Digital analysis of historic drilling data to reconstruct the placer gold distribution in Sulphur Creek and lower Dominion Creek, central Yukon

Sydney van Loon*
Yukon Geological Survey

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ABSTRACT

Yukon Consolidated Gold Corporation (YCGC) conducted an industrious exploration and dredging operation in the Klondike for over four decades. The main objective of their exploration was to determine which creeks were economical for dredging, and create an inventory of Klondike drainages based on placer gold grade and surficial material characteristics. As a result of their exploits, thousands of maps and associated technical reports were produced, which provide records of the economic potential in many Klondike creeks. Despite the vintage of this data, these historical documents are proving to still be valuable to the modern placer exploration and mining industry.

The placer gold distribution of Sulphur Creek can be modeled in a Geographical Information System (GIS) which provides opportunities for analysis and interpretation. After a drillhole dataset is modernized through the process of digitizing, patterns emerge and can be used to analyze gold distribution, investigate tributary influences, and assess untapped side-pay potential. Desktop evaluation using grade information is an economical exploration technique and can be an effective tool for modeling pay channel distribution, potentially leading to additional prospects.

* *sydney.vanloon@gov.yk.ca*

INTRODUCTION

One method used to prospect and evaluate placer potential is through drilling. An extensive drilling program is an effective way to determine irregularities in gold distribution and equalize grade values. Drilling data can then be analyzed to interpret any geological trends and characteristics.

Prospecting in the Klondike by Yukon Consolidated Gold Corporation (YCGC) from 1923 to 1966 resulted in a large dataset of geological information obtained from drilling, shafting, panning and dredging. Converting this data to digital spatial records allows the user to characterize surficial geology and gold distribution. Further modeling and interpretation of the data can provide insight into possible gold sources and be an effective prospecting tool for placer miners. Modern equivalents of this dataset are uncommon due to the cost of drilling and the unlikeliness that an entire drainage is covered by one claim owner.

The main focus of this investigation was to digitize the drill data and model the placer gold distribution in the Sulphur Creek and lower Dominion Creek drainages. Several methods of displaying gold grade information are used to identify spatial patterns and assess whether the economic potential is affected by surficial material depths.

SULPHUR CREEK

Sulphur Creek has produced 122,000 oz. of placer gold since 1980, making it an important contributor to the total production from the Klondike (Fig. 1). Three dredge operations active in the drainage between 1936 to 1966 sluiced 51 million cubic yards of ground, resulting in CDN $18 million worth of gold recovered at $36.58 per ounce (Green, 1977). The modern day value of this resource would exceed CDN $600 million. YCGC operated throughout the region and conducted extensive drilling and dredging, which produced data that remains relevant to exploration on Sulphur Creek today.

A 28 km-long section of Sulphur Creek and lower Dominion Creek from the mouth of Green Gulch downstream to the mouth of Scribner Creek was investigated for this study (Fig. 2). Drillhole data were compiled from eight historic maps dating from 1935, 1943 and 1955 (YCGC 1935, 1943a, 1943b, 1955a, 1955b, 1955c, 1955d). Where possible, the surficial geology stratigraphy derived from drillhole data was checked against active mining cuts located on ten different mine operations that were active between 2013 and 2016.

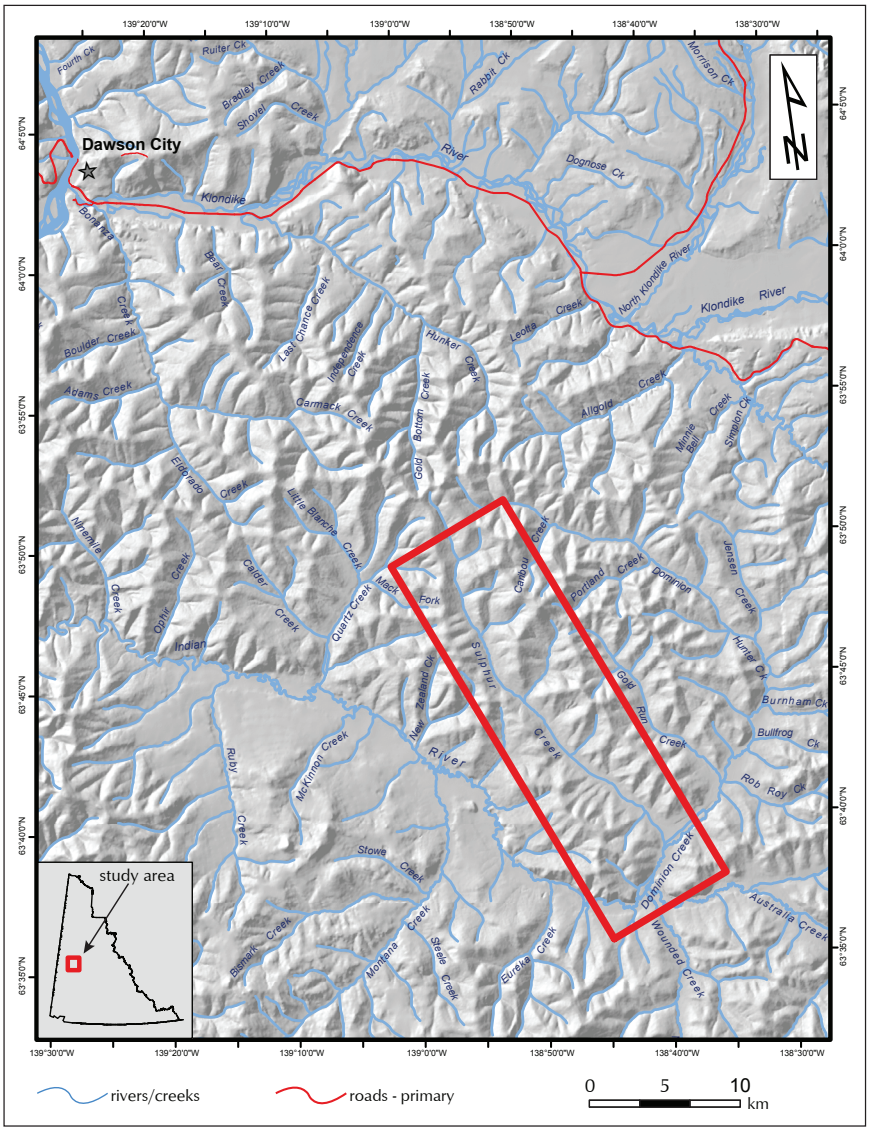

Figure 1. *Study area (delineated with red outline) south of Dawson City on Sulphur Creek and lower Dominion Creek.*

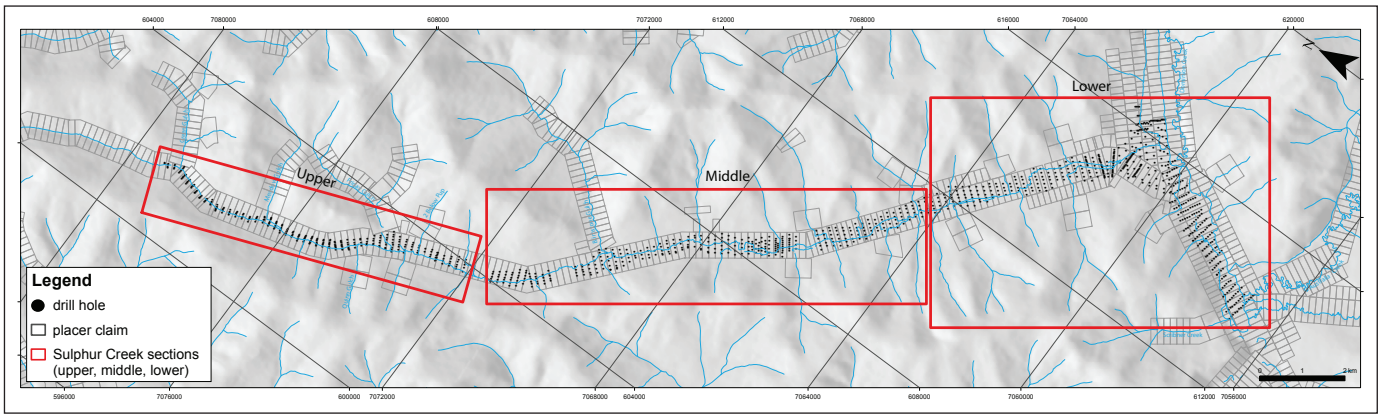

Figure 2. *Sulphur Creek project area including YCGC drilling data. Red outlines indicate the three main areas discussed in this paper: upper, middle and lower Sulphur Creek sections.*

