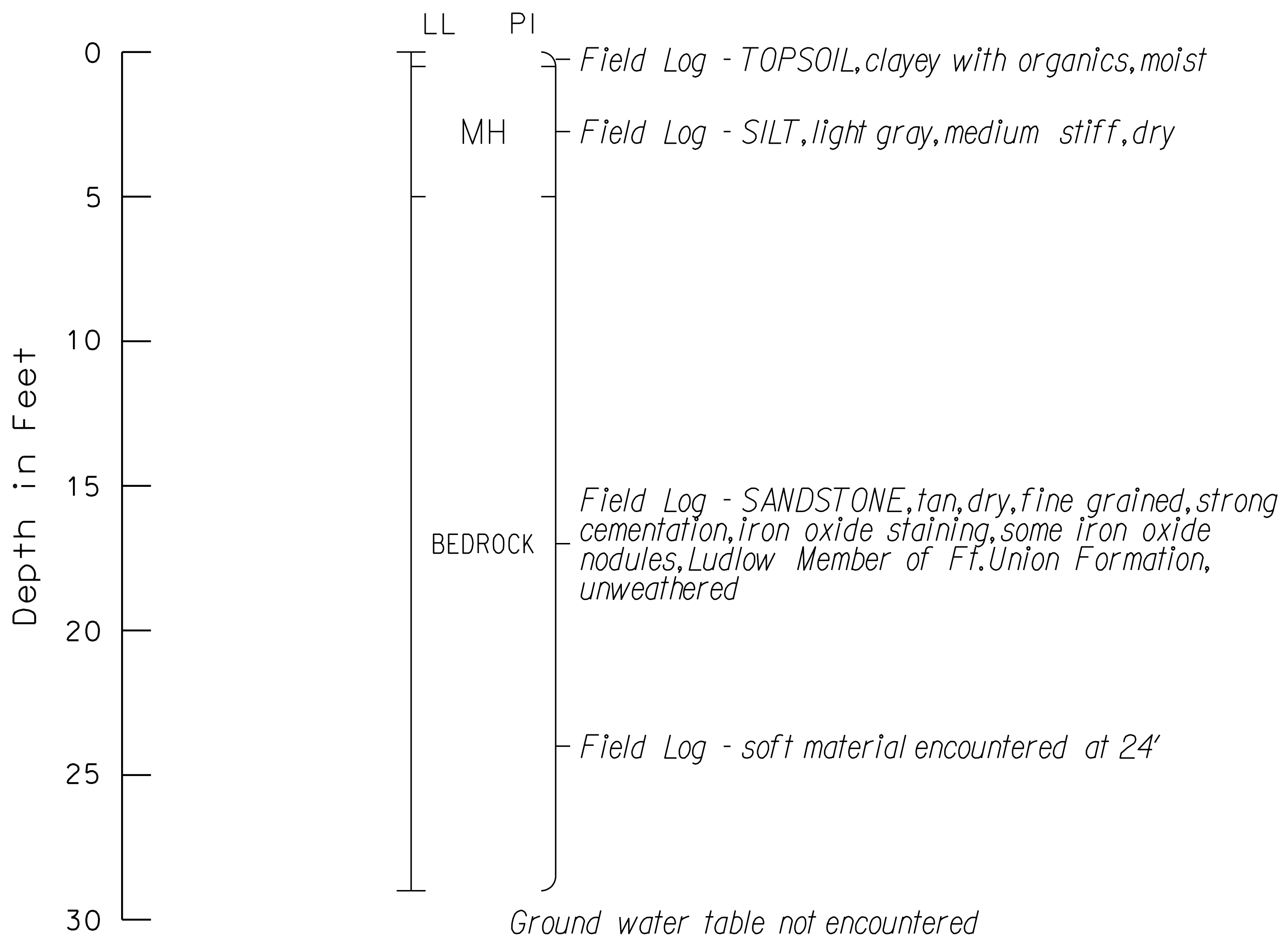
DESIGNED BY: C.A.F.
DWN BY: C.A.F.
CKD BY: T.J.M.
SUBMITTED BY: B.N.J.
FILE NAME: MM04GI113
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER:
PLOT DATE: 8/11/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

SOIL BORING LOGS
DRILL HOLES IMT12-20 THROUGH IMT12-25

SHEET
IDENTIFICATION
NUMBER
GI113

IMT12-26
Oct. 25, 2012



Field Log - TOPSOIL, clayey with organics, moist

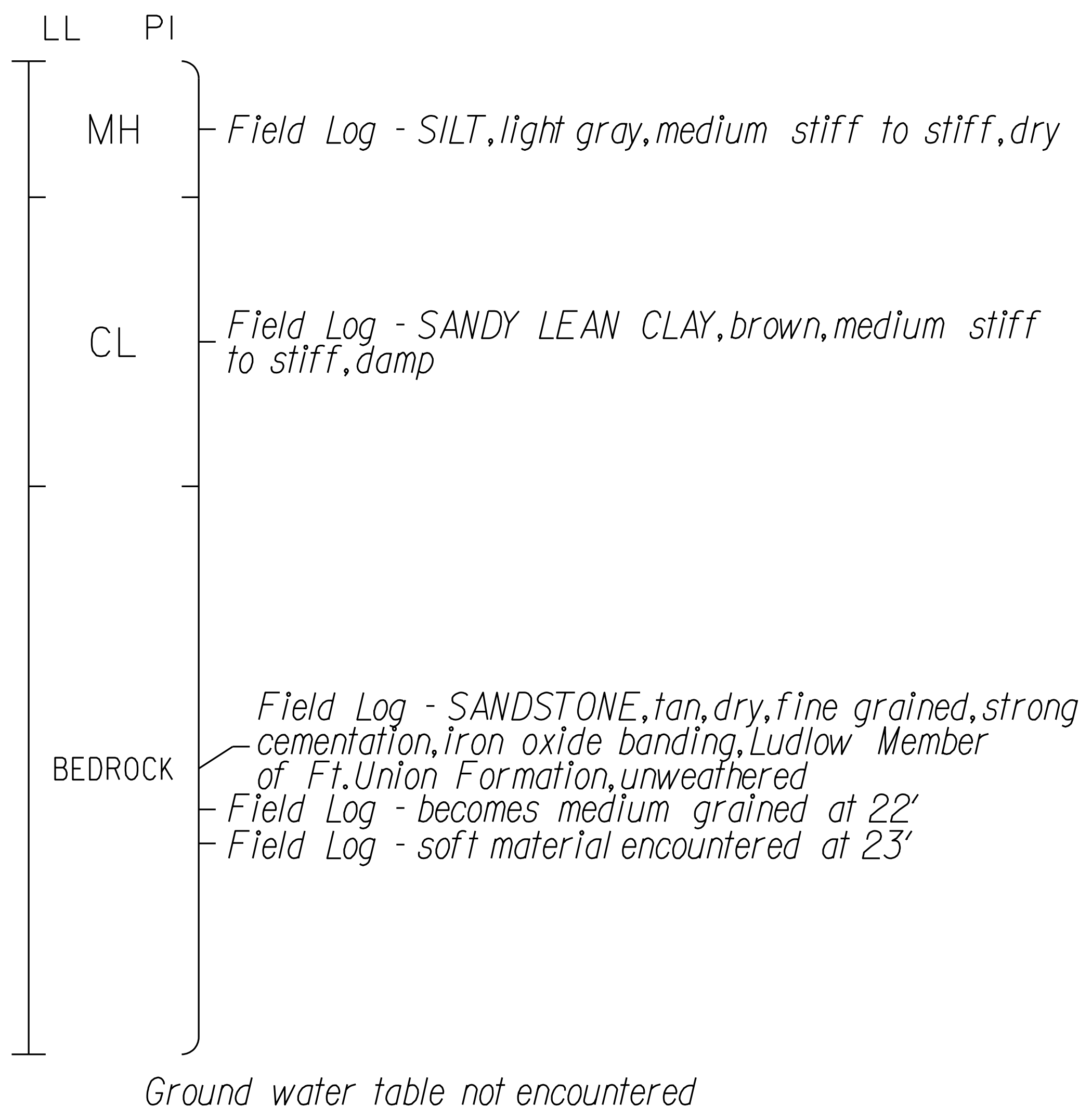
Field Log - SILT, light gray, medium stiff, dry

Field Log - SANDSTONE, tan, dry, fine grained, strong cementation, iron oxide staining, some iron oxide nodules, Ludlow Member of Ft. Union Formation, unweathered

Field Log - soft material encountered at 24'

Ground water table not encountered

IMT12-27
Oct. 26, 2012



Field Log - SILT, light gray, medium stiff to stiff, dry

Field Log - SANDY LEAN CLAY, brown, medium stiff to stiff, damp

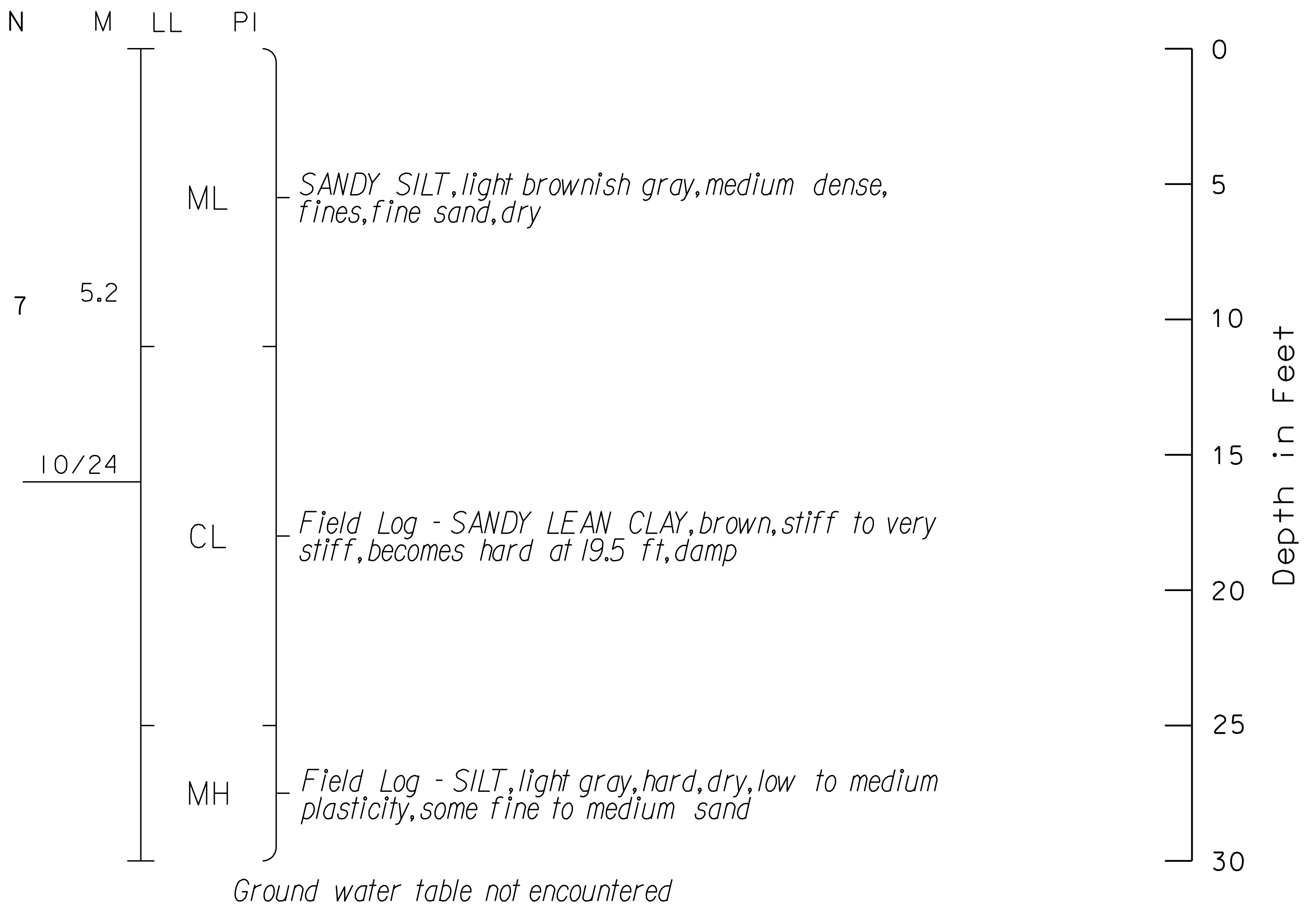
Field Log - SANDSTONE, tan, dry, fine grained, strong cementation, iron oxide banding, Ludlow Member of Ft. Union Formation, unweathered

