



Project Memorandum

TO:	Donlin Gold LLC	REF:	PM-0011186.0068rev3
ATTENTION:	Nick Enos	DATE:	August 12, 2015
FROM:	Shielan Liu, Clint Logue	PROJ. NO.:	0011186-20
COPIES:	James Fuego		
SUBJECT:	Response to RFAI #62 Tailings Release Spill Scenarios		

1. INTRODUCTION

The US Army Corps of Engineers (Corps) is currently completing an Environmental Impact Statement (EIS) for the proposed Donlin Gold Project (Donlin). The Donlin Gold Project is owned by Donlin Gold LLC (Donlin Gold), and BGC Engineering Inc. (BGC) has been retained to provide ongoing engineering support. According to the Request for Additional Information (RFAI) #62, relating to an early stage Failure Modes and Effect Analysis (FMEA) on December 2 and 3, 2014 for the Proposed Action, the effects of the following tailings release spill scenarios for the Tailings Storage Facility (TSF) tailings dam were requested by AECOM (2015) to assess the associated impacts:

An unplanned release of up to two million cubic meters [1,620 acre-ft] of tailings and contaminated water from the TSF from either a partial breach of the dam and resulting downstream failure or a liner rupture leading to a sinkhole and outflow of tailings through the underdrain.

The results of modelling the spill scenario should be completed in sufficient detail to determine the following:

- Reasonable expectations for migration of tailings and water, such as the distance each would travel, the speed and deposition*
- Description of response actions that would be mounted, including equipment, methods to be used, and anticipated duration*
- A discussion of the effect of seasons on a response*
- Percentage of spilled material expected to be contaminated water and solids.*

This memorandum presents an inundation study for a partial dam breach due to piping and for a liner rupture reporting to the underdrain for the TSF tailings dam at the proposed Donlin Gold Project. Each of these spill scenarios were modelled as a release of process affected water only, and as a mixture of process affected water and tailings, resulting in a total of four spill scenarios.

As requested by AECOM, this study estimates the potential downstream consequences for the purpose of informing the EIS. As such, the analyses used to simulate the downstream consequences are, by design, conservative, and the derived response plans are judged to err on the side of caution, and in no way reflect on the structural integrity or safety of the TSF.

A volume of 1,620 acre-ft of tailings and process-affected water released in the spill scenarios requested by AECOM was chosen by the participants of the early stage FMEA. There is no technical basis for this volume, rather it was considered as representative of a significant release consistent with that described in the FMEA.

2. PROJECT SETTING

2.1. General

The Donlin Gold Project is located 277 miles west of Anchorage and 145 miles northeast of Bethel, Alaska. The proposed mine would produce 556 million tons of ore from the proposed open pit mining operations, at a nominal mill throughput rate of 59,000 tons per day for 365 days per year for approximately 27.5 years. A total of 334,300 acre-ft of tailings, 3.0 billion tons of waste rock, and 46.4 million tons of overburden are expected to be generated over the life of the project.

The village of Crooked Creek, located approximately 13 miles downstream of the project site at the confluence of Crooked Creek and the Kuskokwim River (Drawing 01), includes a permanent population of approximately 100 people. Snow Gulch, American Creek and Anaconda Creek, located from north to south at the proposed Donlin Gold project site, are tributaries of Crooked Creek and have approximate watershed areas of 2,270, 4,370 and 4,950 acres, respectively. The watershed area of Crooked Creek is approximately 215,060 acres at the confluence with the Kuskokwim River.

A USGS stream gauge was installed in July 2007 on Crooked Creek near the village of Crooked Creek (#15304010, 61°53'24", 158°09'16", 175 ft asl). Based on data recorded from October 2007 to April 2015 at this USGS station, the mean flow was approximately 50 cfs in the winter months (December to March), 650 cfs in the summer months (May to October), and the maximum recorded flow rate was approximately 7030 cfs on October 18th, 2013. Based on a site-wide water balance model (BGC, 2014) and USGS stream gauge data, the average monthly flows of Anaconda Creek at the confluence of Crooked Creek, Crooked Creek at the confluence with the Kuskokwim River, and the Kuskokwim River at the confluence of Crooked Creek, are summarized in Table 2-1.

Table 2-1. Average monthly flow (units: cfs).

Month	Anaconda Creek at Crooked Creek ¹	Crooked Creek at Kuskokwim River ²	Kuskokwim River at Crooked Creek ²
January	0.6	50	13,300
February	0.7	40	11,800
March	1.0	35	10,800
April	3.5	226	16,100
May	2.3	1290	81,800
June	1.9	604	79,800
July	2.2	445	67,000
August	4.5	569	74,000
September	4.6	644	67,300
October	3.1	357	46,100
November	1.5	133	22,900
December	0.8	72	15,900

Notes: 1. Values are based on BGC (2014).
2. Values are based on USGS stream gauge data.

2.2. TSF Configuration

The TSF will be used to store tailings and process affected water and is located south of the open pit in the Anaconda Creek watershed (Drawing 01). It will be constructed to a Starter Dam height of 198 ft for the start of operations, and raised using the downstream method of construction to its ultimate height of 471 ft incrementally over the mine life. At the end of operations, the TSF will contain 334,300 acre-feet of tailings and 24,000 acre-feet of process affected water. During the closure phase, the operating pond will be pumped to the open pit to facilitate dry closure of the TSF.

The TSF dam will be founded on bedrock and constructed of compacted rockfill and will be lined on its upstream face with 60 mil single-sided textured (down) linear low-density polyethylene (LLDPE) liner. The liner will be underlain by a 3 ft thick bedding layer, two 10 ft thick filter zones, and a 20 ft thick transition rockfill zone. The upstream face of the dam will be benched at each raise with local slopes of 2H:1V. The downstream slope of the dam will be 1.7H:1V.

