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FILED

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**SECRETARY, BOARD OF
OIL, GAS & MINING**

**BEFORE THE BOARD OF OIL, GAS AND MINING
DEPARTMENT OF NATURAL RESOURCES
STATE OF UTAH**

IN THE MATTER OF THE REQUEST	:	NOTICE OF FILING OF
FOR AGENCY ACTION OF LIVING	:	TECHNICAL TESTIMONY
RIVERS TO APPEAL THE DECISION	:	OF CHARLES H. NORRIS
BY THE DIVISION OF OIL, GAS AND	:	
MINING TO APPROVE THE	:	
APPLICATION OF EARTH ENERGY	:	
RESOURCES TO CONDUCT TAR	:	Docket No. 2010-027
SANDS MINING AND RECLAMATION	:	
OPERATIONS AT THE PR SPRINGS	:	Cause No. M/047/0090 A
MINE	:	

Living Rivers, by and through its attorneys, hereby files the prepared supplemental testimony of Charles H. Norris in the above matter.

Dated: February 15, 2011.



**ROB DUBUC
JORO WALKER
Attorneys for Living Rivers**

CERTIFICATE OF SERVICE

I hereby certify that on this 15th day of February, 2011, I served a true and correct copy of this prepared direct testimony of Charles H. Norris to each of the following persons via email:

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ROB DUBUC

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OPERATIONS AT THE PR SPRINGS :
MINE :**

PREPARED SUPPLEMENTAL TESTIMONY

OF

Charles H. Norris

ON BEHALF OF

LIVING RIVERS

February 15, 2011

Exhibit A

COMPUTATION OF WATER CONTENT IN SPENT ORE USING NOI DATA

Daily production run, 2000 bbl. (NOI, p.16)

Daily ore processed, 3000 to 3500 tons (NOI, p 16)

Assumption 1: ore is dry based on site characterization

Bitumen recovery as percent of weight of ore rock, 10-12% (NOI, p. 14)

Assumption 2: use midpoint of range, 11%

Daily dry tailings [89% of (3000 to 3500 tons)], 2670 to 3115 tons

Water consumption, 116 gpm (NOI p.17)

Daily water consumption, $116 \times 60 \times 24 = 167,040$ gallons

Daily water consumption, $167,040 \times 8 / 2000 = 668$ tons

Range of daily wet tailings production, 3338 to 3783 tons

$[2670 + 668 \text{ to } 3115 + 668]$

Range of water content [W-wtr/W-total], 20.0% to 17.6%

Volume = Mass/Density

Quartz has density of 2.65 g/cc, or 1.993 tons/cy

Water has a density of 1.00 g/cc, or 0.752 tons/cy

Volume of daily processed rock, 1340 to 1563 cy

$[2670/1.993 \text{ to } 3115/1.993]$

Daily water volume, $668/0.752 = 888$ cy

Volume of rock + volume of water = volume of tailings; 2228 to 2451 cy

Assumption 3: no unsaturated porosity

Porosity of tailings, volume of water/volume of tailing, 40% to 36%

Notes:

Assumption 3 is reasonable because the resulting total porosity is at or near the upper limit expected for granular, unconsolidated sediments like these. Adding a third phase of air filled porosity would postulate porosity too high to be expected in sediment coming off a shale shaker or similar device.

The use of quartz density is conservative. The use of a grain density greater than quartz at 2.65 g/cc would decrease the volume of rock and resulting even higher porosity..

1 I **INTRODUCTION AND QUALIFICATIONS**

2

3 Q. PLEASE STATE YOUR NAME?

4 A. Charles H. Norris

5 Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT POSITION?

6 A. I am a geologist with Geo-Hydro, Inc. (GHI), a Colorado corporation of which I
7 am majority stockholder. My office is at 1928 E 14th Avenue, Denver, CO 80206.

8

9 Q. HAVE YOU PRESENTED DIRECT TESTIMONY ON BEHALF OF LIVING
10 RIVERS IN THIS DOCKET?

11 A. Yes. That pre-filed direct testimony was filed with the Utah Board of Oil, Gas
12 and Mining (Board) on January 7, 2011.

13

14 Q. FOR WHOM ARE YOU TESTIFYING IN THIS PROCEEDING NOW?

15 A. I am testifying on behalf of Petitioner Living Rivers.

16

17 **II. PURPOSE AND SUMMARY OF TESTIMONY**

18

19 Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

20 A. The purpose of this testimony is three-fold. First, I will offer my expert opinion
21 with respect to newly available data, provided by Earth Energy Resources, Inc. (EER)
22 since I submitted my direct testimony in this matter. Second, I will refute or put into
23 proper context those portions of the deposition testimony given by staff of the Division of

1 Oil, Gas and Mining (Division) in this case that pertain to my previously filed direct
2 testimony. Third, I will either refute or put into proper context those portions of the
3 recently provided expert reports submitted by consultants to EER in this docket that
4 pertain to my previously filed direct testimony.

5
6 Q. WOULD YOU PLEASE SUMMARIZE YOUR TESTIMONY?

7 A. The new data, information and analysis provided in the depositions of Division
8 staff, in expert reports by EER's consultants, and in continuing discovery production by
9 EER do not alleviate or eliminate the errors, inaccuracies, or insufficiencies of the Notice
10 of Intent (NOI). Where these materials provide new information, beyond repeating
11 statements in the NOI as approved, the information confirms and emphasizes the
12 problems to which I testified previously. The NOI submitted by EER should not have
13 been approved. The NOI is still not complete and accurate, as described in my pre-filed
14 direct testimony and as supplemented herein.

15 This testimony is structured largely parallel to my direct testimony. Now that I
16 have had the opportunity to view the material safety data sheets (MSDSs) for the
17 extraction chemicals and related documents submitted by EER in support of its NOI, I
18 will discuss the significance of these materials to the leachate that will form in the
19 processed tailings and other waste material and in the environment of its disposal – either
20 in the waste dumps or in the mine pit. Second, to the extent that new data or information
21 has been provided in depositions or expert reports, I will supplement my previous
22 testimony with respect to the certainty of leachate generation from the processed wastes.
23 Finally, to the extent that new data or information has been provided in depositions or

expert reports, I will supplement my previous testimony with respect to the nature of the leachate from the processed wastes.

III. NEW INFORMATION REVIEWED AND RELIED UPON

Q. WHAT IS THE NEW INFORMATION PRODUCED BY EER REGARDING THE EXTRACTION CHEMICALS?

A. EER provided an MSDS (dated March 5, 1997) authored by Frutech International Corporation of California for a chemical called Orange Terpenes, with Chemical Abstracts Service (CAS) registry # 8026-48-6. Included with the Frutech MSDS were a Technical Specifications Sheet from September 5, 1997 and a Quality Assurance Certificate for a lot of orange terpenes that Frutech shipped September 15, 2005. This latter document included an analysis of the lot that quantified the concentrations of 7 of 8 chemicals analyzed. The analysis accounts for 99.621% of the compounds in Orange Terpenes.

EER provided an MSDS (revised in August, 2001) authored by Florachem Corporation of Florida for a chemical called "d-Limonene" with CAS # 5989-27-5. The chemical d-Limonene constituted more than 96% of the lot analyzed in the Frutech Quality Assurance Certificate described in the previous paragraph.

EER also provided a letter from EER to the United States Environmental Protection Agency (EPA) dated May 29, 2009 regarding Ja Applicability. That letter included a composition of the extracting fluid that was proposed for use at the time of the letter.

1

2 Q. WHAT DEPOSITION TESTIMONY DID YOU REVIEW AND ASSESS?

3 A. I reviewed and assessed the testimony of Division staff Paul Baker, Minerals
4 Program Manager; Leslie Helper, Reclamation Specialist; Thomas Monson, a
5 Reclamation Specialist; and Dana Dean, Associate Director of the Division, all given on
6 February 2, 2011.

7

8 Q. WHAT EXPERT REPORTS DID YOU REVIEW AND ASSESS?

9 A. I reviewed and assessed the expert reports of Robert J. Bayer and of Karla Knoop,
10 both employees of JBR Environmental Consultants, Inc. Neither report is dated, but each
11 post-dates my pre-filed direct testimony and each was provided to Living Rivers as
12 attachments to a cover letter from EER dated February 1, 2011.

13

14 Q. DO YOU CONTINUE TO RELY ON THE MATERIALS YOU LISTED IN
15 YOUR PRE-FILED DIRECT TESTIMONY FOR THIS SUPPLEMENTAL
16 TESTIMONY?

17 A. Yes, I do.

18

19 Q. AS A RESULT OF THE REVIEWS AND ASSESSMENTS DESCRIBED
20 ABOVE, ARE THERE ANY ADDITIONAL MATERIALS YOU REVIEWED AND
21 UPON WHICH YOU RELY?