Field Log - becomes medium grained at 22'

Field Log - soft material encountered at 23'

Ground water table not encountered

IMT12-28
Oct. 24, 2012



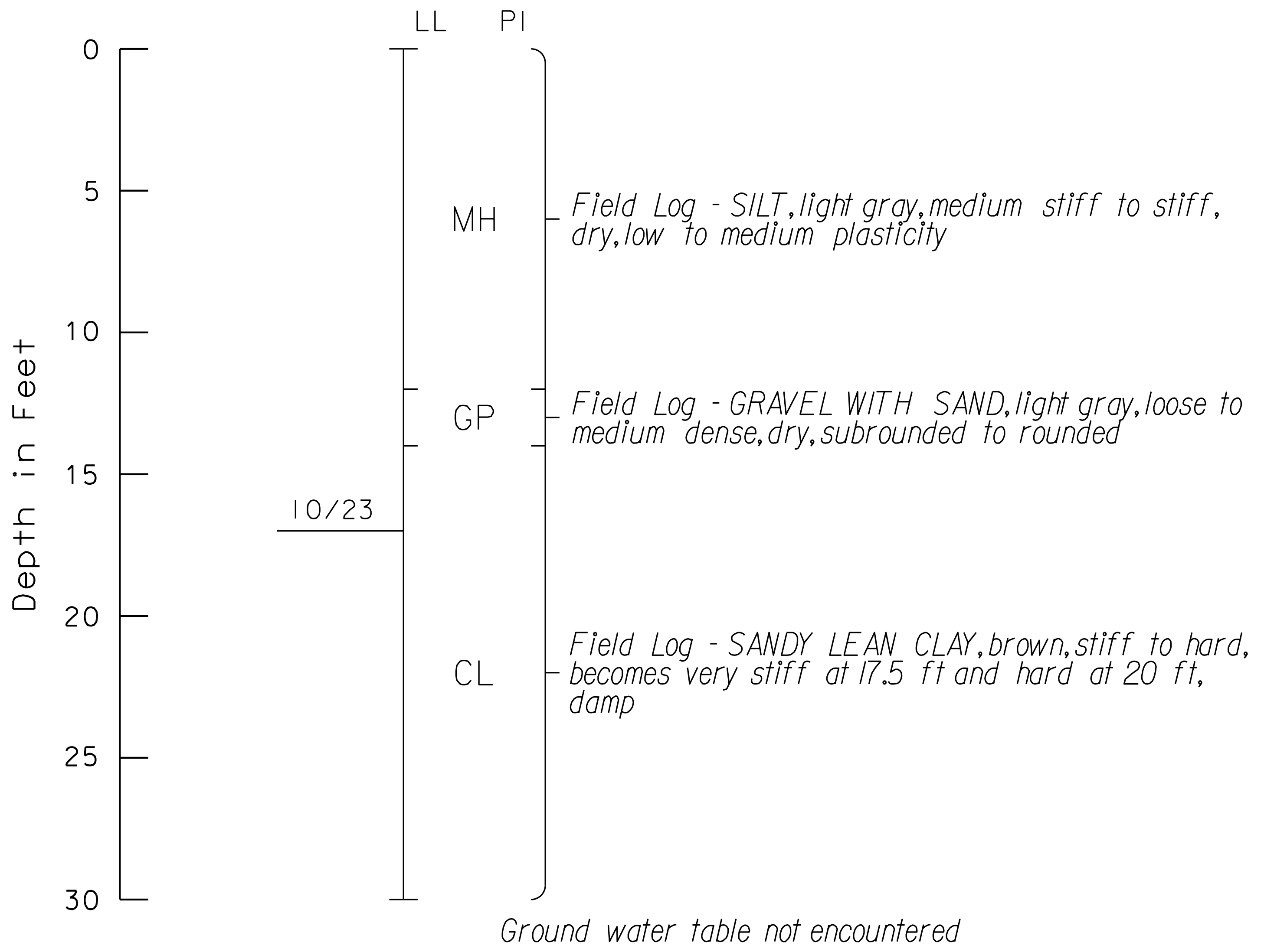
SANDY SILT, light brownish gray, medium dense, fines, fine sand, dry

Field Log - SANDY LEAN CLAY, brown, stiff to very stiff, becomes hard at 19.5 ft, damp

Field Log - SILT, light gray, hard, dry, low to medium plasticity, some fine to medium sand

Ground water table not encountered

IMT12-29
Oct. 23, 2012



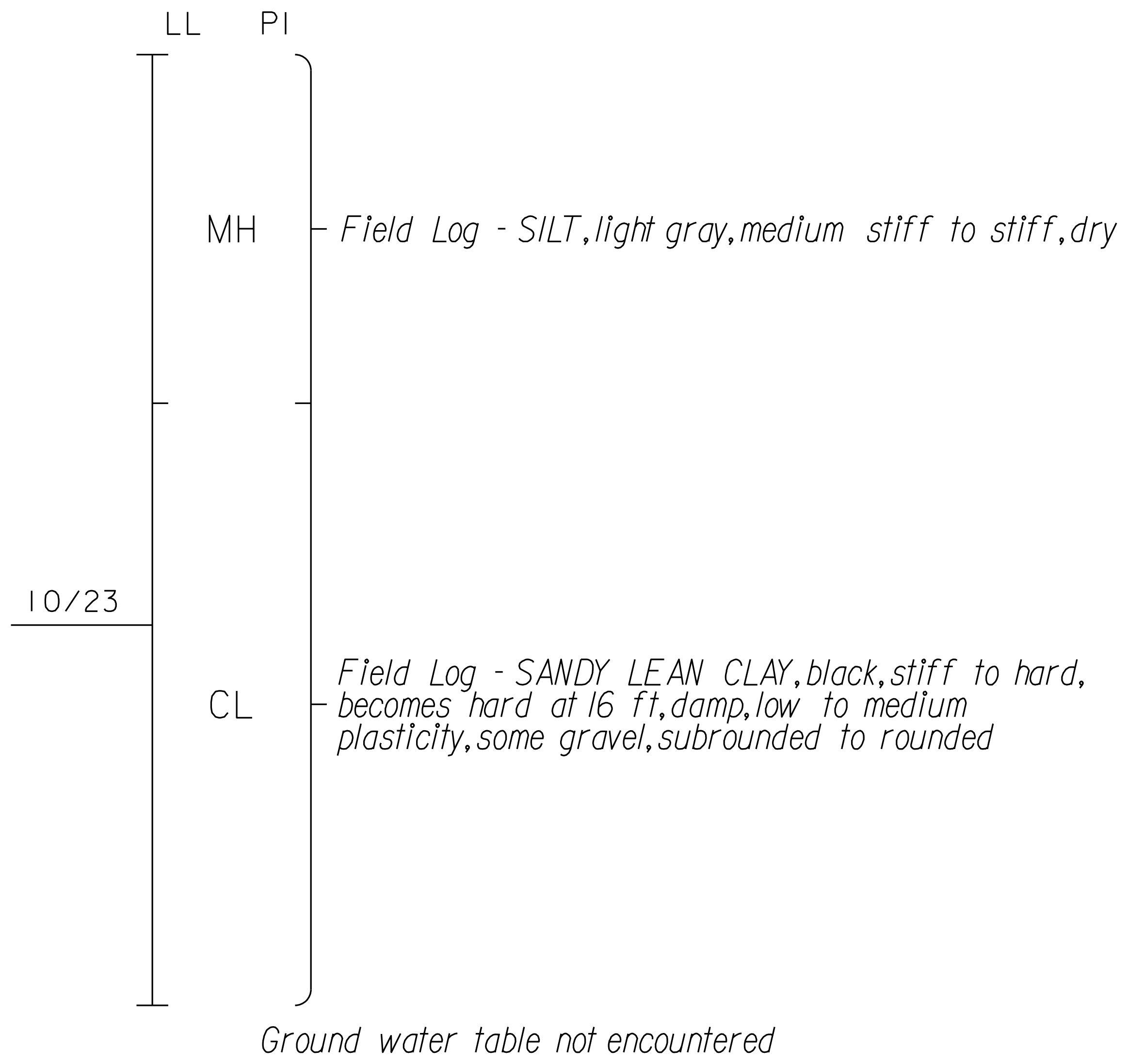
Field Log - SILT, light gray, medium stiff to stiff, dry, low to medium plasticity

Field Log - GRAVEL WITH SAND, light gray, loose to medium dense, dry, subrounded to rounded

Field Log - SANDY LEAN CLAY, brown, stiff to hard, becomes very stiff at 17.5 ft and hard at 20 ft, damp

