The Effects of Haul Roads on Ore Compaction and Wettability of Leach Pads

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Abstract

Ore stacked on leach pads can be transported by an automated conveyance system, or it can be transported manually with haulage equipment. For large haulage equipment, it is necessary to design and maintain wide roads for two-way traffic to pass safely and sometimes turn around. Road widths can exceed 30 m for a kilometer or more across the leach pad, and will be used by haul trucks, graders, dozers, water trucks, and light-duty vehicles. The cyclical and vibrational compaction of the ore from the high traffic loads can significantly impact how the ore will respond to wetting, leaching, and drainage.

To investigate the impact of haul roads across leach pads, we conducted geophysical surveys with electrical resistivity to map the bulk electrical properties of the ore where current and historical haul roads were placed. From the electrical properties, we can make inferences about hydrogeological parameters such as saturation to determine reagent mobility through the leach pad.

In our investigations, we found that haul roads permanently located through the heap life can have significant long-term effects on how the solution percolates, such as creating large swaths of unleachable ore from the top of the pad to the liner. The unleachable ore further divides the flow and drainage of the solution through the pad. Temporary haul roads also have an effect, but their damage is less severe.

Introduction

The efficiency of haulage equipment, in terms of minimal routing, safety, construction, and maintenance, is a necessary component in haul road design and many have used these variables in optimizing for costs and safety in leach pad operation (Baek and Choi, 2017; Chowdhury et al., 2021). Short, wide, and flat routes are desirable for increased tire life, and this may mean that roads traverse leach pads, not only for dumping ore but for general movement through the mine. Given that leach pad materials are not ideally suited for roads, as the bearing capacity is generally lower than those comprising hard rock as the base, subbase, and subgrade in the mine pit (Tannant and Regensburg, 2001). In addition, the constant traffic, vibration, and heavy loads can potentially cause compaction deep within the pad. Compacted and dense material will have lower permeability (Guzman et al., 2013), which affects flow within the leach pad (McBride et al., 2017).

There are few methods for observing flow within porous media to understand compaction issues resulting from haulage equipment. Vibrating-wire piezometers measure changes in pore pressure related to wetting and drying but do not provide a means for tracking the fluid arriving at the piezometer (e.g., Ayala et al., 2013; Reyes and van Zyl, 2015). Geophysical methods that measure variability in electrical properties are well suited to observe broad changes in saturation and fluid flow across leach pads (e.g. Rucker et al., 2009a). For example, the direct-current electrical resistivity and time-domain electromagnetic methods can measure the ore's electrical resistivity (or its reciprocal, electrical conductivity) to determine if the material is generally wet or dry with low resistivity associated with wetter materials. Compacted ore with low porosity and low moisture content will typically have higher resistivity relative to the surrounding material.

This paper shows examples of electrical resistivity geophysical data across leach pads with known haul roads. In some examples, the haul roads were permanent, where the haulage equipment traversed the same geographic location as the leach pad was constructed. In others, the haul road was temporary and either covered with ore or still in use during acquisition of the electrical resistivity data. In each case, high resistivity features were coincident with the road's location and low resistivity could be seen on either side of the road. From a hydrogeological perspective, it appears that the roads can create a divide through the leach pad and segregate leachate from flowing uniformly. From a metallurgical perspective, the compacted areas left behind from the roads represent a significant quantity of material that is underleached or unleached. Our recommendation to minimize impacts from haulage equipment is to ensure adequate deep ripping of roads when new ore is placed and verify that historical roads are not impacting the wettability of the ore.

Haul roads across leach pads

For a truck-dump operation, haul roads are necessary to place ore for leaching. Given their size, the roads are easily viewable in aerial photographs from services such as Google Earth. Figure 1 shows several leach pads over time with haul roads highlighted in yellow. The top row of Figure 1 shows a series of photographs of a run-of-mine gold leach pad between 2011 and 2016 with 15 meter lifts. Some of the roads tend to persist over the duration of the construction, while others are temporary. The middle row, with aerial photos from 2011 to 2017, shows a gold mine of crushed ore. The access to the heap stayed practically at the same location throughout this period. The bottom row is a copper crushed ore leach pad from 2010 to 2018. A couple of main roads remain for the duration, while others are temporary.