METHODS

YCGC CHURN DRILLING

YCGC sampled placer deposits by churn drilling, and used two different techniques depending upon ground conditions (Fig. 3). The drillholes were cased in thawed ground, whereas in frozen ground, open-hole drilling was used (Hester, 1962). Clarkson (1993) described the operation of the churn drill as follows: 1) Casing was driven into the ground with the assistance of a drive shoe to act as a cutting edge (if drilling in thawed conditions); 2) gravel inside the casing was then milled into smaller pieces using a chisel bit; and 3) the pulverized sample was then extracted from the casing using a bailer equipped with a check valve. Water was required for bailing and would be added to the formation if groundwater was not present.

Figure 3. *Keystone churn drill active on Bear Creek in 1913 (Wolfe, 1913).*

Churn drills were initially hand operated, but were later mechanized in the 1940s. These newer versions were branded the lightweight Hillman Airplane drill and Keystone (cable tool) drill (Clarkson, 1993). As churn drills evolved into rigs such as the Koehring Speedstar, Bucyrus Erie and Loomis churn drills, drilling methods became less labour intensive and rigs could drill deeper holes with larger diameters of up to 20 cm (8 in; Clarkson, 1993). These more efficient methods would have been employed in Sulphur Creek during the 1935, 1943 and 1955 drill programs.

Using churn drills to evaluate placer deposits has both positives and negatives. As discussed by Clarkson (1993), churn drills faced challenges penetrating boulder gravel and were relatively slow (1.2 to 2.4 m per hour). Hester (1962) described the errors associated with sampling placer deposits, which included the lack of consistency in the assay data, the varied recovery of material in thawed versus frozen ground, and the fluctuations in gold recovery due to the size of gold grains and their erratic distribution. Churn drills did however collect a relatively large sample size due to the dimensions of the drive shoe in the cased holes. Furthermore, the slow, methodical drilling method allowed for more detailed descriptions of stratigraphic intervals (*i.e.,* overburden thickness). Finally, the confidence in mapping the economic limits of dredging was achieved by increasing drillhole density. This methodology was refined throughout the years of dredging by comparing resource projections derived from exploration to actual production from the dredge.

DIGITIZING

Using ESRI's ArcGIS software, a total of 1,134 drillhole collars were digitized as point feature classes, along with their associated geological attributes (Appendix 1). Attributes include thickness of overburden, thickness of dredge section (gravel plus bedrock), grade measured in cents per cubic yard (gold price at USD $20.67), and surface elevation and bedrock elevation in metres above sea level. Dredge limits were also digitized as a polygon feature to outline areas mined by the dredges. In order to modernize the data after it had been entered, attributes were converted from imperial to metric. Grade data, recorded at the historical price of USD $20.67 per ounce, was converted to modern grade price, using today's price of CDN $1400.00 per fine ounce.

Raster datasets were generated from point data attributes and used to characterize surficial geology and gold distribution throughout the study area. The ArcGIS Spatial Analyst tool "Inverse Distance Weighting" (IDW) algorithm was used to extrapolate data within a 100 m buffer of data points. An overview of placer gold distribution or grade was then derived from the modern grade raster. Similarly, overburden characteristics were modeled within the valley bottom. From these raster datasets, patterns were analyzed and contributions from tributary streams were assessed. A reconstruction of the pay channel was derived and then digitized with zones of highest grade. This was compared to the bedrock surface elevation data where available (in the upper 6 km reach of Sulphur Creek).

Using recent satellite imagery to assess land disturbance, and extrapolating grade information beyond the extent of the drillholes, new exploration targets are identified outside the limits of dredging and modern mining.

RESULTS AND DISCUSSION

For ease of analysis and discussion the study area is divided into three sections (Fig. 2): upper Sulphur, middle Sulphur, and lower Sulphur and Dominion. The upper Sulphur Creek section extends from the mouth of Green Gulch to 1 km upstream of the Brimstone Gulch-Sulphur Creek confluence. The middle Sulphur Creek section encompasses an area from the mouth of Brimstone Gulch, downstream 9 km to the mouth of an unnamed left-limit tributary. Lower Sulphur Creek and Dominion Creek section extends from the unnamed left-limit tributary (at the end of middle Sulphur Creek section) downstream into lower Dominion Creek to the mouth of Scribner Creek.

Presently, gold recovered from Sulphur Creek varies in fineness from 790 to 840 (YGS, 2010). In the upper part of the drainage, gold is coarse (sometimes up to several grams in size) and angular, whereas gold in the lower section is more traveled and finer grained (YGS, 2010). The highest grade recovered from YCGC drillholes was $202 per cubic yard, downstream from the mouth of Meadow Gulch in the upper reaches of Sulphur Creek. The total percentage of YCGC drillholes yielding $50 per cubic yard or greater was 7.6%, whereas 12.5% of the drillholes produced samples that were assayed at $0 per cubic yard. A large majority (46%) of the drillholes recovered samples with grades between trace ($0.1) and $10 per cubic yard.

OVERVIEW OF GOLD DISTRIBUTION

Rich concentrations of gold occur in the upper and middle reaches of Sulphur Creek (Appendix 2). Particularly high values are located downstream from the mouth of Meadow Gulch, at the mouth of Brimstone Gulch, and 2.5 km downstream from confluence of Brimstone Gulch and Sulphur Creek. Other notable concentrations of gold occur downstream of major left-limit tributaries of middle Sulphur Creek.

The paleo pay channel of Sulphur Creek reflects a meandering-style fluvial system (Appendix 2). It is not known whether the pattern of gold distribution originated from a much earlier Pliocene fluvial system or if it corresponds to a more recent style of drainage. The Sulphur Creek pay channel appears to become absorbed into the pay channel of Dominion Creek, which is consistent with tributary streams entering into the main stem or larger creek/river valleys. Although spatial data for Dominion Creek is limited for this study, it appears that the pay channel for lower Dominion Creek is offset towards the right limit of the valley.

UPPER SULPHUR

The pay distribution in upper Sulphur Creek is erratic resulting in isolated pay streaks containing significant zones of high gold concentration (Appendix 3). High-grade gold concentrations are limited upstream from Meadow Gulch, and the highest grade noted was $70 per cubic yard. Downstream of Meadow Gulch there are six locations with grades greater than $100 per cubic yard. Included in this area is a drillhole which yielded a sample having the highest grade documented in the whole data set of $202 per cubic yard, located immediately below the

mouth of Meadow Gulch. This anomaly is not likely due to the nugget effect as it is supported by the other high grades documented in the surrounding area. In general, there is a pattern of high gold concentrations located downstream of most of the left-limit tributaries along the middle and lower reaches of Sulphur Creek. This may be due to contributions of gold from the tributaries and/or due to a change in bedrock mineralization in the Sulphur Creek valley bottom.