Ground water table not encountered

IMT12-30
Oct. 23, 2012

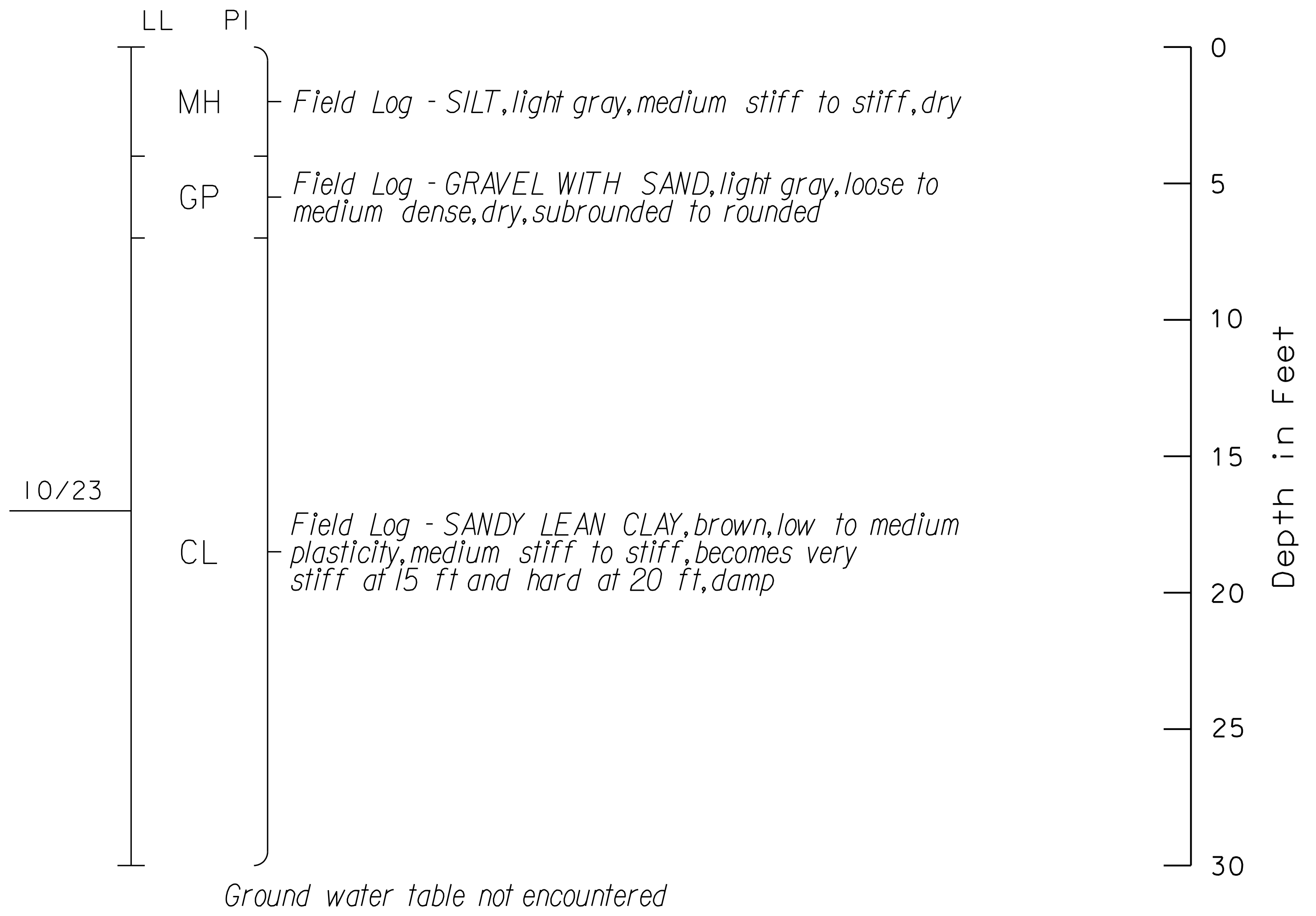


Field Log - SILT, light gray, medium stiff to stiff, dry

Field Log - SANDY LEAN CLAY, black, stiff to hard, becomes hard at 16 ft, damp, low to medium plasticity, some gravel, subrounded to rounded

Ground water table not encountered

IMT12-31
Oct. 23, 2012



Field Log - SILT, light gray, medium stiff to stiff, dry

Field Log - GRAVEL WITH SAND, light gray, loose to medium dense, dry, subrounded to rounded

Field Log - SANDY LEAN CLAY, brown, low to medium plasticity, medium stiff to stiff, becomes very stiff at 15 ft and hard at 20 ft, damp

NOTE: SEE SHEET GI103 FOR BORING LEGEND AND NOTES

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: C.A.F.		DATE: JAN. 2008
DWN BY: C.A.F.	CKD BY: T.J.M.	SOLICITATION NO.: W9128F-0X-X-00XX
SUBMITTED BY: B.N.J.		CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: MM04GI114		FILE NUMBER:
SIZE: 33.1X22	PLOT SCALE: 0.0833 ft / in.	PLOT DATE: 8/11/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

SOIL BORING LOGS
DRILL HOLES IMT12-26 THROUGH IMT12-31

SHEET
IDENTIFICATION
NUMBER
GI114

pw:\\NWO-AP01OMA.nwo.ds.usace.army.mil:CENWO - Omaha District\Documents\Civil Works\United States of America\Missouri River Basin\Yellowstone River\Intake, MT\30500 - Construction E&D\MM04 - Intake Fish Passage\30DA0 - Plans & Specs\dwgs\geotech\MM04GI114

g6edxcas

US Army Corps
of Engineers
Omaha District

PLANS FOR LOWER YELLOWSTONE RIVER INTAKE DAM FISH BYPASS CHANNEL & CREST WEIR

INTAKE
MONTANA

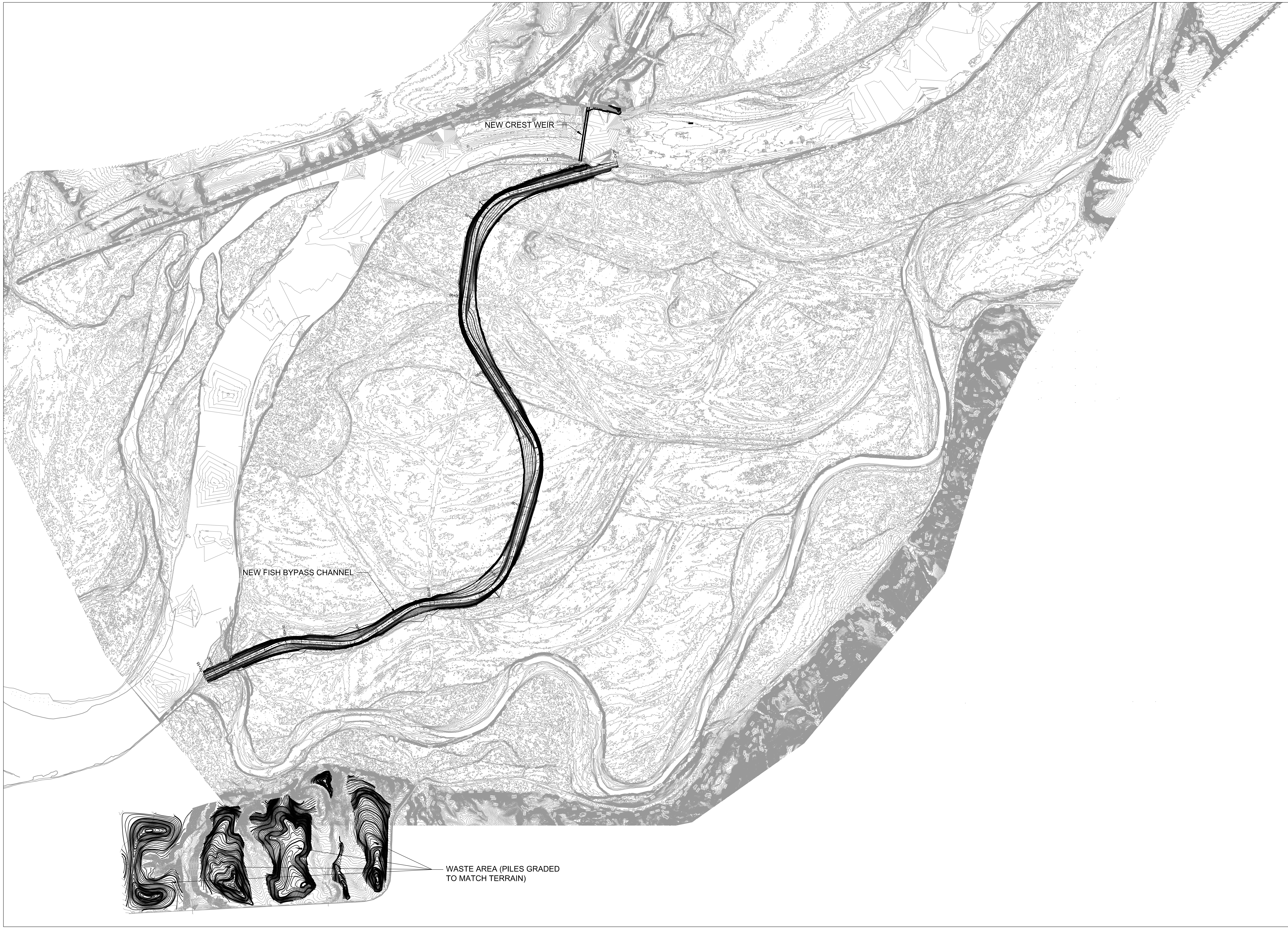
THIS PROJECT WAS DESIGNED BY THE OMAHA DISTRICT OF THE US ARMY CORPS OF ENGINEERS. THE INITIALS OR SIGNATURES AND REGISTRATION DESIGNATIONS OF INDIVIDUALS APPEAR ON THESE PROJECT DOCUMENTS WITHIN THE SCOPE OF THEIR EMPLOYMENT AS REQUIRED BY ER 1110-1-8152.

