# Limited Expert Review of Probably Hydrologic Consequences and Ground Water Model Reports for Bull Mountain Mine Number 1 - AM6

Prepared by:
Dr. W. Payton Gardner
Associate Professor of Hydrogeology
University of Montana

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To: Mr. Shiloh Hernandez – Earth Justice

## Synopsis:

In this report, I perform a limited review of the Probable Hydrologic Consequences (PHC) and Groundwater Model Reports (GMR) prepared for the Bull Mountain Mine as part of the Amendment AM6 (Water and Environment Technologies, 2024b, 2024a). I have reviewed these reports as a practicing researcher in hydrogeology with active research in mountain aquifer hydrology, groundwater modeling and mechanical deformation effects on subsurface flow. The PHC report describes local area hydrology and attempts to estimate potential and probable consequences of long wall mining under the Bull Mountains. The GMR describes the construction and simulation results of a groundwater model intended to simulate groundwater response to mining and forecast relatively near-term groundwater flow and geochemical transport after mining. Both the PHC and the GMR contain significant omissions, demonstrate a lack of quantitative analysis for critical arguments and make untested, non-conservative assumptions. If unaddressed, these issues could lead to an underestimation of mining consequences, and an overestimation of the ability of the system to recover and of mitigation resources. The issues I will discuss are as follows.

1. The amount of relatively fresh water for wildlife, stock and/or domestic consumption in the Bull Mountains is underplayed. The effect of undermining on this groundwater and spring flow is done in a very qualitative manner that does not meet current scientific standards and likely hides quantifiable effects on local springs which are already occurring.
2. The groundwater model does not accurately include fracture flow processes and likely significantly underestimates the connection of the mine to surface hydrology.
3. The assumption of fracture healing for all mudstone layers greater than 10 feet in thickness, regardless of sand content and/or induration, is an untested, large

assumption, which likely significantly underestimates vertical connection between the mine and shallower water resources. This assumption has implications for the effect of mining on existing water resources in the area as well as the ability of the system to recover after mining.

4. The deep underburden aquifer, which will be used for mitigation, is not well characterized and no quantitative evaluation of its ability to meet demand has been undertaken. Given the current parameterization given the PHC and GMR, an initial quantitative analysis shows that the underburden aquifer is likely to be unable to meet replacement demands, and significant adverse effects are likely for existing well owners both within and external to the permit area boundary if this aquifer is used as a mitigation measure.
5. The mean conductivity of spring waters before mining in the area was around 1607 $\mu S/cm$ and shallow overburden water is around 1740 $\mu S/cm$. The mean conductivity of underburden water is 2605 $\mu S/cm$. Replacing shallow overburden groundwater and spring waters with underburden water could cause a change of water from class II to class III water. No quantification of the risk of water quality change due to replacement with the proposed mitigation water has been carried out.

## Specific Concerns:

The Bull Mountains are an arid to semi-arid mountain range and water resources are limited; however, there are important existing shallow water resources in the area as evidenced by over 50 springs which flowed with seasonal discharge over 1 gallon per minute (gpm) (Montana Department of Environmental Quality, n.d.). Shallow groundwater wells in the alluvium and clinker are productive and provide high quality class II water for stock and domestic use (Thompson, 1982). The PHC downplays potential impacts to these springs and or wells but provides little to no quantitative analysis of the actual risk and effects. The analysis of spring flow effects is particularly weak, and no quantitative analysis is provided. Visual analysis of spring hydrographs in the PHC shows several undermined springs that do not have the same seasonal pattern after undermining, and do not flow at all or flow in a reduced fashion, even with wetter than average conditions in the past two years (2022,2023). The PHC claims that this could be due to drier conditions in 2021 and 2022. However, springs external to the mine boundary have flowed in the past two years, which indicate this argument may not be true. While antecedent conditions and storage-discharge relationships are a potential reason for this lack of flow, *the impact of mining has not been ruled out in any way by a quantitative analysis*. It is well within the bounds of common hydrologic science to establish a precipitation-discharge relationship and examine potential changes to the relationship before and after mining. A lack of quantified analysis invalidates any statements made without evidence on the potential effect of lack thereof made in the PHC.

