Paug-Vik Development Corporation
Environmental Services Division
1600 "A" Street, Suite 306
Anchorage, Alaska 99501
Phone: 907-258-1345
FAX 907-222-5423

November 1, 2006

Mr. Randy Romenesko
City Manager
City of Nome
P.O. Box 281
Nome, AK 99762

Subject: Letter Report for Third-Party Evaluation of Moonlight Aquifer and Rock Creek Mine, Nome, Alaska.

Dear Mr. Romenesko:

This letter report is a third-party review and evaluation of information related to potential risks to the City of Nome's water supply from the Rock Creek Mine, which is currently under development. The Rock Creek Mine is located in the Snake River valley approximately four miles north of the City wells (Figure 1). City wells tap a marble aquifer near Moonlight Springs. Moonlight Springs has supplied water for the City of Nome since the Gold Rush days in the early 1900s.

The Rock Creek Mine is a hard rock mine that has recently received permits to begin construction and operations. Extensive documentation of site conditions, projected impacts from the projects, and permits and permit conditions issued are available for public review (Bristol Environmental and Engineering Services Corporation, 2006). These form the basis for much of this review. In addition, I reviewed prior investigations of Moonlight Springs and the City wells (Munter and others, 1992; Stevens Exploration and Management Corp, 2005; and ADEC, 2004). I have also reviewed public concerns as expressed in emails and public meetings, performed a site visit of the Rock Creek Mine vicinity, and presented a summary of my findings at a meeting of the Nome Common Council on September 25, 2006. Although the primary concern about impacts to the water supply are from the potential for water to flow from the mine site to the wells, there is also concern about the physical effects that blasting may have on the wells.

BACKGROUND INFORMATION

Moonlight wells

The City of Nome currently obtains water from three wells ranging in depth from 81 to 122 ft that were drilled into a fractured marble aquifer. Prior to placing these wells in service in 2001, Nome received its water from an infiltration gallery and gravity-feed piped-water system at Moonlight Springs, located a few hundred feet south of the wells and a few tens of feet lower in elevation. The wells tap a water-bearing zone that is characterized as confined or semi-confined, however on a larger scale, the marble aquifer that supplies water to the wells is considered to be the same aquifer that supplies water to Moonlight Springs. The aquifer is described by Munter and others (1992) as a 1000 ft-plus thick unit of marble that comprises most of Anvil Mountain, which rises immediately northeast of the springs and wells to attain an elevation of 1134 ft above msl. For the purposes of this report, the aquifer supplying water to the City's wells or Moonlight Springs is termed the Moonlight aquifer.

Rock Creek Mine

The attached map shows the location of Nome, the Moonlight Springs well field, and the Rock Creek Mine. The host rock unit in the area of the mine is a well-foliated, "wavy" banded quartz-muscovite schist containing varying proportions of carbonate, graphite/carbon, and chlorite. (Water Management Consultants, 2006). Groundwater investigation test wells drilled in the vicinity of the deposit have found "at least moderate bedrock permeability over a significant portion of the site." (Water Management Consultants, 2006). Air-lift pumping showed that well yields up to 200 gallons per minute were achieved from bedrock wells in the vicinity of the pit.

Hydrogeological conditions and the development plan for the Rock Creek Mine are detailed in numerous site studies and environmental documents at the project website (http://www.dnr.state.ak.us/mlw/mining/largemine/rockcreek/pdf/vol2%20.pdf). The mine is planned to be an open-pit type hard-rock mine extending to a depth of approximately 30 ft below mean sea level (msl) from a surface altitude ranging from approximately 250 to 450 ft above msl. Natural groundwater at the minesite is found at a depth ranging from 10 to 40 ft. The elevation of the groundwater table at the mine site varies from 230 ft to 440 ft above msl, confirming that the water table is a muted image of site topography (Water Management Consultants, 2006). At full mine development, the water table will need to be lowered approximately 300-500 ft in the vicinity of the mine to keep it from flooding.

A series of wells surrounding the pit and tapping the bedrock aquifer will pump groundwater as a means of dewatering the mining operations. The water will be treated to attain water quality standards and injected into a series of injection wells and a shallow infiltration gallery near the mine site. The injection wells will extend to an estimated depth of up to 200 ft below msl.

Existing groundwater flow at the mine site, as inferred from a water table map prepared for the project, is from the northeast to the southwest, towards the Snake River. The Snake River is at an elevation of approximately 30 ft above msl near the site and is the local discharge point for shallow groundwaters and local surface waters.