22 A. Yes. Based upon the data in the MSDSs and related documents that were recently
23 provided by EER, I reviewed addition materials, including the MSDS for each of the

1 chemicals analyzed by Frutech to be in Orange Terpenes. I did this to understand more
2 fully the chemical and physical properties of these chemical and any toxicological,
3 ecological and environmental risks associated with their disposal at the proposed mine
4 site. In addition to any MSDS found, I reviewed each chemical on the Hazardous
5 Substance Data Base (HSDB) maintained online by the U. S. National Library of
6 Medicine of the National Institutes of Health (NIH). The following are web sites that
7 provide additional information upon which I rely for my supplemental testimony:

8 MSDS for Linalool (CAS # 78-70-6), updated 2008;
9 <http://fscimage.fishersci.com/msds/21702.htm>

10 NIH HSDB for Linalool (CAS # 78-70-6); [http://toxnet.nlm.nih.gov/cgi-](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+78-70-6)
11 [bin/sis/search/r?dbs+hsdb:@rn+78-70-6](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+78-70-6)

12 MSDS for Myrcene (CAS # 123-35-3), updated 2008;
13 <https://fscimage.fishersci.com/msds/35725.htm>

14 NIH HSDB for Myrcene (CAS # 123-35-3); [http://toxnet.nlm.nih.gov/cgi-](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+123-35-3)
15 [bin/sis/search/r?dbs+hsdb:@rn+123-35-3](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+123-35-3)

16 MSDS for alpha-Pinene (CAS # 80-56-8), revised 2005;
17 <https://fscimage.fishersci.com/msds/18175.htm>

18 MSDS for alpha-Pinene (CAS # 80-56-8), revised 2010;
19 http://www.sciencelab.com/xMSDS-Alpha_Pinene-9926571

20 NIH HSDB for alpha-Pinene (CAS # 80-56-8); [http://toxnet.nlm.nih.gov/cgi-](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+80-56-8)
21 [bin/sis/search/r?dbs+hsdb:@rn+80-56-8](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+80-56-8)

22 MSDS for d-Limonene (CAS # 5989-27-5), revised 2007;
23 <http://www.hvchemical.com/msds/dlimo.htm>

24 MSDS for d-Limonene (CAS # 5989-27-5), revised 2006;
25 <http://services.georgiasouthern.edu/ess/msds/d-Limonene.htm>

26 MSDS for d-Limonene (CAS # 5989-27-5), undated, after 1998;
27 <http://www.chemcas.com/msds/cas/msds45/5989-27-5.asp>

1 NIH HSDB for d-Limonene (CAS # 5989-27-5); [http://toxnet.nlm.nih.gov/cgi-](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+5989-27-5)
2 [bin/sis/search/r?dbs+hsdb:@rn+5989-27-5](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+5989-27-5)

3 USEPA IRIS for d-Limonene (CAS # 5989-27-5), 2002;
4 <http://www.epa.gov/IRIS/subst/0682.htm>

5 MSDS for beta-Pinene (CAS # 18172-67-3), undated;
6 <http://services.georgiasouthern.edu/ess/msds/Beta-Pinene.pdf>

7 MSDS for beta-Pinene (CAS # 18172-67-3), 2008;
8 <https://fscimage.fishersci.com/msds/61288.htm>

9 NIH HSDB for alpha-Pinene (CAS # 127-91-3); [http://toxnet.nlm.nih.gov/cgi-](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~Og1ist:1)
10 [bin/sis/search/f?./temp/~Og1ist:1](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~Og1ist:1)

11 MSDS for Octanal (CAS # 124-13-0), 2010;
12 <http://www.sciencelab.com/msds.php?msdsId=9926308>

13 NIH HSDB for Octanal (CAS # 124-13-0); [http://toxnet.nlm.nih.gov/cgi-](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+124-13-0)
14 [bin/sis/search/r?dbs+hsdb:@rn+124-13-0](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+124-13-0)

15 MSDS for Decanal (CAS # 112-31-2), 2009;
16 <http://www.thegoodscentcompany.com/msds/md101370.html>

17 NIH HSDB for Decanal (CAS # 112-31-2); [http://toxnet.nlm.nih.gov/cgi-](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+112-31-2)
18 [bin/sis/search/r?dbs+hsdb:@rn+112-31-2](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@rn+112-31-2)

19 MSDS for Orange Terpenes (CAS 8028-48-6), undated, UK;
20 http://www.chemcas.org/msds_archive/msds_01/cas/gb_msds/8028-48-6_v1.asp
21

22

23 **IV. THE BITUMEN EXTRACTION CHEMICALS**

24

25 Q. UNDER ITS MOST RECENT PROCESSING PLAN, WHICH CHEMICALS
26 ARE EER GOING TO USE TO EXTRACT BITUMEN FROM THE ORE ROCK?

27 A. EER has recently shared with Living Rivers and the Division its new process that
28 the company plans to use to extract bitumen from ore sands at the PR Spring mine. This
29 new plan post-dates the NOI submitted to the Division and the application submitted to

1 the Utah Division of Water Quality (DWQ). According to EER the only chemical(s) that
2 will be mixed with water for the extraction of the bitumen are terpene(s) that comprise
3 essential oils extracted from orange peels. The current plan is to forego the use of a
4 surfactant chemical to stabilize the extraction fluid to reduce the risks of fire and
5 explosion at the plant.

6
7 Q. WHAT IS THE COMPOSITION OF THE EXTRACTING FLUID NOW
8 PROPOSED TO BE USED?

9 A. EER provided an MSDS from each of two corporations, Florachem and Frutech
10 International. No information has been provided as to whether EER will utilize either or
11 both sources or what mixture of the two materials may be used. The Florachem product
12 lists a single chemical, d-Limonene (CAS # 5989-27-5). The Frutech product is called
13 Orange Terpenes (CAS # 8028-48-6). A chemical analysis included with the MSDS of
14 one lot of Orange Terpenes, shipped in 2005, listed analyses for 8 chemicals. These
15 chemicals with the associated analyses reported as percentage are d-Limonene (96.332),
16 Myrcene (1.984), alpha-Pinene (0.569), Sabinene (0.277), Octanal (0.270), Linalool
17 (0.169), beta-Pinene (0.020) and Decanal (0.000). The total percent concentration of
18 these 8 compounds is 99.621%, indicating one or more trace compound(s) is (are) not
19 reported.

20
21 Q. WHO PROVIDES AN MSDS?

22 A. In the United States, the company selling or manufacturing the substance provides
23 the MSDS. It may be authored by the company or by someone retained by the company.

1

2 Q. HOW RELIABLE IS AN MSDS?

3 A. That depends greatly on the MSDS. Since an MSDS cannot possibly report
4 everything that is known about a chemical, it is necessarily a synopsis of what is known.
5 That synopsis is generally focused on those characteristics of a chemical that are of
6 importance to the buyer. Since these chemicals – d Limonene and Orange Terpenes – are
7 primarily sold to manufacturers of perfumes, scented household products, and food
8 additives, the MSDSs provided to EER and subsequently to the Division and DWQ are
9 focused on dangers associated with work place exposure and work place spills. There are
10 few details associated with environmental risks, presumably because uncontained
11 disposal in the environment as part of mine waste was not envisioned as the fate for these
12 materials. Another potential limitation of an MSDS is its vintage. What is known about
13 a chemical can change substantially over the years, making obsolete or incomplete the
14 information in an older MSDS.

15

16 Q. HOW OLD ARE THE MSDSs THAT WERE PROVIDED TO THE DIVISION
17 AND DWQ?

18 A. The Frutech MSDS is dated March 5, 1997, almost 14 years ago. The Florachem
19 MSDS is dated as revised in August 2001, more than 9 years ago.

20

21 Q. DID YOU CHECK THE RELIABILITY OF THE MSDS DATA PROVIDED
22 BY EER TO THE DIVISION AND DWQ?

23 A. Yes, I did.

1

2 Q. HOW DID YOU DO THAT?

3 A. I went online to seek more recent MSDS data for the same chemicals, cross-
4 referencing by both name and CAS number, which should be unique to each chemical. I
5 also investigated the list of chemicals on a database maintained by the United States
6 National Institutes of Health (NIH), the Hazardous Substance Data Base (HSDB). The
7 specific sites visited are provided in my testimony above.

8

9 Q. ARE THESE RELIABLE SOURCES OF INFORMATION COMMONLY
10 USED BY PROFESSIONALS DOING THIS KIND OF ASSESSMENT?

11 A. The MSDSs that can be retrieved online are only as reliable and complete as the
12 company or organization that produced them. As previously stated, they are necessarily a
13 synopsis, limited by the author's perception of the buyer's need . As such, I have found
14 that when something is stated, it is generally accurate. However, an MSDS may not be
15 complete with respect to an unusual or experimental use of the chemical, as is the case
16 here. The NIH information is much more complete and is fully documented with
17 citations to the information provided, providing routes to yet more information. It also
18 annotates the data as to whether or not information on a particular item is peer reviewed.
19 Since it is a database of information available on a chemical, and not a synopsis
20 developed for a particular audience, it has far more breadth than an MSDS, which is
21 important for assessing a substance with respect to an "off-label" use. The use and
22 management of these chemicals by EER is so far removed from the expectations of

1 MSDS authors that EER's disposal of spent process water in the mine and waste dumps
2 is a type of activity specifically warned against in some MSDSs.

3

4 Q. WHAT INFORMATION DID THE FRUTECH MSDS FOR "ORANGE
5 TERPENES" PROVIDE THAT IS RELEVANT TO THE ENVIRONMENTAL
6 DISPOSAL OF THIS MATERIAL AT THE MINE?