Bedrock and Pay Channels

Bedrock topography data is limited to the upper 6-km section of Sulphur Creek, between Green Gulch and 2 Below Pup. An approximated bedrock-low channel (brown line; Appendix 4) was digitized by connecting the bedrock topographic lows, and the pay channel (red line; Appendix 4) was derived by tracing the extent of high-grade zones (greater than $50 per cubic yard; Appendix 4). The pay channel is ~25 m in width and generally follows the bedrock-low channel, suggesting pay in upper Sulphur Creek is constrained by bedrock topography, and fluvial reworking processes have at least partially redistributed the high-grade channel.

Cross-Valley Profiles

YCGC's comprehensive data set for upper Sulphur Creek, which includes the bedrock profile, grade information and surficial geology, allows for the reconstruction of cross-valley profiles. Cross-valley profiles enable further characterization of the pay channel, and provide a depiction of the lateral grade distribution in a particular area across the valley. Two cross-valley profiles were constructed from the upper Sulphur Creek data set: one downstream from the mouth of Meadow Gulch (~250 m), and the second at the mouth of Friday Gulch (Fig. 4).

The cross-valley profile downstream from the mouth of Meadow Gulch (Cross-Valley Profile 1, Fig. 5) is 300 m long, oriented northeast across the valley, and includes six drillholes; the drillhole yielding the highest gold grade documented in the dataset ($202 per cubic yard) occurs along this section . The alluvial gravel across the valley bottom shows a fairly consistent thickness of 2.5 to 3 m (8 to 10 ft) pre mining (Fig. 5). Thin fluvial deposits were also identified on low terraces on both limits of Sulphur Creek. Overburden accumulations were thickest on the right limit reaching up to 9 m (30 ft). Gold is concentrated on the bedrock low and extends laterally 90 to 100 m across the main channel (Fig. 5). The richest pay gravel is

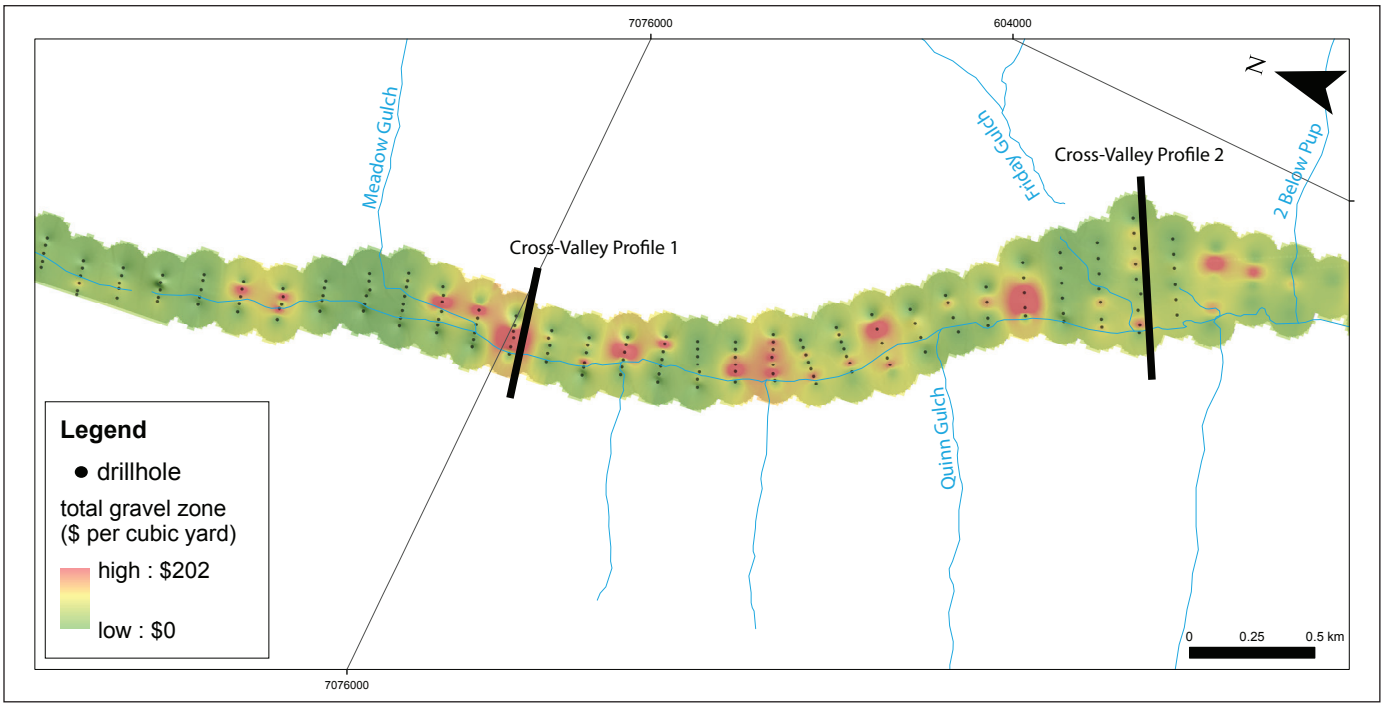

Figure 4. *Location of two cross-valley profiles on the upper section of Sulphur Creek.*

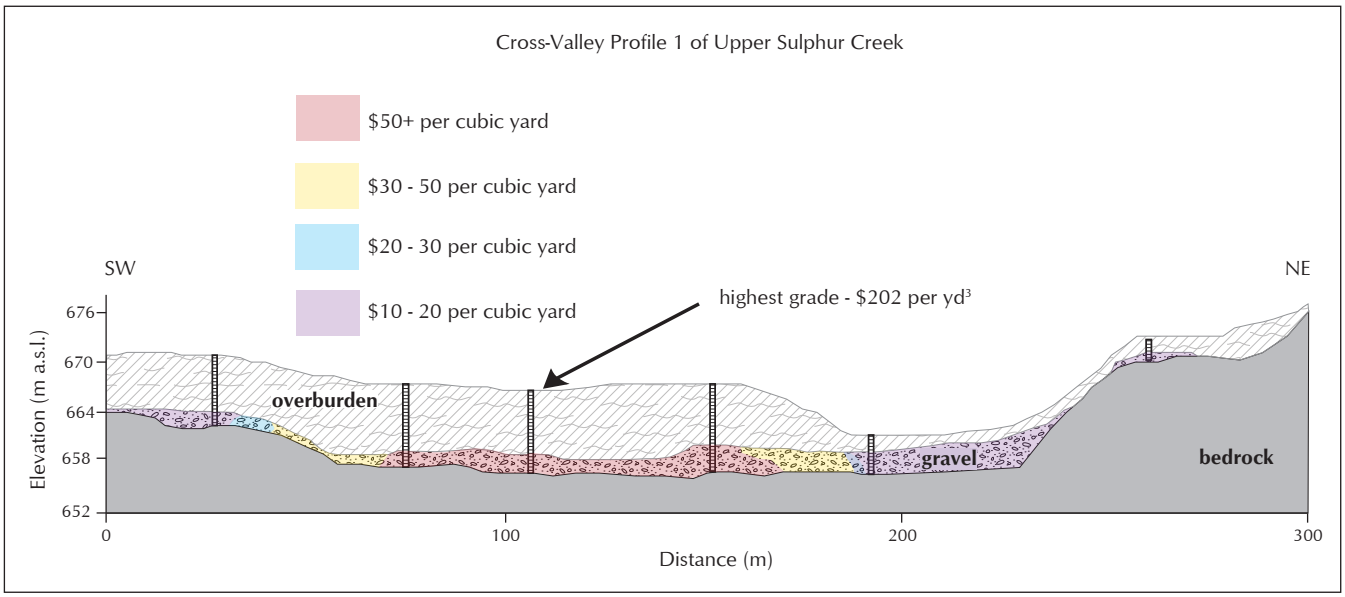

Figure 5. *Cross-Valley Profile 1 of upper Sulphur Creek downstream from the mouth of Meadow Gulch illustrating pay distribution; the view is looking upstream or to the northwest.*

predominantly concentrated along the right limit, following the bedrock low. The alluvial bench located on the left limit of Sulphur Creek (northeast side) has grades varying between $10 and $20 per cubic yard.