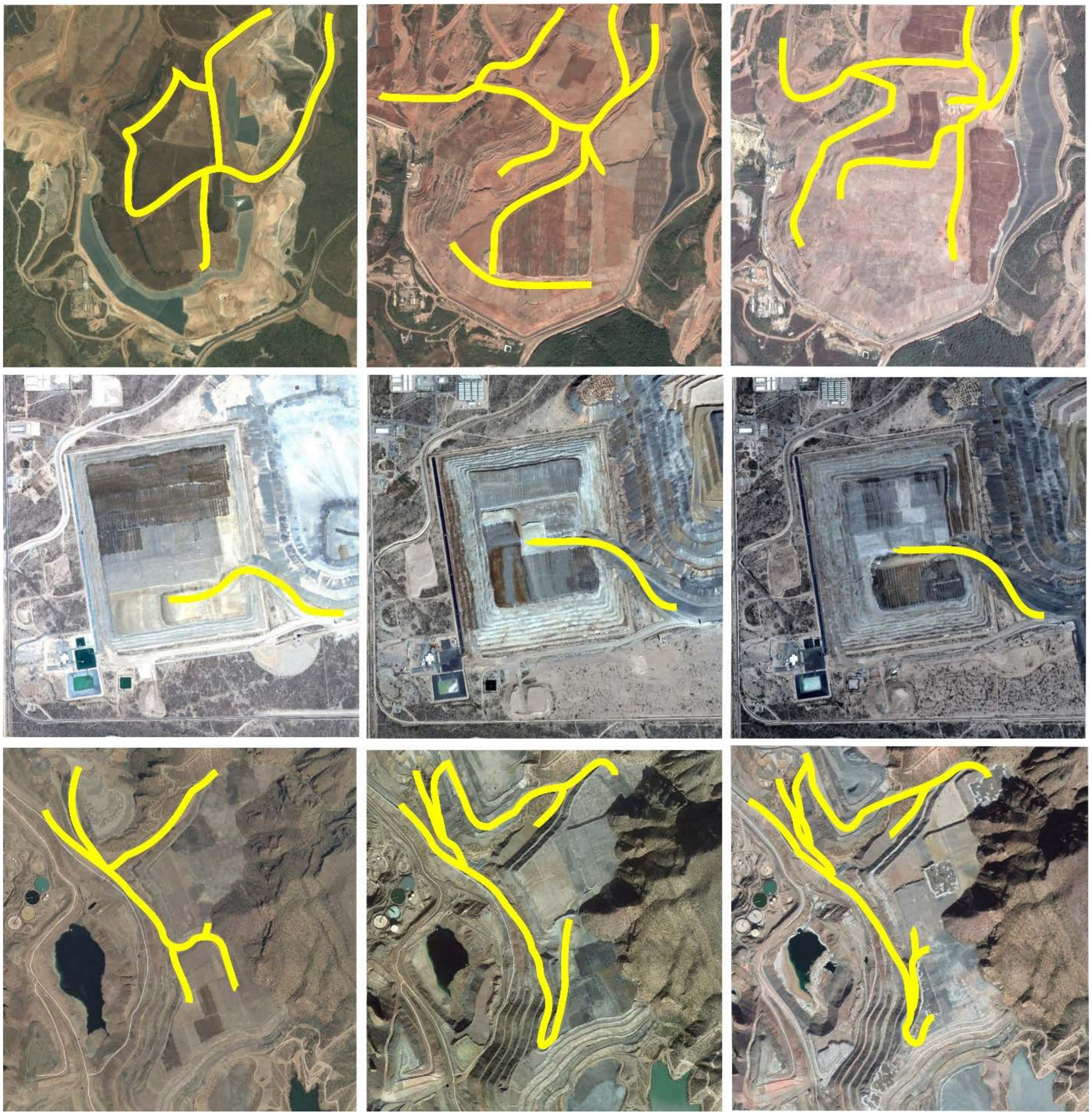

Figure 1: Aerial photos from Google Earth. Haul roads are outlined in yellow
Top row – gold mine with temporary haul roads from 2011 to 2016;
middle row – gold mine with permanent haul road from 2011 to 2017;
bottom row – copper mine with temporary haul roads from 2010 – 2018

Haul roads cover a significant portion of standard mining operations, meaning that the relative volume of the potential area and ore tonnage that haul roads may impact can be quite large. Haul roads across leach pads are designed to have two-way traffic for the efficient dumping of ore, and the recommendations for the road width are shown in Figure 2. Considering that a particular haul truck has a width of X, the total road width (W) for a given number of lanes (L) is (Tannant and Regensburg, 2001):

$$W = (1.5L + 0.5)X \qquad \text{(Equation 1)}$$

For a CAT 797 with a width of 9.15 m, the total two-lane road width can be 32 m. If we make additional assumptions that the ore density increases to 2,000 kg/m^3 at a depth of 15 m (the haul road has been in place during the placement of several lifts), the impacted tonnage of ore is approximately one million metric tonnes per kilometer of haul road or approximately 2% of a lift comprising an area of 200 hectares. This relative mass of ore will have low permeability with likely little chance of leaching metal from the stock. To demonstrate the effects of compaction on haul roads and their impact on wetting the ore beneath the roads, we used electrical resistivity geophysics to image the spatial distribution of electrical resistivity, and we then inferred the degree to which the ore wetted relative to surrounding material.

