Synergy Operating, LLC

PO Box 5513
Farmington, NM 87499
(505) 325-5449
Fax (505) 566-3750

RECEIVED
2007 OCT 29 AM 10 48

October 27, 2007

Oil Conservation Commission
New Mexico Oil Conservation Division
Attn: Ms. Davidson
1220 South Saint Francis Drive
Santa Fe, NM 87505
(505-476-3462-fax)

RE: Case No. 14015 Rule 50: Application of the New Mexico Oil Conservation Division for Repeal of Existing Rule 50 concerning pits and below grade tanks and adoption of a new rule governing pits, below grade tanks, closed loop systems and other alternative methods to the foregoing, and amending other rules to conforming changes, Statewide.

Ms. Davidson:

Synergy Operating, LLC (Synergy) is a Farmington, New Mexico based independent oil and gas company that has six (6) employees. We are a member company of the Independent Petroleum Association of New Mexico (IPANM) and the New Mexico Oil and Gas Association (NMOGA) and support both organizations recommendations regarding this important rule. Synergy was not a direct member of the Industry Committee (IC), but we have reviewed their materials and have actively participated with members of this group on drafting the response and we fully support their recommendations. We have been safely and efficiently drilling oil and natural gas wells for almost twelve (12) years, epitomizing the type of small business that New Mexico relies upon for sustaining and growing high paying industry jobs.

Synergy has two (2) New Mexico registered professional engineers on staff in the discipline of Petroleum Engineering who have actively developed our state's oil and gas resources for a combined thirty (30) plus years. It is Synergy's recommendation that the Oil Conservation Commission (OCC) vote to vacate the application of the New Mexico Oil Conservation Division (NMOCD) with regard to the matter at hand, as being unnecessary for continued development of oil and gas, with insufficient technical justification warranting its adoption as a Rule. This application appears to address a concern or problem that does not exist.

Furthermore adoption of this proposed application will negatively impact the development of the public's State and Federal mineral estate upon which the foundation of our state government is financed and would negate the OCC's principal responsibility to encourage the orderly development of this valuable resource.

Although the NMOCD has the responsibility to regulate the disposition of nondomestic wastes resulting from the exploration, development, production or storage of crude oil or natural gas to protect public health and the environment; The proposed Rule attempts to "Redefine" waste to a standard that will undoubtedly interfere with the NMOCD's primary responsibility to prevent waste and protect the correlative rights as provided under the Oil and Gas Act, Section 70-2-12.1 NMSA 1978 and potentially the proposed rule will attempt to negate the RCRA waste exemptions specifically allocated to our industry. The correlative rights of the State and Federal mineral owners would undoubtedly be negatively affected by this redefinition of the waste standards by the NMOCD, and arguably could be outside of the statutory authority of the NMOCD.

The economic argument that some parties make in support of this matter is, "Industry can afford it". It is interesting to identify that these economic arguments are promulgated by environmentalists. The NMOCD should be concerned when an environmental stakeholder organization must rely solely upon their economic arguments for endorsement of added regulation. The superior question to the OCC remains identifying the benefit of this rule with regard to the protection of public health and the environment. It is clear from the technical evidence,that regardless of the economic impact of this proposed regulation, no positive qualitative, nor positive quantitative benefit can be determined from adoption of the proposed rule over the existing rule.

If the rule is adopted as proposed, economics will undoubtedly drive investment to more favorable locations beyond the state of New Mexico. As an independent oil and gas company with investment opportunities in Utah, Colorado, and Wyoming, I can confirm that Synergy will be forced to reduce our capital investments in New Mexico. This saddens me, as I would prefer to work and invest our organization's profits at home. Some interested parties in this matter suggest that the added costs associated with this unnecessary rule will somehow create additional jobs?, this assertion is beyond conventional economic reality, but must assume a captive socialistic marketplace. It is obvious that by increasing economic burdens from unnecessary regulation, that fewer wells will be drilled.

The OCC should request from the NMOCD an explanation as to why with $ 90 oil and $ 6.00 natural gas, the number of new wells being drilled in New Mexico is declining? Synergy contends that the added regulation from the recent solid waste rule, the revised enforcement rule, the proposed adoption of this "Pit Rule", and the stated intention to revise eighteen (18) additional rules will accelerate the decline in new well applications. Synergy has reviewed numerous industry calculations regarding closed loop requirements and associated dig and haul costs, and we concur with their data and expected range of cost results. We offer our specific example for the record.

Synergy is currently developing a shallow marginally economic Fruitland Coal project in the San Juan Basin. Synergy believes that over the next 2 to 5 years, we can drill up to sixty (60) new wells to an approximate depth of one-thousand feet under the existing requirements of Rule 50. The "New" Rule 50 is overly burdensome, unnecessary for the protection of the public health and the environment and negatively impacts Synergy and other independent small businesses.

The small footprint of our well locations in Northwest New Mexico will undoubtedly have to be expanded with additional surface disturbance area to handle the closed loop equipment and or deep trench burial methods in a safe manner. These trenches may interfere with the tight room that is currently available at many locations due to the "twinning" with existing locations and the existing surface equipment, including separators and tank batteries. In effect, all cuttings would need to be hauled away from the location. The industry has taken great steps to reduce our environmental footprint from an aerial extent, adoption of this rule will expand the area required to safely and adequately develop oil and gas reserves defeating industry's good work.

It should be noted that the safe cost effective industry practice to drill a shallow Fruitland Coal well, is to drill without solids control equipment (i.e. a shaker, cone system, nor centrifuge). This differs from deeper wells where solids control equipment is traditionally employed. These wells utilize the cost effective gravity segregation method for removal of solids. This gravity segregation method is safe, mother nature provides it, and has been proven effective for many years.

During the three (3) days of drilling, Synergy typically utilizes up to thirty – fifty pound sacks of bentonite clay and three (3) five-gallon jugs of polymer in our mud system to drill these shallow wells. It should be noted that the constituent make-up of polymer is 30 % water (MSDS sheets attached) thereby reducing the effective non-aqueous additive volume. Our reserve pits for these shallow wells are small, typically containing 800 barrels of useable capacity. These additives are mixed with fresh water, are circulated down the drill string, and coat the sides of the borehole thereby allowing adequate cuttings removal and sufficient gel strength for safe drilling operations to occur. These are the same additives utilized to drill drinking water wells. Assuming incorrectly that there is no retention of the non-aqueous phase, 10 gallons of chemical is diluted into 16,800 gallons (400 bbls) of fresh water. This yields a concentration of non-aqueous product of 0.059 percent (six one-hundredth's of one percent) in the drilling mud.

Bentonite clay, the principal constituent of drilling mud, will expand when fully hydrated up to 18 times its solid volume. This clay along with naturally occurring clays found in the sedimentary rock (sandstones, silts, and shales) cause the cuttings material from a borehole to be greater than the calculated hole diameter might indicate. This is one of the reasons that the volume of drill cuttings is greater than would be expected and corroborates the industry calculations of expected solids volume. Synergy's solid cutting volume estimate utilizes a 10 to 1 ratio of solids magnification.

On a per well basis, Synergy anticipates that implementation of this rule will add \$ 1,500 to our liner and location costs, \$ 2,000 to our drill equipment mob/demob costs, \$ 15,000 to our solids equipment control cost, \$ 8,000 solids trucking cost (8 trucks - \$ 1000 round trip), \$ 2,800 in solid waste disposal costs, \$ 1,000 in soil testing costs, and \$ 1,500 backhoe/operator charges. This anticipated total of \$ 31,800 would be added to our existing drilling phase cost of \$ 100,000 yielding a new drilling phase cost of \$ 131,800 (32% cost increase). The completion phase of our operation would again be impacted with need to haul solid quartz sand returns to a landfill at approximately \$ 4,000. Estimated financial impact upon each of our shallow 1000 foot Fruitland Coal wells is \$ 35,800. This shallow well example demonstrates that this the one size fits all regulation impact is ill advised.

As the OCC is well aware, marginal Fruitland Coal wells initially produce high water volumes, with little gas production. Gas production improves as the reservoir pressure is lowered over time. Due to the longer dewatering times anticipated in our project area, a thirty-percent cost increase in the initial investment will extend the time to reach payback of our investment and cripple the economic viability of our project. This proposed rule fails to protect our rights and the rights of the Federal mineral estate from whom we had planned to develop these gas reserves. The economic viability of our leases is placed in jeopardy.

I want to briefly discuss temporary lined workover pits, as the majority of the focus has been placed upon temporary lined drilling pits. The dimensional requirements imposed upon a temporary lined workover pit in the proposed rule are not practical. The only requirements a temporary lined workover pit should have is that it have sufficient freeboard to allow containment of fluids, be properly bermed to not allow surface waters to enter the pit, and be adequately fenced under the standard New Mexico definitions of a fence to protect wildlife. The current Rule 50 with "12-mil liners" is adequate with regard to temporary lined workover pits.

These pits are often located in difficult size restricted locations. Most temporary lined workover pits are utilized to contain frac sand returns and cement returns during workover operations, with all fluids properly removed and disposed prior to the solids (quartz sand and portland cement) burial. There are currently over one-hundred-twenty operational workover rigs employed in the San Juan Basin. These workover operations will now be subject to the same closed loop requirements as drilling operations. The unintended consequence of adoption of this proposed rule (targeting drilling pits) will be significantly increased costs of maintaining production at existing wells, and clearly add to the administrative burden of the NMOCD staff.

Often during remedial cementing operations, the quantity of cement that will be returned to the surface cannot be predicted. Current regulations require operators to circulate cement to surface as a best management practice, and a temporary lined workover pit of sufficient capacity allows an operator a cost effective method to achieve this goal. Under the proposed regulation, this cement material, along with any sand material from stimulations will now be required to be hauled to an approved facility. Furthermore testing of the soil will be required beneath this cement filled liner, which clearly seems inappropriate and unnecessary. It should be noted that no samples have been analyzed regarding temporary workover pits by either the NMOCD or industry for evaluation. No background soil or fluid data has been provided. Furthermore no samples have been taken from underneath a lined reserve or workover pit. It is clear that this rule as written has not taken into account impacts relating specifically to the workover operations on existing wells in New Mexico.

Assuming that twenty-five percent of the workover operations in Northwest New Mexico are performing remedial activity, the expected workover related cuttings volumes when added to the drilling rig related cuttings volumes would effectively double the quantity of material that will be hauled to an approved landfill site in the Northwest. This unnecessary burden will in particular impact smaller independent operators in New Mexico, as they acquire "legacy" wells from larger operators who will move their operations out of state or overseas. The cost to workover a well in New Mexico will be increased unnecessarily.

Well abandonment operations also require a temporary lined workover pit in order to circulate the excess cement out of the well. Under the proposed regulations this non-toxic and immobile cement and the liner containment material would be required to be transported to a landfill.

It should be noted that the movement of drill cuttings and wastes on location induces additional safety hazards to equipment and personnel onsite in addition to placement of additional traffic and dust on our roadways to and from wellsite locations. The probability of solids transfer equipment (such as a backhoe) inadvertently damaging wellsite production equipment will increase. This will increase the likelihood of a spill or unintentional gas release.

Synergy specifically objects to the request by the New Mexico Department of Game and Fish (NMDGF) for the imposition of netting requirements and eight foot tall "chain link" fence requirements on all reserve and workover pits. No information, nor examples are presented by NMDGF justifying this request and it is offensive to our industry that the historic cooperation and habitat improvements made by our industry are not reflected in their comments. Under the existing rule, netting and cover of tanks and production pits are required. Industry has supported reasonable seasonal activity restrictions (Timing Limitations) to benefit big game, even though the biological record of benefit is weak. A chain link fence installation requirement is beyond reason, would entail significant cost, offer no improvement over the existing fencing requirements on temporary pits, and one would hope viewed by the OCC as unreasonable.

The United States Geological Survey (USGS) has conducted and is conducting long term analysis regarding of the effects upon waste burial in arid environments and the movement of hydraulic fluids. The results of these studies are summarized in a fact sheet whose link is embedded below. A significant conclusion is summarized here in this sentence: "A study of chloride concentrations in the unsaturated zone indicates that deep percolation of water was limited to the upper 30 feet during the past 16,000 to 33,000 years." Modern day analysis at the site is capable of monitoring "present-day" flow processes to a depth of 45 feet in great detail. http://water.usgs.gov/wid/FS_179-95/

Monitoring has included both disturbed areas and undisturbed areas. It has been shown that in arid environments water movement in both the liquid and vapor phase has consistently been upward. Areas of soil disturbance are protected further through the installation of an impermeable synthetic liner as is currently utilized with temporary oil and gas reserve and workover pits. The probability of leachable salts, metals, and organics impacting the ground water in areas of deep ground water (defined as greater than 50 feet) is conclusively infinitesimal.