Cross-Valley Profile 2, at the mouth of Friday Gulch, is 450 m in length and encompasses nine drillholes yielding samples with grades up to $52 per cubic yard (Fig. 6). The pre-mining gravel thickness is fairly consistent at approximately 2 to 2.5 m (6.5 to 8 ft) across the valley bottom. Gravel thickness decreases toward the left limit (northeast side), where a thin fluvial deposit (1.5 m or 5.0 ft) was identified on a low-level terrace. Overburden reaches its maximum thickness overlying this low-level terrace and is between 7 and 10 m (23 and 33 ft) thick. As was observed in Cross-Valley Profile 1, gold is concentrated along the bedrock low in the valley bottom. Furthermore, the drill data confirmed that favourable gold grades are also present in gravel on the left-limit bench. This target has not been extensively exploited and may represent a significant prospect.

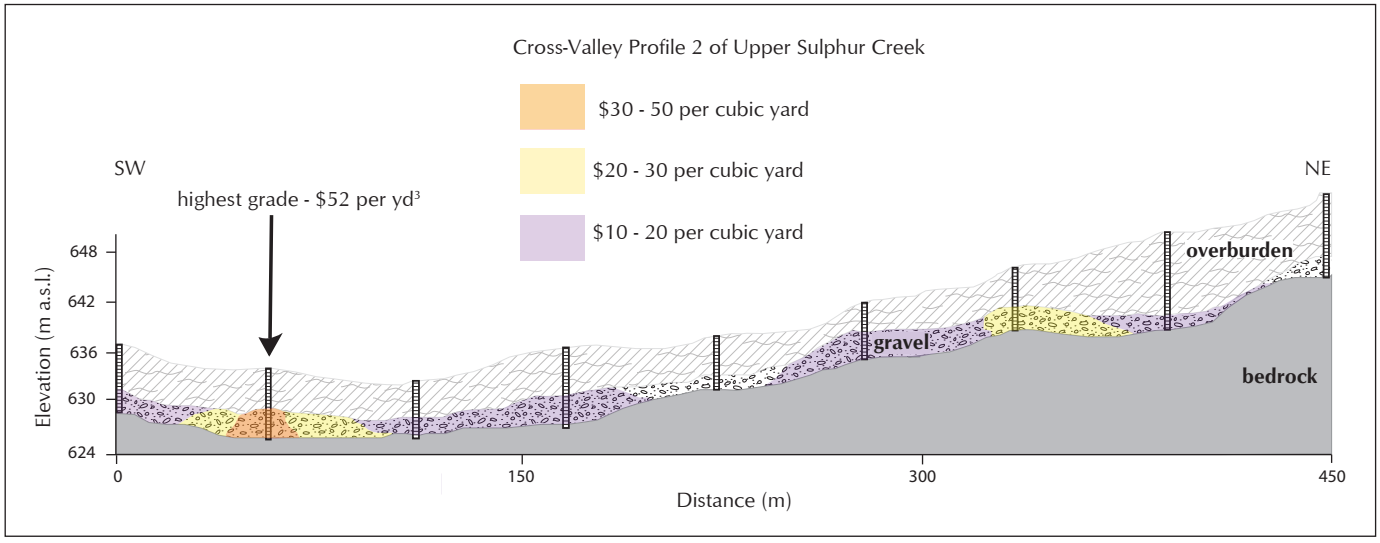

Figure 6. *Cross-Valley Profile 2 of upper Sulphur Creek at the mouth of Friday Gulch illustrating pay distribution; view is looking upstream or to the northwest.*

Longitudinal Section

A longitudinal section was constructed using the lowest bedrock elevations for a section of upper Sulphur Creek between the mouth of Green Gulch and the mouth of 2 Below Pup (Fig. 7). This 6-km section includes 41 drillholes, with gravel thickness ranging from 0.6 to 6.4 m (2 to 21 ft) and overburden thickness up to 15 m (50 ft). Downstream of the confluence of Meadow Gulch with Sulphur Creek, pay increases for a length of 500 m having grades greater than $20 per cubic yard. Further downstream, additional isolated concentrations of gold occur with grades greater than $50 per cubic yard.

A correlation between the slope percentage and gold distribution is apparent in the longitudinal section (Fig. 7). Bedrock slope percent was measured in 1000 m increments and shows an overall gradual decrease downstream along the length of the section. An increase in grade is noted in the low-angle slope segments (0.8 to 1.1%) compared to the steeper segments (1.2 to 1.6%). Gold could be concentrating in these areas due to the decrease in hydraulic energy that occurs as a streambed slope decreases. However, as this correlation is only documented in the upper reaches of Sulphur Creek, increased gold deposition in this particular section may also be a function of bedrock irregularities and/or bedrock lithology and characteristics (blocky, weathered, highly fractured, *etc.*). Slope influences aside, increases in gold grade downstream from Meadow Gulch could also be due to contributions from Meadow Gulch proper and/or the gulch flow inputs changing the hydraulics of Sulphur Creek to create a zone of accumulation.

MIDDLE SULPHUR

The reconstructed placer gold distribution for middle Sulphur Creek illustrates a pay streak having a patchy, discontinuous nature (Appendix 5). The high-grade zones are located downstream of major left-limit tributaries, with values fluctuating between $104 and $190 per cubic yard.

The patchy distribution of gold may have three possible explanations: (1) left-limit tributaries are an important source of gold; (2) the characteristics of stream hydraulics at the mouth of these left-limit tributaries facilitates the concentration of gold; and 3) a coarser gold grain component in the middle reaches of Sulphur Creek may have produced a "nugget effect" in the drill results. Knight *et al.* (1994) collected samples on Sulphur Creek and compiled average gold shape characteritics. Gold derived from middle Sulphur Creek ranged in size from 0.5 to 0.8 mm, while upper and lower Sulphur Creek produced grain sizes from 0.5 to 0.65 mm, and 0.2 to 0.5 mm, respectively. The presence of coarser-grained gold in mid-Sulphur Creek may contribute to the patchy gold distrubtion.