The groundwater model built to assess hydrologic consequences has significant limitations, the influence of which are not adequately explored in the PHC. The model is intended to reproduce the effect of fracture creation and drainage to the mine after collapse. The PHC clearly states that fracturing of strata will occur from the mine gob all the way to the surface.  This enhanced fracturing will lead to increased hydraulic connection between near-surface reservoirs and the gob.  The current model uses porous media parameterization and does not consider fractured flow explicitly.  Fractured flow systems tend to have much higher "hydraulic diffusivities", which is defined as the ratio of hydraulic conductivity to specific storage ($D_{hy} = K/S_s$ ), which leads to stronger connection to surface, as defined by faster propagation of transient changes in the system to depth.  While it is possible to generate porous media properties that do represent facture system response, these parameters should be assigned using physically justified changes in properties, which adequately capture the fracture response (Parizek, 1990).  In the model used in the PHC, vertical changes are largely based upon calibration of a single deterministic model to available data.  In addition, the increase in vertical conductivity due to fracturing is assigned based upon an arbitrary vertical multiplier that is not physically motivated, nor quantitatively assessed, and is not scientifically defensible.  The lack of a fracture media response is non-conservative assumption, which likely leads to underestimation of the vertical hydraulic conductivity and connection between surface and mine aquifers.

Additionally, *the model makes a very large assumption of no increase in vertical hydraulic conductivity due to fracture in mudstones over 10 feet thick*, invoking, without citation, the healing of mudstone fractures.  While healing of fractures in very thick, plastic clays is certainly possible, healing of fractures in indurated clays is not guaranteed (Bourg, 2015).  In fact, long term increases in mudstone from fractures can be expected in many cases, and the degree of healing is a function of the clay content, thickness and induration (Bourg, 2015).  Given the high heterogeneity of the Tongue River Member and the high silt and sand content of the formation, to simply assume that healing occurs is a gross assumption, and one that likely has very large implications for model calibration and prediction.  Indeed, other long wall mining areas have shown long-term changes in surface hydrology, indicative of strong mine to surface reservoir connection (Stout, 2004).  The assumption of healing likely leads to predictions that reduce hydraulic connections between the mine and the surface, isolation of the mine from the surface, and minimization of mining effects.  Long-term increased hydraulic connection between the mine gob and the surface will likely significantly alter the groundwater flow regime, likely lowering of the water table in near surface reservoirs including the productive bedrock mantle and alluvial aquifers. Given the significant potential bias of this assumption, at the very minimum models should be created and tested without this assumption for the predictions to be scientifically defensible.

Vertical connection between the mine gob and the surface can be clearly seen in the strong seasonality of mine drainage (Water and Environment Technologies, 2024b).  The inability of the model to adequately simulate fracture derived increases in connectivity is clearly exhibited by this lack of seasonal response in the model.  Given the strong heterogeneity in the region, the potential for significant change of the vertical hydraulic connection due to fracturing all the way to the surface is high.  Given the relatively poor performance of the model in capturing observed seasonal connections, and the significant assumptions on vertical hydraulic conductivity, the use of a single simulation to base long term predictions with no calculation of predictive uncertainty is not up to current groundwater simulation standards (Moore & Doherty, 2005, 2006). This is even more critical, when the effect of likely conceptual, structural error in the model would lead to predictions that underestimate the consequences of mining.