Another peer reviewed reference regarding Non-Aqueous Phase Liquid (NAPL) mobility limits in soil is detailed in the Soil and Groundwater Research Bulletin No. 9 prepared in June 2000 http://www.api.org/ehs/groundwater/bulletins/index.cfm. This document discusses the soil saturation limits for various chemicals and hydrocarbons including miscible hydrocarbons. It is clear from analysis of Table 2 of this document that the saturation concentration limits in mg/Kg that are retained through adsorption, surface tension, and capillary forces are quite high. This would indicate the concentration of specific NAPLs retained in drill cuttings must exceed these values and be in direct hydrologic communication with groundwater to facilitate their mobility.

Furthermore when a comparison is made of the concentrations present in the publicly available data on solids (soils) within the liners of reserve pits most concentrations are well below these saturation limits. Once traditional soils are mixed with the cuttings and are utilized to bury (cover) industry temporary lined reserve and workover pits, the probability of mobile NAPL constituents becomes infinitesimal. The current Rule 50 practices regarding lined reserve and workover pits adequately protect groundwater resources, the public health, and the environment, without requiring closed loop drilling, deep trench burial, and associated testing.

As a side note to the lay reader, our industry works diligently to recover the maximum amount of oil contained inside of reservoir rock. It is important to state that under primary recovery operations, with our best efforts, industry may recover ten (10) percent of the oil in place. With significant expense and effort, attempting to strip the remaining oil from this reservoir rock (called Secondary and Tertiary recovery), industry often achieves only a few percentage points of additional recovery. Hydrocarbons and NAPLs have resilience in their ability to remain within the pore space.

It should be mentioned that "Closed Loop" drilling practices actually require the use of additional chemicals to help separate fine particulates from the mud assisting the centrifuge. By not utilizing the "Closed Loop" drilling process, fewer NAPL chemicals will be in the mud, and by default fewer NAPL chemicals will be in the solids. Closed Loop drilling is not the panacea that some may believe.

Water is an important resource to all the citizens of New Mexico. It is my belief that industry has been a good steward of water resources in New Mexico. An understanding of both surface water quality and ground water quality standards and the likely mobility contaminants within drill cuttings is warranted. Chemists understand that when you mix two (2) substances of different salinity in equal parts that the salinity of the composite solution will reach equilibrium. It is also well understood that if brine water evaporates that the salts are left behind as precipitants. What is difficult to model and predict with regard to drill cuttings is the percentage of salts, and other metals, that can be placed back into solution following their precipitation due to the presence of bentonite, other clays, silts, and sand grains, which preferentially adsorb and retain salts and minerals?

Under current regulations the fluids remaining in a reserve pit or workover pit are removed and disposed of properly. The salts remaining associated with these drill cuttings can be utilized to estimate the concentration of salt should fresh (low salt) water (i.e. rain water) filter through the material. Although detailed soluble fraction tests were not performed on any of the NMOCD samples, it is possible to infer or estimate the salt concentration of the leachate. I will reference the soil sample taken by the NMOCD from the reserve pit of the Hare # 14M well (Sample DP3-01-Work Order # 7060415) located in Northwest New Mexico (Sec 10-T29NR10W). The Chloride concentration is listed as 704 mg/Kg. The salts are listed as Total Calcium 14200 mg/Kg, Total Mg 2790 mg/Kg, Total K 1230 mg/Kg and Total Sodium (Na) 1570 mg/Kg.

The Chloride figure is determined by taking 1 part soil and 2 parts distilled water and mixing them together (shaking vigoursly) for an extended period of time. This typically places the soluble portion of Sodium, the most soluble salt into solution. This would indicate that approximately 704/1570 or 44% was soluble. It also indicates that 56% of the NaCl salt remained bound in the soil material. It also indicates that the Calcium Chloride ($CaCl2$), Magnesium Chloride ($MgCl2$) and Potassium Chloride (KCl) were not soluble or as soluble and hence likely immobile in this sample. The Calcium in particular is likely associated with the immobile cement. It is possible to perform detailed resoluble fraction tests for these salts, but as stated above these tests were not performed for the NMOCD samples, and their performance would be critical to accurately determine resoluble salt concentrations.

Continuing with our example, one must now assume that rainwater now contains NaCl (Table Salt) leachate 704 mg/Kg (above the proposed limit of 250 mg/Kg), we must assume that at some point another drop of fresh rainwater (2nd drop) will mix with the 1st drop of rain water. This will immediately dilute the concentration in half, reaching an equilibrium of 352 mg/Kg. Adding one more drop of water (3rd raindrop) will now allow the leachate (176 mg/Kg) to meet the proposed standard. This natural dilution process occurs in all soils.

The challenge now is to reconcile the probability that this leachate, continuing to be diluted by freshwater (since rain will occur) will somehow migrate through the remaining soil (note the remaining soil does not contain this high concentration of salts as it is "division-prescribed soil cover", native soil, or top soil to reach the public and harm the environment. Furthermore the assumption must occur that through all of the remaining soil pore throats, the leachate will remain unchanged (no outside impacts positively or negatively changing the salt concentration) until harming the public or the environment. I almost forgot to discuss the synthetic liner which will inhibit flow. The probability of this leachate, as demonstrated in this example, reaching groundwater is minimal, and if it did reach ground water its effect would be infinitesimal.

I would like to review a second Northwest New Mexico public data sample of drilling mud (water) taken directly from the mud tank on the BHGR-Many Canyons 29-04-11 # 34H well (sample T3-01, Work Order 7060432). Review of this document's results are focused upon Total Petroleum Hydrocarbons (TPH), as well as Total Dissolved Solids. The three (3) reported columns regarding TPH at the top of the analysis indicate different hydrocarbon constituents. The TRPHC reading of 385 mg/l is a heavy hydrocarbon reading typically > C35. This material has little mobility. The DRO reading of 18.6 mg/l covers mid-range hydrocarbons from C12 to C28, and also has little mobility. The GRO reading of 0.713 mg/l covers hydrocarbons that have higher mobility C6 to C12. The footnote on this sample at the bottom of page one indicates that the sample had to be diluted due to the amount of solids in the sample. This is reflected when comparing the Chloride reading of 2050 mg/l to the Total Dissolved Solids Reading of 17200 mg/l. This difference demonstrates that a significant portion of the sample material is actually solids, not salts, and would undoubtedly separate from the liquid if given sufficient time. As an engineer, it appears to me that after the drilling fluids are disposed of properly under the existing Rule 50, that the remaining solids in this reserve pit, properly covered and revegetated will not be of harm to the public nor the environment.

A summary spreadsheet of the samples taken by the NMOCD for Northwest New Mexico is attached indicating TPH and chloride concentrations. Most of these items meet New Mexico ground water quality standards without dilution.

Detractors will continue to show pictures of "Legacy Sites" (older sites) whose surface locations contain little to no vegetation, principally in Southeast New Mexico. It should be noted that these reserve pit sites were closed out in accordance with the regulations in place at that time. Current regulations and current re-vegetation practices have improved surface characteristics substantially. It should be referenced that Marathon Oil recently received the 2007 NMOCD Environmental Merit Award for re-habilitating unattractive "Legacy Sites". I would again make the statement that the pictures may not look nice, but the hazard to the public and the environment is not demonstrable. Industry truly is a good neighbor and not the villain portrayed by some, and industry continues to work to improve the condition of "Legacy Sites" and improve forage for wildlife.

Current regulation under Rule 50 adequately protects shallow groundwater. It may surprise the OCC that the average salt concentration in the San Juan River at Bluff, Utah as measured by the Bureau of Reclamation over the past sixty years is 441 mg/l. (See Chart) http://www.usbr.gov/uc/progact/salinity/excel/CRBannual_salinity_data.xls The Bureau of Reclamation also has analyzed the water quality in the San Juan River below Navajo Reservoir, near Archuleta, NM, specifically for salts since 1940. This data is not available in a chart format. http://www.usbr.gov/uc/progact/salinity/pdfs/SanJuanRivernearArchuletaNM.pdf The TDS salinity readings are slightly lower, since it is downstream of the reservoir. The salinity of the Colorado river below Hoover dam is 723 mg/l.

As many New Mexicans know during severe rain events and during the spring run-off, the rivers and washes of New Mexico flow with debris, sediment, and solids. The data regarding turbidity in these washes and the rivers is limited, although quite interesting. The viscosity due to the sediment load of the river must be thicker than a drilling mud at times! It is difficult to reconcile that the NMOCD is requiring a "clean" threshold for reserve pit solids and salts that would often be exceeded in our rivers.

I do not want to leave the impression that drilling fluids and cuttings should be de-regulated or unregulated, rather I believe the technical evidence and my cursory discussion of the technical information demonstrates that the current Rule 50 practice in place regarding the management of oil and gas pits of all types is appropriate, and unnecessary of repeal and/or modification as requested by the NMOCD in this matter.

The oil and gas industry has a long history of cooperative regulatory reform evidenced by the rule changes associated with oil and gas production pits. In Northwest New Mexico, these unlined earthen pits were utilized to dispose of small volumes of produced water. In areas of shallow groundwater, especially along river corridors, associated hydrocarbons came in contact with the ground water and migrated. Industry and regulators investigated this matter and implemented a closure program to eliminate the use of these unlined earthen pits. Remediation activity was performed at dehydration and separation pits throughout the Northwest. It was estimated in 1993 that there may have been up to 62,900 such pits in operation. Although the technical information did not warrant elimination of all earthen pits, principally those where ground water was shallow, industry has been actively working under the existing Rule 50 to remove all these earthen pits and replace them with steel and fiberglass tanks. It should be noted that earthen pit discharges were the rule at that time, but no longer. When analyzed statistically, the contaminant occurrences represent a small fraction of the earthen pits in use at that time. Although an updated list is unavailable from the NMOCD website, the majority of these sites have been properly remediated by industry.

Long term use of production pits is different from the short term use of lined reserve and workover pits. To equate uses and potential impacts of these pits is not appropriate. Liner materials, secondary containment, quantity, and duration of use, among other items clearly disqualify some parties attempts to equate these pit types. Earthen pits have direct hydrologic communication with the soil. This is not the case with temporary lined reserve and workover pits.

The historic record in New Mexico indicates that industry has been a good neighbor with regard to all types of oil and gas pits. The technical information regarding the materials within a temporary lined reserve pit, both solids and fluids, do not warrant a change in the exiting rule.

In conclusion, Synergy supports the specific recommendations made by IPANM, NMOGA, and the Industry Committee (IC) as we have participated in their preparation. This letter is supported by the entire staff of Synergy, as well as several New Mexico small businesses such as TPC, Inc., Delhi-Trading, Inc., and Mullins Energy, Inc. I look forward to personally discussing this matter with you and answering any questions you may have regarding my comments.

As a technical professional working daily to produce clean burning natural gas and oil, while protecting the environment, I respectfully recommend that the OCC vacate this application as proposed and direct the NMOCD to continue effective enforcement of the existing pit rule.

I can be reached at (505) 566-3725, or tom.mullins@synergyoperating.com.

Best regards,

Thomas E. Mullins, P.E.
Engineering Manager

attachments
cc: Karin Foster – IPANM
Stephanie Reid – NMOGA
William Carr – IC

Listing and Order of Exhibits/Attachments

Synergy Closed Loop Impact Spreadsheet – 1 Page

Synergy Summary of NW New Mexico Public Pit Samples – 1 Page (legal)

M-I Drilling Fluid MSDS Sheet (Bentonite "Max-Gel") – 6 Pages

M-I Drilling Fluid MSDS Sheet (Poly-Plus) – 3 Pages

San Juan River, Bluff Utah Salinity – 1 Page Chart
http://www.usbr.gov/uc/progact/salinity/excel/CRBannual_salinity_data.xls

USGS Fact Sheet 179-95 – 4 Pages
http://water.usgs.gov/wid/FS_179-95/

API Soil and Groundwater Research Bulletin No. 9 prepared in June 2000 – 9 Pages
http://www.api.org/ehs/groundwater/bulletins/index.cfm.