7 A. Relevant information was limited and often qualitative, rather than quantitative.

8 No vapor pressure was provided. Vapor pressure is a measure of how easily a substance
9 evaporates. The vapor density relative to air (air = 1, unitless) is reported at 0.0123 at 20

10 C. Vapor density determines whether the chemical in its gaseous state will rise or sink in
11 air. Solubility in water is reported as "negligible." The specific gravity is reported as
12 0.84 (relative to water). It is described as stable, with no hazardous decomposition
13 products. Carcinogenicity for humans is addressed only by listing three directories in
14 which Orange Terpenes is not listed. Effects of exposure are discussed only in terms of
15 human exposure. The MSDS does not address non-human carcinogenicity, non-human
16 toxicity, fate in the environment, biodegradability, abiotic degradation, or
17 bioconcentration.

18

19 Q. DID YOU INVESTIGATE OTHER SOURCES OF INFORMATION ON
20 "ORANGE TERPENES?"

21 A. Yes, I did. The HSDB of NIH did not list anything for either Orange Terpenes or
22 CAS # 8028-48-6. This presumably is because this material is a mixture, as described

1 above, and not a single chemical. I found a second MSDS for Orange Terpenes (CAS #
2 8028-48-6), at the site provided above.

3

4 Q. WHAT DID THAT MSDS FOR “ORANGE TERPENES” PROVIDE THAT IS
5 RELEVANT TO THE ENVIRONMENTAL DISPOSAL OF THIS MATERIAL AT
6 THE MINE?

7 A. The MSDS states, as environmental precautions, “Keep away from drains, soils,
8 surface & groundwaters.” It lists decomposition products as carbon monoxide, carbon
9 dioxide, and other non-identified organic compounds. It provides toxicity data (lethal
10 dose 50% concentrations (LD50)) for oral exposure of both rat and rabbit. Under
11 Ecological information precautions, it states, “Prevent surface contamination of soil,
12 ground & surface water.” Under disposal consideration, the MSDS says, “Avoid
13 disposing into drainage systems and into the environment.”

14

15 Q. WHAT INFORMATION IS PROVIDED IN THE MSDS FROM FLORACHEM
16 THAT PERTAINS TO THE ENVIRONMENTAL DISPOSAL OF D-LIMONENE AT
17 THE MINE?

18 A. The Florachem MSDS indicates that d-Limonene is a marine pollutant, without
19 any further detail. Under environmental precautions, it states, “Do not discharge into
20 surface waters. May be toxic to aquatic organisms.” This MSDS lists the solubility as
21 being less than 0.1%, providing an upper limit. Other physical and chemical

1 characteristics are similar to those given by Frutech for Orange Terpenes, which is to be
2 expected because that material is analyzed as being composed of more than 96% d-
3 Limonene. One distinct difference is the vapor density, which is reported by Florachem
4 at greater than 1, relative to air (air=1, unitless). This is more than 80 times the density
5 reported by Frutech. The values are clearly inconsistent with each other.

6 Under toxicological information, the lowest published lethal doses are listed for
7 dermal and oral exposure of mice. Under ecological information, the MSDS indicates
8 that biodegradability has not been determined and repeats that it is a marine pollutant.
9 This MSDS also describes d-Limonene as immiscible in water, *i.e.*, it remains a separate
10 liquid phase in contact with water. The MSDS asserts it will biodegrade and evaporates
11 quickly, and speculates from those statements that it “should not cause long-term
12 effects.” The MSDS indicates the potential for bioaccumulation has not been determined.

13

14 Q. WHAT IS THE SIGNIFICANCE OF THE VAPOR DENSITY DIFFERENCE
15 BETWEEN THE FRUTECH MSDS AND THE FLORACHEM MSDS?

16 A. A vapor with a density greater than air will tend to sink or stay in low areas,
17 whereas one with a density less than air will rise. In the former case, the gas will remain
18 near the source of evaporation, inhibiting further evaporation. In the latter case, the gas
19 will rise away from the source of evaporation, readily allowing further evaporation. This
20 difference is particularly important if the evaporation occurs within pore space below the
21 ground surface.

1

2 Q. DOES THE INFORMATION IN THE FLORACHEM MSDS MATCH OTHER
3 DATA YOU REVIEWED FOR THIS CHEMICAL?

4 A. No.

5

6 Q. WHAT DIFFERENCES DO YOU SEE THAT ARE SIGNIFICANT FOR THE
7 ENVIRONMENTAL DISPOSAL OF THIS CHEMICAL AT THE MINE?

8 A. MSDSs and other sources of information are readily available for d-Limonene as
9 a chemical name and under CAS # 5989-27-5. I reviewed five additional sources of
10 information on this compound; three MSDSs that are more recent than the Florachem
11 MSDS, the NIH HSDB entry, and the EPA IRIS database entry for this chemical. The
12 websites for each of these is provided above.

13 The relevant physical and chemical characteristics of d-Limonene that are
14 reported from these sources are sometimes consistent with the Florachem data. All
15 sources show the chemical to be highly volatile, flammable, and less dense than water, as
16 does the Florachem MSDS.

17 The solubility of this chemical in water is described qualitatively as “insoluble” in
18 some sources, as did Florachem, or quantitatively reported as 13.8 mg/L. The vapor
19 density was either unreported or reported as 4.7 times that of air. Florachem reported the
20 vapor to be denser than air, but did not quantify the magnitude of the difference.

1 All sources characterize d-Limonene as stable, but they vary widely in what is
2 provided as the decomposition products. Some, like Florachem, report “no hazardous”
3 decomposition products, some just carbon dioxide, and some are more detailed. For
4 example, one MSDS states the decomposition products are “Carbon monoxide, irritating
5 and toxic fumes and gasses, [and] carbon dioxide.” The NIH HSDB specifies the
6 compounds that form from decomposition in sunlight and air as formaldehyde, formic
7 acid, acetaldehyde, peroxyacetyl nitrate, and acetone, in addition to carbon monoxide and
8 carbon dioxide. The NIH list is certainly consistent with a qualitative description of
9 “irritating and toxic fumes and gases.” Formaldehyde is a known carcinogen,
10 acetaldehyde is a probable carcinogen, peroxyacetyl nitrate is a mutagen, and acetone is
11 multiply toxic.

12 Collectively the additional MSDSs and other sources provide toxicological data
13 far beyond the Florachem MSDS. They provide data on exposure for rats, mice, rabbits,
14 dogs, earthworms, and water fleas under various exposure scenarios and provided the
15 reported doses that proved lethal to 50% of the test population (LD50) for each species.
16 Other studies establish lowest published lethal dose (rat, mouse, dog), respiratory
17 depression (rat), seizure threshold (rat), paralysis (mouse), kidney/bladder abnormalities
18 (rat, dog), tumor development (testicular and kidney, rat; gastrointestinal, mouse), and
19 reproductive/developmental impacts on offspring (mouse, rat). NIH HSDB lists non-
20 food and non-cosmetic uses of d-Limonene including insecticide, insect repellent, dog
21 and cat repellent, and flea and tick dips.

1 All sources either indicate that the compound is not on lists of human carcinogens
2 while some acknowledged that there was insufficient information to determine whether it
3 is or is not a human carcinogen. Some MSDSs and both IRIS and HSDB report there is
4 clear evidence of carcinogenicity in male rats, but not for female rats or mice. There is
5 also research that shows d-Limonene can help suppress some tumors caused by coal tar
6 compounds. Collectively the information shows d-Limonene to be a biologically active
7 agent with complex manifestations of that activity.

8 There was more environmental/ecological data for d-Limonene available from the
9 newer sources. NIH reports organisms isolated from soil and water in the laboratory
10 were unable to biodegrade limonene, although inoculation with organisms from soils with
11 natural limonene initiates biodegradation in aerobic conditions. NIH also reports
12 resistance to biodegradations in anaerobic environments.

13 The NIH HSDB reports “high potential” for bioconcentration. Two of the
14 MSDSs report bioconcentration of the compound is expected in aquatic organisms and
15 fish. Depentene, a form of d-Limonene is a marine pollutant. European regulations
16 require it be labeled as follows: “Very toxic to aquatic organisms, may cause long-term
17 adverse effects in the aquatic environment” and “Avoid release to the environment.”

18
19 Q. BASED UPON YOUR REVIEW OF THE MSDS DATA THAT WAS
20 INCLUDED WITH THE NOI AND THE DWQ APPLICATION AND YOUR REVIEW
21 OF THE ADDITIONAL INFORMATION YOU HAVE IDENTIFIED, DOES THE

1 INFORMATION PROVIDED BY EER TO THE AGENCIES GIVE A COMPLETE
2 AND ACCURATE DESCRIPTION OF THE NATURE OF EITHER “ORANGE
3 TERPENES” OR D-LIMONENE WITH RESPECT TO THE POTENTIAL IMPACTS
4 OF DISPOSING OF THESE MATERIALS IN THE ENVIRONMENT AT THE MINE?

5 A. No. The information provided by EER to the Division and DWQ does not
6 provide a complete and accurate description of either of the two materials described in
7 the MSDS documents. Further, the discussions in the NOI and application submitted to
8 DWQ do not convey either the uniqueness of the proposal to allow these materials to be
9 released in the environment of the mine site or the potential risks of doing so.

10

11 Q. WHAT DO YOU MEAN WHEN YOU REFER TO THE UNIQUENESS OF
12 THE EER PROPOSED ACTIONS?

13 A. Nothing in any of the data I have researched and reviewed remotely contemplates
14 the dumping in unlined piles and pits of millions of tons of sediments that are wet with
15 water that has fully mixed with “Orange Terpenes” or d-Limonene. The normal uses for
16 these materials are to add scent to cosmetics and food in tiny, tiny concentrations. At
17 higher concentrations, they are used to kill aphids, tomato worms, fire ants, fleas, wasps
18 and ticks. They are used to keep other pests, insects and mammals, away. And, nearer
19 full strength, with great care, they are used in factories to degrease parts and tools.