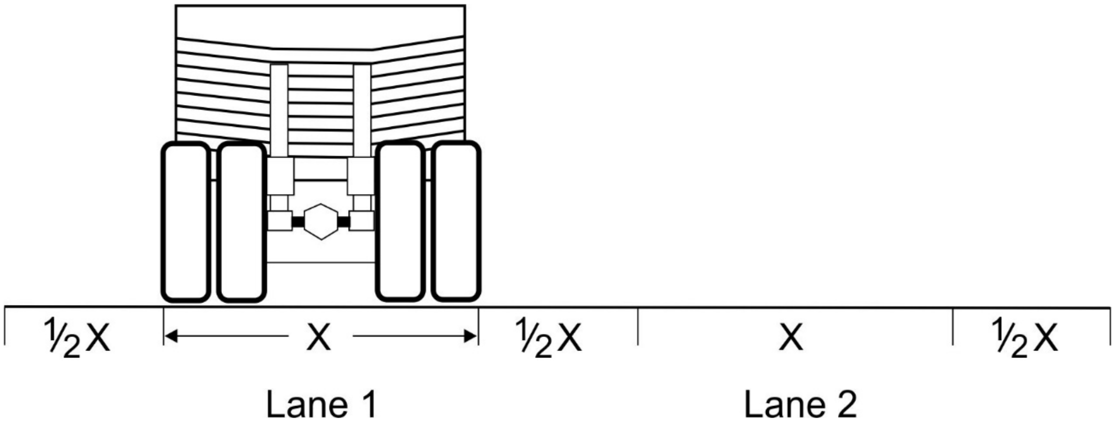

Figure 2: Haul road design for accommodating road widths (adapted from Tannant and Regensburg, 2001)

Description of electrical resistivity geophysics

Electrical Resistivity Tomography (ERT) comprises both field data and numerical models. To acquire ERT data, DC electrical current is transmitted through the ground via stainless steel electrodes. The electrodes are driven into the ground at regular intervals and connected to a resistivity meter through a cable. Electricity flows by way of an electrolytic conduction mechanism. The resistivity meter controls which pair of electrodes are to pass current at any given time. At other electrodes along the line, the receiving voltage is measured, and data for a full profile of data is acquired by sequencing between many possible electrical current transmitting electrode pairs and voltage receiving pairs. The specific sequencing of pairs is called an array; the Schlumberger and Alt3 Wenner arrays (Cubbage et al., 2017) were primarily used to characterize the haul roads. A more thorough description of electrical resistivity methods can be found in Loke et al. (2013).

Automated inverse methods applied through numerical models convert the measured current and voltage data to an estimate of the electrical resistivity structure (Rucker and Glaser, 2015). The inverse method relies on nonlinear optimization, requiring an iterative procedure to march towards a solution. Its objective is to minimize the difference between the modeled and measured data, usually in a weighted least-squares sense. The objective function has been updated many times over the years to also include other terms, such as smooth model constraints (i.e., a smooth model based on minimizing the second spatial derivative of the resistivity) and known boundaries such as those posed by liners beneath a leach pad.

Results of electrical resistivity profiling

Leach pad 1

The first electrical resistivity example is shown in Figure 3. The line was collected on an 80 m deep gold heap with crushed ore using a 6 m electrode spacing and the Schlumberger array. The haul road was in a permanent location throughout the heap's construction and operation, and it is unlikely that any surface preparations were conducted to remove and prepare the area for leaching. The figure shows a range of resistivity values, with the highest values associated with the under-liner that collects the pregnant leach solution at the bottom of the pad. Because the liner is an electrically insulating boundary, its resistivity values are greater than 10,000 ohm-meters (or 4 as a logarithmically transformed value). The lowest resistivity values are shown to be associated with areas of active leaching in the left and right halves of the figure. Between the active leach areas is a vertical, high resistivity dry area that coincides with the haul road. The road is about 35 m wide.