The entire TSF impoundment area will be stripped of organics and ice-rich soils and lined with the same 60 mil LLDPE liner and 3 ft thick liner bedding layer as that of the TSF dam. An underdrain, comprising coarse processed rockfill with a mean diameter of 1.0 ft and wrapped in geofabric will be incorporated along topographic lows beneath the liner and liner bedding within the TSF impoundment area. The underdrain will be approximately 10 ft deep along the valley bottom, with an invert width of 3 ft, a maximum width of approximately 33 ft at the top and side slopes of 1.5H:1V.

3. TAILINGS SPILL SCENARIOS

As requested by AECOM, the tailings spill scenarios include a partial dam breach due to piping of the dam fill, and for a liner rupture reporting to the underdrain for the TSF. The modelled release volume for both scenarios is 1,620 acre-ft. Limited by the dimension of the underdrain channel, outflow of tailings through the underdrain due to a liner rupture would have a lower flow discharge rate compared to a piping breach.

Each potential spill scenario was modelled two ways: (1) as process affected water only; and (2) as a mix of tailings and water, to bracket the range of flow travel distances, flow velocities, and flow depths. For both spill scenarios, the tailings release location was assumed to be at the dam toe at the invert elevation of the underdrain channel. In both scenarios, the operating pond was assumed to be that corresponding to normal operating conditions, or 24,000 acre-ft at the time of the spill.

The tailings deposited at the bottom of the TSF were assumed to be fully consolidated at the end of operations. The solids concentration by volume of the tailings was estimated at approximately 50%. Therefore, the mixture of solid and water was assumed to have a constant sediment concentration by volume of approximately 50%.

For the scenario where tailings and water are released with a sediment concentration by volume of approximately 50%, the outflow would behave like a Bingham fluid with the flow resistance dominated by the dynamic viscosity and yield stress of the solids-water mixture. Given this, the tailings are expected to start depositing when traversing topography flatter than about 3°.

The scenarios modelled are summarized in Table 3-1.

Table 3-1. Scenarios modelled.

Scenario Number	Scenario Description
1	Partial piping breach under normal operating conditions, tailings and water released
2	Partial piping breach under normal operating conditions, only water released
3	Liner rupture leading to underdrain flow, tailings and water released
4	Liner rupture leading to underdrain flow, only water released

4. MODEL METHODOLOGY

FLO-2D, a U.S. Federal Emergency Management Agency (FEMA) approved two-dimensional hydraulic model, was selected for this study because of its ability to model both tailings (slurry) and “clear water” flow inundation processes.

FLO-2D is a depth-averaged, volume conservation based flood routing model that was developed specifically for the analysis of muddy flows travelling over complex 3D terrain, making it well-suited for tailings run out analysis. For a slurry with a volumetric sediment concentration greater than

20% (the estimated slurry concentration is expected to be approximately 50%), the flow resistance of the slurry is governed by a non-Newtonian quadratic rheological model. FLO-2D requires the input of several rheological parameters including the yield stress and viscosity of the slurry.

For flows with volumetric sediment concentrations less than 20%, the influence of the solids component on the rheology of the breaching fluid is considered negligible and the material is expected to flow like water. In this case, FLO-2D reverts to a conventional clear water flood routing model, in which the breaching fluid is treated as clear water and flow resistance is governed simply by surface roughness along the path. The surface roughness along the path is characterized by spatially-variable Manning n-values. Appropriate values can be selected from established hydraulic engineering tables (Chow, 1959).

The model requires an input hydrograph at the point of flow initiation generated from the piping breach analysis or underdrain flow estimate, in addition to a digital elevation model (DEM) of the potential inundation area. The results of the model include a summary file and a number of spatial data files showing, for example, the maximum and final flow depth and velocity recorded in each grid element during the simulated time span.

It is important to note that FLO-2D does not account for the influence of deep standing or flowing water along the path, including displacement waves which might occur upon impact by the flow front. This is not expected to materially affect the inundation model results as there are no pools of deep water along the flow path from Anaconda Creek to Crooked Creek, nor from Crooked Creek to the Kuskokwim River.

5. MODEL INPUTS AND ASSUMPTIONS

5.1. Released Tailings Flow Discharge Rate Estimate

Several assumptions were made to estimate the released tailings flow discharge rate, as described below:

- For a partial piping failure (Scenarios 1 and 2), the maximum pipe size was limited to 33 ft (width and height). The maximum pipe size was estimated based on the released volume requested by AECOM as described in Section 1.0, and is comparable to the maximum underdrain channel width of approximately 33 ft;
- The initial progression of the partial breach from a piping failure was omitted;
- When the tailings release starts for Scenarios 3 and 4, the rock fill material in the underdrain channel is eroded at the exit of the underdrain due to the high hydraulic pressure;
- Flow through a partial breach from a piping failure and a liner rupture resulting in underdrain flow are controlled by orifice flow assuming a water level at operational pond levels, approximately 6.6 ft lower than the ultimate main dam height; and

- Given the surface area of the ultimate TSF impoundment of approximately 2,390 acres, the water level drop during a 1,620 acre-ft release is considered to be negligible for orifice flow calculations.

The following equation, as presented in the BREACH (Fread, 1991) program, was used to calculate the orifice flow due to piping erosion at the downstream toe and a liner rupture resulting in underdrain flow.

$$Q = A \left[2g(H - H_p) / \left(1 + \frac{fL}{D} \right) \right]^{0.5} \quad [\text{Eq. 5-1}]$$

in which Q is the flow (cfs) through the pipe, g is the gravity acceleration constant, A is the cross-sectional area (ft²) of the pipe channel, (H-H_p) is the hydrostatic head (ft) on the pipe, L is the length (ft) of the pipe channel, D is the diameter or width (ft) of the pipe, and f is the Darcy friction factor.

Using this equation, the maximum flow rate through a 33 ft wide piping failure would be approximately 106,000 cfs at the downstream toe of the dam and 19,420 cfs through the underdrain.