Specific Sample BHGR Many Canyons 29-4-11 # 34H (Sample T3-01) – 5 pages

Specific Sample COPC-Hare # 14M (Sample DP3-01) – 5 pages

Synergy Operating, LLC
Closed Loop Drilling Impacts
Rule 50 Comments

Synergy Operating, LLC
Shallow 1000' Fruitland Coal Calculations
Closed Loop Analysis
Cement Calculations

12.25" Hole Size
8-5/8" Casing Size
ANNULAR AREA CEMENT CALCULATIONS

12.25	ID OF HOLE
8.625	OD OF PIPE
0.073504	Bbls per Ft
0.412722	Ft3 per Ft
1.42	Cement Yield (ft3 per sack)
0.290649	Sacks per Ft
120	DEPTH OF CASING
8.820423	BBLS OF CEMENT 100%
49.52667	FT3 OF CEMENT NEEDED 100%
34.87794	SACKS OF CEMENT PER 100%
17.64085	DOUBLED BBLS OF CEMENT
99.05335	FT3 OF CEMENT (W EXCESS)
69.75588	SACKS WITH EXCESS

7" Hole Size
5-1/2" Casing Size
ANNULAR AREA CEMENT CALCULATIONS

7.88	ID OF HOLE
5.50	OD OF PIPE
0.030855	Bbls per Ft
0.173253	Ft3 per Ft
1.39	Cement Yield (ft3 per sack)
0.124642	Sacks per Ft
1000	DEPTH OF CASING
30.85539	BBLS OF CEMENT 100%
173.253	FT3 OF CEMENT NEEDED 100%
124.6425	SACKS OF CEMENT PER 100%
61.71078	DOUBLED BBLS OF CEMENT
346.506	FT3 OF CEMENT (W EXCESS)
249.2849	SACKS WITH EXCESS

Drilling Phase Costs	
Location Size Adjustment & Liner change	1,500
Trucking Charges Mob/Demob	2,000
Solids Equipment (3 days @ $ 5,000)	15,000
Trucking Solids (8 trucks @ $ 1,000)	8,000
Solid Waste charges from landfill	2,800
Soil Testing Costs	1,000
Backhoe/Loader w/ operator	1,500
Subtotal through Drilling	31,800
Mob/Demob/Backhoe (Combined)	2,000
Trucking Solids (2 trucks @ $ 1000)	2,000
Subtotal on Completion	4,000
Grand Total Estimated Impact	**35,800**

Hole Calculations

0.1457625	bbls/ft 12.25" hole
17.49	*bbls of surface hole exact waste*
10	Multiplier Waste 10 times
174.92	bbls of surface hole waste expected
	Historical Estimate
15	bbls surface cement waste expected
0.0602386	bbls/ft 7-7/8" hole size
53.009956	bbls of production hole exact waste
10	Multiplier Waste 10 times
530.09956	bbls of production hole waste expected
	Historical Estimate
15	bbls production hole cement waste expected
735.01	Total bbls of solid waste @ 22.4 ppg when dry
4,127.11	cubic feet of solid waste (5.615 ft3 per bbl)
152.86	cubic yards of solid waste (27 ft3 = 1 yd3)
7.6	Number of 20 yard trucks to use
$2,751.40	Cost $ 18/yd Waste Cost

No NM Gross Receipt Taxes Estimated

Prepared by TEM, 10-27-2007

HDD Mining & Waterwell

MATERIAL SAFETY DATA SHEET

MSDS NO. 10618 **Trade Name:** MAX GEL* **Revision Date:** 12/17/2004

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Trade Name: MAX GEL*
Chemical Family: Mixture
Product Use: Oil well drilling fluid additive.
Emergency Telephone (24 hr.): 281-561-1600

Supplied by:
M-I HDD MINING & WATERWELL
A Business Unit of M-I L.L.C.
P.O. Box 42842
Houston, TX 77242
www.drilling-fluids.com

Telephone Number: 281-561-1512
Contact Person: Joanne Galvan, Product Safety Specialist

Revision Number: 4

HMIS Rating

Health: 1* **Flammability:** 0 **Physical Hazard:** 0 **PPE:** E

HMIS Key: 4=Severe, 3=Serious, 2=Moderate, 1=Slight, 0=Minimal Hazard. *Chronic effects - See Section 11. See Section 8 for Personal Protective Equipment recommendations.

2. HAZARDS IDENTIFICATION

Emergency Overview: Caution! May cause eye, skin, and respiratory tract irritation. Long term inhalation of particulates may cause lung damage. Cancer hazard. Contains crystalline silica which may cause cancer.

Canadian Classification:
UN PIN No: Not regulated **WHMIS Class:** D2A

Physical State: Powder **Odor:** Odorless **Color:** Tan to grey

Potential Health Effects:

Acute Effects

Eye Contact: May cause mechanical irritation
Skin Contact: May cause mechanical irritation. Long term contact can cause skin dryness.
Inhalation: May cause mechanical irritation.
Ingestion: May cause gastric distress, nausea and vomiting if ingested.

Carcinogenicity & Chronic Effects: See Section 11 - Toxicological Information.
Routes of Exposure: Eyes. Dermal (skin) contact. Inhalation.

Target Organs/Medical Conditions Aggravated by Overexposure: Eyes. Skin. Respiratory System.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Ingredient	CAS No.	Wt. %	Comments:
Bentonite	1302-78-9	80 - 95	No comments.
Silica, crystalline, quartz	14808-60-7	2 - 15	No comments.
Gypsum (Calcium sulfate) (CAS 7778-18-9 also applies.)	13397-24-5	0 - 1	No comments.
Silica, crystalline, Tridymite	15468-32-3	0 - 1	No comments.

4. FIRST AID MEASURES

Eye Contact: Promptly wash eyes with lots of water while lifting eye lids. Continue to rinse for at least 15 minutes. Get medical attention if any discomfort continues.

Skin Contact: Wash skin thoroughly with soap and water. Remove contaminated clothing and launder before reuse. Get medical attention if any discomfort continues.

Inhalation: Move person to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Ingestion: Dilute with 2 - 3 glasses of water or milk, if conscious. Never give anything by mouth to an unconscious person. If signs of irritation or toxicity occur seek medical attention.

General Notes: Persons seeking medical attention should carry a copy of this MSDS with them.

5. FIRE FIGHTING MEASURES

Flammable Properties

Flash Point: F (C): NA
Flammable Limits in Air - Lower (%): NA
Flammable Limits in Air - Upper (%): NA
Autoignition Temperature: F (C): NA
Flammability Class: NA
Other Flammable Properties: ND
Extinguishing Media: This material is not combustible. Use extinguishing media appropriate for surrounding fire.

Protection Of Fire-Fighters:

Special Fire-Fighting Procedures: Do not enter fire area without proper personal protective equipment, including NIOSH/MSHA approved self-contained breathing apparatus. Evacuate area and fight fire from a safe distance. Water spray may be used to keep fire-exposed containers cool. Keep water run off out of sewers and waterways.

Hazardous Combustion Products: Not determined.

6. ACCIDENTAL RELEASE MEASURES

Personal Precautions: Use personal protective equipment identified in Section 8.

Spill Procedures: Evacuate surrounding area, if necessary. Wet product may create a slipping hazard. Contain spilled material. Avoid the generation of dust. Sweep, vacuum, or shovel and place into closable container for disposal.

Environmental Precautions: Waste must be disposed of in accordance with federal, state and local laws. Do not allow to enter sewer or surface and subsurface waters.

7. HANDLING AND STORAGE

Handling: Put on appropriate personal protective equipment. Avoid contact with skin and eyes. Avoid generating or breathing dust. Product is slippery if wet. Use only in a well ventilated area. Wash thoroughly after handling.

Storage: Store in dry, well-ventilated area. Keep container closed. Store away from incompatibles. Follow safe warehousing practices regarding palletizing, banding, shrink-wrapping and/or stacking.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Exposure Limits (TLV & PEL - 8H TWA):

Ingredient	CAS No.	Wt. %	ACGIH TLV	OSHA PEL	Other	Notes
Bentonite	1302-78-9	80 - 95	NA	NA	NA	(1)
Silica, crystalline, quartz	14808-60-7	2 - 15	0.05 mg/m^3	see Table Z-3	NIOSH: 0.05 mg/m^3 TWA (10H day/40H wk)	(R)
Gypsum (Calcium sulfate) (CAS 7778-18-9 also applies.)	13397-24-5	0 - 1	10 mg/m^3	15 mg/m^3 (total); 5 mg/m^3 (respirable)	NA	None
Silica, crystalline, Tridymite	15468-32-3	0 - 1	0.05 mg/m^3	see Table Z-3	NA	(R)

Notes
(1) Control as an ACGIH particulate not otherwise specified (PNOS): 10 mg/m^3 (Inhalable); 3 mg/m^3 (Respirable) and an OSHA particulate not otherwise regulated (PNOR): 15 mg/m^3 (Total); 5 mg/m^3 (Respirable).
(R) Respirable fraction (ACGIH);
Table Z-3: PEL for Mineral Dusts containing crystalline silica are 10 mg/m^3 / (%SiO2+2) for quartz and 1/2 the calculated quartz value for cristobalite and tridymite.

Engineering Controls: Use appropriate engineering controls such as, exhaust ventilation and process enclosure, to ensure air contamination and keep workers exposure below the applicable limits.

Personal Protection Equipment

Eye/Face Protection: Dust resistant safety goggles.

Skin Protection: Wear appropriate clothing to prevent repeated or prolonged skin contact. Chemical resistant gloves recommended for prolonged or repeated contact. Use protective gloves made of: Nitrile. Neoprene.

Respiratory Protection: Use at least a NIOSH-approved N95 half-mask disposable or reuseable particulate respirator (dusk mask).
In work environments containing oil mist/aerosol, use at least NIOSH-approved P95 half-mask disposable or reuseable particulate respirator.
For exposure exceeding 10 x PEL use a NIOSH-approved N100 Particulate Respirator.

Refer to Exposure Limits table (Section 8) for component specific respiratory protection recommendations.

General Hygiene Considerations: Work clothes should be washed separately at the end of each work day. Disposable clothing should be discarded, if contaminated with product.

9. PHYSICAL AND CHEMICAL PROPERTIES

Color:	Tan to grey
Odor:	Odorless
Physical State:	Powder
pH:	ND
Specific Gravity (H2O = 1):	2.3 - 2.6
Solubility (Water):	Insoluble
Melting/Freezing Point:	ND
Boiling Point:	ND
Vapor Pressure:	NA
Vapor Density (Air=1):	NA
Evaporation Rate:	NA
Odor Threshold(s):	ND

10. STABILITY AND REACTIVITY

Chemical Stability:	Stable
Conditions to Avoid:	ND
Materials to Avoid:	ND.
Hazardous Decomposition Products:	For thermal decomposition products, see Section 5.
Hazardous Polymerization:	Will not occur

11. TOXICOLOGICAL INFORMATION

Component Toxicological Data: Any adverse component toxicological effects are listed below. If no effects are listed, no such data were found.

Ingredient	Component Toxicological Summary
Silica, crystalline, quartz	Crystalline silica is the most widely occurring of all minerals. The most common form of silica is sand. The International Agency for Research on Cancer (IARC) has designated crystalline silica in the form of quartz or cristobalite a Group 1 (carcinogenic to humans). This designation was based on an increased risk of lung cancer among crystalline silica exposed workers. IARC did note that carcinogenicity of crystalline silica in humans was not detected in all industrial circumstances studied. Further, carcinogenicity of crystalline silica may be dependent on inherent characteristics of the crystalline silica or external factors affecting its biological activity or distribution of polymorphs. (IARC Vol. 68, 1997, p. 41). The National Toxicology Program (NTP) classifies crystalline silica as "reasonably anticipated to cause cancer in humans" (6th Annual Report on Carcinogens, 1991). Long term inhalation of crystalline silica can also result in the lung disease, silicosis. Symptoms of this disease include coughing and shortness of breath. (NJ HSFS, January 1996)

Product Toxicological Information:
Long term inhalation of particulate can cause irritation, inflammation and/or permanent injury to the lungs. Illnesses such as pneumoconiosis ("dusty lung"), pulmonary fibrosis, chronic bronchitis, emphysema and bronchial asthma may develop.

12. ECOLOGICAL INFORMATION

Product Ecotoxicity Data:	Contact M-I Environmental Affairs Department for available product ecotoxicity data.
Biodegration:	ND
Bioaccumulation:	ND
Octanol/Water Partition Coefficient:	ND

13. DISPOSAL CONSIDERATIONS

Waste Classification: ND

Waste Management: Under U.S. Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA), it is the responsibility of the user to determine at the time of disposal, whether the product meets RCRA criteria for the hazardous waste. This is because product uses, transformations, mixtures, processes, etc., may render the resulting materials hazardous. Empty containers retain residues. All labeled precautions must be observed.

Disposal Method: Recover and reclaim or recycle, if practical. Should this product become a waste, dispose of in a permitted industrial landfill. Ensure that the containers are empty by the RCRA criteria prior to disposal in a permitted industrial landfill.

14. TRANSPORT INFORMATION

U.S. DOT Shipping Description:	Not regulated for transportation by DOT, TDG, IMDG, ICAO/IATA.
Canada TDG Shipping Description:	Not regulated.
UN PIN No:	Not regulated
IMDG Shipping Description:	Not regulated.
ICAO/IATA Shipping Description:	Not regulated.

15. REGULATORY INFORMATION

U.S. Federal and State Regulations

SARA 311/312 Hazard Catagories: Delayed (chronic) health hazard.

SARA 302/304, 313; CERCLA RQ, California Proposition 65: Note: If no components are listed below, this product is not subject to the referenced SARA and CERCLA regulations and is not known to contain a Proposition 65 listed chemical at a level that is expected to pose a significant risk under anticipated use conditions.