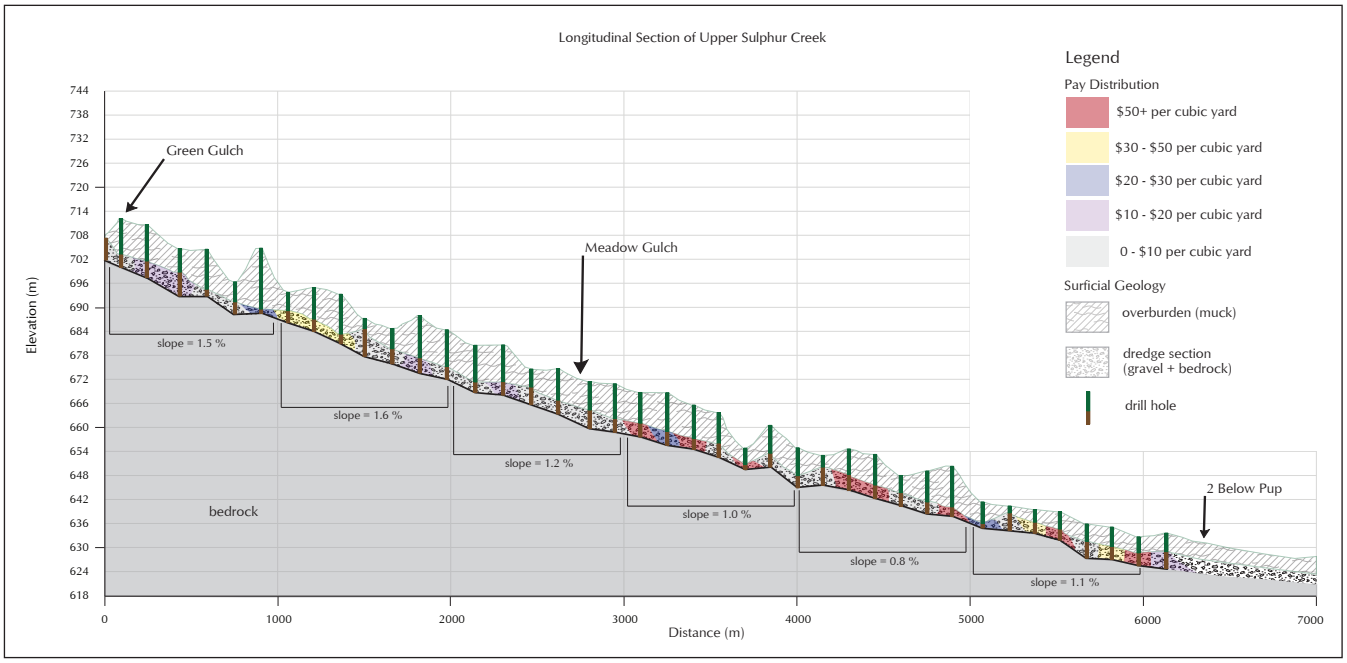

Figure 7. *Longitudinal section of upper Sulphur Creek from the mouth of Green Gulch downstream to 2 Below Pup.*

LOWER SULPHUR AND DOMINION CREEKS

The patchy nature of the pay streak continues into lower Sulphur Creek but appears to intensify in Dominion Creek (Appendix 6). Hot spots are present in and around the confluence of Sulphur and Dominion creeks, along the right limit of Dominion Creek. In this area, gold grades range from $40 to $90 per cubic yard. At the mouth of Sulphur Creek, low grades are documented, and the highest gold grade value was noted at $26 per cubic yard. Grades increase in the Dominion Creek valley, although the pay streak is somewhat patchy and has an apparent meandering character. The highest grades range between $55 and $108 per cubic yard.

Further investigation was performed on lower Sulphur Creek in order to try and decipher the low grades near the mouth of the drainage. At the mouth of Sulphur Creek, the gravel reaches its maximum thickness and ranges between 10 m (33 ft) and 17 m (56 ft; Fig. 8). Due to dredging methods, where the entire gravel section is processed, grades are calculated based on a total gravel zone thickness (Fig. 9) and can therefore dilute grade results where gravel is very thick. Base on the assumption that the majority of the placer gold is concentrated in the lower 0.9 m (3 ft) of the alluvial gravel, a recalculation was completed to understand the true grade near the bedrock interface of lower Sulphur Creek. To do this, the original grade derived from the total gravel section was multiplied by a dilution factor introduced by the upper, low-grade component of the gravel section. For example, if the total gravel section was 10 m (33 ft) then the original gold grade was multiplied by 11 (the dilution factor) based on the assumption that the majority of the gold is derived from the bottom 0.9 m (3 ft). While it is recognized that some gold will be derived from the upper portions of the gravel section, and therefore this dilution factor will be generous, it does provide a more realistic grade that is relevant to modern open-pit mining.

As expected, there was a slight increase in gold grade after recalculation (Fig. 10). In particular, the pay streak is confined to the right limit at the mouth of Sulphur Creek, which may be caused by hydraulic influences from Dominion Creek which is flowing to the northwest. The recalculation also demonstrates that grades in the 'thinner pay zone' at the mouth of Sulphur Creek are comparable to grades in other hot spots found along Sulphur Creek. Therefore, it is important to note that although previous records document low grades at the mouth of Sulphur Creek, this may be due to a dilution factor from dredging and some of these areas may be prospective placer targets.

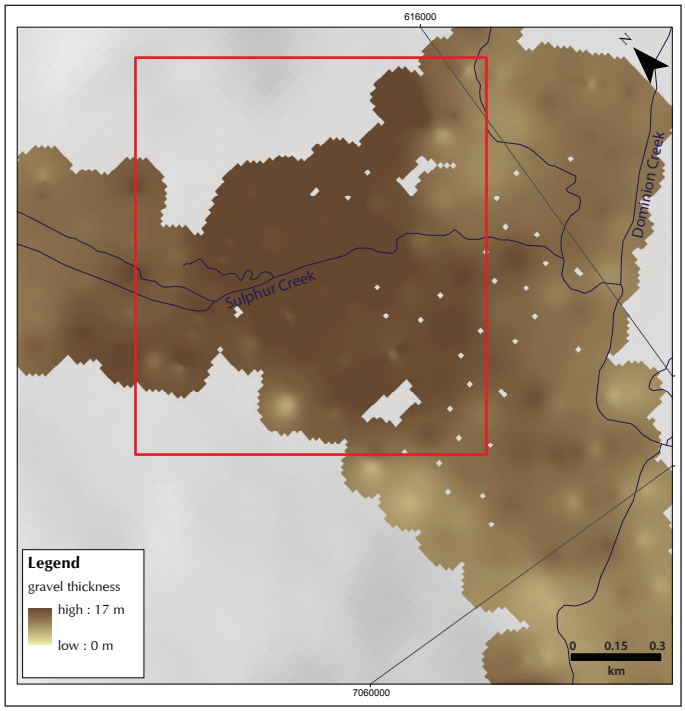

Figure 8. *Raster image of gravel thickness at the mouth of Sulphur Creek. Dark brown shades represent areas of thicker gravel accumulation.*

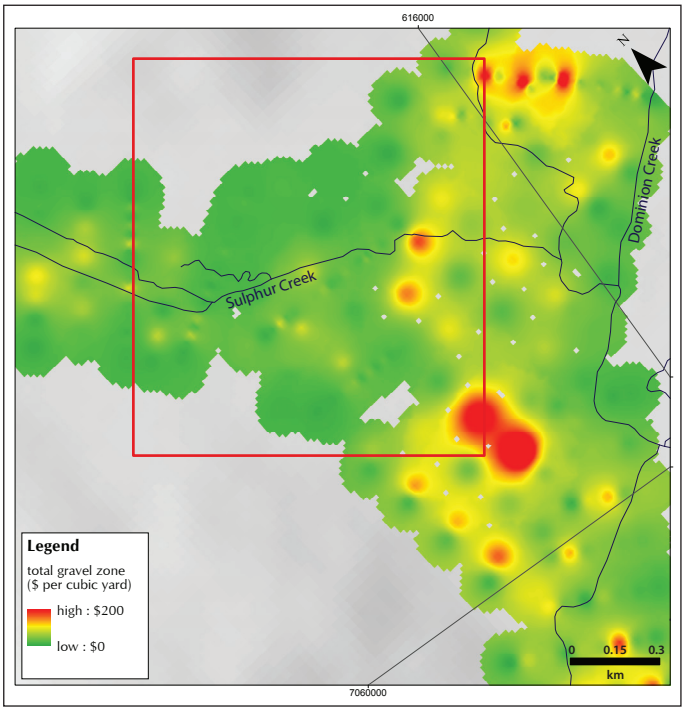

Figure 9. *Raster image of total gravel zone grade. Red outline delineates the area with the thickest total gravel zone where there is a possible dilution of documented gold grades.*