5.2. Topography Data

Floodplain topography was determined using topographic data provided by Donlin Gold or sourced from the USGS. The most recent LiDAR data that were provided by Donlin Gold and dated 2007 covered only the area in Anaconda Creek and the middle section of Crooked Creek, located approximately three miles downstream of the confluence of Anaconda Creek and Crooked Creek. The DEM data for the area further downstream along Crooked Creek were downloaded from USGS, with an approximately 150 feet resolution. The two data sets were merged to form the topographic base data for inundation modelling. FLO-2D's pre-processing program, GDS, was used to generate a DEM, with an approximately 65 ft grid spacing, for the Anaconda Creek and Crooked Creek valleys. This DEM covers an area of approximately 288,000 acres. Due to the resolution of the DEM, the detailed river bed cross section and sinuosity were not captured by the model. However, given the ratio between the total volumes released from the TSF versus the area of the floodplain, the limitation of the resolution of the DEM is considered adequate for the quantitative impact analysis herein.

5.3. Tailings Rheological Parameters

For the slurry flow simulations (Scenarios 1 and 3), FLO-2D requires the input of several rheological parameters, including parameters that control the yield stress and viscosity of the slurry. The parameters in Table 5-1, based on typical values for gold mine tailings from FLO-2D (2007), were applied.

Table 5-1. Yield stress and viscosity of tailings inputs.

Resistance Component	Estimated Parameter	
	α	β
Yield Stress (Pa)	0.0473	21.1
Viscosity (Pa-s)	0.128	12.0

5.4. Floodplain Roughness

For both slurry flow and water flow simulations, the floodplain roughness in the model domain was estimated from site photos, aerial photographs, and Google Earth imagery. Given the resolution of the FLO-2D grid, a Manning's n-value of 0.075 that reflects dense brush conditions along the creek was applied to the entire domain.

5.5. Base Flow in Crooked Creek

It was assumed the river bed was frozen during the winter and the mean summer flow was constrained in the river channel during the summer (Table 2-1).

6. RESULTS AND DISCUSSION

The flow inundation extent, flow travel distance, total duration time, flow front arrival time and maximum flow depth at the confluence of Anaconda Creek with Crooked Creek and the confluence of Crooked Creek with the Kuskokwim River, for the four modelled scenarios are summarized in Table 6-1.

Table 6-1. Summary of modelling results.

Scenario	Total Duration (hrs)	Confluence of Anaconda Creek and Crooked Creek (1.6 miles downstream of TSF)		Confluence of Crooked Creek and Kuskokwim River (13 miles downstream of TSF)	
		Front Arrival Time (hrs)	Maximum Flow Depth (ft)	Front Arrival Time (hrs)	Maximum Flow Depth (ft)
1	5.0	0.6	7.9	-	-
2	>48	0.7	6.8	24.9	1.0
3	6.5	1.1	7.9	-	-
4	>48	1.6	4.5	25.5	1.0

The results for Scenario 1 are presented in Drawing 01 (maximum flow depth and extent) and Drawing 02 (deposition depth and extent). The results for Scenario 2 are summarized in Drawing 03 (maximum flow depth and extent). The results for Scenario 3 are shown in Drawing 04 (maximum flow depth and extent) and Drawing 05 (tailings deposition depth and extent). The results for Scenario 4 are summarized in Drawing 06 (maximum flow depth and extent).

The results indicate the following:

- For the tailings and water scenarios (Scenarios 1 and 3), the travel distances were limited from the TSF dam toe to the confluence of Anaconda Creek with Crooked Creek. However, if the spill scenario were to occur during the summer months, Crooked Creek would likely be temporarily blocked by the deposited tailings, and a significant portion of the deposited tailings would then be remobilized by Crooked Creek and transported downstream. Should the spill scenario occur in the winter months, the cone shaped deposit of tailings could be excavated and transported back to the tailings facility thereby limiting the impact of the spill during the following spring thaw.
- The maximum flow depth for Scenario 1 was approximately 5 ft higher than that for Scenario 3 at the downstream toe of the TSF Dam in Anaconda Creek, but almost identical at the confluence of Anaconda Creek with Crooked Creek for both scenarios.
- The final inundation maps for Scenarios 1 and 3 were almost identical. The tailings deposition depths varied from less than 2 ft to 8 ft along Anaconda Creek. A cone

shaped tailings deposition formed at the mouth of Anaconda Creek with a maximum deposition depth of approximately 10 ft.

- For both Scenarios 1 and 3, the deposited tailings form a 1° slope from the downstream limit of the tailings dam and the confluence of Anaconda Creek with Crooked Creek. In the flood plain of Crooked Creek, the cone shaped tailings deposit forms a slope of 0.1°, the margins of which steepen to a slope of 0.6°.
- The total deposition volumes in Crooked Creek were estimated for Scenarios 1 and 3 to be approximately 1,300 acre-ft.
- For the water-only flows (Scenarios 2 and 4), it took approximately 24 to 25 hours for the front to arrive at the confluence of Crooked Creek with the Kuskokwim River with a maximum flow rate of approximately 600 cfs for both scenarios.
- The flow depths for Scenario 2 were approximately 5 ft higher than those for Scenario 4 at the downstream toe of the TSF Dam in Anaconda Creek. However, the flow depths for Scenarios 2 and 4 were each 1 ft or less at the confluence of Crooked Creek with the Kuskokwim River.

Based on the above observations, the flow discharges impact flow depths and flow velocities in Anaconda Creek, but do not have a significant impact on flow depths and velocities in Crooked Creek. This is because the Crooked Creek floodplain is wide (approximately 0.5 miles) and the bed gradient is very gentle (approximately 0.3%) from the confluence of Anaconda Creek to the confluence of Kuskokwim River, resulting in significant flood attenuation along Crooked Creek. Compared to the average monthly flow rates in the Kuskokwim River at Crooked Creek (Table 2-1), the maximum flow rates for Scenarios 2 and 4 were approximately 4.0% of flow rates of the Kuskokwim River in the winter months (November to April), and approximately 1.8% of flow in Kuskokwim River in the summer months (May to October).