Ingredient	SARA 302 / TPQs	SARA 313	CERCLA RQ	CA 65 Cancer	CA 65 Dev. Tox.	CA 65 Repro. F	CA 65 Repro. M
Silica, crystalline, quartz	---	---	---	X	---	---	---
Silica, crystalline, Tridymite	---	---	---	X	---	---	---

International Chemical Inventories

Australia AICS - Components are listed or exempt from listing.
Canada DSL - Components are listed or exempt from listing.
China Inventory - Components are listed or exempt from listing.
European Union EINECS - Components are listed or exempt from listing.
Japan METI ENCS - Components are listed or exempt from listing.
Korea TCCL ECL - Components are listed or exempt from listing.
Philippine PICCS - Components are listed or exempt from listing.
U.S. TSCA - Components are listed or exempt from listing.
U.S. TSCA - No components are subject to TSCA 12(b) export notification requirements.

Canadian Classification:

Controlled Products Regulations Statement: This product has been classified in accordance with the hazard criteria of the CPR and the MSDS contains all the information required by the CPR.

16. OTHER INFORMATION

The following sections have been revised: 1, 2, 3, 16

NA - Not Applicable, ND - Not Determined.

*A mark of M-I L.L.C.

Disclaimer:

MSDS furnished independent of product sale. While every effort has been made to accurately describe this product, some of the data are obtained from sources beyond our direct supervision. We can not make any assertions as to its reliability or completeness; therefore, user may rely on it only at user's risk. We have made no effort to censor or conceal deleterious aspects of this product. Since we cannot anticipate or control the conditions under which this information and product may be used, we make no guartantee that the precautions we have suggested will be adequate for all individuals and/or situations. It is the obligation of each user of this product to comply with the requirements of all applicable laws regarding use and disposal of this product. Additional information will be furnished upon request to assist the user; however, no warranty, either expressed or implied, nor liability of any nature with respect to this product or to the data herein is made or incurred hereunder.

SAFETY DATA SHEET
POLY-PLUS (LIQUID)

1 IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND COMPANY/UNDERTAKING

PRODUCT NAME	POLY-PLUS (LIQUID)
APPLICATION	Flocculant
SUPPLIER	M-I Drilling Fluids UK Ltd, Pocra Quay, Footdee, Aberdeen. AB11 5DQ T -44 (0)1224-584336 F -44 (0)1224-576119
EMERGENCY TELEPHONE	+44(0)208 762 8322

2 COMPOSITION/INFORMATION ON INGREDIENTS

Name	EC No.	CAS-No.	Content	Classification
DISTILLATES (PETROLEUM), HYDROTREATED LIGHT; KEROSINE-UNSPECIFIED			30-60%	-
SYNTHETIC COPOLYMER			30-60%	-
WATER			30-60%	-

The Full Text for all R-Phrases are Displayed in Section 16

COMPOSITION COMMENTS

The Data Shown is in accordance with the latest EC Directives.

3 HAZARDS IDENTIFICATION

Not regarded as a health or environmental hazard under current legislation.

4 FIRST-AID MEASURES

INHALATION

Move the exposed person to fresh air at once. Keep the affected person warm and at rest. Get prompt medical attention.

INGESTION

Do not induce vomiting. Rinse mouth thoroughly with water and give large amounts of milk or water to people not unconscious. Get medical attention immediately!

SKIN CONTACT

Remove contaminated clothing immediately and wash skin with soap and water. Get medical attention if irritation persists after washing.

EYE CONTACT

Promptly wash eyes with plenty of water while lifting the eye lids. Continue to rinse for at least 15 minutes. Get medical attention if any discomfort continues.

5 FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA

Water spray, foam, dry powder or carbon dioxide.

SPECIAL FIRE FIGHTING PROCEDURES

Use water to keep fire exposed containers cool and disperse vapours.

SPECIFIC HAZARDS

Fire or high temperatures create: Oxides of: Carbon. and Nitrogen.

PROTECTIVE MEASURES IN FIRE

Self contained breathing apparatus and full protective clothing must be worn in case of fire.

6 ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS

Wear protective clothing as described in Section 8 of this safety data sheet.

ENVIRONMENTAL PRECAUTIONS

Do not allow to enter drains, sewers or watercourses.

SPILL CLEAN UP METHODS

Stop leak if possible without risk. Absorb spillage with non-combustible, absorbent material. Shovel into dry containers. Cover and move the containers. Flush the area with water. May be slippery when wet.

7 HANDLING AND STORAGE

USAGE PRECAUTIONS

Do not use contact lenses. Avoid spilling, skin and eye contact. Provide good ventilation. Avoid inhalation of vapours.

STORAGE PRECAUTIONS

Store in tightly closed original container in a cool, dry well-ventilated place.

8 EXPOSURE CONTROLS/PERSONAL PROTECTION

Name	Std	LT - ppm	LT - mg/m3	ST - ppm	ST - mg/m3
SYNTHETIC COPOLYMER	WEL		4 mg/m3 resp. dust		
DISTILLATES (PETROLEUM), HYDROTREATED LIGHT; KEROSINE-UNSPECIFIED	WEL		5 mg/m3		10 mg/m3

INGREDIENT COMMENTS

WEL (LT. EXP) = 5mg/m3 and (ST. EXP) = 10mg/m3. Oil mist, mineral workplace exposure limits are currently under review by legislative authorities. Workplace exposure level (WEL) standards applicable to highly refined mineral oils are provided as guidance limits only. Because this product is a liquid, the dust-related WEL'S (workplace exposure limits) for the components do not apply.

PROTECTIVE EQUIPMENT

ENGINEERING MEASURES

Provide adequate general and local exhaust ventilation.

RESPIRATORY EQUIPMENT

Respiratory protection must be used if air contamination exceeds acceptable level. Wear mask supplied with: Gas cartridge suitable for organic substances.

HAND PROTECTION

Use protective gloves made of: Impermeable material. Rubber, neoprene or PVC.

EYE PROTECTION

If risk of splashing, wear safety goggles or face shield.

OTHER PROTECTION

Wear appropriate clothing to prevent any possibility of liquid contact and repeated or prolonged vapour contact. Provide eyewash station.

9 PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE	Viscous liquid		
COLOUR	Milky.		
ODOUR	Asphaltic		
VAPOUR PRESSURE	0.002 mmHg @ 20 °c	pH-VALUE, CONC. SOLUTION	6-8 @ 5g/l for product series
VISCOSITY	>7 cSt @ 20°C	FLASH POINT (°C)	>212°F (100°C)

AUTO IGNITION TEMPERATURE (°C>392°F (200°C)
)

10 STABILITY AND REACTIVITY

STABILITY

Stable under normal temperature conditions.

CONDITIONS TO AVOID

Avoid extremes of temperature.

HAZARDOUS POLYMERISATION

Will not polymerise.

MATERIALS TO AVOID

Strong oxidising substances.

HAZARDOUS DECOMPOSITION PRODUCTS

Fire or high temperatures create: Oxides of: Carbon. and Nitrogen.

11 TOXICOLOGICAL INFORMATION

TOXIC DOSE 1 - LD 50 > 5000 mg/kg (oral rat)

INHALATION

Gas or vapour may irritate respiratory system.

INGESTION

May cause discomfort if swallowed.

SKIN CONTACT

Irritating to skin. Repeated exposure may cause skin dryness or cracking.

EYE CONTACT

Spray and vapour in the eyes may cause irritation and smarting.

12 ECOLOGICAL INFORMATION

ECOTOXICITY

Contact M-I Swaco's QHSE Department for ecological information.

13 DISPOSAL CONSIDERATIONS

DISPOSAL METHODS

Recover and reclaim or recycle, if practical. Dispose of waste and residues in accordance with local authority requirements.

14 TRANSPORT INFORMATION

GENERAL The product is not covered by international regulation on the transport of dangerous goods (IMDG, IATA, ADR/RID).

15 REGULATORY INFORMATION

RISK PHRASES

NC Not classified.

SAFETY PHRASES

NC Not classified.

UK REGULATORY REFERENCES

Chemicals (Hazard Information & Packaging) Regulations. The Control of Substances Hazardous to Health Regulations

EU DIRECTIVES

Dangerous Substance Directive 67/548/EEC. Dangerous Preparations Directive 1999/45/EEC.

GUIDANCE NOTES

Workplace Exposure Limits EH40.

16 OTHER INFORMATION

GENERAL INFORMATION

HMIS Health - 1 HMIS Flammability - 1 HMIS Physical Hazard - 1 J - Splash Goggles, Gloves, Synthetic Apron, Dust and Vapor Respirator.

INFORMATION SOURCES

Material Safety Data Sheet, Misc. manufacturers. Sax's Dangerous Properties of Industrial Materials, 10th ed., Lewis, R.J. Sr., (ed.).

REVISION COMMENTS

The following sections have been revised: 1, 2, 4, 5, 6, 7, 8, 9, 12, 13, 14, 15 and 16. Revised by Bill Cameron

ISSUED BY

Sam Hoskin

REVISION DATE 25-10-05

REV. NO./REPL. SDS GENERATED 5

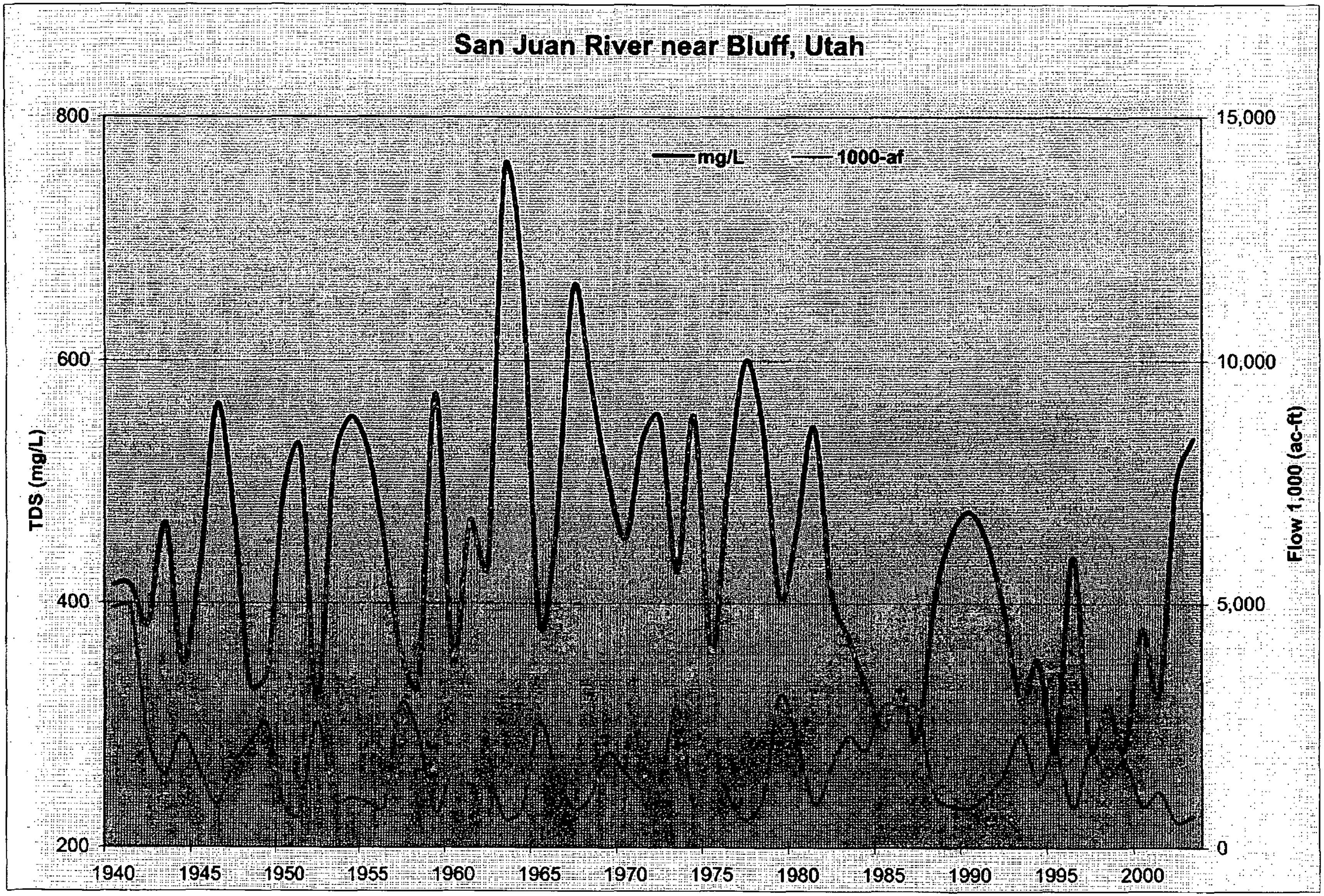
SDS NO. 10086

RISK PHRASES IN FULL

NC Not classified.