There are several mapped faults in the vicinity of the ore deposit at Rock Creek. These faults are characterized as being gouge-filled and act as barriers to groundwater flow in some cases, and openly fractured in some cases, acting as permeable zones for groundwater flow (Water Management Consultants, 2006).

APPROACH

Several independent lines of evidence are available to evaluate the potential for groundwater flow from the Rock Creek Mine to the Moonlight wells. If all lines of evidence provide similar conclusions, this reinforces the likelihood that conclusions reached from each line of evidence, while perhaps not compelling or conclusive on their own, are correct.

The independent lines of evidence are:

1. The known hydrology of the Moonlight aquifer and proximity of recharge compared to the distance to the Rock Creek Mine.

2. Geological faulting between Rock Creek Mine and the Moonlight wells as barriers to groundwater flow.

3. Multiple shallow groundwater flow systems and divides between Rock Creek Mine and Moonlight wells as barriers to shallow groundwater flow.

4. The low topographic setting of the Rock Creek Mine means that high hydraulic gradients that would be needed to drive sub-regional or deep groundwater flow systems are absent.

5. Chemistry of water and geochemical indicators of separate and distinct groundwater flow systems.

6. Hydrogeologic conditions created by pumping, injection, and pit development and creation of a closed-loop flow system at Rock Creek Mine.

In addition to evaluating conditions during operation of the mine, post-closure groundwater conditions are also reviewed and addressed. All but the last of the lines of evidence described above are also applicable during the post closure period. Potential impacts from blasting are also addressed.

Hydrologic response time and mapped recharge areas for the Moonlight aquifer

Prior studies have shown that Moonlight Springs discharge increases in a matter of hours to days to sudden recharge events (Munter and others, 1992). During sudden snowmelt events, the temperature of water discharged at the springs also drops suddenly in response to recharge of near-freezing water. These characteristics indicate that the springs (and by inference the marble aquifer in the vicinity of the springs) receive at least some amount of recharge within relatively close proximity. Based on these and other data, Munter and others (1992) and Stevens (2005) both drew maps showing recharge areas for the Moonlight aquifer that are focused on areas near Moonlight Springs where the marble rocks occur and exclude the Rock Creek Mine area.

Geologic faults

The most significant geological fault in the area of evaluation is the Anvil Creek Fault zone. This fault zone is located in the Anvil Creek valley (oriented parallel to Anvil Creek) (Munter and others, 1992) and is considered to be a barrier-type fault with low-permeability fault gouge exposed by mining operations in the valley. Numerous test holes drilled for mining purposes also reportedly encountered low-permeability fault gouge.

The low-permeability fault zone is estimated to be approximately 2000 ft wide, and is likely to be nearly vertical, making a significant potential barrier to groundwater flow. In fact, the presence of this fault is a likely contributor to the presence of Moonlight Springs. Water generally emerges at springs like Moonlight Springs when groundwater flow is blocked by geologic conditions. In this case, flow is likely blocked from flowing southward through the coastal plain sediments by thick permafrost and is blocked from discharging southwestward towards Anvil Creek and its associated alluvium by the Anvil Creek Fault.

The Anvil Creek Fault is located directly between the City wells and the Rock Creek Mine, is not known to be broken up by any mapped faults transverse to Anvil Creek, and is a likely barrier to groundwater flow from the mine to the wells.

Shallow groundwater flow systems as barriers

The water table map of the Rock Creek Mine shows that shallow groundwater flows in a southwesterly direction from the locations of the proposed injection wells towards the Snake River. Groundwater modeling results (Water Management Consultants, 2006) indicate that some of the injected water will return-flow towards the pit but that most of the water would join the southwest-flowing groundwater flow system and ultimately discharge into the Snake River.

This investigation focuses on the concern that injected water may flow into a deeper groundwater flow system or fracture system that ultimately flows to the Moonlight wells. Analysis of this concern relies on concepts of local, intermediate (or sub-regional), and regional groundwater flow systems.

The importance of local topographic relief on development of local versus sub-regional or regional groundwater flow systems was first developed by Toth (1963). Toth found, through modeling studies, that areas with more topographic relief tended to develop local groundwater flow systems that discharge to local creeks. Groundwater flow system boundaries occur at ridge-top divides where flow directions diverge and also at stream bottoms where flow boundaries converge.