20 The clear, unambiguous warnings and safety admonitions from every other source
21 of safety data are **not** to do exactly what EER proposes to do. The safety data state that

1 these chemicals should not be disposed of where they can get into drainages or where
2 they have potential contact with surface water or ground water. The conclusion of this
3 information is that these chemicals should not be disposed of in the environment. But
4 that is just what EER proposes to do.

5

6 Q. WHAT DO YOU MEAN WHEN YOU REFER TO THE POTENTIAL RISKS
7 OF THESE MATERIALS BEING RELEASED IN THE ENVIRONMENT OF THE
8 MINE SITE?

9 A. These materials are toxic. They are documented as toxic to rats, mice, dogs,
10 rabbits, cats, earthworms, insects, fish and aquatic invertebrates, moths, butterflies and
11 bees. The complete list is long and virtually a description of the ecosystem of the area of
12 the mine. As a result of this toxicity, any organism that inhabits the drainages, springs or
13 land nearby the mine site or that preys on any organism that inhabits these areas is at risk
14 from EER's proposal. The level of that risk has not been laid out in a careful, deliberate,
15 defensible study by EER. It has not even been acknowledged. And, the information that
16 exists, and that would allow the Division and DWQ to perform even a minimal analysis
17 of the risks associated with this proposal was not provided by EER to the agencies, nor
18 even acknowledged by EER to exist.

19

20 Q. BEYOND THE TWO MATERIALS DESCRIBED IN THE MSDS
21 DOCUMENTS THAT EER PROVIDED TO THE DIVISION AND DWQ, ARE

1 THERE CHEMICIALS THAT WILL BE DISPOSED OF AT THE MINE SITE WHICH
2 WILL CREAT RISKS TO THE ENVIRONMENT?

3 A. Yes, there are. Each of the identified chemicals that are part of the mixture that
4 constitutes “Orange Terpenes” raises its own concerns and issues.

5

6 Q. WHAT RELEVANT INFORMATION DID YOU IDENTIFY FOR THE
7 DISPOSAL OF LINALOOL IN THE ENVIRONMENT AT THE MINE?

8 A. I reviewed one MSDS for Linalool and the NIH HSDB entry. The websites for
9 each of these is provided above.

10 Linalool is volatile, flammable and explosive, and less dense than water, with a
11 fluid specific density around 0.86 that of water according to both sources. The solubility
12 of Linalool in water is described as “soluble” in the MSDS and reported as 1,590 mg/L in
13 NIH HSDB. Neither the MSDS nor the NIH HSDB reports the vapor density of the
14 chemical.

15 Both sources characterize Linalool as stable. The MSDS lists carbon monoxide
16 and carbon dioxide as decomposition products. The NIH HSDB does not specify the
17 compounds that form due to decomposition.

18 The MSDS provides LD50 data for oral and skin exposure for both rat and rabbit
19 without details, as well as eye and skin irritation study data for rabbit. The NIH HSDB
20 provides LD50 data for Bobwhite quail, trout, blue gill, and aquatic invertebrates. The

1 toxicity concentrations showed toxicity greatest for the invertebrates. It is noted that the
2 EPA does not require environmental or ecological testing for Linalool because normal
3 use will not result in environmental exposure. The HSDB also provided LD50 data for
4 Golden orfe, and EC50 data for water flea, two green algae, and a soil bacterium.

5 The MSDS indicated that the compound is not on lists of human carcinogens.
6 The NIH HSDB does not report testing performed to assess the potential for
7 carcinogenicity in humans.

8 The MSDS provides no environmental/ecological data for Linalool. The NIH
9 HSDB reports low potential for bioconcentration.

10

11 Q. WHAT RELEVANT INFORMATION DID YOU IDENTIFY FOR THE
12 DISPOSAL OF MYRCENE IN THE ENVIRONMENT AT THE MINE?

13 A. I reviewed one MSDS for Myrcene and the NIH HSDB entry. The websites for
14 each of these is provided above.

15 Myrcene is volatile, flammable and explosive, and less dense than water, with a
16 fluid specific density around 0.80 that of water according to both sources. The solubility
17 of Myrcene in water is not provided in the MSDS and reported as 5.6 mg/L in NIH
18 HSDB. The MSDS reports a vapor density of 4.7 relative to water, while vapor density is
19 not reported in the NIH HSDB.

Both sources characterize Myrcene as stable. The MSDS lists carbon monoxide and carbon dioxide as decomposition products. The NIH HSDB does not specify the compounds that form due to decomposition.

The MSDS provides LD50 data for oral exposure for rat without details, as well skin exposure data for rabbit. The NIH HSDB provides only links to ongoing studies of toxicity/carcinogenicity and of genotoxicity.

The MSDS indicated that Myrcene is not on lists of human carcinogens. The NIH HSDB does not report testing performed to assess the potential for carcinogenicity in humans.

The MSDS provides limited environmental/ecological data for Myrcene with the admonition to “[a]void runoff into storm sewers and ditches which lead to waterways.” The NIH HSDB reports high potential for bioconcentration.

Q. WHAT RELEVANT INFORMATION DID YOU IDENTIFY FOR THE DISPOSAL OF ALPHA-PINENE IN THE ENVIRONMENT AT THE MINE?

A. I reviewed two MSDSs for alpha-Pinene and the NIH HSDB entry. The websites for each of these is provided above.

Alpha-Pinene is volatile, flammable and explosive, and less dense than water, with a fluid specific density around 0.86 that of water according to all sources. The solubility of alpha-Pinene in water is reported as insoluble in one MSDS and insoluble in

1 cold water in the other MSDS. It is reported as 2.49 mg/L in NIH HSDB. Each of the
2 sources reports a vapor density of 4.7 relative to water.

3 All sources characterize alpha-Pinene as stable. One MSDS lists carbon
4 monoxide, irritating and toxic fumes and gases, and carbon dioxide as abiotic
5 decomposition products. The other MSDS provides no information. The NIH HSDB
6 indicates nighttime vapor-phase reaction with ozone produces carbon monoxide, carbon
7 dioxide, formaldehyde, acetaldehyde, formic acid, peroxyacetylnitrate, cis-pinonic acid,
8 nopinene, acetone, pionaldehyde, glyoxal, and hydroxyl radicals (citation), and with
9 nitrogen radicals produces 3-acetyl-2,2-dimethyl cyclobutane acetaldehyde, pinane
10 epoxide, 3-oxypinane-2-nitrate, and 2-hydroxy-3-nitrate as decomposition products.
11 Direct decomposition due to sunlight is not expected.

12 Each MSDS provides a single LD50 data for oral exposure for rat without details.
13 One MSDS also provide summary data from one irritation test to skin on rabbit. The
14 NIH HSDB lists LD50 data in animal research for rabbit and rat and extensive non-lethal
15 toxic effect studies with rabbit, rat, hamster, and mouse. The NIH HSDB provides
16 information on the ecotoxicity of alpha-Pinene, including LD50 data for water flea and an
17 aquatic arthropod. It also includes EC50 data for flathead minnow.

18 One MSDS indicated that alpha-Pinene is not on lists of human carcinogens and
19 the other say nothing on the concern. The NIH HSDB does not report testing performed
20 to assess the potential for carcinogenicity in humans. Toxic levels in humans of this
21 compound are as low as 15 ml in children and the LD50 is estimated between 4 and 6

1 ounces. These figures may reflect mixtures with beta-Pinene and Limonene, other
2 components of Orange Terpenes.

3 The one MSDS provided limited environmental/ecological data for alpha-Pinene
4 with the admonition to “[a]void runoff into storm sewers and ditches which lead to
5 waterways.” One MSDS notes that the long-term biodegradation products are “more
6 toxic” than the short-term products, but provides no details or citations. The NIH HSDB
7 reports very high potential for bioconcentration and one MSDS states that
8 bioconcentration is expected. The other MSDS is silent on bioconcentration.

9

10 Q. WHAT RELEVANT INFORMATION DID YOU IDENTIFY FOR THE
11 DISPOSAL OF BETA-PINENE IN THE ENVIRONMENT AT THE MINE?

12 A. I reviewed two MSDSs for beta-Pinene (CAS # 18172-67-3) and the NIH HSDB
13 entry for beta-Pinene (CAS # 127-91-3). The websites for each of these is provided
14 above.

15 Beta-Pinene is volatile, flammable and explosive, and less dense than water, with
16 a fluid specific density around 0.86 or 0.87 that of water according to all sources. The
17 solubility of beta-Pinene in water is reported as insoluble in one MSDS and no solubility
18 is mentioned in water is mentioned in the other MSDS. It is reported as 4.89 mg/L in
19 NIH HSDB. Each of the sources reports a vapor density of 4.7 relative to water.

1 All sources characterize beta-Pinene as stable. One MSDS lists carbon monoxide,
2 irritating and toxic fumes and gases, and carbon dioxide as decomposition products. The
3 other MSDS lists carbon monoxide and carbon dioxide. The NIH HSDB indicates vapor-
4 phase reaction with OH or ozone produces formaldehyde, acetone, nopinone, HCHO; 3-
5 hydroxynopinone, HCOOH and cis-pinic acid as decomposition products. Direct
6 decomposition due to sunlight is not expected.