Depending on the volumetric sediment concentration of released tailings, the duration of flow could vary from approximately six hours for tailings and water flow to longer than 48 hours for water flow only. Regardless of the scenario modelled, all fluid and solids released from the TSF are considered contaminated.

7. EMERGENCY ACTION PLAN

The RFAI requested the following with respect to emergency response to the spill scenarios. In particular:

- *Description of response actions that would be mounted, including equipment, methods to be used, and anticipated duration; and*
- *A discussion of the effect of seasons on a response.*

The State of Alaska Dam Safety Program regulations require development of an Emergency Action Plan (EAP) for Class I dams (11 AAC 93.164(b)(4)) and that the EAP be developed in accordance with FEMA guidelines (*Federal Guidelines for Dam Safety: Emergency Action*

Planning for Dam Owners (FEMA, 1998)). ADNR's Guidelines for Cooperation with the Alaska Dam Safety Program (2005) provides additional guidance on the content of EAPs.

An EAP would include the following:

- *Notification flowcharts that cover non-failure, potential failure, and imminent or action failure situations;*
- *Procedures for emergency detection, evaluation, and classification for these situations;*
- *Procedures for emergency and remedial response and how these would vary in winter vs. summer;*
- *Inundation maps based on dam break analyses; and*
- *Plans for training, exercising, updating, and posting the EAP.*

The RFAI requested information on response actions that would occur for the scenarios evaluated. The response would be conducted in line with the EAP and would include the following steps:

1. Assessment of the situation and as required, the General Manager, or designate would activate the EAP;
2. Notification of primary notifications for emergency initiators and for downstream residents within the inundation area, and secondary and tertiary notifications;
3. Steps to ensure the safety of mine employees and any other people in the inundation area including evacuation of downstream residents;
4. Response actions:
 - a. Lower the pond level – shut down the mill operating process to cease the flow of process water and tailings to the tailings facility. Water can be removed from the tailings pond by utilizing the reclaim system to divert water to the open pit for temporary storage.
 - b. Arrest or retard dam internal erosion – once excess and/or cloudy seepage caused by internal erosion of the dam is detected, a weighted filter buttress should be promptly placed along the seepage exit area. The filter berm would allow free exit of seepage water without carrying away existing dam fill and or foundation materials. The filter berm is to be constructed of filter and drainage materials with progressively increasing particle size towards the berm outer surface. If in the seepage exit area, the initial flow velocity is too high for the placement of filter materials, material of larger size and heavier weight may have to be placed first to slow the seepage velocity allowing for placement of properly zoned filter materials. If sinkholes develop, they should be immediately filled with dam fill materials. Stockpiles of fine and coarse filter materials, as well as rockfill and transition rockfill should be located in the vicinity of the dam to be readily available for the EAP
 - c. Arrest or retard dam external erosion – concurrent with lowering of the tailings pond level, granular materials should be placed to plug any erosion channels that may

have formed on the dam crest or downstream face. Materials of sufficient size and weight can be dozed into the breach from alternate sides of the channel. As the channel is gradually closed, materials used to plug the channel should increase in size and weight to cope with the increasing flow velocity.

5. Remedial action – Remove contaminated tailings from Crooked Creek and surrounding areas to the extent feasible.
6. Monitoring - Monitoring of water quality, fisheries, and soils during the situation and after to determine the actual extent of contamination and success of remedial actions; and
7. Follow-up - Reporting of the incident and monitoring results with the intent to provide information on impacts and prevent future incidents.

If a situation arises that requires immediate attention, including the spill scenarios that are the subject of this memorandum, Donlin Gold would have the necessary equipment, material, labor, and engineering expertise already on site to support the mining operations such that they could be deployed to respond to the emergency immediately. The specific equipment and supplies needed would be outlined in the EAP.

8. CLOSURE

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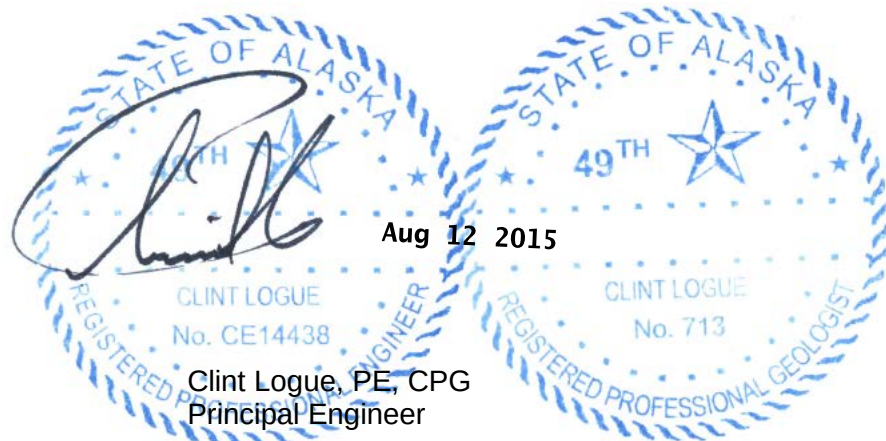
We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING INC.
per:



Shielan Liu, Ph.D.
Numerical Model Specialist



Clint Logue, PE, CPG
Principal Engineer

Reviewed by:

Jack Seto, M.Sc., PE
Principal Engineer

Hamish Weatherly, M.Sc., CPG
Principal Hydrologist

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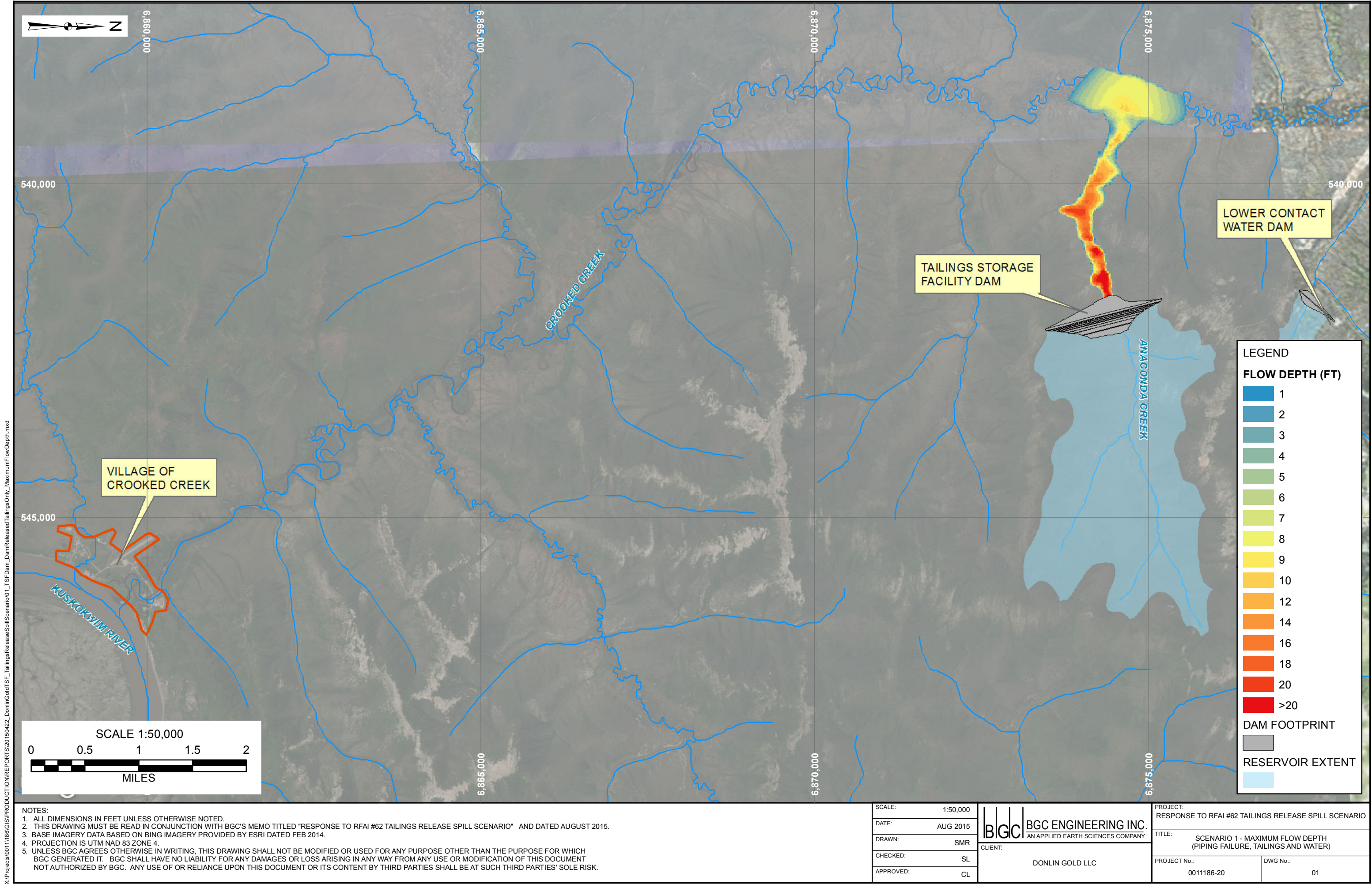
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