DISCLAIMER

MSDS furnished independent of product sale. While every effort has been made to accurately describe this product, some of the data are obtained from sources beyond our direct supervision. We cannot make any assertions as to its reliability or completeness; therefore, user may rely only at user's risk. We have made no effort to censor or conceal deleterious aspects of this product. Since we cannot anticipate or control the conditions under which this information and product may be used, we make no guarantee that the precautions we have suggested will be adequate for all individuals and/or situations. It is the obligation of each user of this product to comply with the requirements of all apprlicable laws regarding use and disposal of this product. Additional information will be furnished upon request to assist the user; however, no warranty, either expressed or implied, nor liability of any nature with respect to this product or to the data herein is made or incurred hereunder.



Bureau of Reclamation Data

Soil Science Society of
America Journal -

Waste Burial in Arid Environments—Application of Information From a Field Laboratory in the Mojave Desert, Southern Nevada

U.S. Department of the Interior—U.S. Geological Survey

Accumulation and management of waste is a pressing problem facing the United States today. Improper disposal of hazardous wastes poses a threat to public health and environmental quality. As arid sites increasingly are being sought for disposal of the Nation's radioactive and other hazardous wastes, concern about the potential effect of contaminants on water resources in the arid western United States is being raised. In addition, volumes of locally generated municipal and industrial wastes are increasing because of rapid population growth and industrialization of the region.

The suitability of a waste-burial site or landfill is a function of the hydrologic processes that control the near-surface water balance. Precipitation that infiltrates into the surface of a burial trench and does not return to the atmosphere by evapotranspiration from the soil and plants can percolate downward and come in contact with buried waste. Water that contacts the waste can enhance the release of contaminants for subsequent transport by liquid water, water vapor, or other gases.

A prevalent assumption is that little or no precipitation will percolate to buried wastes at an arid site. Thick unsaturated zones, which are common to arid regions, also are thought to slow water movement and minimize the risk of waste migration to the underlying water table. On the basis of these assumptions, reliance is commonly placed on the natural system to isolate contaminants at waste-burial sites in the arid West.

Few data have been available to test the validity of assumptions about the natural soil-water flow systems at arid sites, and even less is known about how the construction of a waste-burial facility alters the natural environment of the site. The lack of data is the result of (1) technical complexity of hydraulic characterization of the dry, stony soils and (2) insufficient field studies that account for the extreme temporal and spatial variations in precipitation, vegetation, and soils in arid regions. In 1976, the U.S. Geological Survey (USGS) began a long-term study at a waste-burial site in the Mojave Desert near Beatty, Nev., to collect the necessary data and evaluate untested assumptions. This fact sheet summarizes the findings of investigations at the site and discusses how this information is important to issues of waste burial in an arid environment.

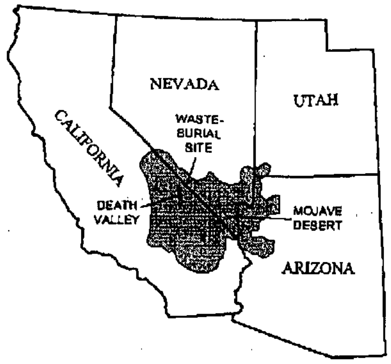


Figure 1. Location of waste-burial site, Death Valley, and Mojave Desert of southwestern United States.

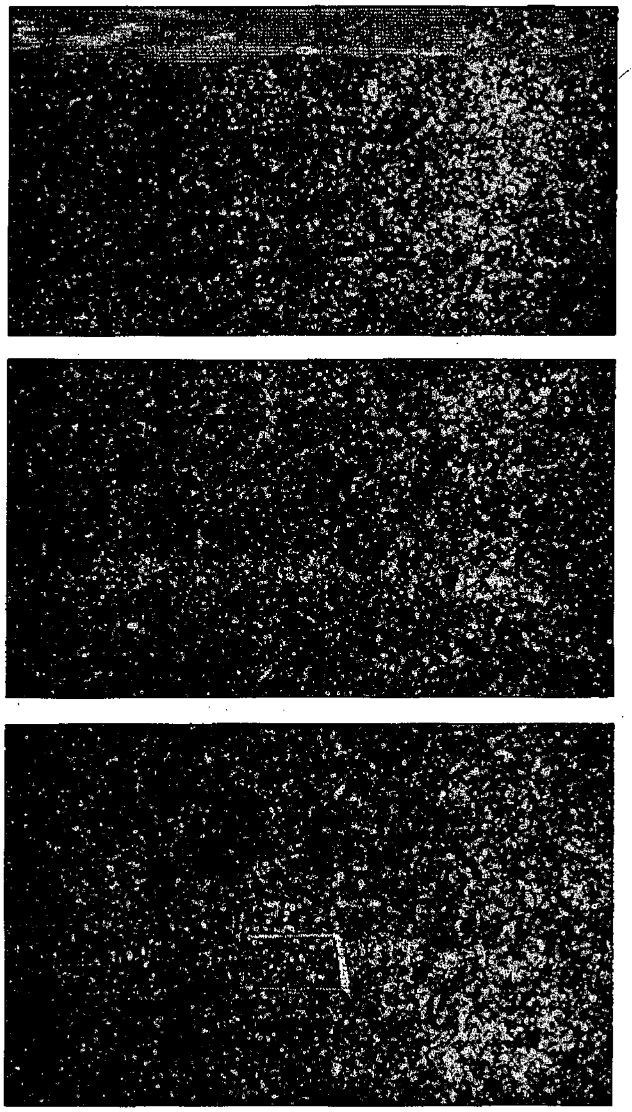


Figure 2. Undisturbed, vegetated area near waste-burial site, October 1991 (*A*); low-level radioactive waste burial trench (*B*); and nonvegetated surface of backfilled waste-burial trench with identifying monument, June 1988 (*C*).

Mojave Desert Waste-Burial Site

The waste-burial site, 30 miles east of Death Valley National Park, is in one of the most arid parts of the United States (fig. 1). Precipitation in the area averages about 4 inches per year. The water table is about 360 feet below land surface. Vegetation in the area is sparse (fig. 2*A*). Burial trenches at the site have been used for disposal of low-level radioactive waste (1962-92) and hazardous-chemical waste (1970-present). Burial-trench construction includes excavation of native soil, emplacement of waste, and backfilling with previously stockpiled soil (fig. 2*B*). The surfaces of completed burial trenches and perimeter areas are kept free of vegetation (fig. 2*C*). Regulations governing burial of low-level radioactive waste do not require that trenches be lined with impervious materials. Prior to 1988, linings were not required for chemical-waste trenches. As a result, only the most recent chemical-waste trench at the site is lined.

Field Laboratory Established

Recognizing the need for long-term data collection, the USGS established a study area adjacent to the waste-burial site through agreements with the Bureau of Land Management and the State of Nevada. This 40-acre area serves as a field laboratory for long-term data collection and the study of hydrologic processes under natural-site and waste-burial conditions.

Lessons Learned to Date

Early (1962) evaluation of the general hydrologic conditions at and near the waste-burial site suggested that low average annual precipitation and high average annual evapotranspiration would prevent water from percolating downward more than 1 or 2 feet below land surface. This assumption, however, did not consider the extreme annual and seasonal variations in a desert climate. During 1985-92, annual precipitation measured at the USGS study site ranged from 0.55 to 6.51 inches and monthly precipitation ranged from 0 to 2.34 inches. Monthly average temperature ranged from 38 to 92 degrees Fahrenheit. Most of the precipitation falls during the cool winter months when evaporative demands are low (fig. 3). Initial water-balance modeling by the USGS demonstrated that, under particular climate and soil-moisture conditions, the potential for deep percolation does exist, in spite of high annual evaporative demands (Nichols, 1987).

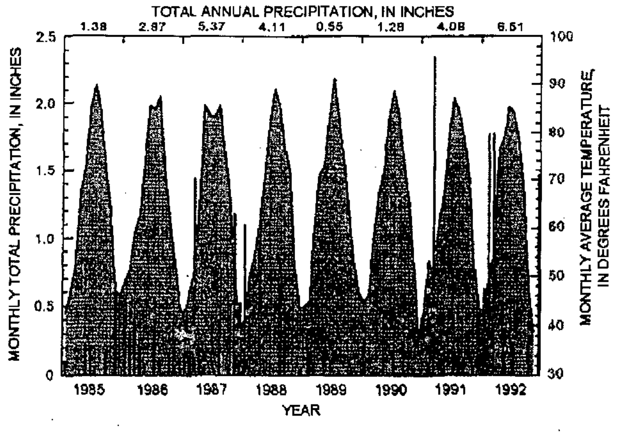


Figure 3. Annual and monthly total precipitation and monthly average temperature measured at U.S. Geological Survey field laboratory during 1985-92.

Field investigations to define the rates and directions of water movement through the deep unsaturated zone beneath an undisturbed, vegetated area began in the early 1980's and continue today. A study of chloride concentrations in the unsaturated zone indicates that deep percolation of water was limited to the upper 30 feet during the past 16,000 to 33,000 years (Prudic, 1994a). To monitor present-day flow processes, an instrument shaft was installed that allows access for operation of electronic devices to a depth of 45 feet (fig. 4; Fischer, 1992). Additional instrumentation has been installed to study flow processes throughout the unsaturated zone (Prudic, in press). Meteorological data are collected by an automated weather station (Wood and Andraski, 1995).

Water movement in the unsaturated zone is complex. Several variables—water content, water potential, humidity, and temperature—must be monitored to define rates and

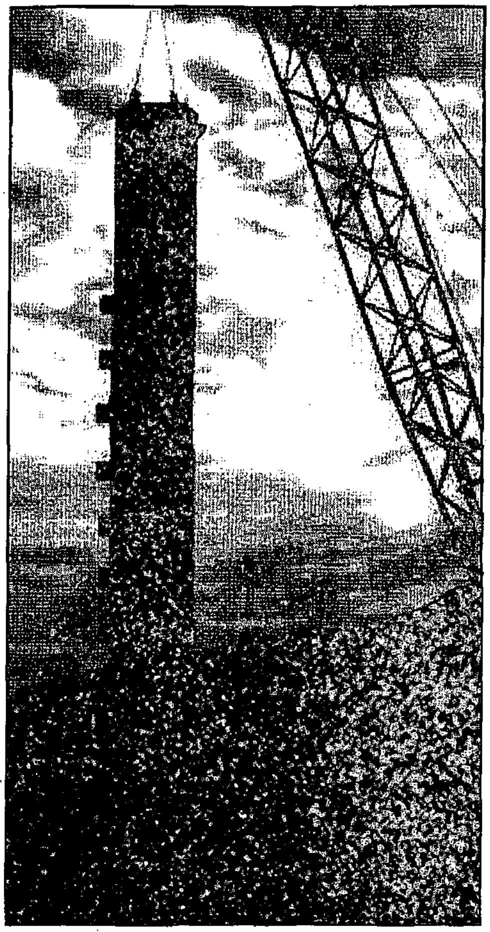


Figure 4. Installation of vertical shaft used for soil-moisture monitoring in upper 45 feet of unsaturated zone beneath undisturbed, vegetated area. Photograph by David S. Morgan, U.S. Geological Survey, August 1983.

directions of water movement. Water content indicates how much water is held in the soil. Water potential indicates how tightly the water is held by the soil matrix. Water moves through soil in liquid and vapor form, and the two forms can move simultaneously as a consequence of water-potential, humidity, and temperature gradients in the soil.

Ongoing investigations at the undisturbed, vegetated site indicate that the natural soil-plant-water system effectively limits the potential for deep percolation. During more than 5 years of monitoring, downward percolation was limited to the upper 3 feet of soil (Fischer, 1992; Andraski, 1994). Between the depths of 40 and 160 feet, water movement, as liquid and as vapor, is consistently upward. Preliminary evidence indicates that upward flow of water vapor through the thick unsaturated zone may potentially serve as a contaminant-release pathway (Prudic, 1994b; Prudic and Striegl, 1994).

Little is known about how, or to what degree, features of the natural system may be altered by installation of a disposal facility. Investigations to determine the effects of disturbance on soil properties and the long-term soil-water balance began in 1987. Two nonvegetated test trenches and an area of bare soil are monitored (fig. 5; Andraski, 1990). The effects of disturbance are evaluated in terms of observed differences between data collected at the undisturbed, vegetated site and data collected at the disturbed sites.

Accurate characterization of hydraulic properties is critical to calculations of water movement through soil. Characterization data normally are measured to a minimum water-potential value referred to as the permanent wilting point for crops. Below this value, water is held so tightly by the soil matrix that a crop plant cannot extract the water and will wilt and die. Data collected by the USGS at the Mojave Desert site, however, show that this lower limit is not adequate for nonirrigated, desert soils and plants, nor is it appropriate for the extremely dry backfill material produced by trench construction. Thus, characterization of hydraulic properties at the site has been extended to include data measured over a soil-moisture range that is representative of seldom-studied arid conditions (Andraski, in press).