Given the already observable and likely impacts from mining on shallow aquifer systems, the PHC states without any quantifiable calculations that underburden aquifer in the Sandstone UB2A is an adequate reservoir to supply all mitigation water in the area. Whether or not this aquifer could supply the needed mitigation water is an important question, which is not addressed in the PHC. These sandstones were deposited if a fluvial environment, tend to not be laterally extensive, and are highly heterogeneous (Thompson, 1982). Initial calculations from a well contractor, using a transmissivity that was deemed to be in error, and is one to two orders of magnitude higher that the accepted transmissivities given in the PHC, indicate that even using this artificially high transmissivity, observable drawdown would be seen at the nearest private well in less than a year (Hydrometrics, 2009). No drawdown calculations were made in the PHC at all with the current accepted transmissivities. In addition, the effect of heterogeneity, and the strong likelihood that the aquifer has large range of transmissivities is completely ignored. As an example calculation, which incorporates the current reported hydraulic conductivity, thickness and specific storage data (GWR) and attempts to characterize the uncertainty given expected heterogeneity, I have predicted the drawdown in a confined aquifer using 1000 different realizations of aquifer parameters (hydraulic conductivity (K), specific storage (S_s) and aquifer thickness (b)), drawn from statistical distributions fit to the data for sandstone UB2A presented in the GWR. Here hydraulic conductivity and specific storage are assumed to come from lognormal distributions and aquifer thickness to come from a gamma distribution all fit to the data given in the GWR. Drawdown is calculated using the Theis method (Theis, 1935), a standard solution for estimating drawdown a confined aquifer, where the aquifer transmissivity $T = Kb$ and storativity $S = S_s b$ for each realization are calculated from a random from the fitted distributions. The median, and 10$^{th}$, and 90$^{th}$ quantiles of all simulations for drawdown at the mine boundary (2.5-mile radial distance) due to a single pumping well in the center of the mine, pumping at 6 gallons per minute, is shown in Figure 1. The median drawdown for all realizations, which is representative of the most likely outcome is 60 ft after 100 years. The 90$^{th}$ percentile, which is representative of the upper bound of what could be expected, shows the drawdown at the boundary reaching the reported height freestanding water above the aquifer within 10 years. The 10th percentile drawdown, which is representative of the minimum amount of drawdown expected at the boundary is around 7 feet at 100 years, *from a single well pumping at 6 gpm*. It is important to note that drawdown at smaller radii will be higher, drawdown will increase if the pumping rate is increased, and the adding more pumping wells will also increase the drawdown.