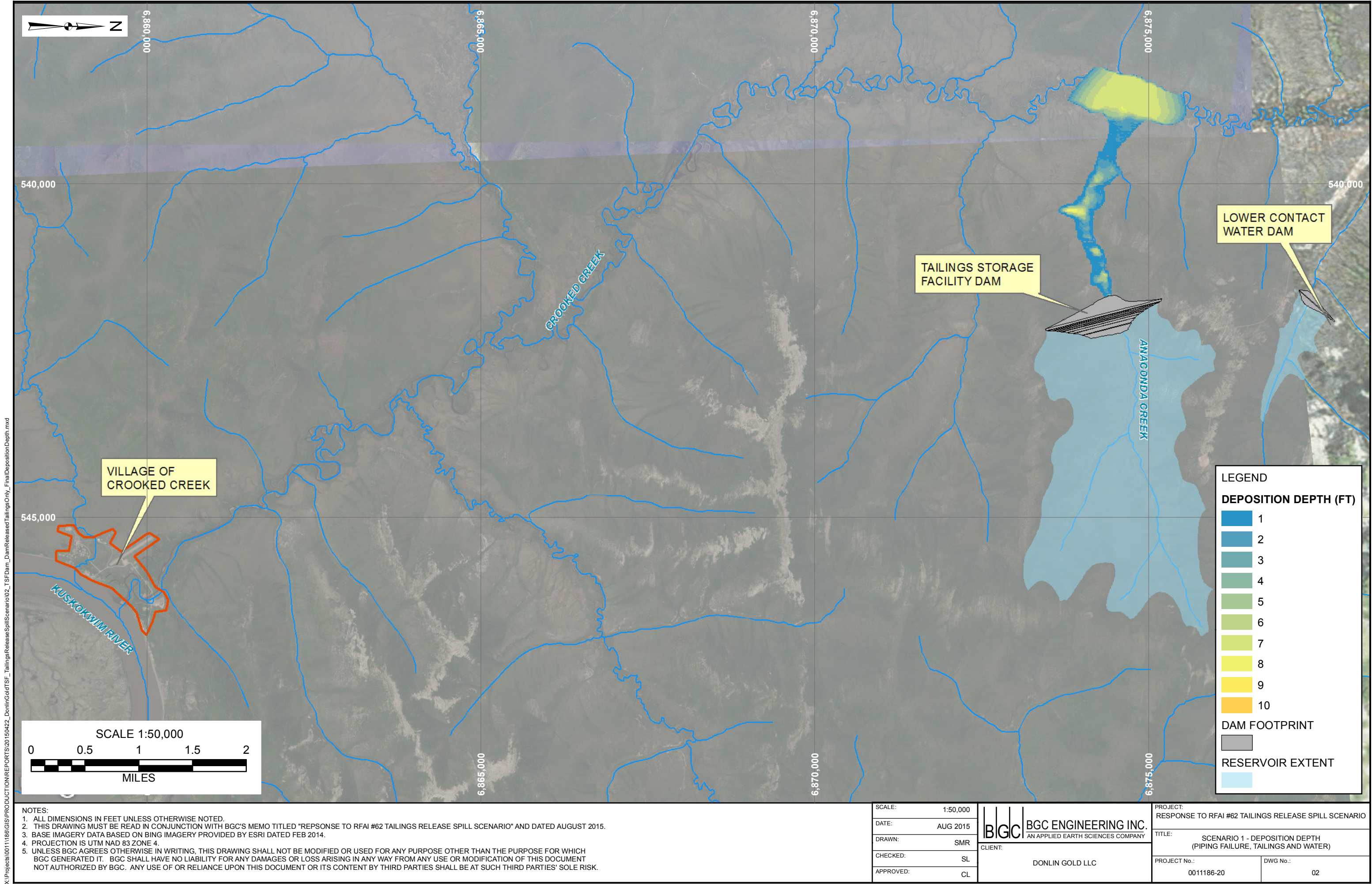
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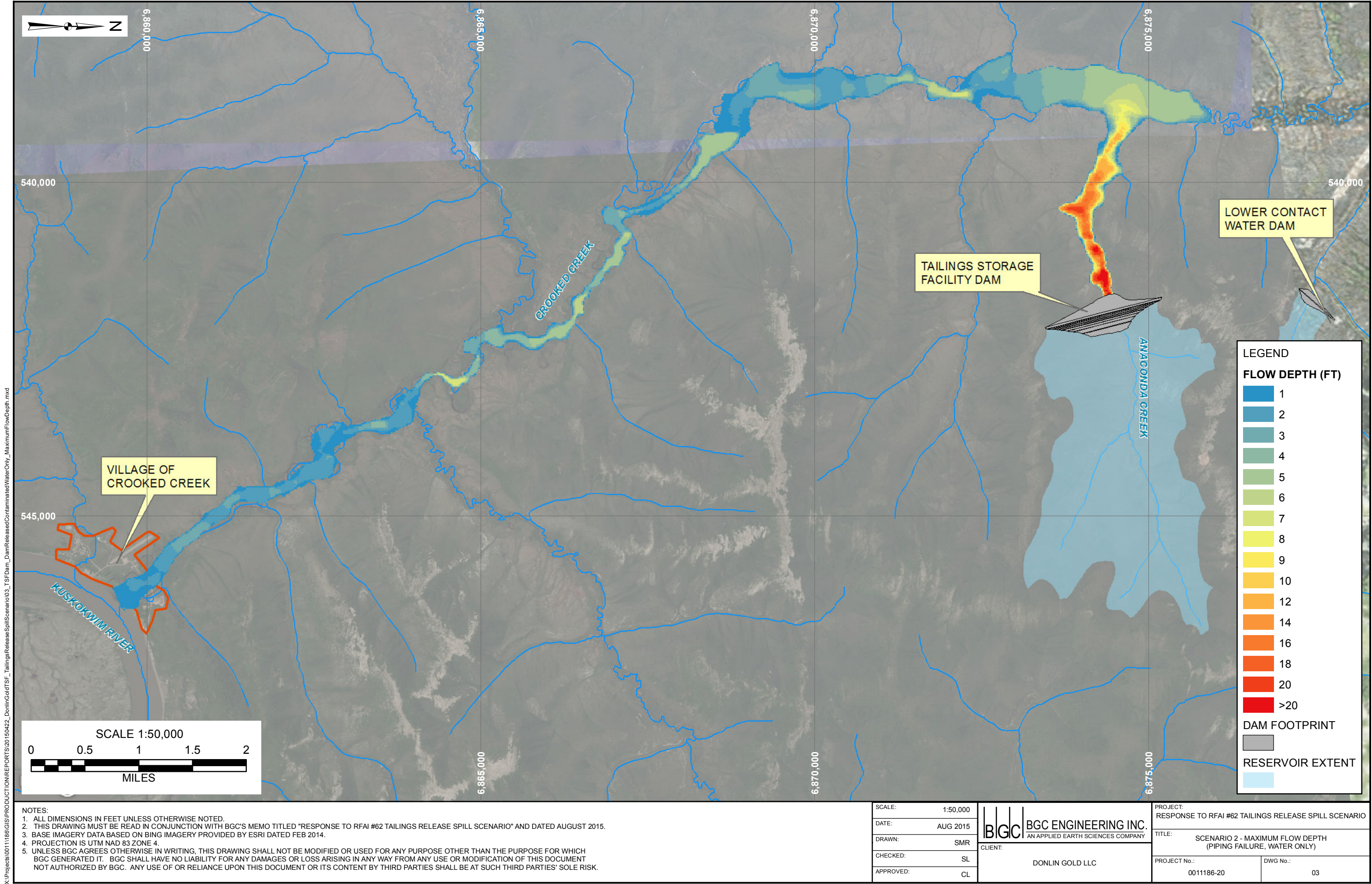
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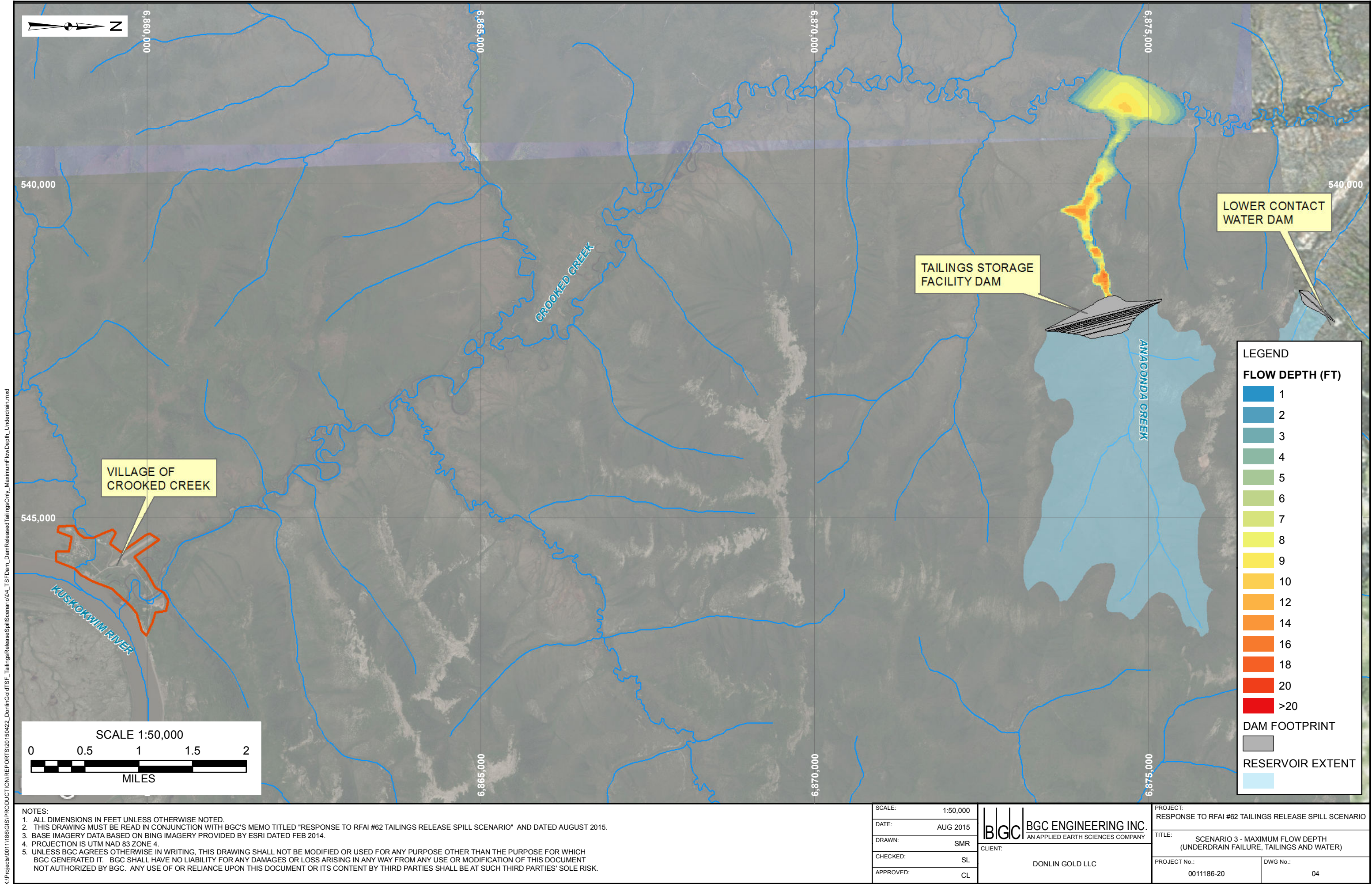