Backfilling with very dry material will, at least initially, increase the importance of vapor flow as a potential transport mechanism in the trench fill (Andraski, in press). These initial dry conditions can change substantially, however, in response to subsequent precipitation and a lack of vegetation. On an annual basis, no water accumulates in the vegetated soil because water is removed by the plants (fig. 6). In contrast, even under conditions of extreme aridity, water accumulates in the nonvegetated soil and test trenches. Water that has accumulated at the three disturbed sites is continuing to percolate downward (Andraski, 1994). Thus, the construction of waste-burial trenches and removal of native vegetation markedly alters the natural site environment and may increase the potential for release of contaminants (Gee and others, 1994). Surprisingly, such changes typically are not considered in the evaluation of a proposed waste site and may not be considered in management of existing sites.

Well-Informed Decisions Needed

Regulations governing the licensing of solid-waste landfills and hazardous-waste sites require an assessment of the potential for deep percolation of water through buried waste before disposal operations can begin. Numerical models commonly are relied on for this assessment. For a proposed low-level radioactive waste site, 1 year of preoperational monitoring of site conditions also is required. Thus, data used in numerical

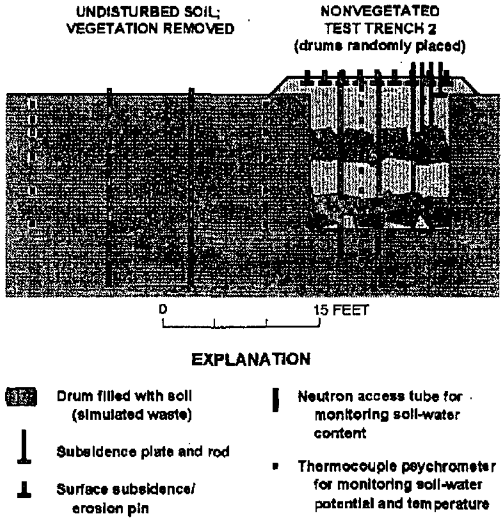


Figure 5. Schematic diagram of instrumentation used to determine effects of vegetation removal and trench construction on water movement through unsaturated zone. Subsidence and erosion are monitored to determine changes in structural integrity of test trenches. In second test trench (not shown), soil-filled drums are stacked in orderly fashion.

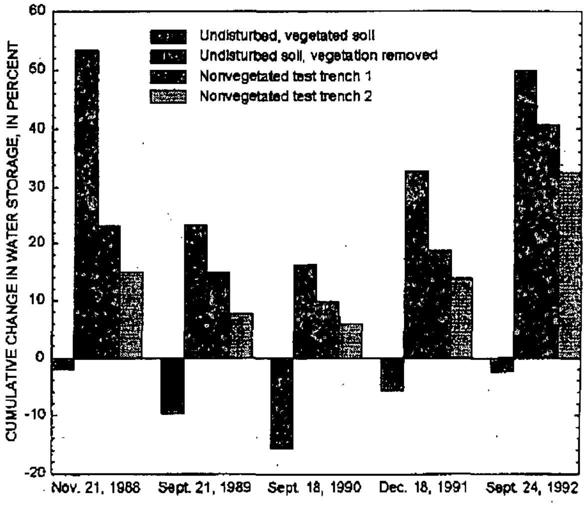


Figure 6. Cumulative changes in quantity of water being held in uppermost 4 feet at four monitoring sites: undisturbed, vegetated soil; undisturbed soil where native vegetation was removed; and two nonvegetated test trenches. Values are based on measurements during first 5 years following vegetation removal and trench construction at disturbed study site in October 1987.

analysis of a proposed waste-burial site may be based solely on hydraulic information available in the literature, or the data may include some site-specific information, which typically is limited to natural conditions and a short period of time. This approach is of particular concern for waste sites in arid regions because, compared with the amount of information available for more humid sites, the amount of hydraulic-property data and long-term field data for arid sites is negligible. In addition, although significant advances have been made in the development of soil-water flow models, the lack of long-term field data has resulted in these models remaining largely untested as to how well they represent flow systems at arid sites.

Long-Term Benchmark Information

Ongoing work by the USGS at the Mojave Desert field laboratory continues to provide long-term, quantitative "benchmark" information about the hydraulic characteristics, water movement, and the potential for release of contaminants through the unsaturated zone in an arid environment. Monitoring methods developed and tested at the Mojave Desert site have helped others in their study and evaluation of waste-isolation processes at the Nevada Test Site, and at proposed waste sites in Texas and California. The U.S. Nuclear Regulatory Commission and Pacific Northwest Laboratory have chosen the Mojave Desert waste site for use in numerical modeling of infiltration because it is representative of burial operations in an arid environment. Data collected at the USGS field laboratory are being provided for this effort. The National Academy of Sciences also has used information from the site in the evaluation of issues related to waste disposal in an arid environment.

Because of the potentially harmful effect of improper waste disposal on water resources in the arid West, comprehensive laboratory and field studies are critical to identifying likely contaminant-release pathways and the potential for waste migration at arid sites. However, the quandary for those charged with assessment of the suitability of potential disposal sites is that site characterization and evaluation must be accomplished in a relatively short period of time—only 1 to 2 years.

Data collection at the Mojave Desert field laboratory provides the needed long-term benchmark against which short-term data from proposed arid sites can be compared. The data base and monitoring facilities developed at the field laboratory also provide an excellent foundation upon which to build collaborative efforts with universities and local, State, and other Federal agencies to further the study and understanding of hydrologic processes in an arid environment.

—*B.J. Andraski, David E. Prudic, and William D. Nichols*

References Cited

Andraski, B.J., 1990, Water movement and trench stability at a simulated arid burial site for low-level radioactive waste near Beatty, Nevada: LaGrange Park, Ill., American Nuclear Society, Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, Nev., September 1989, Proceedings, p. 166-173.

——1994, Disturbance effects on soil properties and water balance at a low-level radioactive waste site, Amargosa Desert, Nevada [abs.]: American Society of Agronomy, Agronomy Abstracts, v. 86, p. 227.

——in press, Properties and variability of soil and trench fill at an arid waste-burial site: Soil Science Society of America Journal.

Fischer, J.M., 1992, Sediment properties and water movement through shallow unsaturated alluvium at an arid site for disposal of low-level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 92-4032, 48 p.

Gee, G.W., Wierenga, P.J., Andraski., B.J., Young, M.H., Fayer, M.J., and Rockhold, M.L., 1994, Variations in water balance and recharge potential at three western desert sites: Soil Science Society of America Journal, v. 58, no. 1, p. 63-72.

Nichols, W.D., 1987, Geohydrology of the unsaturated zone at the burial site for low-level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Water-Supply Paper 2312, 57 p.

Prudic, D.E., 1994a, Estimates of percolation rates and ages of water in unsaturated sediments at two Mojave Desert sites, California-Nevada: U.S. Geological Survey Water-Resources Investigations Report 94-4160, 19 p.

——1994b, Effects of temperature on water movement at the arid disposal site for low-level radioactive wastes near Beatty, Nevada [abs.]: Geological Society of America, Abstracts with Programs, v. 26, no. 7, p. 391.

—— in press, Water-vapor movement through unsaturated alluvium in Amargosa Desert near Beatty, Nevada—Current understanding and continuing studies, *in* Stevens, P.R., and Nicholson, T., eds., Conference on Disposal of Low-Level Radioactive Waste, Reston, Va., May 1993: U.S. Geological Survey Water-Resources Investigations Report 95-4015.

Prudic, D.E., and Striegl, R.G., 1994, Water and carbon dioxide movement through unsaturated alluvium near an arid disposal site for low-level radioactive waste, Beatty, Nevada [abs.]: Eos, American Geophysical Union Transactions, v. 75, no. 16, p. 161.

Wood, J.L., and Andraski, B.J., 1995, Selected meteorological data for an arid site near Beatty, Nye County, Nevada, calendar years 1990 and 1991: U.S. Geological Survey Open-File Report 94-489, 49 p.

For more information about the Mojave Desert studies, contact:

Brian J. Andraski
U.S. Geological Survey
333 W. Nye Lane
Carson City, NV 89706
(702) 887-7600, ext. 7636
andraski@usgs.gov

American
Petroleum
Institute

gri

SOIL & GROUNDWATER RESEARCH BULLETIN

A summary of research results from the American Petroleum Institute & GRI.

June 2000 No. 9

NON-AQUEOUS PHASE LIQUID (NAPL) MOBILITY LIMITS IN SOIL

EDWARD J. BROST • GEORGE E. DEVAULL • EQUILON ENTERPRISES LLC • WESTHOLLOW TECHNOLOGY CENTER • HOUSTON, TEXAS

ABSTRACT

Conservative screening concentrations for non-aqueous phase liquids (NAPL) that could be considered *immobile* in unsaturated zone soils are presented. Total concentrations measured at a crude oil or petroleum product release site (using total petroleum hydrocarbon [TPH] or a similar analysis method) can be compared to the screening concentrations to determine the potential for NAPL to migrate in soil. The screening values are based on an analysis of published data for a range of soil texture classifications and a range of NAPL density from 0.7 to 1.5 g/cm3.

The paper includes summary tables and histograms of residual NAPL void fraction, Sr, as a function of soil type. These provide a basis for selecting conservative values used in calculating screening concentrations for immobile NAPL. For example, in medium to coarse sands, with Sr = 0.06 cm3-oil/cm3-void, one would expect that NAPL would be immobile in 90% of samples with equivalent NAPL concentration levels for this soil type.

Measured concentrations of immobile NAPL reported in the literature vary considerably with soil type, chemical composition, and the measurement method. The proposed screening levels are conservative (lower range) estimates within the range of measured residual NAPL concentration values. Higher values could be applicable in many cases, both in unsaturated and saturated soil conditions.

This paper addresses immobile bulk NAPL in soils at concentrations up to the threshold of mobility. This document does not address the movement and flow of NAPL, the dissolution of NAPL chemical into soil pore water solution, nor NAPL volatilization into soil pore air. Transport by these mechanisms may be estimated using other published and accepted methods.

INTRODUCTION

Organic chemicals released to soil may migrate as vapors in soil gas, as dissolved constituents in soil pore water, or as a bulk phase liquid which is immiscible in water. Assessment of potential migration pathways for chemical releases into the environment are discussed in several related documents (USEPA 1996, 1991; ASTM E1739, PS104-98). These migration pathways are important in a general risk-based site assessment. This paper is confined to discussion of the mobility of non-aqueous phase liquids, either as pure chemicals or as chemical mixtures.

Many organic chemicals, including hydrocarbons, are nearly immiscible in water. Release of a non-aqueous phase liquid (NAPL) to near-surface unsaturated soil can result in downward gravity-driven migration of the NAPL towards the water table. At the water table, light nonaqueous phase liquids (LNAPL), including petroleum, which are less dense than water, will mound and spread horizontally. LNAPL may also move with the groundwater gradient. Dense nonaqueous phase liquids (DNAPL) will migrate downward, mound, and spread horizontally, until a path of least resistance further downward into the saturated region is found. This could be when the accumulation is great enough to exceed the capillary entry pressure into the saturated zone, or when the DNAPL mound reaches a region of high vertical permeability, or when it reaches a fracture.

The volume of mobile NAPL depletes as immobile residual chemical is left behind through the soil column in which the NAPL is descending. NAPL migration may be limited by this depletion, or by physical barriers, such as low permeability layers. Our intent in this paper is to determine conservative NAPL concentrations in unsaturated soil, below which the NAPL will be immobile. By "conservative" we mean under-predicting the concentration at which mobility would actually occur.

PRESENCE OF A NAPL IN SOIL

For a pure chemical, NAPL will not be present at concentrations below the soil saturation limit (USEPA, 1996; ASTM E1739, PS104-98), defined as:

$$C_{sat,soil,i} = S_i \cdot \left(\frac{\theta_w + K_{oc,i} \cdot f_{oc} \cdot \rho_s + H_i \cdot \theta_a}{\rho_s} \right) \qquad [1]$$

with

$C_{sat,soil,i}$	soil saturation limit for chemical i (mg/kg)
S_i	*pure chemical aqueous solubility limit for* chemical i (mg/L)
θ_w	soil water content (cm^3-water/cm^3-soil)

$K_{oc,i}$	organic carbon/water partition coefficient for chemical i (L-water/kg-oc)
f_{oc}	mass fraction of organic carbon in soil (g-oc/g-soil)
ρ_s	dry soil bulk density (g/cm^3)
H_i	Henry's law coefficient for chemical i (cm^3-water/cm^3-air)
θ_a	soil air content (cm^3-air/cm^3-soil)

For a pure chemical, $C_{sat,soil}$ is a value above which the chemical is present in soil pore water at its aqueous solubility limit, and is present in soil pore air at its saturated vapor concentration. Equilibrium partitioning of the chemical between soil (sorbed), pore water, and pore vapors at concentrations below $C_{sat,soil,i}$ is presumed.