Examination of the topographic map for the Nome area (Figure 1) shows that considerable local topographic relief is present in the area. A local topographic divide is present between the mine site and Glacier Creek. A major divide is also present between Glacier Creek and Anvil Creek, rising to an elevation of over 500 ft above msl. Anvil Creek is incised deeply into the landscape, occurring at an elevation of approximately 100 to 250 ft above msl in its lower reaches prior to flowing out onto the coastal plain near the Nome-Teller highway. The Moonlight wells are at altitudes ranging from 140 to 160 ft above sea level.

These differences in elevation create local groundwater flow system divides. There are two topographic divides and two major streams separating the Rock Creek Mine from the Moonlight wells. Assuming that the water table is a subdued replica of the topography, this means that there are likely four groundwater flow system boundaries (one at each topographic divide and one at each stream location) that separate the Rock Creek Mine from the Moonlight wells. These groundwater flow system boundaries likely extend to depths of at least several hundred feet below sea level. These flow system boundaries, which are oriented transverse to a direct line between the Rock Creek Mine and the Moonlight wells, form effective hydrodynamic barriers to shallow groundwater flow and confirm that groundwater from the area of the injection wells should flow towards the Snake River.

Regional or deep flow systems

There is also a concern that injected water may flow into a groundwater flow system or fracture system that is deeper than the shallow systems described above and could ultimately flows to the Moonlight wells.

Toth (1963) also showed that regional to sub-regional groundwater flow systems can develope in areas with hilly or mountainous topography. Recharge occurs in very high-elevation areas such as mountain tops and can enter deep flow systems that underlie local flow systems, discharging at regional or sub-regional discharge areas. The high elevation of the mountainous areas, combined with the adequate permeability of geologic units, can cause water to flow underneath local or intermediate flow systems before rising and emerging at regional discharge points.

The Rock Creek Mine occurs at a relative low to moderate topographic elevation which would not be considered to be a recharge area for a regional or deep flow system. The land surface elevation at the mine site (approximately 250 to 450 ft above msl), is lower than the topographic divide separating the Glacier Creek and Anvil Creek drainages. This means that groundwater at this location is highly unlikely to have enough potential energy (as determined by elevation above sea level) to flow under the local groundwater flow system boundaries described previously to emerge near the Moonlight wells.

Looked at another way, the hydraulic head difference between the injection well sites (estimated to be 200 to 400 ft above msl) and the Moonlight wells (approximately 100 to 150 ft above msl) is considered to be too small to drive groundwater flow under the divides (groundwater elevation as high as approximately 400 ft and as low as approximately 130 ft) and across a distance of four miles, even if a permeable geological zone were present to facilitate the flow.

Chemistry of water

Piper diagrams are commonly used in regional groundwater studies to distinguish groundwaters of different major ion chemical composition that are differentiable based on their flow paths through different geologic units. Munter and others (1992) showed that groundwater from schist terranes were geochemically differentiable based on major ion composition, generally containing higher concentrations of sulfate compared to water from marble aquifers. The groundwater at Rock Creek Mine was also found to have higher concentrations of sulfate than water from the Moonlight aquifer. (Bristol Environmental and Engineering Services Corporation, 2006). Since sulfate ions are not normally easily removed or broken down in groundwater flowing through fractured metamorphic rocks, this indicates that water from Rock Creek Mine area does not naturally flow to the Moonlight aquifer.

Trace metal composition of different groundwaters can also be used to help differentiate groundwaters from different areas. Natural arsenic concentrations in the vicinity are as high as 1.35 mg/L, which is near the high end of the reported ranges for natural occurrences of dissolved arsenic, compared to water at the Moonlight aquifer, which is below 0.01 mg/L. This supports the concept that groundwater from Rock Creek Mine area does not naturally flow to the Moonlight wells.

Interception by the pit

The water management plan for the mine calls for dewatering wells surrounding the pit, a water treatment facility and reinjection of water into injection wells and a shallow infiltration gallery. The shallow infiltration should not have any significant effect on groundwater flows other than in the immediate vicinity of the gallery. Water will be introduced into shallow alluvial fan sediments associated with Rock Creek, which will likely increase base flows of the creek and discharge to the Snake river without affecting deeper bedrock flow systems.