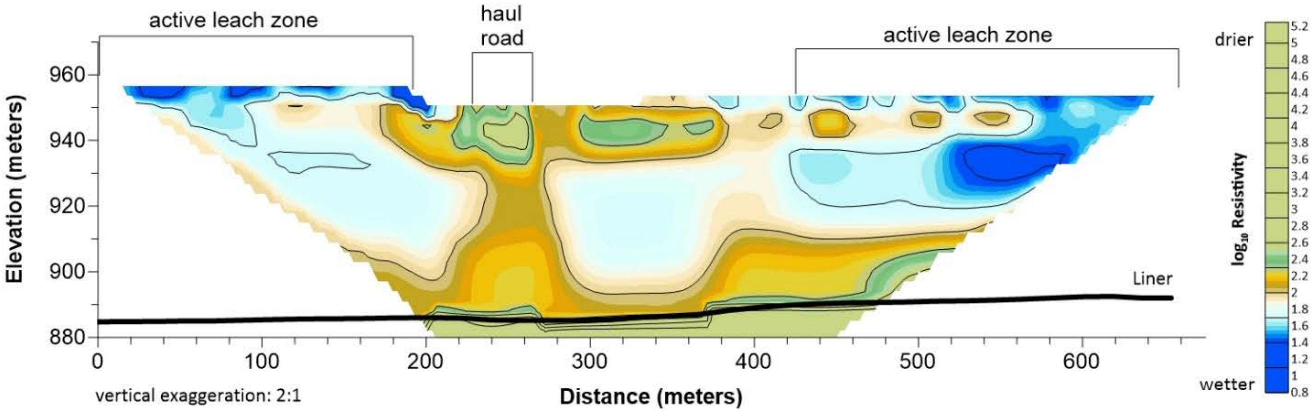

Figure 3: Electrical resistivity acquired across a crushed gold heap with a permanently placed haul road

When considering the shape of the leach pad, we estimate that four million metric tonnes of material have been impacted by haul roads, where little to no leaching can occur. Historical documents showed a mean gold grade of 0.3 g/t with 75% recoverability. It is estimated that up to 27,000 ounces are trapped in the volume of material affected by the haul road when extrapolating these numbers across the affected haulage area. This is a significant amount, but likely represents the high end of the estimate.

Leach pad 2

In Figure 4, we show an electrical resistivity section acquired across a ROM gold heap roughly 60 m deep. The data were acquired with a Schlumberger array with 6 m electrode spacing. Across the top of the section, we have identified two types of roads: haul roads and light-duty (LD) roads. There is high resistivity material that is likely compacted beneath each of the four roads. This is contrasted with material actively being leached shown as low resistivity. Moving from left to right, the first LD road shows a small footprint as expected, with a limited depth of impact at 16 m. The road is temporary, in existence for a couple of lifts. Being a haul road, it does not have active irrigation that could contribute to high resistivity values.

The next haul road to the right is relatively narrow, accommodating two lanes of traffic with a width of 28 m. Its impact depth is noticeably greater at 25 m. The second haul road to the right is extremely wide at 75 m and likely accommodates several lanes. The road was created shortly after construction began. We consider this a semi-permanent haul road that is unlikely to be removed in the future. The last LD road is between the large haul road and the edge of the heap. Similar to the first LD road, its impact depth is relatively shallow.

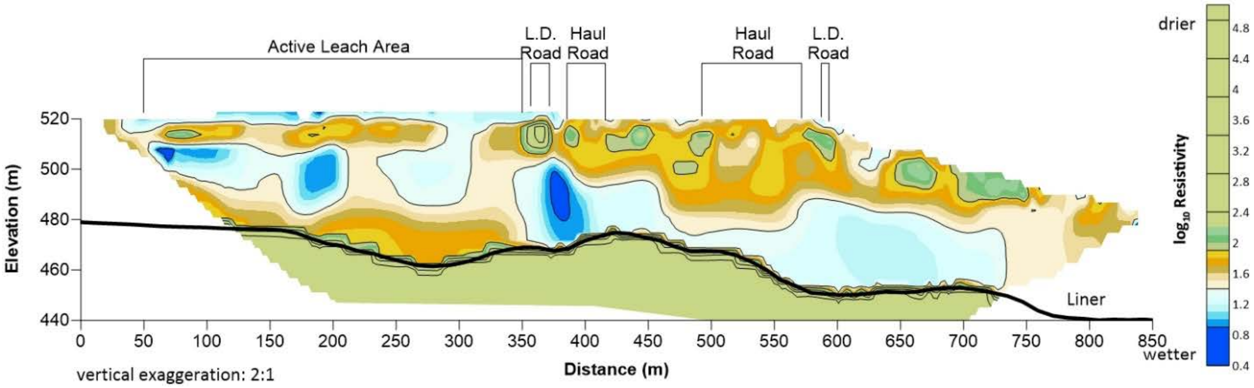

Figure 4: Electrical resistivity acquired across a ROM gold heap with a semi-permanently placed haul road, temporary haul road, and light-duty roads