THE FOLLOWING SIGNATURES BELOW INDICATE OFFICIAL APPROVAL OF ALL DRAWINGS IN THIS SET DATED __________

SUBMITTED BY: CHIEF: ARCH	RA SECTION
SUBMITTED BY: CHIEF: CIVIL	PE SECTION
SUBMITTED BY: CHIEF: ELECT	PE SECTION
SUBMITTED BY: CHIEF: ENVIR	PE SECTION
SUBMITTED BY: CHIEF: MECH	PE SECTION
SUBMITTED BY: CHIEF: PLANS/SPECS	PE SECTION
SUBMITTED BY: CHIEF: STRUCT/INTER	PE SECTION
SUBMITTED BY: CHIEF: GEOT	PE SECTION

US Army Corps
of Engineers
Omaha District

60%
AUGUST 2014



US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: TJM
DATE: JAN. 2008
DWN BY: BMG
CKD BY: TJM
SOLICITATION NO.: W9128F-0X-X-00XX
SUBMITTED BY: BNJ
CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: mm04-gplan2012.dgn
FILE NUMBER: X
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
PLOT DATE: 8/25/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

CONSTRUCTION LIMITS

SHEET
IDENTIFICATION
NUMBER
G-001

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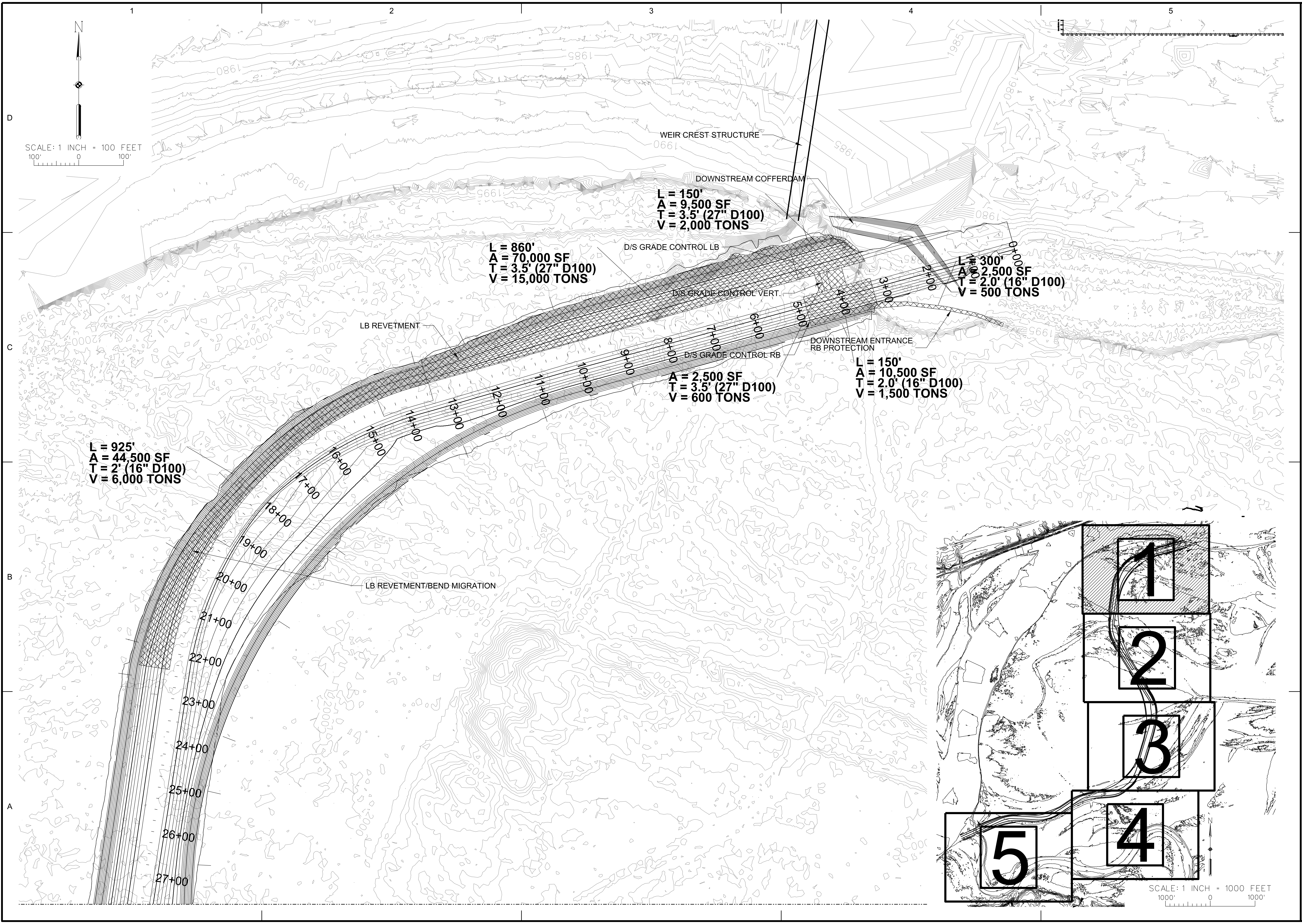
g6edxtjm



H:\Intake 60% Design\MM04-CG101.dgn

g6edxtjm

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

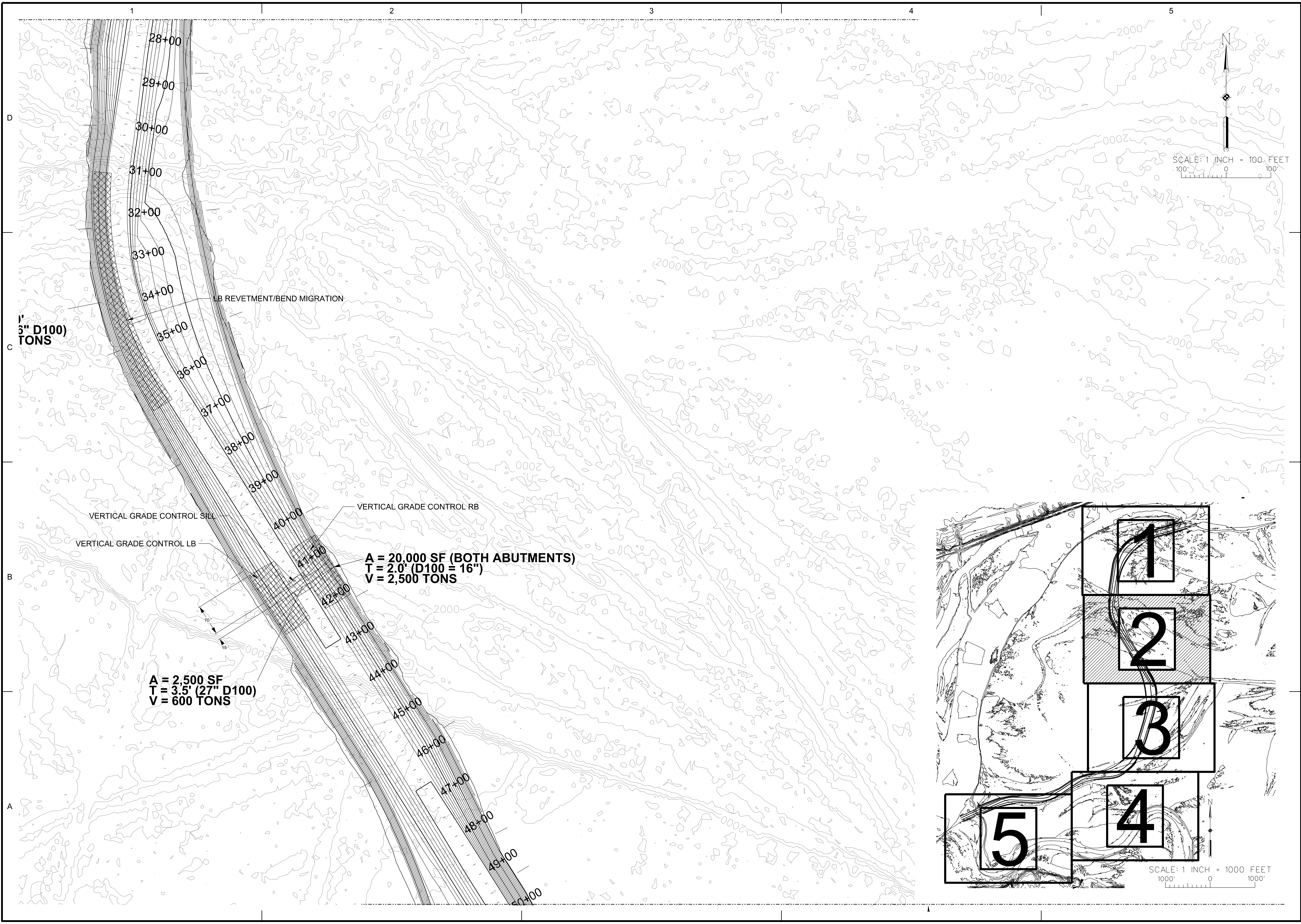
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: TJM
DWN BY: BMG
CKD BY: TJM
SUBMITTED BY: BNJ
FILE NAME: MM04-CG101.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER: X
PLOT DATE: 8/27/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

GRADING PLAN
AREA 1

SHEET
IDENTIFICATION
NUMBER
CG101



H:\Intake 60% Design\MM04-CG102.dgn

g6edxtjm

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY:
TJM

DWN BY:
BMG

CKD BY:
TJM

SUBMITTED BY:
BNJ

FILE NAME:
MM04-CG102.dgn

SIZE:
33.1X22

PLOT SCALE:
0.0833 ft / in.