The locations for the reinjection wells is west to northwest of the pit area, at a distances ranging from approximately 1000 to 4000 ft from the pit. One of the permit conditions is that the reinjection pressures will not be large enough to cause discharges of water at the land surface in the vicinity of the wells. This will be a practical limit on the allowable reinjection pressure that is likely to preclude creating a high-head flowpath with the ability to propagate significant distances from the site. Some of the reinjected water will flow to the dewatering wells surrounding the pit (or if the well pumps are turned off, to the pit itself). There will likely be a closed cell circulation loop established of reinjected water flowing towards the pit, being intercepted by the dewatering wells, and being treated and reinjected. The presence of the pit itself and the surrounding dewater wells will create additional groundwater flow system boundaries that will prevent at least some of the reinjected water from traveling off-site. Modeling performed as part of the environmental studies showed that the remainder of the reinjected water would flow along with the background groundwater flow system ultimately to discharge into the Snake River west of the site.

It is also important to note that not all of the water pumped by the dewatering wells will be reinjected back into the bedrock aquifer. Some of the water will be injected into an infiltration gallery located near Rock Creek alluvial fan and some will be used for process water by the mill. This will have the effect of limiting the potential for creating high groundwater heads in the bedrock aquifer and causing unexpected groundwater discharges away from the injection wells.

Post-mining conditions

The mine pit is expected to take 1.5 to 3 yrs to fill with water to the spill elevation of 223 ft above msl after mining is completed. This will return the groundwater flow systems to close to their pre-mining configuration. It is expected that all of the features described above except the dewatering/reinjection item would apply to keep groundwater from the mine site from the Moonlight wells.

Potential effects from blasting

As a hard rock mine, the mining plan includes blasting rock to break and loosen it for transport. Blasting activity inevitably transmits shock waves for some distance out into the country rock from the mine site. This is not considered to present a significant risk to the Moonlight wells for the following two main reasons.

1. The wells are four miles from the blast site at the mine, which would attenuate shock waves to minimal levels.

2. The Moonlight aquifer is comprised of marble, which contains secondary porosity in the form of brittle fractures of hard rocks. Such fractures are typically held open by rock-to-rock points of contact and are not susceptible to settling or plugging as would aquifers with appreciable fine-grained gouge or other sediment.

Additionally, blasting has reportedly been performed much closer to Mooonlight aquifer in the Nome area, without apparent detrimental effects.

FINDINGS AND CONCLUSIONS

The findings of this review are:

1. Studies of existing groundwater flow systems and groundwater chemistry in the vicinity of the Rock Creek Mine have resulted in a relatively well understood groundwater flow system in the area of the proposed mine (Bristol Environmental and Engineering Services Corporation, 2006, and Water management Consultants, 2006). This understanding has been used to prepare reasonable conceptual and mathematical models of the likely impacts of mine development and prepare a water management plan that provides a realistic assessment of dewatering and reinjection activities needed to facilitate the mine.

2. Six separate lines of evidence separately and consistently indicate that it is unlikely that water from planned mining operations or post-mining closure conditions will travel underground to affect the Moonlight wells. The concordant findings from these lines of evidence reinforces the conclusion that the wells are highly protected by natural conditions in the area.

   These natural conditions are:

- The long distance (four miles) from the mine to the wells. Prior studies of Moonlight Springs shows that at least a portion of the water emerging from the springs has a rapid response time (hours to days) to recharge events such as sudden and significant snowmelt or rainfall. Mapped recharge areas by prior investigators indicate that most or all recharge to the Moonlight aquifer occurs closer in the immediate vicinity of Moonlight Springs and not from the Rock Creek Mine site.

- The presence of at least one major high-angle fault zone, located between Moonlight Springs and the mine site, with low permeability fault gouge that acts a barrier to groundwater flow.

- The presence of two intervening topographic divides and two stream valleys that create separate and distinct shallow groundwater flow systems.

- The low elevation of the Rock Creek Mine that precludes the likelihood of water flowing through a regional or sub-regional scale groundwater flow system to emerge at the Moonlight wells.

- The natural pre-mining groundwater chemistry at Rock Creek Mine that shows groundwater with a different geochemical pattern than water from the Moonlight aquifer and implies that the waters from the schist area have not traveled to the marble aquifer.

Additionally, the proposed well pumping and dewatering plan appears to limit the potential for offsite migration by practical limits on how high injection pressures can be sustained without surface discharges of water or creation of closed-cell flow systems that recycle water from pumping wells to injection wells and back again.