Performing a similar exercise on the potential gold inventory remaining in the pad beneath haul roads, the smaller of the two haul roads is estimated to have affected a mass of 840,000 tonnes at an estimated stacked grade of 0.16 g/t at 50% recoverability, equating to nearly 2,000 oz. The larger haul road shows an approximate mass affected by haulage at 3.3 million metric tonnes, equating to 8,200 oz. Together, both roads represent a significant inventory for the mine that should be considered for some type of secondary recovery operation that can overcome the mechanical strength of the compacted materials. This would include either physical removal or high-pressure injection (e.g. Rucker et al., 2009b).

Leach pad 3

In the third example, we investigated a copper leach pad with crushed ore placed atop native bedrock without a liner. Figure 5 shows the electrical resistivity line placed over the top of the heap where a semi-permanent haul road was buried under a new lift and irrigated with leachate. The data were acquired with a 6 m electrode spacing using the Alt3 Wenner array (Cubbage et al., 2017). The location of the haul road is obvious in the electrical resistivity data as the highly resistive haul road material bisects two areas of the leach pad with conductive material. The buried haul road has rough dimensions of 70 m width and 50 m height, extending for 200 m in length across the pad. With an acid soluble copper grade of 0.2%, this equates to nearly 2.8 million kilograms of copper lost to extraction from surface leaching.

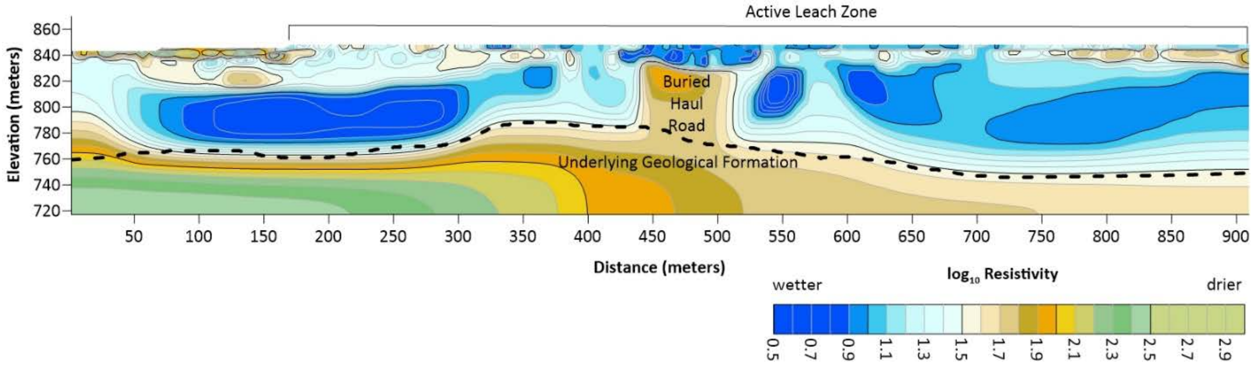

Figure 5: Electrical resistivity acquired across a crushed copper ore heap with a buried historical haul road

Conclusion

Haul roads across leach pads were investigated with electrical resistivity geophysics to determine the impact of compaction on the efficacy of surface irrigation. Haul roads can be large to accommodate wide haulage equipment, and if not routinely moved can have impacts extending deeply within a leach pad. The effects of haulage equipment were obvious in the electrical resistivity data because their signatures were of consistently higher resistivity relative to the surrounding material. The high resistivity is hypothesized to result from compacted ore and lower saturation. When multiplying the tonnage of ore that is impacted by compaction by the specific grades across several leach pads, we estimate that millions of dollars' worth of metal inventory is left behind.

Based on our findings, we recommend that electrical resistivity geophysics be conducted routinely over haul roads to determine the significance of their impacts to the operation of the leach pad. The method can also test the effectiveness of existing ripping operations by acquiring data before and after haul road removal. Lastly, if the haul road has made deep impacts into the leach pad, below what is feasible for ripping, then material removal or injection may be the only methods available for inventory drawdown (e.g. Rucker et al., 2017).

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