DATE:
JAN. 2008

SOLICITATION NO.:
W9128F-0X-X-00XX

CONTRACT NO.:
W9128F-0X-C-00XX

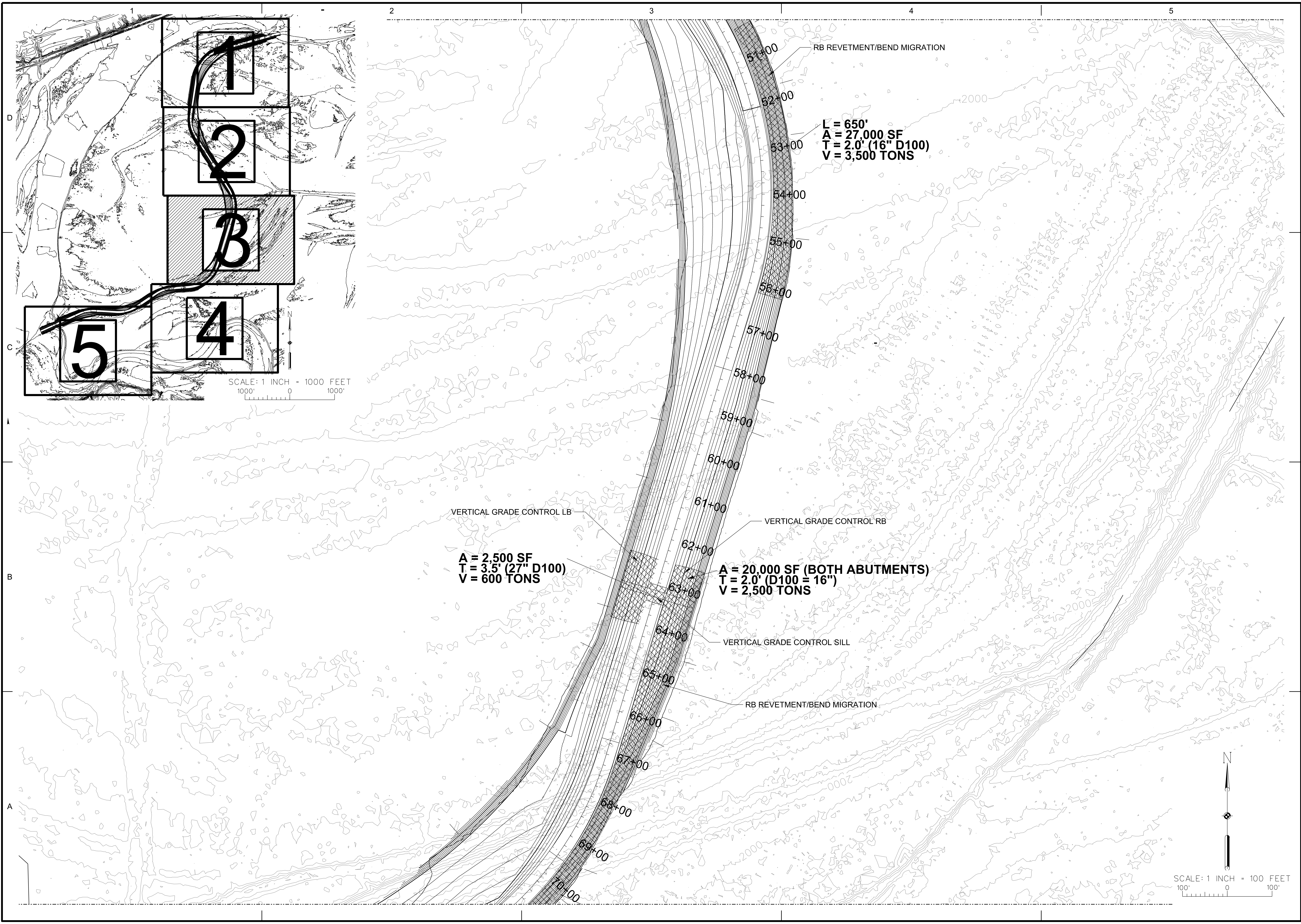
FILE NUMBER:
X

PLOT DATE:
8/27/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

GRADING PLAN
AREA 2

SHEET
IDENTIFICATION
NUMBER
CG102



H:\Intake 60% Design\MM04-CG103.dgn

g6edxtjm

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

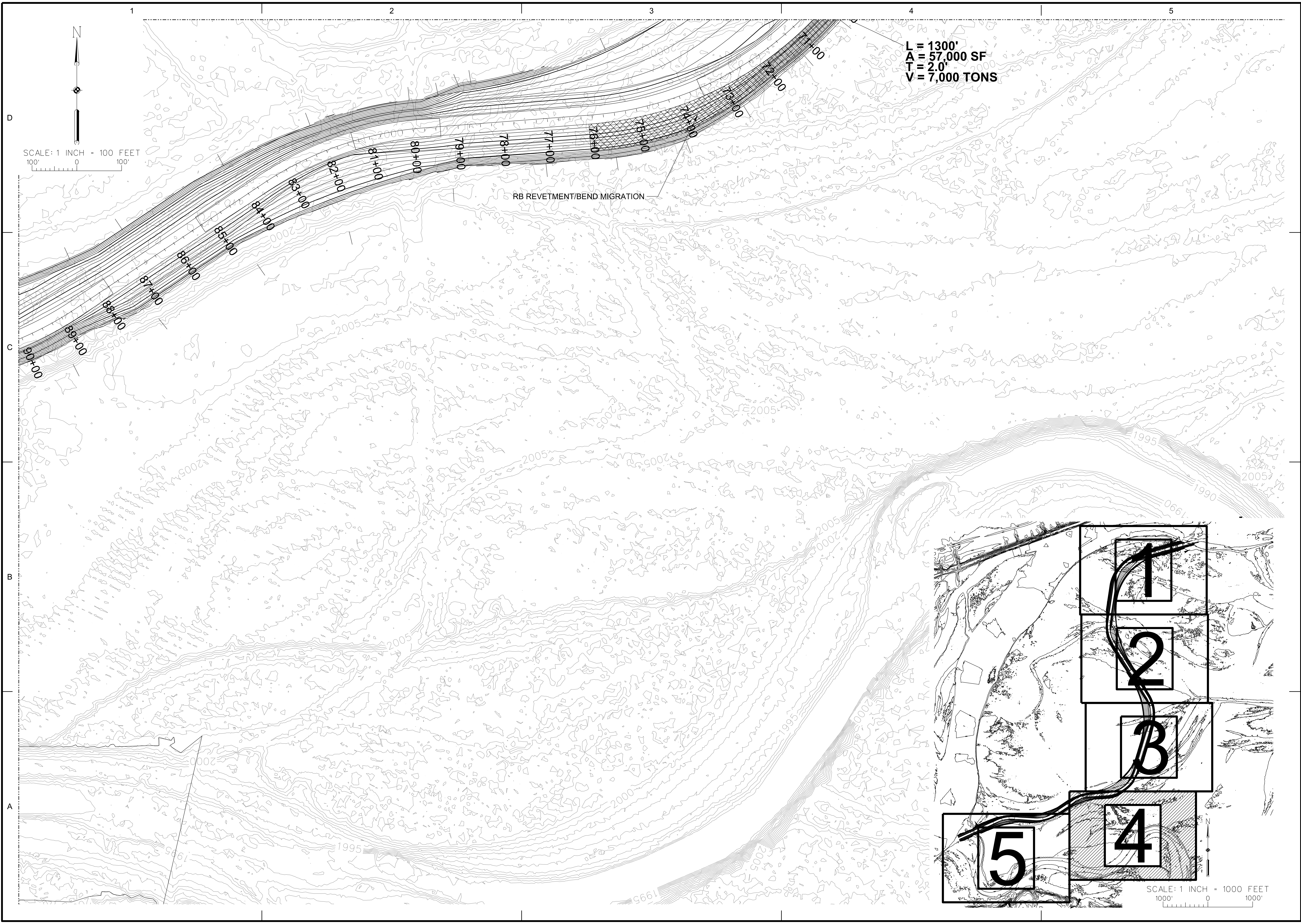
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: TJM	DATE: JAN. 2008
DWN BY: BMG	CKD BY: TJM
SOLICITATION NO.: W9128F-0X-X-00XX	
SUBMITTED BY: BNJ	CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: MM04-CG103.dgn	FILE NUMBER: X
SIZE: 33.1X22	PLOT SCALE: 0.0833 ft / in.
PLOT DATE: 8/27/2014	

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

GRADING PLAN
AREA 3

SHEET
IDENTIFICATION
NUMBER
CG103



H:\Intake 60% Design\MM04-CG104.dgn

g6edxtjm

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY:
TJM

DWN BY:
BMG

CKD BY:
TJM

SUBMITTED BY:
BNJ

FILE NAME:
MM04-CG104.dgn

SIZE:
33.1X22

PLOT SCALE:
0.0833 ft / in.