7 One MSDS provides a single LD50 data for oral exposure for rat without details.
8 One MSDS indicates LD50 data are not available. The NIH HSDB lists LD50 data in
9 animal research for rabbit and rat and non-lethal toxic effect studies with Guinea pig and
10 mouse. The NIH HSDB provides information on the ecotoxicity of beta-Pinene,
11 including LD50 data for water flea, green algae, rainbow trout, and flathead minnow.

12 One MSDS indicated that beta-Pinene is not on lists of human carcinogens and
13 the other say nothing on the concern. The NIH HSDB does not report testing performed
14 to assess the potential for carcinogenicity in humans. Toxic levels in humans of this
15 compound are reported as 150mL and as between one ounce and one pint, depending
16 upon the source.

17 One MSDS provides, as environmental/ecological information for beta-Pinene,
18 the admonition: "Prevent contamination of soil, ground and surface water. Do not
19 discharge product unmonitored into the environment." The other MSDS states that no
20 ecological information is available. The NIH HSDB reports high potential for
21 bioconcentration. Neither MSDS comments upon bioconcentration potential.

1

2

3 Q. WHAT RELEVANT INFORMATION DID YOU IDENTIFY FOR THE
4 DISPOSAL OF OCTANAL IN THE ENVIRONMENT AT THE MINE?

5 A. I reviewed one MSDS for Octanal and the NIH HSDB entry. The websites for
6 each of these is provided above.

7 Octanal is volatile, flammable and explosive, and less dense than water, with a
8 fluid specific density around 0.82 that of water according to both sources. The solubility
9 of Octanal in water is reported as very slightly soluble in cold water in the MSDS and
10 reported as 560 mg/L in NIH HSDB. The MSDS reports a vapor density of 4.4 relative
11 to water while vapor density was not reported in the NIH HSDB.

12 Both sources characterize Octanal as stable. The MSDS does not list
13 decomposition products, but states that long-term biodegradation products are not
14 harmful. The NIH HSDB states that decomposition in sunlight may occur but does not
15 specify the compounds that form due to decomposition.

16 The MSDS provides LD50 data for oral exposure for rat without details. The
17 NIH HSDB provides LD50 data for rat, rabbit, common bleak (saltwater fish), flathead
18 minnow (fresh water) and Harpacticoid (fresh and salt water benthic crustacean). NIH
19 HSDB also reports on non-lethal impacts for rat.

1 Neither the MSDS nor the NIH HSDB discusses human or non-human
2 carcinogenicity.

3 The MSDS provides no environmental/ecological data for Octanal. The NIH
4 HSDB reports low potential for bioconcentration.

5

6 Q. WHAT RELEVANT INFORMATION DID YOU IDENTIFY FOR THE
7 DISPOSAL OF DECANAL IN THE ENVIRONMENT AT THE MINE?

8 A. I reviewed one MSDS for Decanal and the NIH HSDB entry. The websites for
9 each of these is provided above.

10 Decanal is volatile, flammable and explosive, and less dense than water, with a
11 fluid specific density around 0.83 that of water according to both sources. The solubility
12 of Decanal in water is reported as very slightly soluble in the MSDS and reported as
13 insoluble in NIH HSDB. The MSDS reports a vapor density > 1 relative to water while
14 vapor pressure is not reported in the NIH HSDB.

15 Both sources characterize Decanal as stable. The MSDS lists decomposition
16 products as carbon monoxide and carbon dioxide. The NIH HSDB does not specify the
17 compounds that form due to decomposition.

18 The MSDS provides LD50 data for oral exposure for mouse and rat without
19 details and dermal exposure to rabbit. The NIH HSDB reports Decanal is toxic to the

1 bacterium that was used to test for mutagenicity. NIH HSDB also reports on non-lethal
2 impacts for rabbit.

3 The MSDS lists those agencies for which Decanal is not listed as a carcinogen.
4 The NIH HSDB does not discuss human or non-human carcinogenicity.

5 The MSDS provides the following environmental/ecological information for
6 Decanal: 1) "Harmful to [aquatic] organisms, may cause long-term adverse effects in the
7 aquatic environment." 2) "To avoid possible contamination of the environment, do not
8 discharge into any drains, surface waters or groundwaters." 3) "Prevent contamination of
9 soil, ground and surface waters. Do not discharge product unmonitored into the
10 environment." The NIH HSDB reports the potential for bioconcentration as "important"
11 to its fate and it is expected to bioconcentrate in aquatic organisms.

12

13 Q. WHAT RELEVANT INFORMATION DID YOU IDENTIFY FOR THE
14 DISPOSAL OF SABINENE IN THE ENVIRONMENT AT THE MINE?

15 A. Sabinene does not have an entry in the NIH HSDB and I did not find an MSDS
16 online. I did request an MSDS from a seller and the MSDS that was sent indicated it was
17 strictly a laboratory chemical used for research only. It is described as a flammable oil
18 that is harmful if swallowed, inhaled or absorbed through the skin, irritating eyes, mucous
19 membranes and upper respiratory tract. Because no use outside the laboratory is
20 anticipated, the MSDS provides no environmental, ecological or non-human health
21 information.

1

2 Q. DO THESE COMPOUNDS YOU PREVIOUSLY JUST DESCRIBED CARRY
3 ANY LESS RISK OR THREAT OF RISK TO THE ENVIRONMENT OR THE
4 ECOSYSTEM AROUND THE MINE THAN DO THE CHEMICALS FOR WHICH
5 EER PROVIDED MSDSs?

6 A. No, they do not. While there are variations from chemical to chemical with
7 respect to individual dangers, as a group they describe comparable toxicities to
8 comparable varieties of animals, plants, and ecosystems. They exhibit common physical
9 and chemical properties, similar likelihood for bioconcentration, similar degradation
10 products, and similar admonitions against open, uncontained placement in water and the
11 environment.

12

13 V. **LEACHATE GENERATION**

14

15 Q. DID YOU REVIEW THE TESTIMONY OF THE DIVISION STAFF AND THE
16 EXPERT REPORTS PROVIDED BY BAYER AND KNOOP WITH RESPECT TO
17 THE POTENTIAL FOR LEACHATE GENERATION?

18 A. I did.

19

20 Q. WHAT IS LEACHATE AND WHY DOES IT MATTER?

1 A. Leachate is fluid that is in contact with waste or that has contacted waste. It is
2 important because it provides a primary method to transport contaminants from the waste
3 to humans or to the environment.

4

5 Q. WHAT, IF ANY NEW DATA OR NEW INFORMATION IS PROVIDED IN
6 THE EXPERT REPORTS OR THE TESTIMONY THAT ADDRESS THE ISSUE OF
7 LEACHATE GENERATION FROM THE PROCESSED WASTE?

8 A. There were no new data introduced and very little new in the way of
9 interpretation. The data from the NOI (p. 17) for the waste stream, *i.e.*, rates of
10 discharged water and spent ore, from which I computed the high levels of water that will
11 be in the processed tailings remain the only data with which one can quantify the water
12 content of these tailings. The cautionary email from EER to the lab regarding water
13 content and probable water separation is unchallenged as to its significance.

14 Bayer's expert report (pp. 4 and 5) subscribes to the NOI assertions of "no free-
15 water" (*e.g.*, NOI, p. 17) and moisture content that is "near optimal for compaction" (*e.g.*,
16 NOI, p. 19). The former assertion remains unsupported by the data in the NOI and the
17 latter is neither supported with any data in the NOI nor relevant to the issue of the
18 disposal of saturated and free-draining wastes. The principle new interpretation
19 contained within the Bayer expert report is the discussion of the texture(s) of the spent
20 ore rock and the purported significance of that texture to the issue of whether or not the
21 disposed spent ore is capable of producing leachate at the time it is disposed. (Bayer, p.
22 4) As part of that discussion, Bayer erroneously purports the analysis I performed was only
23 on the coarse fraction of the waste stream. The calculations considered the combined,

1 total mass of spent ore and the conclusions, even that of “unconsolidated sand,” applies
2 fully to the combined fine and coarse tailings.

3

4 Q. VERY BRIEFLY, UPON WHAT DATA DID YOU RELY TO CONCLUDE
5 HIGH WATER CONTENT IN THE DISPOSED WASTE, AND HOW DID YOU
6 COME TO THAT CONCLUSION?

7 A. I relied upon the data in the NOI describing daily runs of ore processed (NOI p.
8 16), and amounts of bitumen recovered from the ore, (NOI p. 14), and water lost to
9 disposal with the spent ore (p. 17). The data in the NOI apply to the combined waste
10 streams, both coarse and fine, and not just the coarse fraction. (*Id.*) The interpretation and
11 conclusions are therefore relevant to a combination of all spent ore, not just the coarse
12 fraction. The data establish that the spent waste as transported to the mine is
13 unconsolidated and saturated with water. I include with this supplemental testimony
14 Exhibit A, a work sheet showing the calculations that led me to my conclusion.

15

16 Q. ARE THERE ANY ADDITIONAL OR NEW DATA IN THE EXPERT
17 REPORTS OR IN THE TESTIMONY OF THE DIVISION STAFF THAT
18 INVALIDATE YOUR CALCULATIONS OR YOUR CONCLUSIONS?