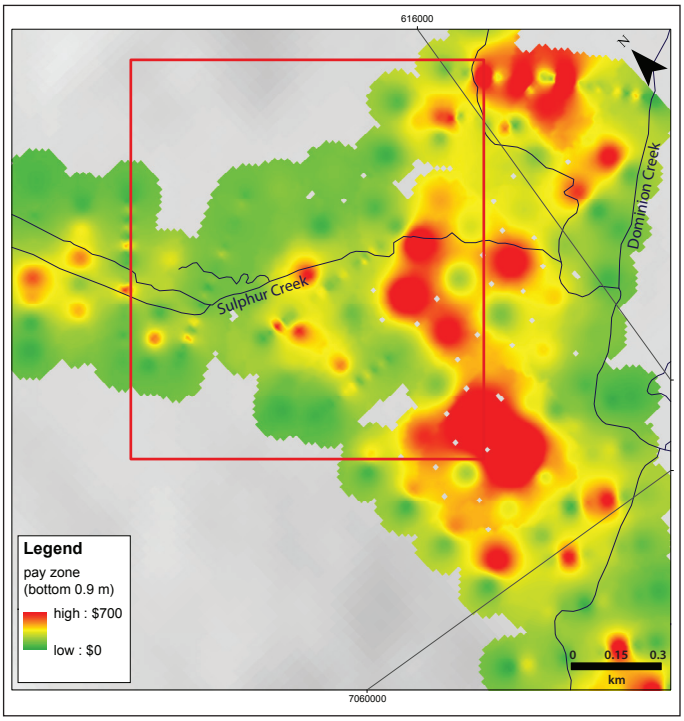

Figure 10. *Raster image of pay zone (bottom 0.9 m of total gravel section) at the mouth of Sulphur Creek illustrating the increases in gold grade values.*

EXPLORATION PROSPECTS

Using total gravel zone grade, overburden thickness, dredge section (gravel) thickness, historical drilling extent, dredge limits and recent satellite imagery, we can identify prospective areas that remain unmined. Extrapolating grade data into the valley margins can focus exploration targets towards locations of predicted high grades. Outside the dredge limits, overburden and dredge section thickness can also be examined in conjunction with grade data to identify targets, that is areas where grade remains high but overburden is thin and gravel is thick. Hot spots within the dredge limits could also be re-evaluated by drilling or test pitting to confirm that the dredge sufficiently mined the pay streak at the bedrock-gravel interface.

Assessing side pay is a function of overburden thickness, dredge section thickness, and grade. In sections with thick overburden there is potential for intermediate bench deposits and buried placers to be preserved. Due to the frozen ground conditions and the thickness of the muck deposits (overburden), YCGC stripping programs and cat miners may not have been able to work this type of ground. Furthermore, in areas where extrapolated gravel thicknesses are high, there is the possibility of discovering buried bench placers or unmined side pay. If we narrow down exploration targets to favourable locations that include these two attributes (thickness of muck and gravel deposits) and compare it to modern satellite imagery, we can identify prospects outside of dredging and modern mining limits. In middle Sulphur Creek, near the mouth of Brimstone Gulch, there are several targets along the right limit and two targets on the left limit (Appendix 7).

In the upper Sulphur Creek section, untapped side-pay potential exists, as is displayed in the cross-valley profiles in Figures 5 and 6. In these areas, buried low-level terraces were delineated by drilling and have not been thoroughly exploited. As the extent of these bench deposits are not well known (both laterally and vertically within the drainage), these areas may be potential targets for Sulphur Creek that may result in the discovery of easily accessible, economic placer deposits.

Further prospective targets generated from this compilation include left-limit tributaries of Sulphur Creek. More specifically, exploration on those left-limit tributaries in the middle section of Sulphur Creek is warranted due to the increase in gold grade immediately downstream of the mouth of these tributaries (Appendix 5).

CONCLUSION

A digital analysis of YCGC historic drilling data allowed for reconstruction of pay distribution and surficial material characterization of Sulphur Creek, a significant Klondike drainage. After high-grade zones were identified, a pay channel of Sulphur Creek and lower Dominion Creek was generated. The reconstructed pay distribution of Sulphur Creek was patchy throughout the study area, and displayed concentrated high-grade zones in the middle reaches of Sulphur Creek. The highest grade zones noted occurred downstream from the mouth of Meadow Gulch, around Brimstone Gulch, as well as immediately downstream from the mouths of several unnamed left-limit tributaries along middle Sulphur Creek. Low grades documented by YCGC at the mouth of Sulphur Creek were further examined using alternative grade calculations to account for possible grade dilution in thick gravel accumulations. The recalculation resulted in the same patchy distribution, however gold grades improved. In the Dominion Creek valley, high-grade zones are generally more continuous and exhibit a meandering character.

Digital analysis of the YCGC drilling data for Sulphur Creek has proven to be an effective and economical tool to evaluate placer potential and identify prospects. In addition to the likely contributions from left-limit tributaries along middle Sulphur Creek, additional prospects derived from the data set include untapped side pay and buried low-level terraces. Exploration targets identified from this study would benefit from additional geophysical analyses such as ground-penetrating radar (GPR), resistivity geophysics and ground magnetic surveys.

ACKNOWLEDGEMENTS

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Many thanks are also owed to the placer industry for supporting the acquisition of the YCGC data collection and recognizing the value of the application of this tremendous dataset in discovering new opportunities. Also, without the current dialog with the miners in the region, the interpretation of this historical data would not have the same value or significance – so thank you to all the miners who support and assist us in the work we do.

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APPENDICES

Appendix 1. Sulphur Creek study area with YCGC drilling data and dredge limits.

Appendix 2. Pay channel reconstruction using YCGC grade data.

Appendix 3. Upper Sulphur total gravel zone grade raster (calculated using the price of gold at CAD $1,400/oz); red shading indicates areas containing the richest ground.

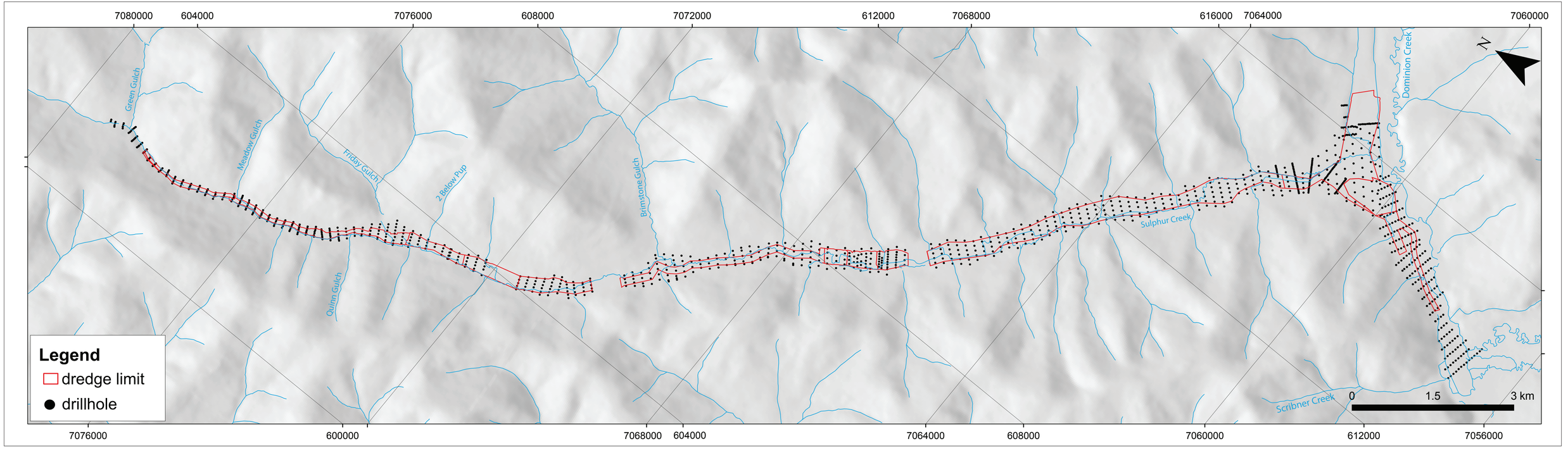
Appendix 4. Approximate bedrock-low channel (brown line) including classified grade information. Pay channel (red line) is also displayed.