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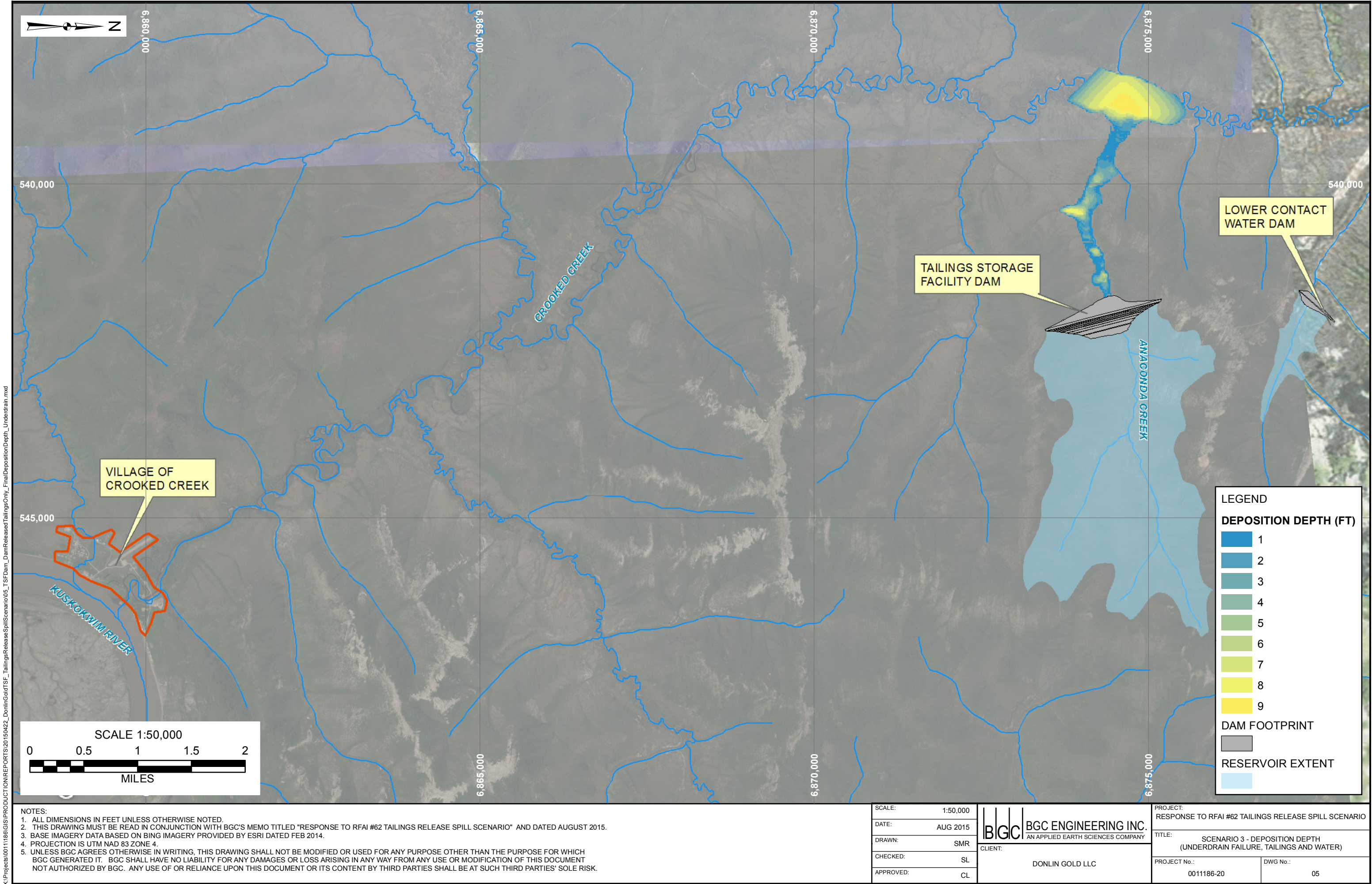
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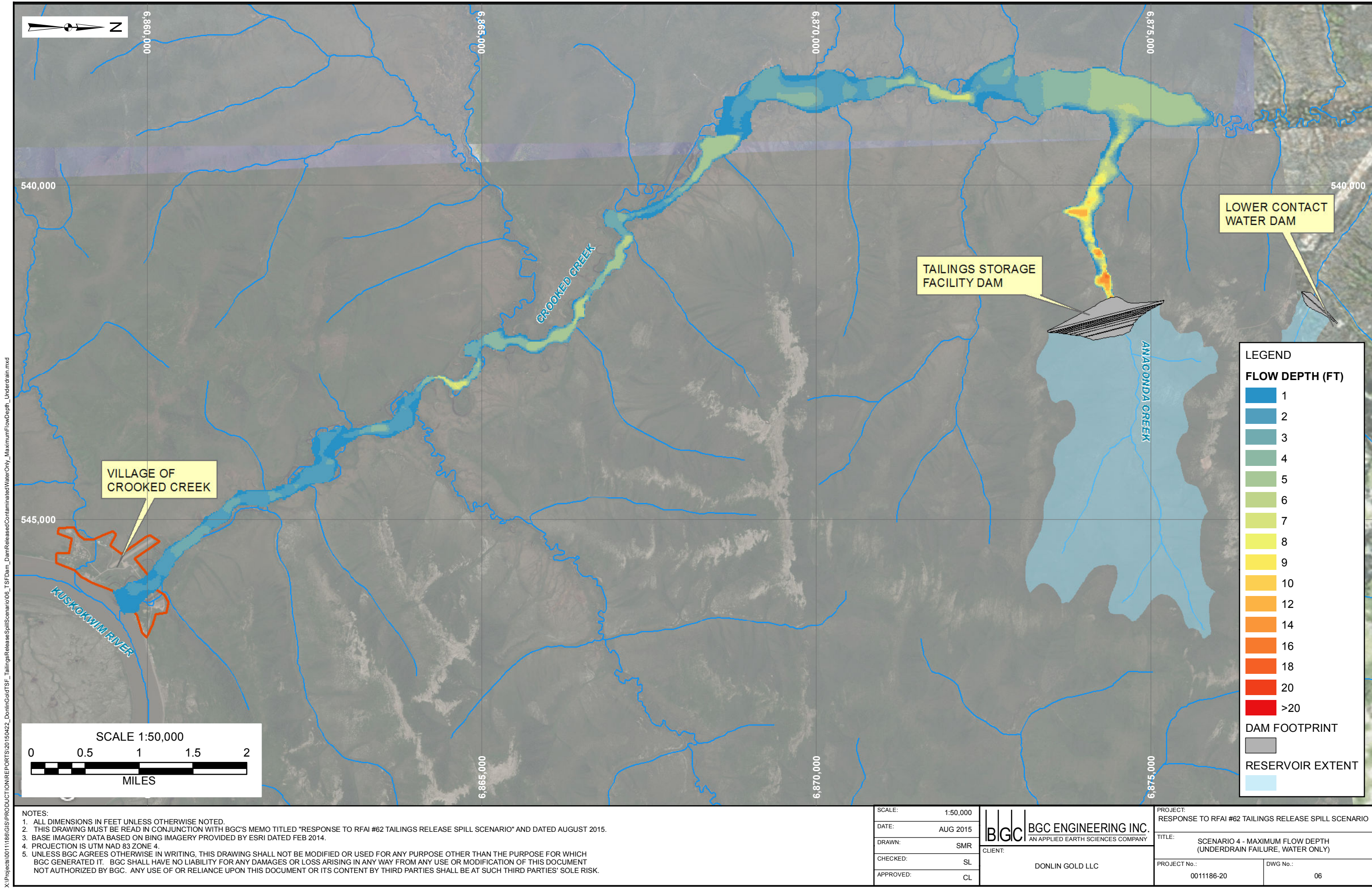












NOTES:
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PROJECT: RESPONSE TO RFAI #62 TAILINGS RELEASE SPILL SCENARIO	
TITLE: SCENARIO 4 - MAXIMUM FLOW DEPTH (UNDERDRAIN FAILURE, WATER ONLY)	
PROJECT No.: 0011186-20	DWG No.: 06