LIMITATIONS

Work for this project was performed, and this letter report prepared, in accordance with generally-accepted professional practices for the nature and conditions of the work completed in the same and similar localities, at the time the work was performed. It is intended for the exclusive use of the City of Nome. This letter report is not meant to represent a legal opinion, and no other warranty, express or implied, is made.

Should have questions regarding this report, please contact me at (907) 258-1345.

Sincerely,
Paug-Vik Development Corporation

James A. Munter

James A. Munter, CGWP, CPG
Project Manager

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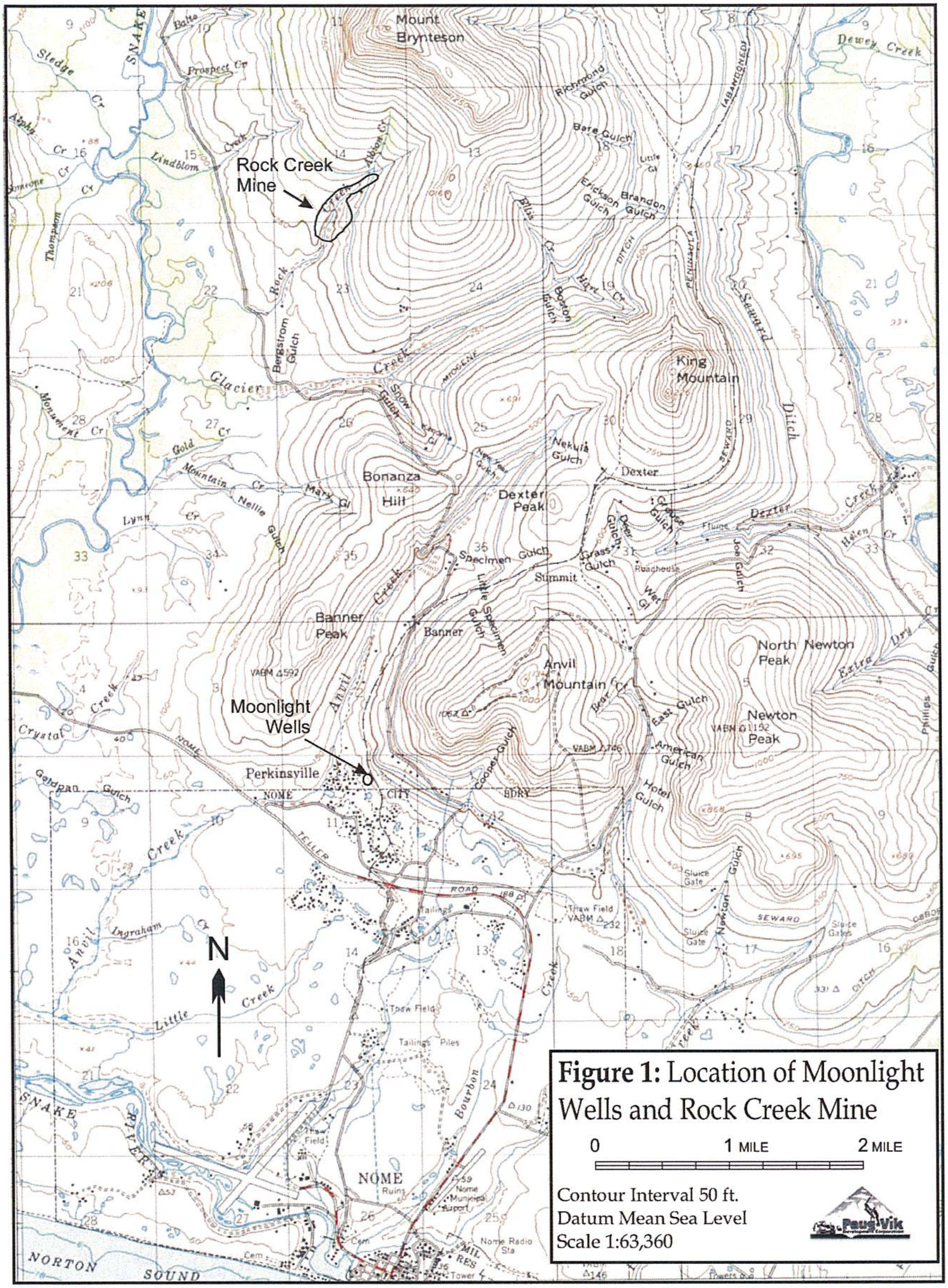

Figure 1: Location of Moonlight Wells and Rock Creek Mine

Base Map: USGS Nome (C-1) Alaska