DATE:
JAN. 2008

SOLICITATION NO.:
W9128F-0X-X-00XX

CONTRACT NO.:
W9128F-0X-C-00XX

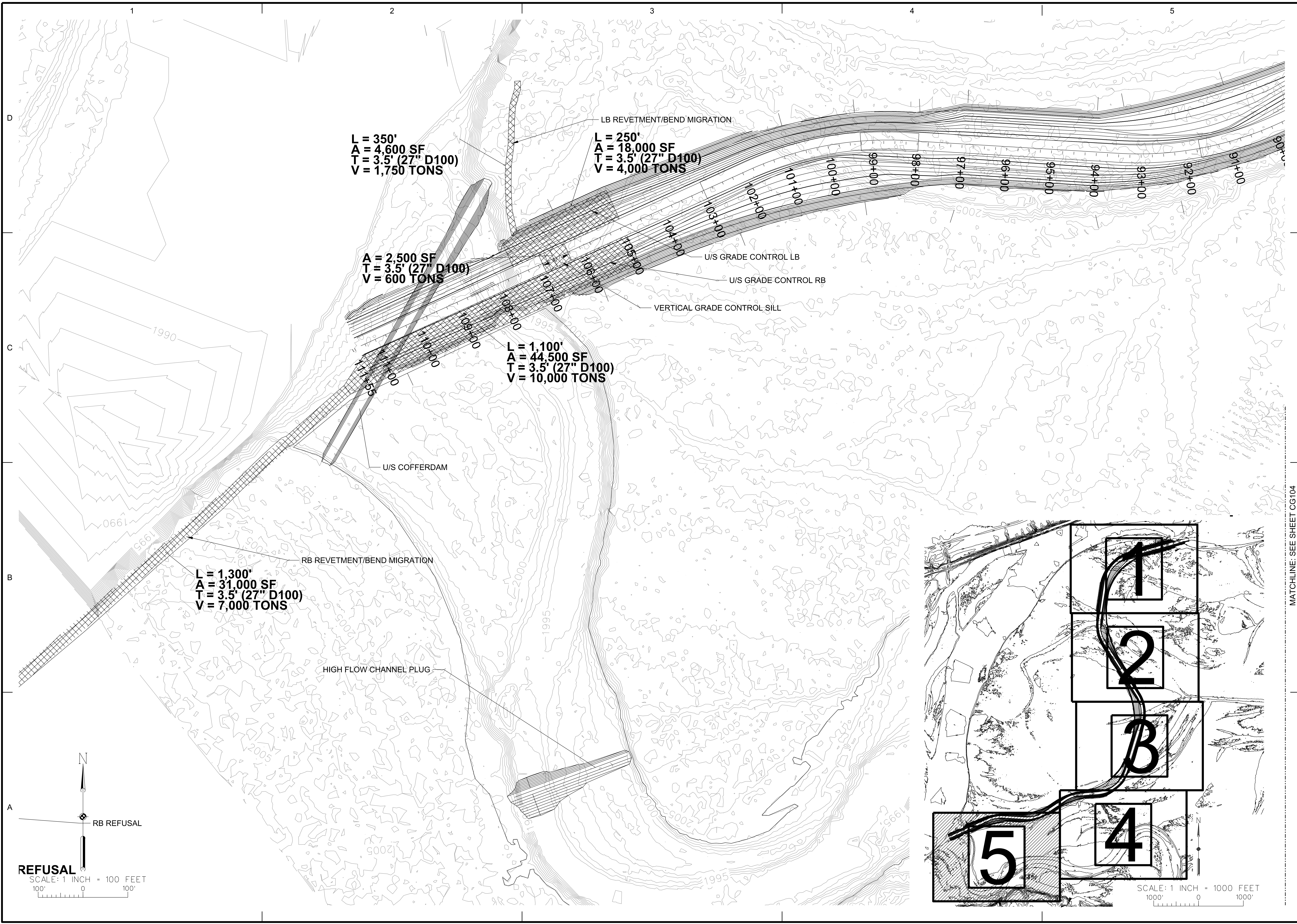
FILE NUMBER:
X

PLOT DATE:
8/27/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

GRADING PLAN
AREA 4

SHEET
IDENTIFICATION
NUMBER
CG104



H:\Intake 60% Design\MM04-CG105.dgn

g6edxtjm

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY:
TJM

DATE:
JAN. 2008

DWN BY:
BMG

CKD BY:
TJM

SOLICITATION NO.:
W9128F-0X-X-00XX

SUBMITTED BY:
BNJ

CONTRACT NO.:
W9128F-0X-C-00XX

FILE NAME:
MM04-CG105.dgn

FILE NUMBER:
X

SIZE:
33.1X22

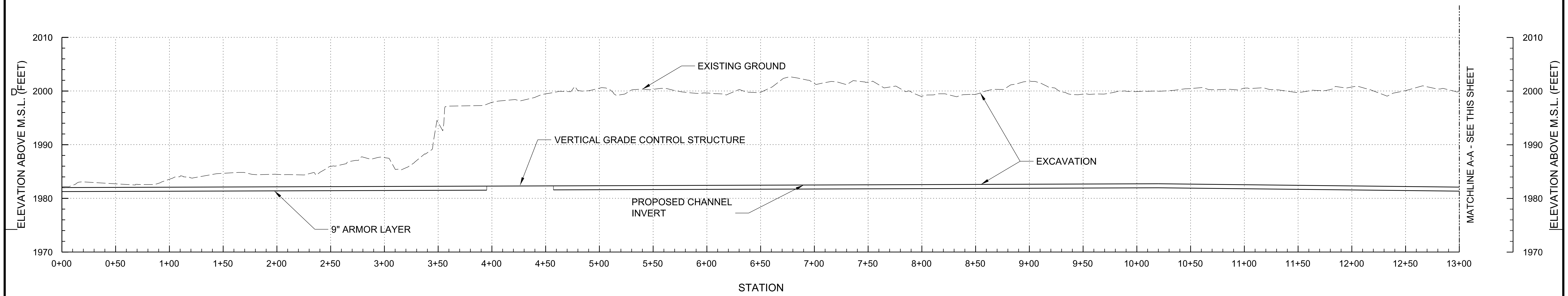
PLOT SCALE:
0.0833 ft / in.

PLOT DATE:
8/27/2014

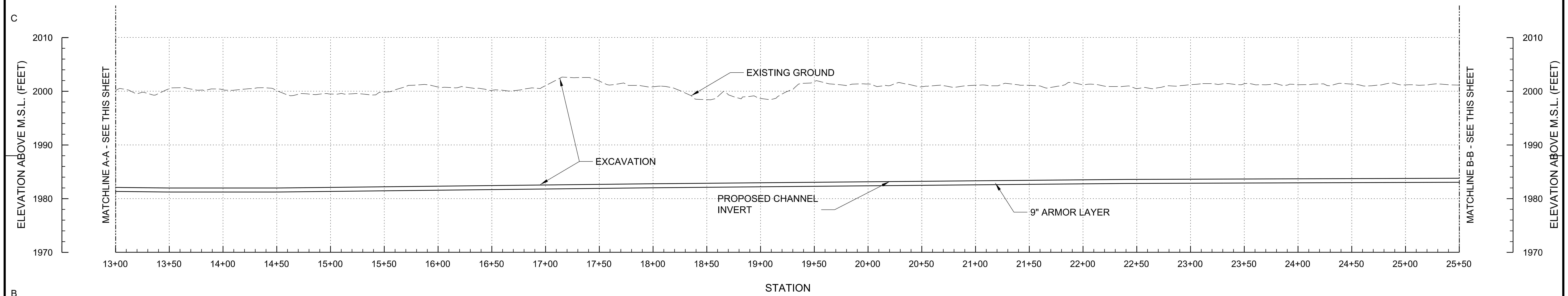
LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

GRADING PLAN
AREA 5

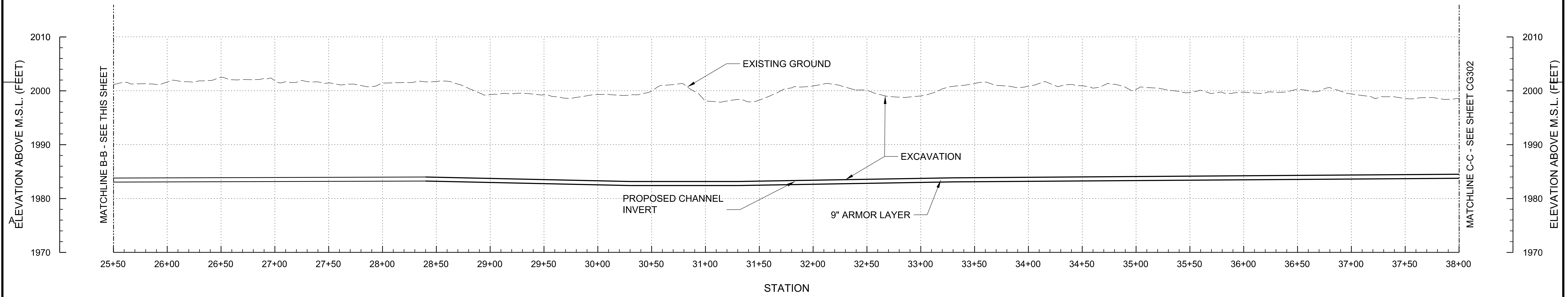
SHEET
IDENTIFICATION
NUMBER
CG105



FISH BYPASS CHANNEL STA. 0+00 TO 13+00



FISH BYPASS CHANNEL STA. 13+00 TO 25+50



FISH BYPASS CHANNEL STA. 25+50 TO 38+00

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g6edxtjm

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

DESIGNED BY:
TJM

DWN BY:
BMG

CKD BY:
TJM

SUBMITTED BY:
BNJ

FILE NAME:
MM04-CG301.dgn

SIZE:
33.1X22

PLOT SCALE:
0.0833 ft / in.

DATE:
JAN. 2008

SOLICITATION NO.:
W9128F-0X-X-00XX

CONTRACT NO.:
W9128F-0X-C-00XX

FILE NUMBER:
X

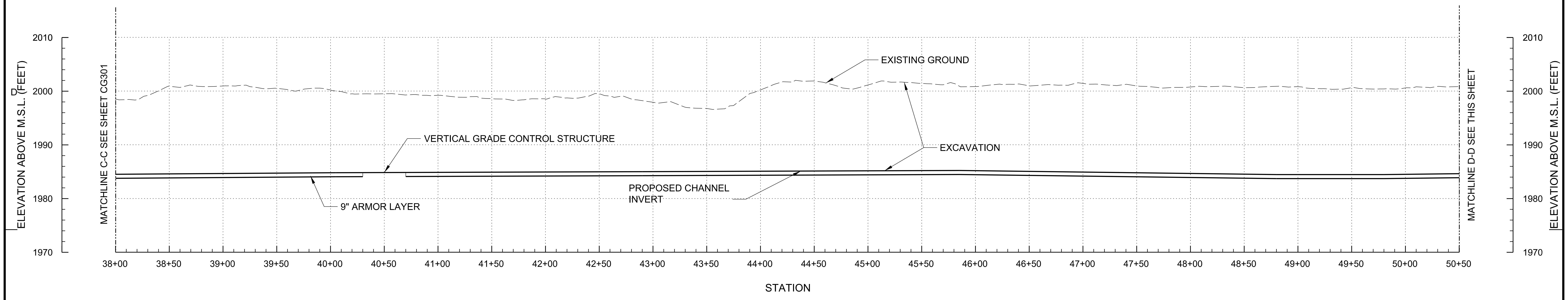
PLOT DATE:
8/19/2014

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

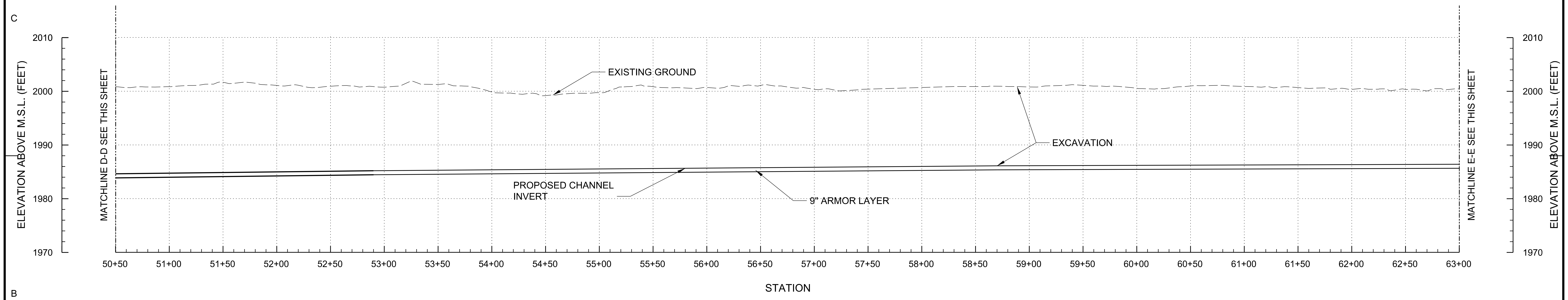
LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

FISH BYPASS CHANNEL PROFILE
STA. 0+00 TO 38+00

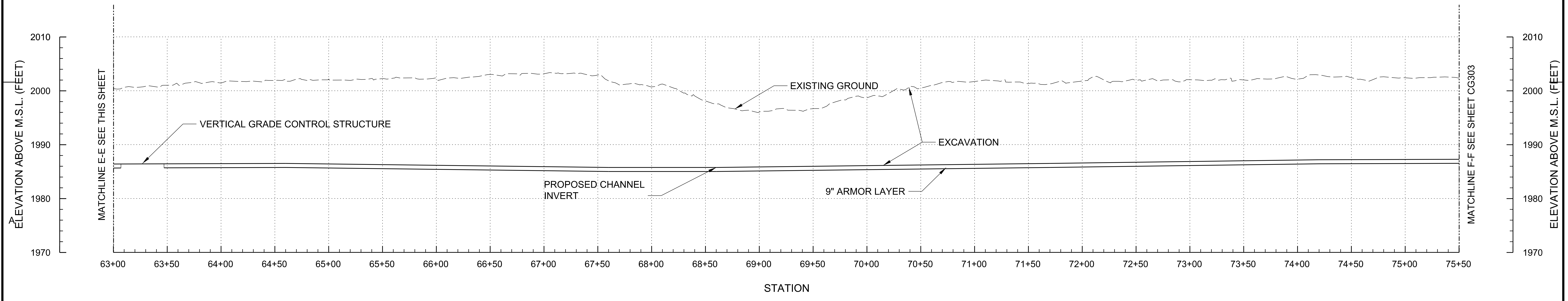
SHEET
IDENTIFICATION
NUMBER
CG301



FISH BYPASS CHANNEL STA. 38+00 TO 50+50



FISH BYPASS CHANNEL STA. 50+50 TO 63+00



FISH BYPASS CHANNEL STA. 63+00 TO 75+50

US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: TJM
DWN BY: BMG
CKD BY: TJM
SUBMITTED BY: BNJ
FILE NAME: MM04-CG302.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER: X
PLOT DATE: 8/19/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