19 A. No. There is anecdotal information in the Bayer report (p. 5) that a horizontal belt
20 filter will be used instead of a shale shaker, as the extraction process continues to be
21 redesigned. However, the anecdotal information continues by noting that the re-use rate
22 for water remains essentially unchanged from “approximately 85%” as provided in
23 EER’s application to DWQ to “estimate in excess of 85%” in Bayer’s report. There has

1 been no change to the NOI and no anecdotal information that reduces the 116 gallons per
2 minute water use I relied upon to calculate the water content of the processed tailings.

3 Bayer (p. 5) also alludes to an expectation that the spent ore coming out of the
4 process will drain free water, stating, “The tailings are planned to be moved from the
5 plant to a handling area where any water draining from the tailings will be captured for
6 recycling,” and citing the NOI at p.17. The statement by Boyer is clouded, however,
7 because there is no such statement at NOI p.17, nor anywhere else that I have found in
8 the NOI.

9

10 Q. ARE THERE ANY DATA OR INFORMATION IN THE NOI, EXPERT
11 REPORTS, OR THE TESTIMONY OF THE DIVISION STAFF THAT SUPPORT THE
12 ASSERTION THAT WATER CONTENT OF THE SPENT ORE IS TOO LOW TO
13 DRAIN FROM THE SPENT ORE WHEN IT IS DISPOSED?

14 A. There are not.

15

16 Q. WHAT DO YOU MEAN WHEN YOU SAY THAT THE ASSERTION THAT
17 THE MOISTURE CONTENT OF THE SPENT WASTE IS NEAR THAT FOR
18 OPTIMAL COMPACTION IS UNSUPPORTED?

19 A. Optimal moisture content for compaction is a material-specific property that is
20 also specific to a desired degree of compaction. It is determined by multiple tests of the
21 material over a range of water contents. Those test results of compaction produce a curve
22 from which one observes the optimal for that material for the tested degree of
23 compaction. There is no generic “optimal moisture content.” The assertions are offered

1 without specification as to the level of compaction being referenced and they are offered
2 without any compaction test data of any kind.

3

4 Q. WHAT DO YOU MEAN WHEN YOU SAY THAT OPTIMAL MOISTURE
5 CONTENT FOR COMPACTION IS NOT RELEVANT TO WHETHER OR NOT THE
6 SPENT WASTE WILL DRAIN WHEN DISPOSED?

7 A. Optimal moisture content for compaction is the amount of water that allows for
8 the densest mass to be made from a particular granular material when compacted to a
9 predetermined degree. It is a characteristic that applies to sediment at the time of
10 compaction. What determines whether or not water drains from the sediment is whether
11 or not the water content is above or below the field capacity. If the water content is
12 above field capacity, the sediment will passively drain water. If the water content is
13 below field capacity, it will not passively drain. The field capacity of a material will
14 change if and as it is compacted. Thus, the field capacity for the disposed, spent ore is
15 different when it is dumped in the mine than it is if it were compacted. But, field
16 capacity and optimal moisture content are not directly related. Whether or not the spent
17 ore, as delivered to the mine, is “near” optimal moisture content for some particular level
18 of compaction – and there is no test data to establish that content – has nothing to do with
19 whether or not the spent waste will drain water, as delivered or if compacted.

20

21 Q. WHAT IS THE TEXTURAL INTERPRETATION OF THE SPENT ORE THAT
22 IS PROVIDED IN THE EXPERT REPORTS AND IN TESTIMONY OF THE
23 DIVISION STAFF?

1 A. The expert report of Bayer represents that the spent ore sediments to be disposed
2 in the mine, when combined, have a texture, *i.e.*, grain size and grain-size distribution,
3 that is equivalent to a “fine loamy sand” (Bayer, p. 4).

4

5 Q. WHAT SIGNIFICANCE IS ATTACHED TO THIS INTERPRETED
6 TEXTURE?

7 A. Based upon that characterization as “fine loamy sand,” Bayer asserts the spent ore
8 will “have a field capacity and saturation much greater than that of sand.” (*Id.*). Bayer
9 does not indicate what the NOI data establish the saturation to be, or venture a value or
10 range for the field capacity. Bayer provides no conflicting demonstration of differing
11 saturation or water content than that presented in my direct testimony. His only dispute is
12 a preference to refer to the tailings as “fine loamy sand” instead of “unconsolidated
13 sand.”

14

15 Q. DOES THE DISCUSSION OF THE TEXTURE OF THE PROCESSED ORE
16 AND ITS INFLUENCE ON SATURATION AND FIELD CAPACITY IN ANY WAY
17 REFUTE YOUR OBSERVATIONS REGARDING THE WATER CONTENT OF THE
18 SPENT ORE WASTES AS DISPOSED IN THE MINE AND IN WASTE DUMPS?

19 A. No, it does not. The evaluation that I performed using the NOI data was based on
20 the characteristics and properties of all of the spent ore, both coarse and fine. As noted
21 above, my analysis was not an evaluation of only the coarse fraction. The resulting
22 calculations of water content and saturation derived from the NOI data are fully
23 consistent with and applicable to a sand of the combined texture indicated by the limited

1 grain-size values provided in the NOI, regardless of the descriptive name given it. Those
2 calculations have never been refuted.

3

4 Q. WHAT DATA ARE PROVIDED IN THE NOI REGARDING THE TEXTURE
5 OF THE SPENT ORE?

6 A. Bayer (p. 4) relies upon “a very small amount” grain-size distribution data that
7 has been performed. The only quantitative data for grain size distributions in the NOI
8 appear to be on page 19, in the second paragraph of the *Pit Backfill* section. That data is
9 indeed “a small amount.” The only data that is provided are the range and d50 (the grain-
10 size diameter dividing the coarser 50% of a sample from the finer 50% of a sample) for
11 the coarse spent ore, and the range and d50 for the fine spent ore. The boundary between
12 coarse and fine spent ore is 80 micrometer.

13

14 Q. WHAT DOES THE SMALL AMOUNT OF GRAIN-SIZE DATA TELL
15 ABOUT THE SPENT ORE?

16 A. I will use terms as defined by the standard Atterberg scale. The coarse spent ore
17 is 100% sand; half is fine- to coarse sand and half is fine sand. The fine spent ore ranges
18 from fine sand to less than medium silt. Half of the fine spent ore is medium silt to fine
19 sand and half is less than medium silt.

20 Because the analyses are not completely reported, and the relative amounts of the
21 fine- to coarse fractions are given as a range of from 20%-80% to 15%-85%, an exact
22 characterization is not possible. However, the data that are provided in the NOI indicate
23 that the spent ore is not less than 80% sand, and not less than 90% sand and silt. Not

1 more than 10% of the spent ore is medium silt or finer and this fraction may be as low as
2 7.5%. Using the Unified Soil Classification System (USCS), the spent ore is a coarse-
3 grained sediment, a sand, and, most specifically, a silty sand and denoted by the symbol
4 SM.

5
6 Q. WHAT IS THE DIFFERENCE BETWEEN “SILTY SAND” AND “FINE
7 LOAMY SAND”?

8 A. *Silty sand* (or SM) is standard USCS nomenclature, and it has standardized limits
9 to its textural composition. I am unfamiliar with any similarly standardized definition for
10 *fine loamy sand*. The term *loam* typically denotes a combined textural and compositional
11 make up of a soil with approximately two parts sand, two parts silt and one part clay, as
12 both grain size and as clay minerals. Loam also traditionally has a high concentration of
13 humic organic matter. Loam is valued garden soil because it both retains water well with
14 the organic matter and the clay minerals and freely drains due to its sand and silt content.
15 Since the spent ore contains no humic organic matter and less clay mineralogy than
16 customary in loam, it is not clear what *fine loamy sand* means in the context of the spent
17 ore disposal.

18
19 Q. WITH RESPECT TO LEACHATE GENERATION FROM THE SPENT ORE,
20 DOES IT MAKE ANY DIFFERENCE WHETHER IT IS SILTY SAND OR FINE
21 LOAMY SAND?

22 A. No, none whatsoever. The spent ore is what it is and the labeling is not what is
23 important. The important thing to appreciate is that, according to the data provided in the

1 NOI, the spent waste is expected to go to the mine with high porosity, calculated at about
2 35%, nearly full saturated and at or near field capacity. Therefore, it will drain when it is
3 disposed.

4

5 Q. DOES THE PRODUCTION OF LEACHATE FROM THE SPENT ORE
6 DEPEND UPON THE SPENT ORE BEING FREE DRAINING AT THE TIME IT IS
7 DISPOSED?

8 A. No, not at all. Precipitation will fall on the spent ore in the mine pit and the waste
9 piles and infiltrate it, even after compaction. Once the mine is closed, a portion of the
10 precipitation will infiltrate the closed mine and move into the spent ore. Bayer (p.5)
11 asserts that the climate and low precipitation rates will combine to evapotranspire all
12 precipitation that falls on or into the mine and waste piles. This assertion is offered
13 without any supporting data beyond a qualitative comparison of annual
14 evapotranspiration rates and annual precipitation rates, neither of which Bayer provides.
15 It is an assertion that is, quite simply, egregiously wrong. Annual rain does not fall
16 uniformly 24/7/365. The annual evapotranspiration rate does not uniformly remove
17 water 24/7/365. Simply comparing those two statistics is tells nothing about leachate
18 formation.