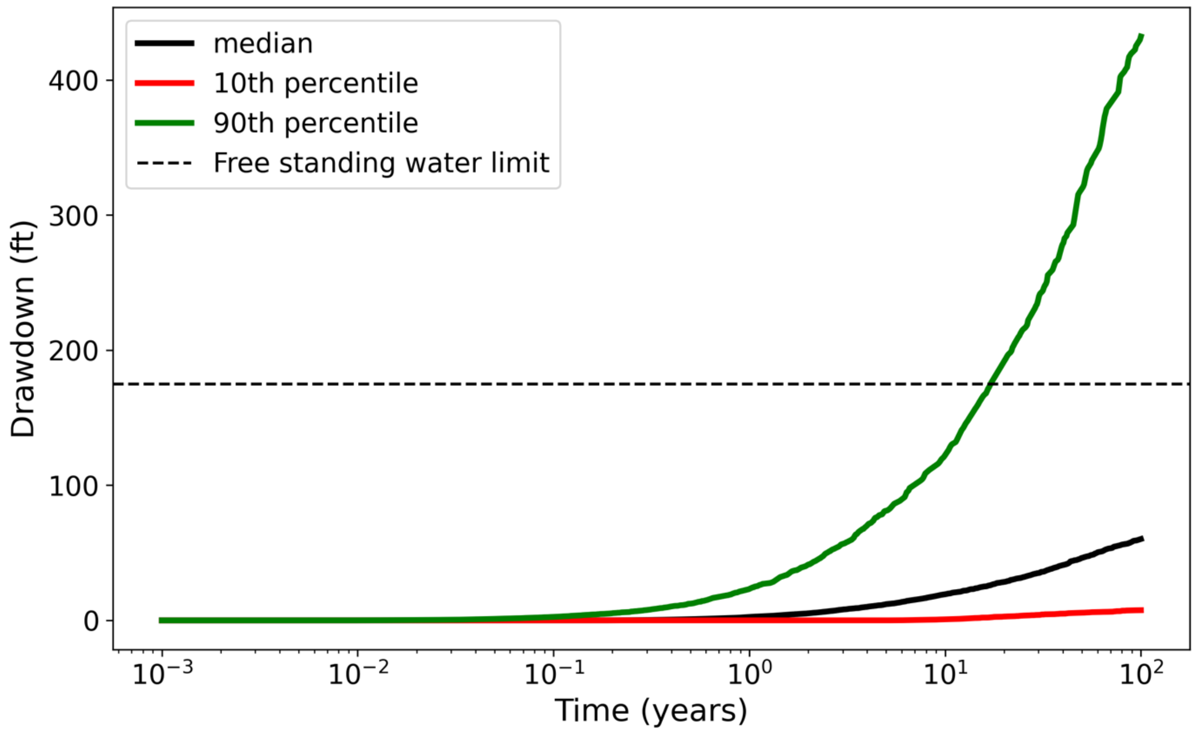


*Figure 1 - Estimated drawdown from a single pumping well in the center of the mine permit area at a radius of 2.5 miles, pumping at 6 gpm. Median, 10th and 90th percentile of simulated drawdown from 1000 realizations of aquifer parameters based upon field characterization data.*

Current mine drainage from shallower groundwater is around 1000 gpm, and model forecasted drainage is over 800 gpm for over 50 years (Water and Environment Technologies, 2024b). If even a fraction of this drainage water needed to be mitigated, far more the 6 gpm will need to be pumped from the sandstone aquifer. Given this probabilistic analysis of drawdown from a single well, and the fact the mitigation water could be needed for many shallow groundwater wells and springs due to mining it is highly unlikely that the lower aquifer can be expected to supply more than a few pumping wells at all, and very unlikely mitigation would occur without very significant adverse effects to existing users of this aquifer both within and outside of the mine boundary. The PHC simply states that this confined sandstone has adequate water, without any quantifiable calculation, which is not scientifically justifiable, and likely incorrect.

Even if sandstone UB2A water could supply the required mitigation needs, the mitigation water likely be of reduced water quality. The mean conductivity for alluvial aquifer and bedrock mantle wells is 1740 $\mu S/cm$ and the mean conductivity for spring water is 1607 $\mu S/cm$ (Water and Environment Technologies, 2024a) which classifies them as Type II groundwaters (Water and Environment Technologies, 2024a). The average conductivity of UB2A water is 2605 $\mu S/cm$, which is Type III groundwater (Water and Environment Technologies, 2024a). Given the expected effects of mining including lowered shallow aquifer heads and reduced spring drainage (Parizek, 1990; Water and Environment Technologies, 2024a), is it likely that current users of shallow high-quality groundwater will require mitigation water. Given the average conductivities of the shallow and deep groundwater it is likely that this mitigation water is of reduced water quality. No quantifiable analysis of the probability of water quality degradation is carried out, thus it is impossible to adequately determine the probability of mitigation water reducing the water quality.

## Summary

To summarize, the PHC and GWR suffer from a lack of scientifically defensible, quantifiable calculations demonstrating the lack impact on current water resources. They make systematic, no justifiable assumptions in the modeling process which lead the model to be biased towards showing isolation of mine and shallow surface waters. The effect of these assumptions is not explored in any quantifiable fashion. In fact, the predictive uncertainty in model response is not explored or discussed at all. Despite indications that considerable high quality mitigation water might be needed, the currently proposed mitigation water source is likely to be inadequate to supply large amounts of remediation water. Finally, even if the mitigation water is adequate, is likely to be of decreased water quality.

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