For mixtures of miscible chemicals that are fractionally soluble in water, including petroleum, the concentration at which NAPL will be present is a function of the mixture composition. The soil saturation limit for the mixture, using methods presented in Johnson *et al.*, (1990), Mott (1995), and Mariner (1997), is:

$$\sum_{i=1}^{N}\left(\frac{C_{sat,soil,T}\cdot\chi_i\cdot\rho_s}{S_i\cdot(\theta_w+K_{oc,i}\cdot f_{oc}\cdot\rho_s+H_i\cdot\theta_a)}\right)=1 \qquad [2]$$

with

$C_{sat,soil,T}$	soil saturation limit for the NAPL mixture, total concentration (mg/kg)
χ_i	mass fraction of each chemical i in the NAPL mixture (kg/kg)
N	the number of individual chemicals in the mixture

Note that Eq. [2] simplifies to Eq. [1] for a single chemical. The component concentration of a chemical i at the soil saturation limit in a mixture is ($C_{sat,soil,T}\cdot\chi_i$). The soil saturation limit calculated for a pure chemical, in every case, will be greater than the chemical component concentration ($C_{sat,soil,T}\cdot\chi_i$) calculated for a mixture, that is:

$$C_{sat\text{-}soil,i}\geq C_{sat,soil,T}\cdot\chi_i$$

Eq. [1] overstates $C_{sat\text{-}soil,i}$ for components in a mixture because it does not consider effective vapor pressure and solubility limits (Rault's law) for the mixture components (USEPA, 1996). The soil saturation limits for mixtures (and pure chemicals) tabulated in this paper were calculated with computer codes included with DeVaull *et. al.*, (1999). This method is consistent with the references cited above.

RESIDUAL NAPL CONCENTRATION

Our intent in this paper is to define a soil concentration, $C_{res,soil}$, below which the NAPL, if present, will not migrate due to convection or gravity. This refers to a pure chemical concentration or a total chemical mixture concentration, as applicable. This residual NAPL concentration in soil is specified as:

$$C_{res,soil}=\left(\frac{\theta_o\cdot\rho_o}{\rho_s}\right)\cdot 10^6\ \frac{mg}{kg} \qquad [3]$$

with

$$\theta_o=S_r\cdot\theta_T$$

and

$C_{res,soil}$	residual NAPL concentration in soil (mg-res/kg-soil)
θ_o	residual non-aqueous phase volume fraction (cm^3-res/cm^3-soil)
ρ_o	density of chemical residual non-aqueous phase liquid (g-res/cm^3-res)
ρ_s	dry soil bulk density (g-soil/cm^3-soil)
θ_T	soil porosity (cm^3-void/cm^3-soil)
S_r	fraction of residual non-aqueous phase filled void (cm^3-res/cm^3-void)

Residual non-aqueous phase volume fraction (θ_o, or retention capacity) is similarly defined by Cohen and Mercer (1990) and Zytner *et. al.*, (1993), but in dimensional units of (cm^3-res/L-soil). The value of $C_{res,soil}$ is generally much larger than the soil saturation limit, $C_{sat,soil}$. Eq. [3] includes only the residual NAPL volume. Additional chemical mass within the soil matrix is contained in soil pore water and soil pore air, and is sorbed onto soil. These volumes may be included in a slightly more complicated equation consistent with the assumptions in Eqs. [1] and [2]; these terms may generally be neglected. This leaves the residual NAPL concentration in soil, $C_{res,soil}$, directly related to the residual NAPL volume fraction in soil, θ_o, or the residual NAPL fraction in the voids, S_r.

Below the residual NAPL concentration in soil, $C_{res,soil}$, capillary retention forces are greater than the gravitational forces which tend to mobilize the NAPL. These capillary forces (in this context, including surface tension effects, van der Waals, and Coulombic forces), particularly at low residual non-aqueous phase levels, may exceed the gravitational force by several orders of magnitude. The residual NAPL concentration in soil, $C_{res,soil}$, may depend on NAPL properties including liquid density, surface tension, and viscosity. It also may depend on soil properties including porosity, organic carbon fraction, moisture content, relative permeability, moisture wetting history, and soil heterogeneity.

For concentrations greater than the threshold $C_{res,soil}$ level, capillary retention forces are less than the gravitational forces, and the NAPL is mobile. Movement of NAPL in soil is beyond the scope of this paper. It is covered in a number of references, however, including Charbeneau (1999), Huntley and Beckett (1999), USEPA (1991), Cohen and Mercer (1990), and Pfannkuch (1983).

This paper describes the determination of screening values for NAPL immobility in soil. Screening values are expressed as the residual NAPL concentration in soil, $C_{res\text{-}soil}$, the non-aqueous phase volume fraction in soil, θ_o, and the residual non-aqueous phase fraction in the soil voids. Our study included a review of existing measured data on residual NAPL concentration in soil, published empirical models, and methods of field measurement.

The calculated value, $C_{sat,soil}$, as previously defined in Eqs. [1] and [2] predicts the presence or absence of a residual NAPL. Since a NAPL must be present to be mobile, it also represents a conceivable screening concentration for NAPL mobility. However, observed residual NAPL concentrations based either on laboratory measurement or physical removal of NAPL from impacted sites are typically several *orders of magnitude* higher

Table 1. Residual NAPL Concentration in Soil Compared to Soil Saturation Limit.

Name	Ref	S_r residual NAPL in the void fraction (cm^3/cm^3)	$C_{res,soil}$ residual NAPL concentration in soil (mg/kg)	$C_{sat,soil}$ soil saturation limit (mg/kg)	ρ_o liquid chemical density (g /cm^3)	MW molecular weight (g/g-mol)	S aqueous solubility (mg/L)	P_{vap} vapor pressure (mm Hg)
trichloroethylene (TCE)	a	0.2	70,000	1,045	1.46	131	1,100	75
benzene	b	0.24	53,000	444	0.88	78	1,750	95
o-xylene	c	0.01	2,000	143	0.88	106	178	6.6
gasoline	d,e	0.02 to 0.6	3,400 to 80,000	106	0.78	99	164	102
diesel	d,f	0.04 to 0.2	7,700 to 34,000	18	0.94	207	3.9	0.79
fuel oil	d,f	0.08 to 0.2	17,000 to 50,000	18	0.94	207	3.9	0.79
mineral oil	g	0.1 to 0.5	20,000 to 150,000	3	0.81	244	0.36	0.035

Notes: Unsaturated zone fine to medium sand. Nominal values $\theta_w = 0.12$ cm^3/cm^3, $f_{oc} = 0.005$ g/g in $C_{sat,soil}$ calculation.
a = Lin et al. (1982); b = Lenham and Parker (1987); c = Boley and Overcamp (1998); d = Fussell et al. (1981); e = Hoag and Marley (1986); f = API (1980); g = Pfannkuch (1984).

than $C_{sat,soil}$. The value $C_{sat,soil}$ specifies the presence or absence of a residual phase; it does not address mobility. In this effort, we have used available data to define values for $C_{res,soil}$ which can be conservatively used to screen sites for NAPL mobility. A comparison of calculated $C_{sat,soil}$ values with measured values of $C_{res,soil}$ is shown in Table 1 for selected chemicals and hydrocarbon mixtures.

The trend of $C_{sat,soil}$ in Table 1 decreases with decreasing chemical (or mixture) solubility and vapor pressure. The measured values of residual NAPL concentration in soil and residual NAPL fraction in voids do not show a similar decreasing trend. Therefore, using a calculated $C_{sat,soil}$ value as a screening level for the mobility of a residual phase becomes increasingly and significantly more conservative for less soluble, less volatile chemicals and chemical mixtures.

Screening levels for NAPL mobility consistent with the definition of residual NAPL concentration n soil, $C_{res,soil}$, have already been implemented in a number of programs. The State of Ohio [OAC 3745-300-08 Generic Numerical Standards] has promulgated rules, including values of residual NAPL concentration in soil, for several combinations of specified soil types and petroleum composition ranges. The State of Washington [WAC 173-340-747 Part VII Cleanup Standards] has proposed values based on a similar methodology. CONCAWE (1979, 1981) provides residual NAPL concentration in soil values for a range of petroleum products and soil types.

EXISTING MODELS AND METHODS

Monographs are available which detail the movement of NAPL in soils (Charbeneau, 1999; Huntley and Beckett, 1999; USEPA, 1991; Cohen and Mercer, 1993; and Pfannkuch, 1983). Several investigators have specifically developed empirical models for predicting immobile NAPL, as a residual NAPL concentration in soil, $C_{res,soil}$, for a limited number of NAPL types in various soil matrices. Summaries of two published approaches follow.

Hoag and Marley (1986) proposed an empirical method to estimate residual NAPL saturation values for gasoline in dry sand and in sand matrices containing moisture at field capacity. Their equations, which relate measured gasoline retention at residual saturation with soil particle surface area, are:

$$C_{res,soil} = \left(1.154 \cdot 10^{-2} \cdot d_p + 0.652 \cdot 10^{-3} \right) \cdot \frac{6}{2.65 \cdot d_p \cdot \rho_w} \cdot 10^6 \frac{mg}{kg} \qquad [4a]$$

zero soil moisture

$$C_{res,soil} = \left(1.136 \cdot 10^{-2} \cdot d_p + 0.131 \cdot 10^{-3} \right) \cdot \frac{6}{2.65 \cdot d_p \cdot \rho_w} \cdot 10^6 \frac{mg}{kg}$$

field capacity soil moisture [4b]

with

$C_{res,soil}$	residual NAPL concentration in soil (mg-res/kg-soil)
d_p	average sand particle diameter (cm)
ρ_w	density of water (g/cm^3) = 1

Eqs. [4a] and [4b] refer, respectively, to residual NAPL concentration in dry soil and soil initially at field moisture capacity. An assumption in these equations is that the soil particles and soil surface area can be defined by an average soil particle diameter (Sauter mean diameter). These authors found that changes in soil surface area adequately predicted changes in residual NAPL saturation. Smaller soil particles have greater available surface area in a given volume or weight of soil, and the associated narrower pores will result in greater capillary forces. Residual NAPL concentration in soil therefore decreases with increasing particle size. At field capacity moisture content, measured $C_{res,soil}$ was reduced. At field capacity moisture, many of the smaller pore spaces are saturated with water. This reduces the overall pore volume available for trapping NAPL.

Eqs. [4a] and [4b] were developed using Connecticut sands sieved into three classifications; fine (d_p = 0.0225 cm), medium (d_p = 0.0890 cm) and coarse (d_p = 0.2189 cm). A fourth set of experiments was conducted using mixed sands with the mixture being made from equal portions of each of the above three classifications. Effectively, Eqs. [4a] and [4b] have been developed for data in the range of:

$$0.02 \text{ cm} < d_p < 0.22 \text{cm}$$

Zytner *et. al.*, (1993) correlated measured soil retention capacity with soil porosity, soil bulk density, and NAPL density. Their experiments included several NAPL types in a variety of natural soils. The soils were air dried (less than 1.5% moisture), saturated with NAPL, and then allowed to drain. Their empirical equation, for dry soils is:

$$C_{res,soil} = \left(1.05 \cdot \theta_T \cdot \frac{\rho_o}{\rho_s} - 0.15 \right) \cdot 10^6 \frac{mg}{kg} \qquad [5]$$

with

$C_{res,soil}$	residual NAPL concentration in soil (mg-res/kg-soil)
θ_T	soil porosity (cm^3-void/cm^3-soil)
ρ_o	density of chemical residual NAPL (g-res/cm^3-res)
ρ_s	dry soil bulk density (g-soil/cm^3-soil)

This study was limited to air dried soils and did not specifically include sand. It does, however, show a dependence of $C_{res,soil}$ on soil porosity, θ_T, and chemical density, ρ_o.

A wide range of natural soils was used in the development of Eq. [5], including sandy loam ($\theta_T = 0.45$), clay ($\theta_T = 0.466$), organic top soil ($\theta_T = 0.555$), two different peat mosses ($\theta_T \sim 0.8$), as well as mixtures of these soils. Three NAPL types were included in their work to assess the influence of NAPL density on retention capacity: tetrachloroethene (ρ_o = 1.622 g/cm^3), trichloroethene (ρ_o = 1.456 g/cm^3), and gasoline (ρ_o = 0.75 g/cm^3). $C_{res,soil}$ values obtained in their study ranged from 414,000 to 6,894,000 mg/kg for PCE, 329,000 to 5,219,000 mg/kg for TCE, and 94,000 to 2,738,000 mg/kg for gasoline. Effectively, Eq. [5] has been developed for data in the range of:

$$0.23 < \left(\theta_T \cdot \frac{\rho_o}{\rho_s} \right) < 6.7 \qquad [6]$$

The broad range of values for $C_{res,soil}$ can be attributed to the range in soil densities, from 0.2 g/cm^3 (peat moss) to 1.5 g/cm^3 (sandy loam).

Although the $C_{res,soil}$ measurements used in developing Eqs. [4] and [5] were conducted by different researchers using different soils, a comparison of dry fine sand data (Hoag and Marley, 1986; θ_T = 0.4, and ρ_s = 1.6 g/cm^3) with dry sandy loam data (Zytner *et. al.*, 1993; θ_T = 0.45, ρ_s = 1.5 g/ cm^3) show very good agreement of $C_{res,soil}$ of 104,000 and 115,000 mg/kg, respectively, for gasoline.