19 I recently finished reviewing infiltration projections at a facility in the desert north
20 of Las Vegas, investigating recharge to sediments very similar in texture to the sediments
21 anticipated to come from the PR Spring mining operation. There, with far less rainfall
22 and far higher evapotranspiration rates, significant infiltration was simulated to occur and
23 leachate moved through the waste. That will happen here, too. The rates can be readily

1 determined through long-used and well-calibrated models, models such as HELP. But, it
2 is a certainty that leachate will form in time, even were the spent ores being deposited
3 bone dry. The water content of the spent ore at disposal will influence when leachate
4 forms, but not if leachate forms. The timing and rates of leachate production should be a
5 part of EER's NOI; an analysis of impacts and a statement of mitigation cannot be
6 completed without it. This is because the leachate from the spent ore in the mine and
7 waste piles will necessarily migrate away from the mine, carrying with it its
8 contaminants, and impact ground and surface water. The magnitude of that impact is
9 dependent upon the rates of leachate production.

10
11 **VI. CHARACTERIZATION OF LEACHATES FROM WASTE MATERIALS**

12
13 Q. AS A RESULT OF THE ADDITIONAL INFORMATION YOU HAVE
14 RECEIVED, REVIEWED, AND ASSESSED AS A RESULT OF THE PRODUCTION
15 OF THE EXPERT REPORTS AND THE TESTIMONY OF DIVISION STAFF, DO
16 YOU HAVE ADDITIONAL UNDERSTANDING OF THE CHARACTER OF THE
17 LEACHATE THAT WILL EXIST IN AND FORM AS A RESULT OF THE
18 PROPOSED MINING AND ORE PROCESSING?

19 A. Yes, I do have additional understanding. It is still not a full understanding,
20 however, because EER either failed to characterize the leachate that will form or, if it has
21 characterized the leachate that will form, EER failed to share that evaluation with the
22 Division and DWQ. The failure applies to both organic and inorganic characterization of
23 the leachate. The organic characterization focuses primarily on the concentration and

1 volumes of the toxic extraction chemicals in the spent process water. The inorganic
2 characterization would focus on the importation of lower quality water to feed the
3 process and the increased weather rates that will result from the pulverization of the ore
4 rock and the release of reactive minerals.

5

6 Q. HOW HAS YOUR UNDERSTANDING OF THE INORGANIC
7 CHARACTERIZATION OF LEACHATE CHANGED AS A RESULT OF THE
8 ADDITIONAL INFORMATION YOU HAVE RECEIVED, REVIEWED, AND
9 ASSESSED?

10 A. The new information I have received, reviewed and assessed does not address any
11 of the inadequacies of inorganic characterization to which I testified previously. There is
12 still no characterization or attempt to characterize the inorganic composition of ground
13 and surface water. Bayer (pp. 13 and 14) acknowledges that the testing requested and
14 relied upon by DWQ does not provide the agency with data that is descriptive of the
15 leachate that will exist or form at the mine. Division staff in testimony accepts the EER
16 representation to DWQ that because the extracting liquid will not change pH and will not
17 therefore increase dissolution of mineral, the Orphus Process will not increase TDS (*e.g.*,
18 Monson, p. 256 *et seq.*). This ignores the fact that the Orphus Process pulverizes the ore,
19 dramatically increasing surface area and thereby increasing the rates of weathering
20 reactions that do generate TDS. It also fails to recognize that the grinding of the rock and
21 extraction of bitumen will allow exposure of previously sequestered reactive minerals to
22 weather that would not have occurred without this grinding and pulverizing. And, it fails

1 to recognize that water with significantly higher TDS will be imported for use in the
2 Orphus Process and that this water will be discharged to the mine with spent ore.

3

4 Q. HOW HAS YOUR UNDERSTANDING OF THE ORGANIC
5 CHARACTERIZATION OF LEACHATE CHANGED AS A RESULT OF THE
6 ADDITIONAL INFORMATION YOU HAVE RECEIVED, REVIEWED, AND
7 ASSESSED?

8 A. Now that we know what the extracting chemicals are, we understand something
9 of the biological and ecological risks associated with those chemicals, of the physical and
10 chemical properties of the extraction chemicals in and with the discharged water, and of
11 the degradation products of the chemicals. The composition of the process water
12 provided to EPA in 2009, although now outdated, provides some understanding of
13 aspects of the likely characteristics of the spent process water discharged with the spent
14 ore to the mine and waste dumps.

15

16 Q. WHAT DO YOU NOW UNDERSTAND REGARDING THE BIOLOGICAL
17 AND ECOLOGICAL RISKS OF THE EXTRACTING CHEMICALS?

18 A. The chemicals in Orange Terpenes are documented toxic across a wide range of
19 organisms and ecosystems. Testing has established concentrations that are toxic and or
20 lethal to cats, dogs, rodents, insects, crustaceans, birds, fish, aquatic vegetation including
21 algae, and benthic organisms. The biodegradability of these chemicals varies by
22 chemical and depends upon whether conditions are aerobic or anaerobic. Abiotic
23 degradation, particularly in sunlight, can produce degradation products that are

1 themselves toxic and/or carcinogenic. Most of the individual compounds have high or
2 very high potential to bioconcentrate. This information has been provided in detail in the
3 testimony above, based on individual chemistry.

4
5 Q. WHAT ARE THE IMPORTANT PHYSICAL AND CHEMICAL PROPERTIES
6 OF THE EXTRACTION CHEMICALS?

7 A. The chemicals are immiscible and universally lighter than water. The result is
8 that when these chemicals are discharged with water, they will remain as separate drops
9 that tend to migrate upward even when water is not migrating. The particles will tend to
10 coalesce into larger masses as they contact other droplets. Since the viscosity of these
11 chemicals is comparable to that of water and the surface tension is substantially less, they
12 move more easily than water through the porosity of the spent ore and surrounding rock.

13 The vapor density of these chemicals is between 4 and 5 times that of air. As
14 discussed above, this will tend to pool the chemical vapor at the surface of evaporation,
15 inhibiting further evaporation.

16 Each of these chemicals is soluble in water at significantly variable rates as
17 described above. This will result in a dissolved composition that can differ significantly
18 from the analyzed composition in the extracting fluid itself. For determining impacts to
19 the environment and ecosystems, the dissolved composition in water is more significant,
20 because water will be a vehicle of transport, and EER has not shared any data regarding
21 the dissolved composition of these chemicals in the spent extracting fluid that will be
22 discharged to the mine. The solubilities of these chemicals range from around one to
23 more than 1500 mg/L, their solubilities are thousands or millions of times greater than the

1 natural concentrations of the chemicals, which are often quantified in nano- or
2 picograms/L (billionths and trillionths of a gram per liter, respectively).

3 These chemicals readily partition into solid phase hydrocarbons, *e.g.*, bitumen,
4 which is why they are used in the Orphus Process to extract bitumen. Thus, the residual
5 hydrocarbons in the spent ore will be reservoirs of the extraction chemical and transport
6 the chemicals to the mine with their disposal. EER provides no data on the concentration
7 of these chemicals partitioned into the residual bitumen. This is a substantial omission as
8 the application to the DWQ reports that the residual bitumen concentrations in the fine
9 sediments is as high as 3% and therefore the potential mass of the chemical in the
10 residual may be significant.

11
12 Q. WHAT IS KNOWN ABOUT THE CONCENTRATIONS OF THE
13 EXTRACTING CHEMICALS IN THE SPENT PROCESS WATER THAT IS BEING
14 DISPOSED IN THE MINE WITH THE SPENT ORE?

15 A. Both the DWQ and the NOI acknowledge that the extracting chemicals will be
16 part of the spent process water that is disposed with the spent ore and placed in the mine
17 and in the waste dumps. However, neither the NOI nor the DWQ application gives any
18 specific information regarding the concentrations of these chemicals or the masses of
19 these chemicals that will be disposed in the mine. The NOI and the DWQ application are
20 without any analytical or quantitative data with respect to concentrations of the extracting
21 chemicals in the spent process water, which is the initial leachate at the mine.

1 Q. FROM THE INFORMATION AVAILABLE, WHAT CAN BE DETERMINED
2 ABOUT THE CONCENTRATIONS OF THE EXTRACTING CHEMICALS IN THE
3 SPENT PROCESS WATER THAT IS BEING DISPOSED OF IN THE MINE AND
4 WASTE DUMPS WITH THE SPENT ORE?

5 A. There are three mechanisms by which the extracting chemicals associated with
6 the spent process water that is being disposed of in the mine and waste dumps with the
7 spent ore can be transported; dissolved in water, as free liquids mixed with the water, and
8 in solid phase partitioned into the residual hydrocarbons in the spent ore. None of these
9 is characterized by EER.

10 The dissolved chemicals may occur at or near their solubility limits based upon
11 the high concentration of extracting chemical in the process water, according to the
12 composition of the process water given EPA in 2009, a long average period of contact,
13 and extensive agitation in the extraction process. This would result in a total dissolved
14 concentration of about 2170 mg/L, or approximately 2170 parts per million. Water loss
15 with the spent waste is 116 gallons per minute (gpm) according to the NOI, or 167,040
16 gallons per day. Using the above dissolved mass ratio, this constitutes a load to the mine
17 of 3023 pounds per day. Converting to volume based upon a typical density of about
18 0.84 of water, the approximate the discharge rate of extracting chemicals is 450 gallons
19 per day.

20 There are no data available in the NOI or in the application to DWQ that allows
21 one to extract or estimate the amount of the extracting chemical that will be partitioned
22 into the residual hydrocarbons of the spent ore. It is only known that this is an additional,
23 and potentially significant source of transport to the mine.