Appendix 5. Middle Sulphur total gravel zone grade raster (calculated using the price of gold at CAD $1,400/oz); red shading indicates areas containing the richest ground.

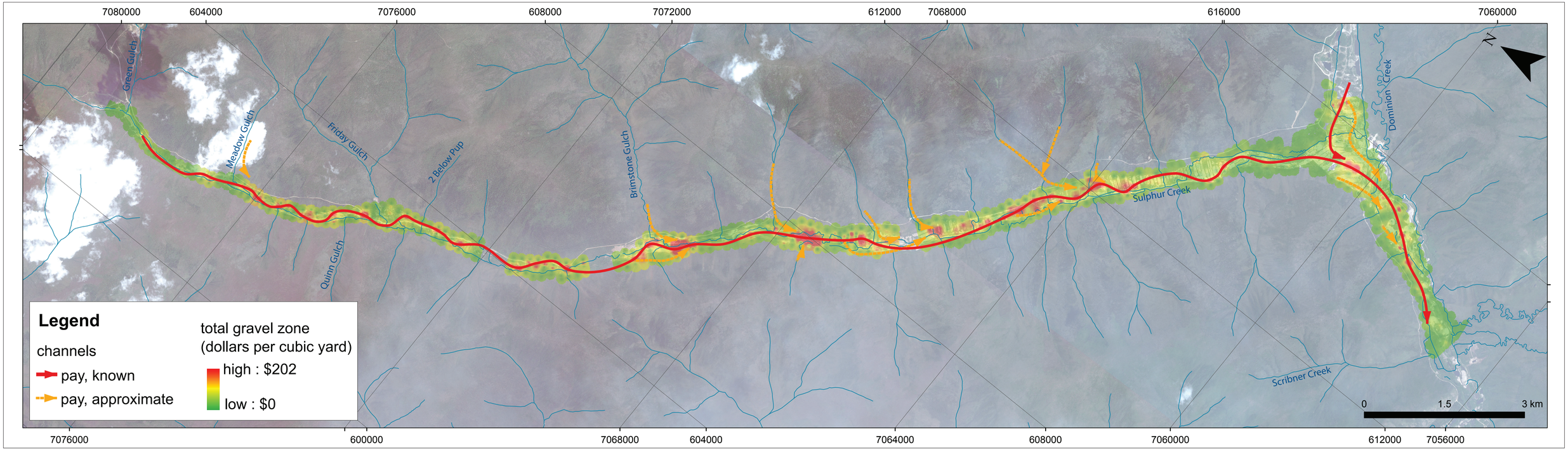
Appendix 6. Lower Sulphur total gravel zone grade raster (calculated using the price of gold at CAD $1,400/oz); red shading indicates areas containing the richest ground.

Appendix 7. Prospective targets around the mouth of Brimstone Gulch of mid-Sulphur Creek; red outlines delineate those areas that appear to be outside the limit of dredging and modern mining.

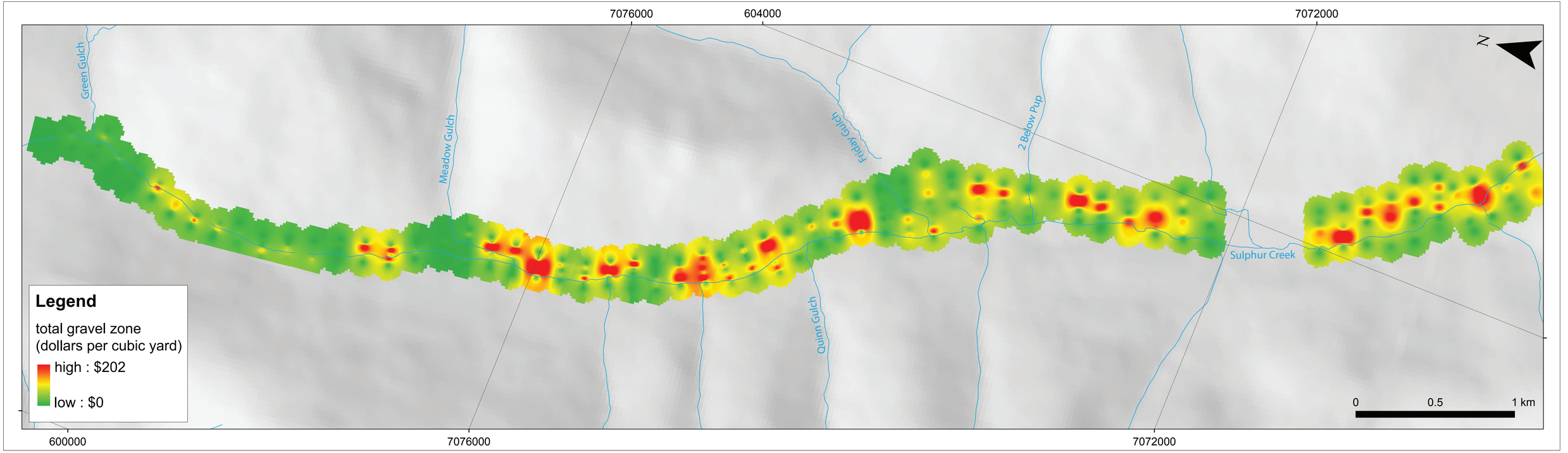
APPENDIX 1. *Sulphur Creek study area with YCGC drilling data and dredge limits.*



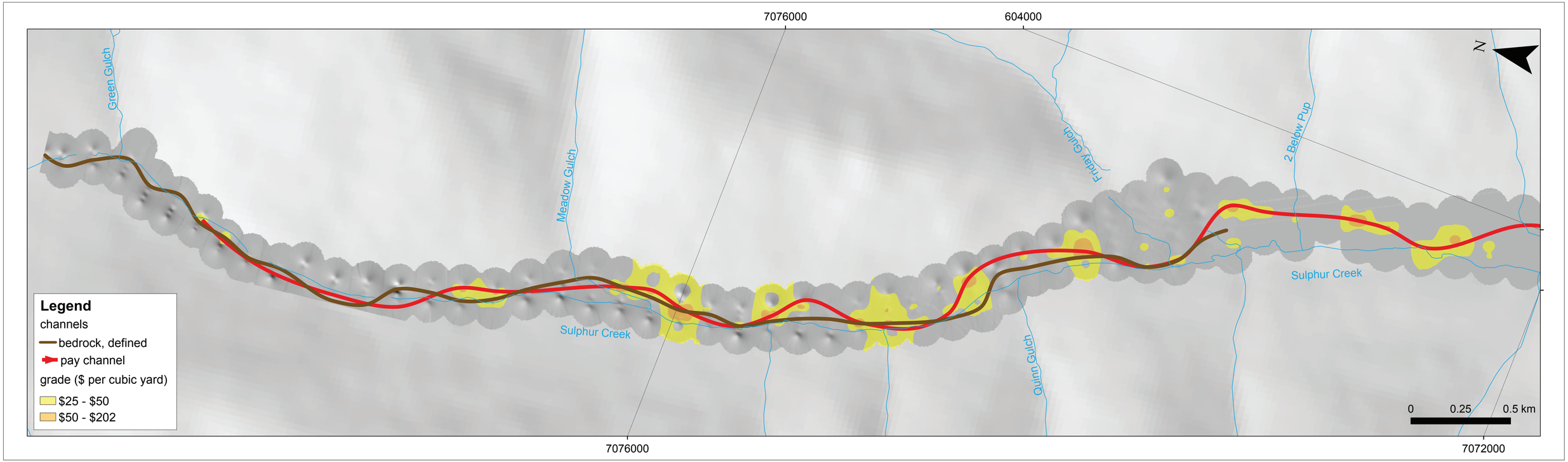
APPENDIX 2. *Pay channel reconstruction using YCGC grade data*