FISH BYPASS CHANNEL PROFILE
STA. 38+00 TO 75+50

SHEET
IDENTIFICATION
NUMBER
CG302

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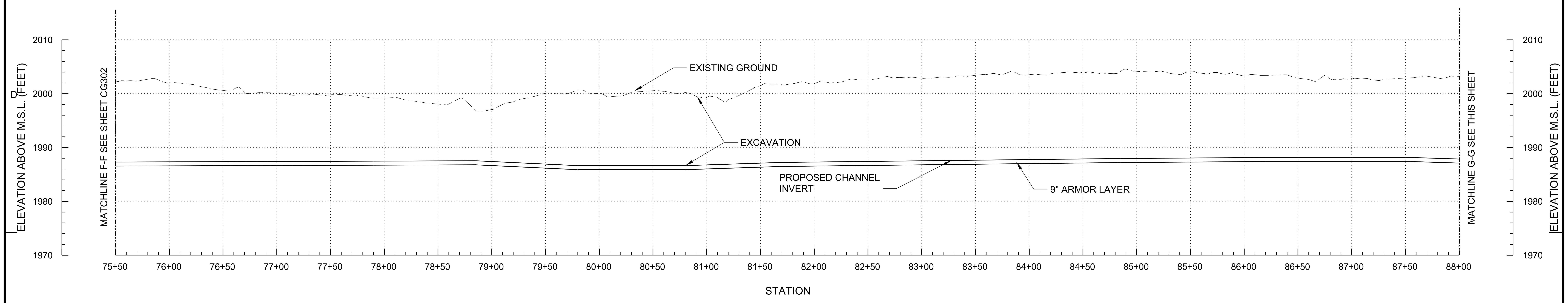
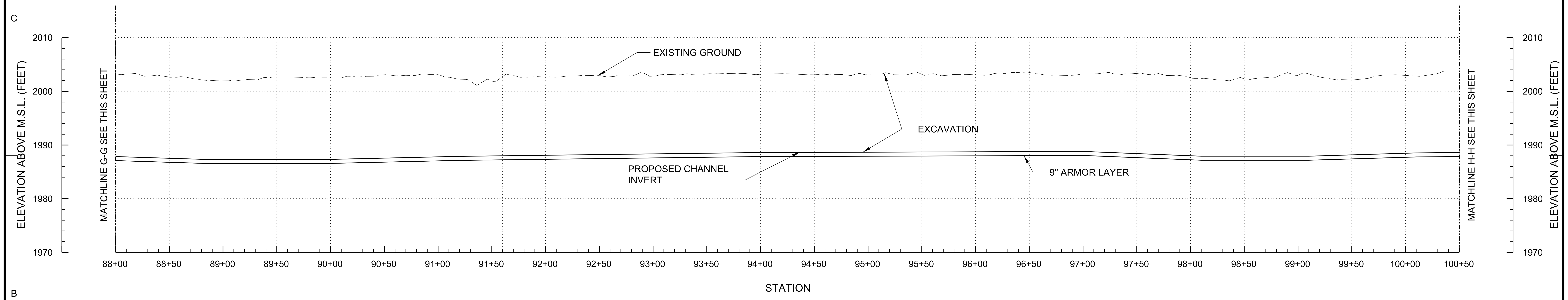
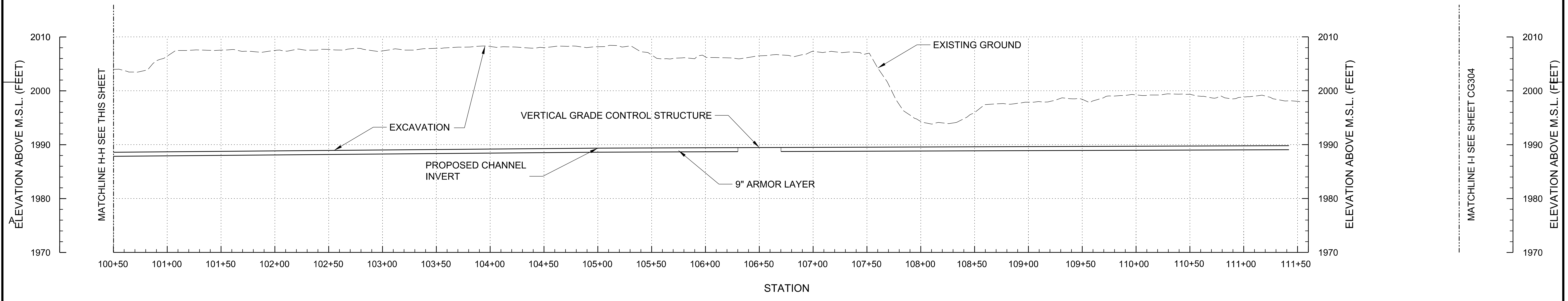


FISH BYPASS CHANNEL STA. 75+50 TO 88+00



B

FISH BYPASS CHANNEL STA. 88+00 TO 100+50



FISH BYPASS CHANNEL STA. 100+50 TO 111+50

H:\Intake 60% Design\MM04-CG303.dgn

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US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR.

MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

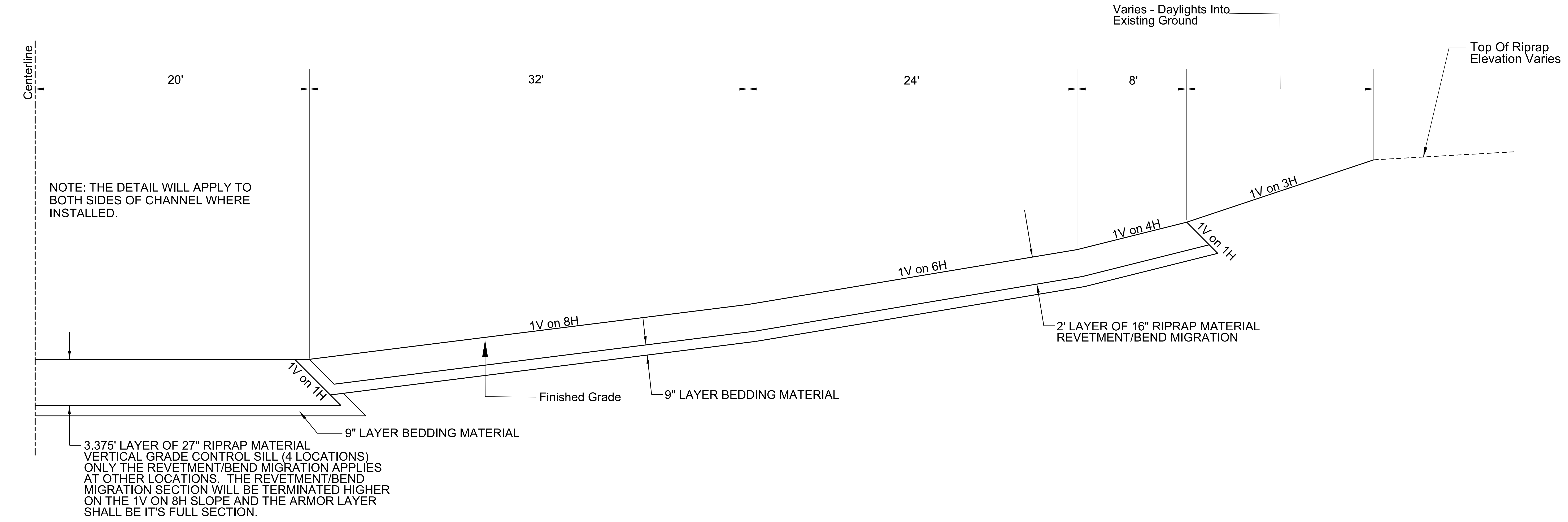
DESIGNED BY: TJM
DWN BY: BMG
CKD BY: TJM
SUBMITTED BY: BNJ
FILE NAME: MM04-CG303.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER: X
PLOT DATE: 8/19/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

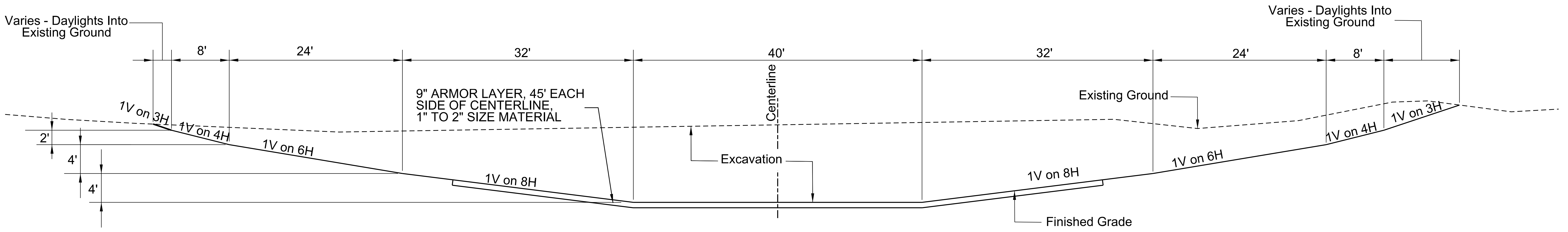
FISH BYPASS CHANNEL PROFILE
STA. 75+50 TO 111+50

SHEET
IDENTIFICATION
NUMBER
CG303

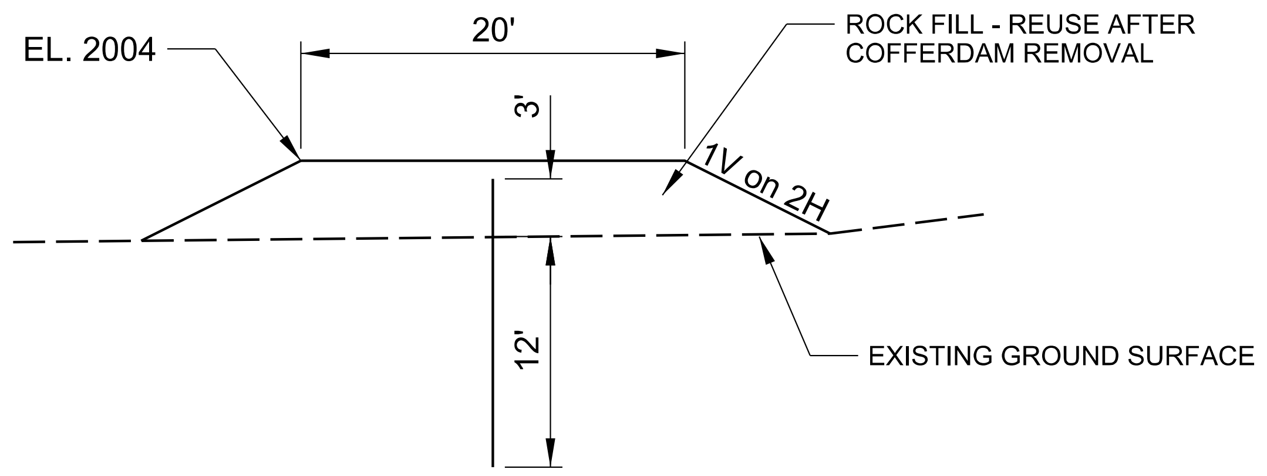
US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT



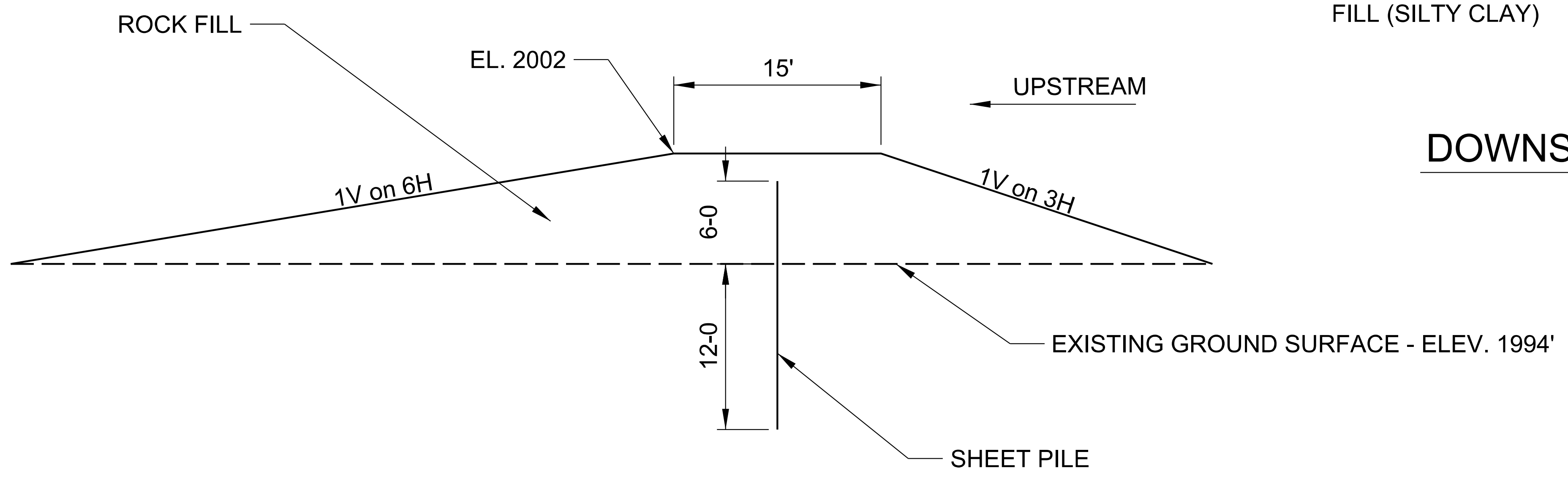
VERTICAL GRADE CONTROL & REVETMENT/BEND MIGRATION SECTION



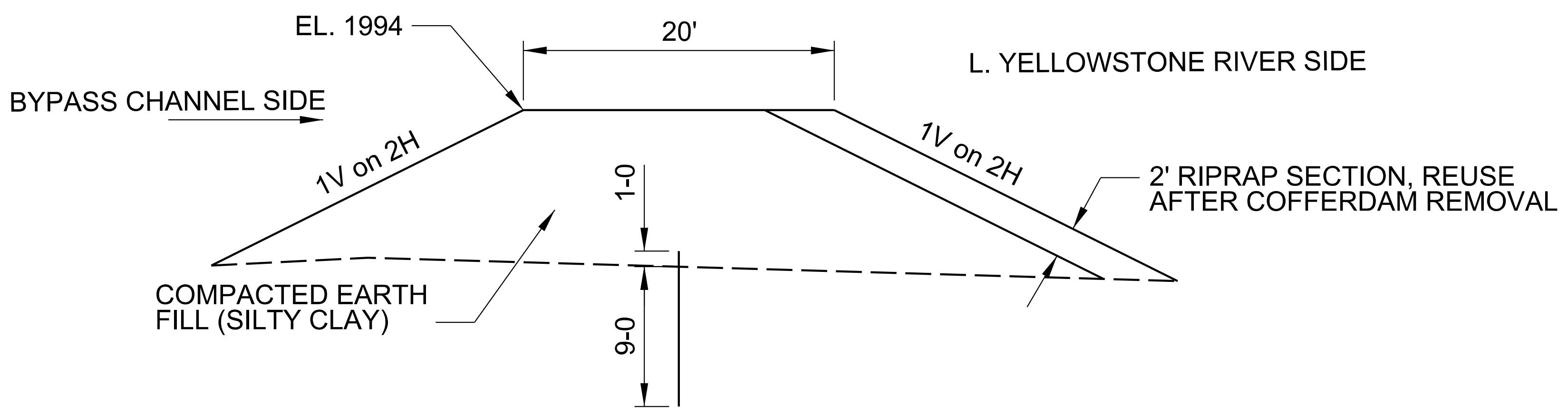
TYPICAL BYPASS CHANNEL SECTION & ARMOR LAYER DETAIL X



UPSTREAM COFFER DAM SECTION



HIGH FLOW CHANNEL BLOCK STRUCTURE SECTION



DOWNSTREAM COFFER DAM SECTION

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g6edxtjm

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

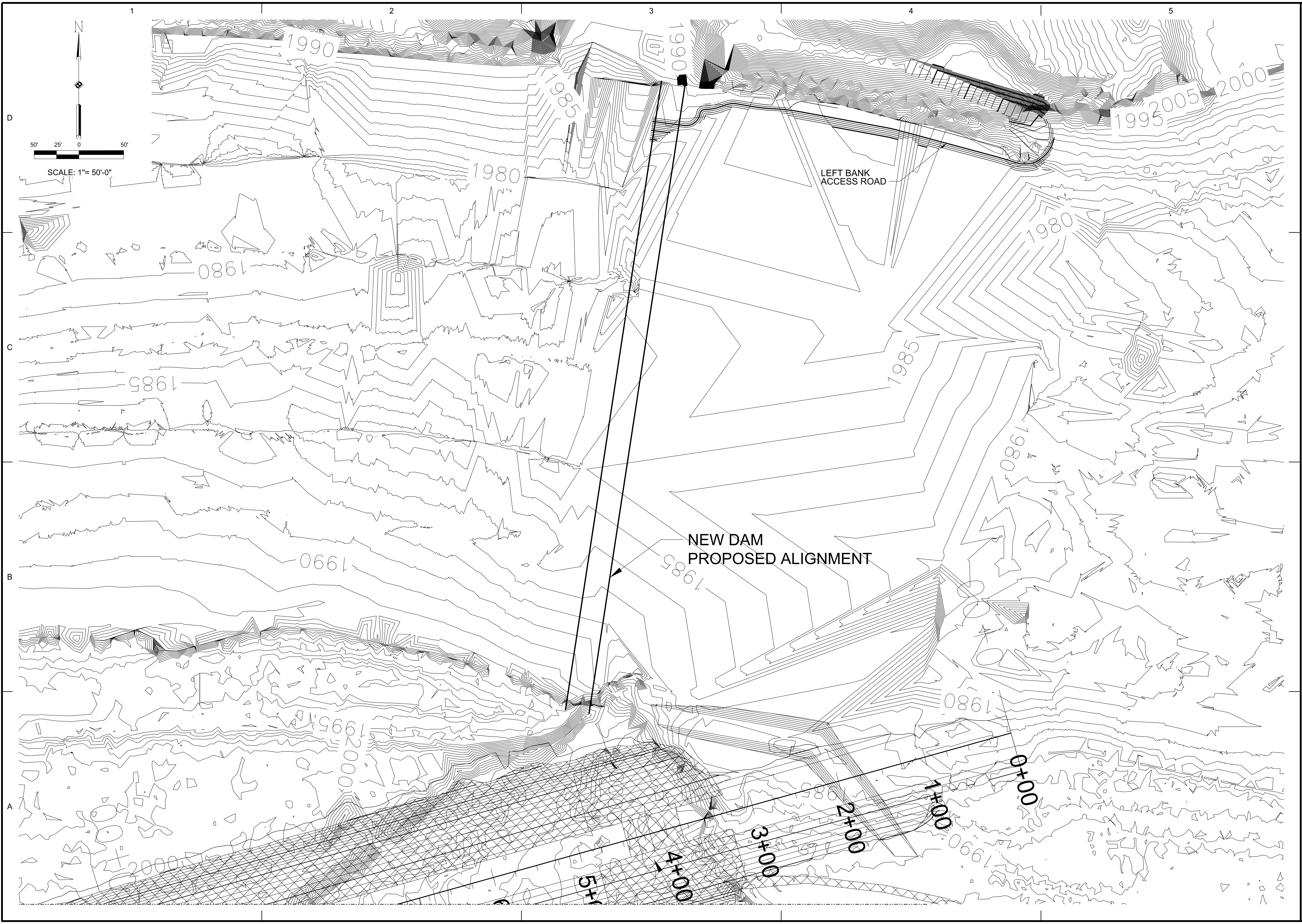
U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: TJM
DWN BY: BMG
CKD BY: TJM
SUBMITTED BY: BNJ
FILE NAME: MM04-CG206.dgn
SIZE: 33.1X22
PLOT SCALE: 0.0833 ft / in.
DATE: JAN. 2008
SOLICITATION NO.: W9128F-0X-X-00XX
CONTRACT NO.: W9128F-0X-C-00XX
FILE NUMBER: X
PLOT DATE: 8/19/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

FISH BYPASS CHANNEL
TYPICAL BYPASS CHANNEL SECTION
& LATERAL STABILITY STRUCTURE DETAILS

SHEET
IDENTIFICATION
NUMBER
CG206



US ARMY CORPS
OF ENGINEERS
OMAHA DISTRICT

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

U. S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS

DESIGNED BY: TJM		DATE: JAN. 2008
DWN BY: BMG	CKD BY: TJM	SOLICITATION NO.: W9128F-0X-X-00XX
SUBMITTED BY: BNJ		CONTRACT NO.: W9128F-0X-C-00XX
FILE NAME: MM04-CG207.dgn		FILE NUMBER: X
SIZE: 33.1X22	PLOT SCALE: 0.0833 ft / in.	PLOT DATE: 8/25/2014

LOWER YELLOWSTONE RIVER
FISH BYPASS CHANNEL
INTAKE, MONTANA

GRADING PLAN
LEFT BANK ACCESS ROAD

SHEET
IDENTIFICATION
NUMBER
CG207

H:\Intake 60% Design\MM04-CG207.dgn

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