1 There are no direct data available in the NOI or in the application to DWQ that allows
2 one to extract or estimate the amount of the extracting chemical that will be released as a
3 free-phase mixture of the extracting chemicals with the spent process fluid discharged
4 with the spent ore. The 2009 letter from EER to EPA states that the extracting fluid is
5 35.9% extracting chemicals. However, what is going to the mine is spent extracting
6 fluid, not fresh, and it will have substantially less of the chemical in it. How much less is
7 known to EER, because the company repeatedly states that the lost extracting fluid, both
8 water and chemical, must be added back to refresh the process fluid for new extraction.
9 EER does not provide that information in either the NOI or the DWQ application.

10 However, EER has stated in public forums describing the Ophus process that 98%
11 of the chemical is recycled. Based upon the 116 gpm loss of process water, the process
12 water chemistry reported to EPA, and a total of 2% chemical loss, the chemical content in
13 the disposed water could be as high as 2200 gallons per day or 14,800 pounds per day.
14 The dissolved concentration can only account for about ¼ of this amount, so transport
15 with the residual hydrocarbons in solid phase or as free liquid are likely significant
16 factors.

17

18 VII. CONCLUSIONS

19

20 Q. WILL THE OPHUS PROCESS PRODUCE LEACHATE THAT IS
21 CONTAMINATED WITH THE EXTRACTING FLUID THAT IT USES?

22 A. Yes. EER projects a production rate of contaminated leachate of 116 gpm for a
23 bitumen production rate of 2000 barrels per day.

1

2 Q. WHAT ARE THE LEVELS OF CONTAMINATION OF THAT LEACHATE
3 WITH EXTRACTING CHEMICALS?

4 A. Only EER knows at this point, because EER does not disclose the composition of
5 the spent fluid that constitutes the discharged leachate. The leaching procedure analyses
6 provided to DWQ as part of the application did not test for the extraction chemicals.
7 Using a reasonable assumption that the spent fluid is saturated with the extracting
8 chemicals, the dissolved concentration of these chemicals is about 2179 mg/L. Free-
9 phase concentrations of the extracting chemicals have not been disclosed. The discharge
10 of chemicals to the mine solely in dissolved phase, under the assumption of concentration
11 at solubility, is about 1 ½ tons per day, or about 450 gallons per day. If all of the
12 chemical loss described by EER in public (2%) are part of the waste water disposed with
13 the spent ore, the total chemical in the waste water would be as high as 2200 gallons per
14 day, or 14,800 pounds per day.

15

16 Q. ARE THE MINE AND WASTE DUMPS CONTAMINATED WITH
17 EXTRACTING CHEMICALS IN ANY MANNER OTHER THAN DISSOLVED AND
18 FREE-PHASE LIQUID?

19 A. Yes. The extracting chemicals partition into the bitumen. Some of the bitumen is
20 returned to the mine as residual hydrocarbons. According to data provided in the
21 application to DWQ, the overall concentration of residual hydrocarbon is 0.84% and
22 some spent ore has as much as 3% residual hydrocarbons. The concentration of
23 extracting chemicals in these materials is not disclosed.

1

2 Q. WILL LEACHATE IN THE MINE AND WASTE DUMPS BE MOBILE AND
3 ABLE TO MOVE OUTSIDE THE MINE AND DUMPS?

4 A. Yes. Based upon the materials handling data in the NOI, the discharge rate of
5 spent process fluid from the processing of the ore is sufficient to generate water levels in
6 the disposed spent ore that will be at or over levels at which it will drain at the time of
7 disposal. Therefore, as proposed in the NOI, leachate drainage would begin immediately.
8 Were the process to be changed to reduce that level of water discharge, movement of the
9 leachate would begin when sufficient water falls on or infiltrates into the waste to raise
10 water levels to or above field capacity. This addition of water will occur. The technical
11 effort needed to estimate a time frame has not been shared by EER, if it has been done.

12

13 Q. MIGHT THE EXTRACTING CHEMICALS IN THE MINE MOVE, EVEN IF
14 THE WATER IS STATIONARY?

15 A. Yes. The extraction chemicals are immiscible in water, less dense than water, and
16 can move more readily through porous material than water. Free-phase liquid chemicals
17 will tend to migrate vertically upward, whether or not the water is moving.

18

19 Q. DO THE EXTRACTING CHEMICALS DISPOSED IN SPENT PROCESSING
20 WATER AND IN SPENT ORE PRESENT A THREAT OR RISK TO THE
21 ENVIRONMENT, ECOLOGY, SURFACE WATER AND GROUND WATER AT THE
22 MINE?

1 A. Yes. There are abundant toxicological, ecological, and environmental studies and
2 data that establish these chemicals are toxic, and potentially lethal to, virtually every type
3 of life and ecosystem in and around the mine, including earthworms, aquatic plants,
4 benthic animals, fish, insects, rodents, predator mammals, birds, and soil bacteria. Most
5 of the chemicals have high or very high potential for bioconcentration. Some biodegrade
6 under some conditions, but abiotic degradation (degradation by non-biological processes)
7 for some of these chemicals produce degradation products that are themselves toxic or
8 carcinogenic.

9

10 Q. CAN THE FULL RISK OF DISPOSING OF THESE ORGANIC CHEMICALS
11 IN THE WASTES AT THIS MINE BE FULLY QUANTIFIED AT THIS TIME?

12 A. No. Not until EER elects to release withheld information and undertake
13 additional analysis and elects to characterize the site sufficiently to understand migration
14 paths, migration rates, and timing of migration can these risks be described or quantified.
15 Confirming the risks or identifying damage after operations begin would require
16 monitoring programs and protocols that are not part of the current mining plan.

17

18 Q. IS ORGANIC CONTAMINATION THE ONLY PROBLEM THAT WILL
19 OCCUR WITH THIS MINING?

20 A. No. The mining plan at this site will create contamination due to inorganic
21 materials as well. The very limited existing data establish very low TDS water in the
22 seeps and springs that discharge local shallow groundwater, as documented in the NOI
23 and included in the application to the DWQ. The mining and processing of the oil sands

1 as proposed in the NOI will necessarily generate lower quality water even without the
2 organic contamination. Water higher in TDS than the shallow water in the area is being
3 imported from deep zones several miles away for use as process water. Pulverizing the
4 ore rock will decrease grain size and increase surface area, increasing the rate at which
5 this water will weather and increasing TDS as a result. Reactive minerals that are
6 currently sequestered in the bitumen will be exposed to oxidizing air and water and will
7 what weather at rates far higher than currently occur.

8

9 Q. CAN THE FULL RISK OF DISPOSING OF THE INORGANIC
10 CONTAMINATION AT THIS MINE BE FULLY QUANTIFIED AT THIS TIME?

11 A. No. Unless and until EER disclosed or collects the necessary data to allow an
12 assessment of the materials and processes that will be specifically involved and active at
13 this specific mine, the impacts and risks cannot be characterized or quantified. The
14 composition of the water to be used for making the process water is easily obtained. The
15 inorganic composition of the spent process water that constitutes the initial leachate is
16 easily obtained. Characterizing the reactive mineralogy of the spent ore is easily done.
17 From these data, the risk and impact of inorganic contamination is easily determined.
18 The NOI is not complete without this information and no finding of impacts to water – *de*
19 *minimis* or otherwise - can be validly done without it.

20

21 Q. Does this conclude your testimony for now?

1 A. Yes, it does.

2

3


4

5

6

7

8

A handwritten signature in black ink, appearing to read "Charles H. Norris". The signature is written in a cursive, slightly slanted style.

Charles H. Norris
1928 E 14th Ave
Denver CO 80206

Exhibit A

COMPUTATION OF WATER CONTENT IN SPENT ORE USING NOI DATA

Daily production run, 2000 bbl. (NOI, p.16)

Daily ore processed, 3000 to 3500 tons (NOI, p 16)

Assumption 1: ore is dry based on site characterization

Bitumen recovery as percent of weight of ore rock, 10-12% (NOI, p. 14)

Assumption 2: use midpoint of range, 11%

Daily dry tailings [89% of (3000 to 3500 tons)], 2670 to 3115 tons

Water consumption, 116 gpm (NOI p.17)

Daily water consumption, $116 \times 60 \times 24 = 167,040$ gallons

Daily water consumption, $167,040 \times 8 / 2000 = 668$ tons

Range of daily wet tailings production, 3338 to 3783 tons

$[2670 + 668 \text{ to } 3115 + 668]$

Range of water content [W-wtr/W-total], 20.0% to 17.6%

Volume = Mass/Density

Quartz has density of 2.65 g/cc, or 1.993 tons/cy

Water has a density of 1.00 g/cc, or 0.752 tons/cy

Volume of daily processed rock, 1340 to 1563 cy

$[2670/1.993 \text{ to } 3115/1.993]$

Daily water volume, $668/0.752 = 888$ cy

Volume of rock + volume of water = volume of tailings; 2228 to 2451 cy

Assumption 3: no unsaturated porosity

Porosity of tailings, volume of water/volume of tailing, 40% to 36%

Notes:

Assumption 3 is reasonable because the resulting total porosity is at or near the upper limit expected for granular, unconsolidated sediments like these. Adding a third phase of air filled porosity would postulate porosity too high to be expected in sediment coming off a shale shaker or similar device.

The use of quartz density is conservative. The use of a grain density greater than quartz at 2.65 g/cc would decrease the volume of rock and resulting even higher porosity..