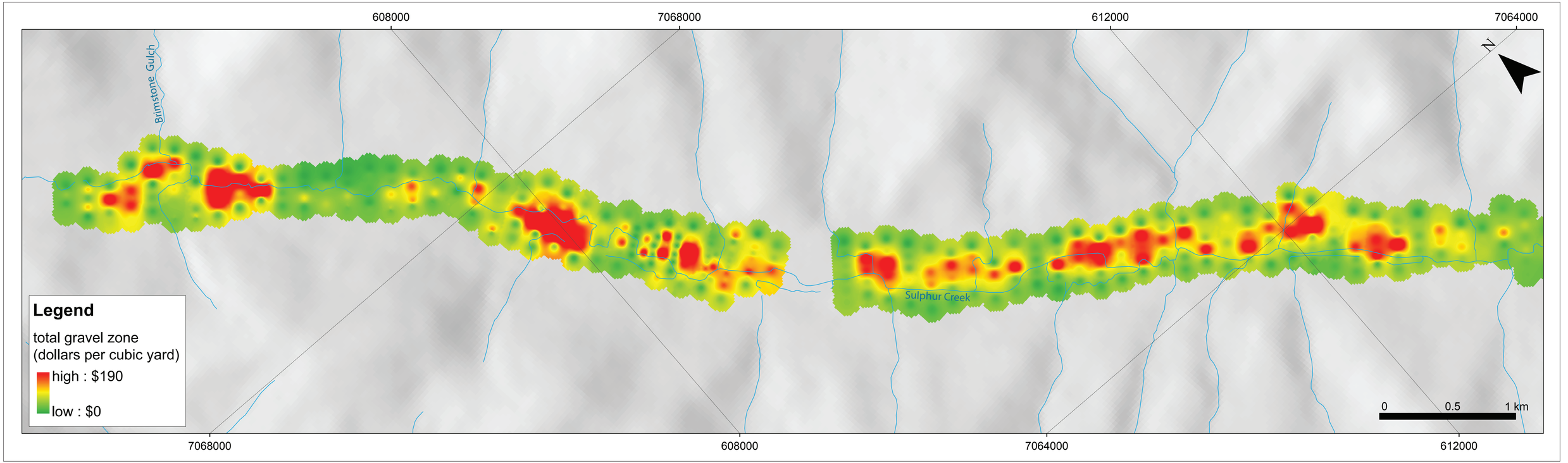
APPENDIX 3. *Upper Sulphur total gravel zone grade raster (calculated using the price of gold at CAD $1,400/oz); red colour indicates areas containing the richest ground.*



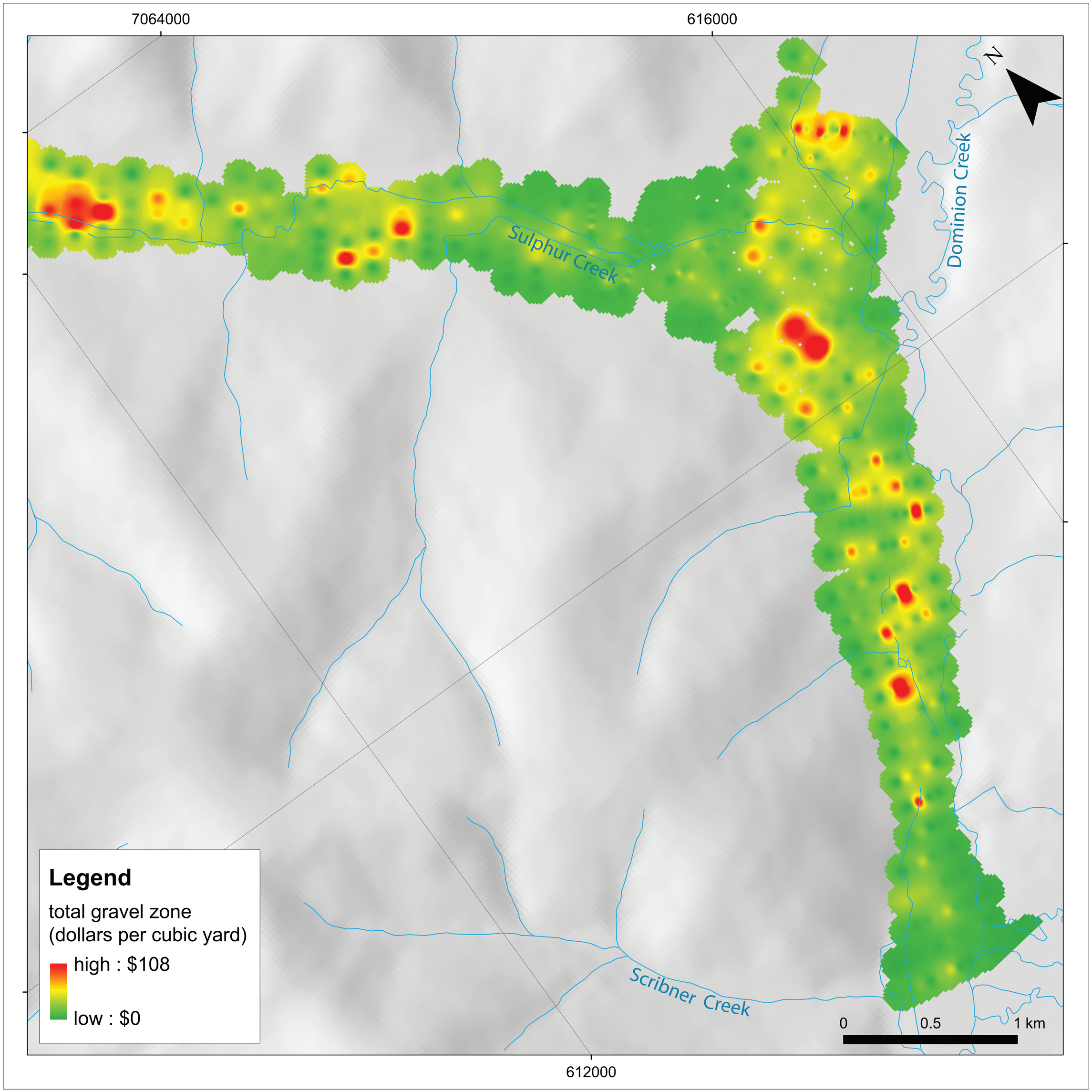
APPENDIX 4. *Approximate bedrock-low channel (brown line) including classified grade information. Pay channel (red line) is also displayed.*



APPENDIX 5. *Middle Sulphur total gravel zone grade raster (calculated using the price of gold at CAD $1,400/oz); red colour indicates areas containing the richest ground.*



APPENDIX 6. *Lower Sulphur total gravel zone grade raster (calculated using the price of gold at CAD $1,400/oz); red colour indicates areas containing the richest ground.*



APPENDIX 7. *Prospective targets around the mouth of Brimstone Gulch of mid-Sulphur Creek; red outlines delineate those areas that appear to be outside the limit of dredging and modern mining.*