MEASURED DATA AND COMPARISON WITH MODELS

Cohen and Mercer (1990) compiled measured residual NAPL saturation data from several investigators, including residual NAPL fraction in the voids, S_r, or residual NAPL volume fraction, θ_o, for a number of organic liquids and soil types. These values represent the residual amount of hydrocarbon remaining in soil pore volume after the soil was saturated with hydrocarbon and then allowed to drain. Values from Cohen and Mercer, with additional tabulated data from other references, are included in Table 2 (see pages 5 and 6). This table also includes additional values derived from the experimental data, including the residual NAPL concentration in soil, $C_{res,soil}$.

The values in Table 2 vary considerably between experiments, soil types, and chemicals. While this may be due to differences in laboratory test methods, it may also indicate the reasonable range in measured residual NAPL concentration in soils encountered between different soil types, chemical types, and measurement observations.

Calculated values for the soil saturation limit, $C_{sat,soil}$, for the indicated chemicals or chemical mixtures, are included in Table 2. These values are plotted in Figure 1. In all cases, $C_{res,soil}$ is greater than $C_{sat,soil}$. As a measure of immobile NAPL, $C_{sat,soil}$

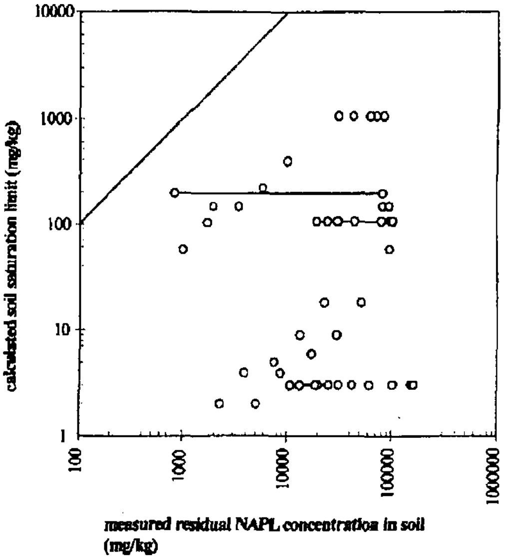


Figure 1. Comparison of data for residual NAPL concentration in soil, $C_{res,soil}$, to the calculated soil saturation limit, $C_{sat,soil}$. All plotted values are from Table 2. The solid diagonal line marks a direct correspondence between residual NAPL concentration in soil and soil saturation limit. For ranges of residual NAPL concentration in soil data in the same test series (Table 2), the upper and lower values are joined by a horizontal line. In all cases the calculated soil saturation limit is much less than the measured residual NAPL concentration in soil.

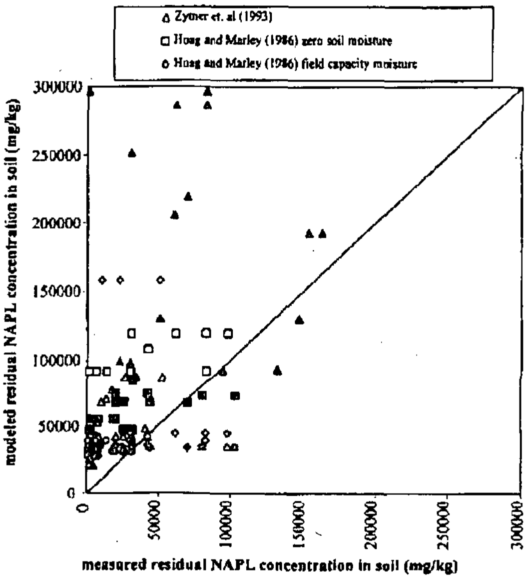


Figure 2. Comparison of data for residual NAPL concentration in soil, $C_{res,soil}$, from Table 2 to the models of Eq. [4a] Hoag and Marley (1986), zero soil moisture; Eq. [4b] Hoag and Marley (1986), field capacity soil moisture; and Eq. [5] Zytner et al., (1993). Filled points indicate the data value is within the intended range of model applicability. For ranges of residual NAPL concentration in soil data (Table 2), both the upper and lower values are shown as points. The solid diagonal line marks a direct correspondence between measured and modeled residual NAPL concentration in soil. The plot indicates that the empirical models generally predict higher residual NAPL concentration in soil than the measured values given in Table 2.

Table 2. Summary values of residual NAPL concentration in soil, $C_{res,soil}$, residual NAPL volume fraction, θ_o, and residual NAPL fraction in the voids, S_r. Calculated values for soil saturation limit, $C_{sat,soil}$, are also shown. Parameters for the calculations are shown in the second part of the table.

			Ref	Measured			
	NAPL	Soil Type		S_r (cm^3/cm^3)	$1000 \cdot \theta_o$ (cm^3/cm^3)	$C_{res,soil}$ (mg/kg)	$C_{sat,soil}$ (mg/kg)
1.	Gasoline	coarse gravel	1	*0.01*	2.5	1,000	57
2.	Gasoline	coarse sand and gravel	1	*0.01*	4	1,697	102
3.	Gasoline	medium to coarse	1	*0.02*	7.5	3,387	143
4.	Gasoline	fine to medium sand	1	*0.03*	12.5	5,833	215
5.	Gasoline	silt to fine sand	1	*0.05*	20	10,000	387
6.	Middle distillates	coarse gravel	1	*0.02*	5	2,286	2
7.	Middle distillates	coarse sand and gravel	1	*0.02*	8	3,879	4
8.	Middle distillates	medium to coarse	1	*0.04*	15	7,742	5
9.	Middle distillates	fine to medium sand	1	*0.06*	25	13,333	9
10.	Middle distillates	silt to fine sand	1	*0.1*	40	22,857	18
11.	Fuel oils	coarse gravel	1	*0.04*	10	5,143	2
12.	Fuel oils	coarse sand and gravel	1	*0.05*	16	8,727	4
13.	Fuel oils	medium to coarse	1	*0.08*	30	17,419	6
14.	Fuel oils	fine to medium sand	1	*0.1*	50	30,000	9
15.	Fuel oils	silt to fine sand	1	*0.2*	80	51,429	18
16.	Light oil & gasoline	soil	2	0.18	*72*	40,800	9 (a)
17.	Diesel & light fuel oil	Soil	2	0.15	*60*	34,000	NE (b)
18.	Lube & heavy fuel oil	Soil	2	0.2	*80*	53,067	NE
19.	Gasoline	coarse sand	3	0.15 to 0.19	*61 to 77*	24,954 to 31,609	106
20.	Gasoline	medium sand	3	0.12 to 0.27	*48 to 109*	19,767 to 44,476	106
21.	Gasoline	fine sand	3	0.19 to 0.6	*76 to 240*	31,065 to 98,100	106
22.	Gasoline	Graded fine-coarse	3	0.46 to 0.59	*184 to 236*	80,500 to 103,250	106
23.	Mineral oil	Ottawa sand	4	0.11	*39*	20,116	3
24.	Mineral oil	Ottawa sand	4	0.14	*49*	25,602	3
25.	Mineral oil	Ottawa sand	4	0.172	*60*	31,454	3
26.	Mineral oil	Ottawa sand	4	0.235	*82*	42,975	3
27.	Mineral oil	glacial till [NA]	4	0.15 to 0.28	*30 to 56*	13,500 to 25,200	3
28.	Mineral oil	glacial till	4	0.12 to 0.21	*24 to 42*	10,800 to 18,900	3
29.	Mineral oil	alluvium [NA]	4	0.19	*95*	61,071	3
30.	Mineral oil	Alluvium	4	0.19	*95*	61,071	3
31.	Mineral oil	loess [NA]	4	0.49 to 0.52	*240*	154,000 to 163,800	3
32.	Paraffin oil	coarse sand	5	0.12	48	27,000	
33.	Paraffin oil	fine sediments	5	0.52	229	147,086	
34.	Paraffin oil	Ottawa sand	5	0.11 to 0.23	39	20,382 to 42,618	
35.	Trichloroethene	medium sand	6	0.2	*78*	70,448	1045
36.	Trichloroethene	fine sand	6	0.15 to 0.2	*65 to 86*	62,344 to 83,125	1067
37.	Trichloroethene	loamy sand	7	0.08	*33*	30,713	1057
38.	Tetrachloroethene	Fine/med. beach sand	8	0.002 to 0.20	1 to 82	830 to 83,025	195
39.	O-Xylene	Coarse sand	9	0.01	3	1,936	143
40.	Gasoline	Sandy loam	10	0.42 to 0.59	189 to 266	94,500 to 132,750	
41.	Tertrachloroethene	Sandy loam	10	0.85	383	413,000	
42.	Trichloroethene	Sandy loam	10	0.75 to 0.92	338 to 412	328,000 to 401,208	

Notes: 1 = Fussell et al. (1981); 2 = API (1980); 3 = Hoag and Marley (1986); 4 = Pfannkuch (1984); 5 = Converly (1979); 6 = Lin et al. (1982); 7 = Cary et al. (1989); 8 = Poulsen and Kueper (1992); 9 = Boley and Overcamp, (1998); 10 = Zytner et al. (1993).
(a) - Assumed 50:50 mixture diesel and gasoline to estimate $C_{sat,soil}$. (b) - NE = Not estimated, composition data not available.
Between reported S_r or θ_o, the italicized values represent the calculated term. These values were converted to concentrations in soil using available values for NAPL density, soil bulk density and porosity, as shown in the table.

Table 2. (continued) Values for soil properties used in the calculations.

	Hydrocarbon NAPL	Soil Type	θ_T Soil Porosity (cm^3/cm^3)	θ_w Pore Water (cm^3/cm^3)	f_{oc} Fraction of Organic Carbon (f_{oc})	ρ_s Soil Bulk Density (g/cm^3)	ρ_o Liquid Density (g/cm^3)	d_p Soil Particle Size (mm)
1.	Gasoline	coarse gravel	0.28	0.02	0.001	1.75	0.7	2 to 4
2.	Gasoline	coarse sand and gravel	0.35	0.03	0.002	1.65	0.7	0.5 to 4
3.	Gasoline	medium to coarse sand	0.39	0.04	0.003	1.55	0.7	1 to 0.25
4.	Gasoline	fine to medium sand	0.41	0.043	0.005	1.5	0.7	0.5 to 0.1
5.	Gasoline	silt to fine sand	0.44	0.045	0.01	1.4	0.7	0.25 to 0.002
6.	Middle distillates	coarse gravel	0.28	0.02	0.001	1.75	0.8	2 to 4
7.	Middle distillates	coarse sand and gravel	0.35	0.03	0.002	1.65	0.8	0.5 to 4
8.	Middle distillates	medium to coarse sand	0.39	0.04	0.003	1.55	0.8	1 to 0.25
9.	Middle distillates	fine to medium sand	0.41	0.043	0.005	1.5	0.8	0.5 to 0.1
10.	Middle distillates	silt to fine sand	0.44	0.045	0.01	1.4	0.8	0.25 to 0.002
11.	Fuel oils	coarse gravel	0.28	0.02	0.001	1.75	0.9	2 to 4
12.	Fuel oils	coarse sand and gravel	0.35	0.03	0.002	1.65	0.9	0.5 to 4
13.	Fuel oils	medium to coarse sand	0.39	0.04	0.003	1.55	0.9	1 to 0.25
14.	Fuel oils	fine to medium sand	0.41	0.043	0.005	1.5	0.9	0.5 to 0.1
15.	Fuel oils	silt to fine sand	0.44	0.045	0.01	1.4	0.9	0.25 to 0.002
16.	Light oil and gasoline	soil	0.4	0.04	0.005	1.5	0.75	
17.	Diesel and light fuel oil	Soil	0.4			1.5	0.9	
18.	Lube and heavy fuel oil	Soil	0.4			1.5	0.9	
19.	Gasoline	Coarse sand	0.4	0.04	0.002	1.6	0.7	1 to 0.5
20.	Gasoline	Medium sand	0.4	0.04	0.002	1.6	0.7	0.5 to 0.25
21.	Gasoline	fine sand	0.4	0.04	0.002	1.6	0.7	0.25 to 0.1
22.	Gasoline	well graded fine-coarse sand	0.4	0.04	0.002	1.6	0.7	1 to 0.1
23.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.5
24.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.35
25.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.25
26.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.18
27.	Mineral oil	glacial till [NA]	0.2	No water	0.002	2	0.9	
28.	Mineral oil	glacial till	0.2	0.02	0.002	2	0.9	
29.	Mineral oil	alluvium [NA]	0.5	No water	0.002	1.4	0.9	
30.	Mineral oil	Alluvium	0.5	0.03	0.001	1.4	0.9	
31.	Mineral oil	loess [NA]	0.49	No water	0.002	1.4	0.9	
32.	Paraffin oil	coarse sand	0.4			1.6	0.9	1 to 0.5
33.	Paraffin oil	fine sediments	0.44			1.4	0.9	0.05 to 0.002
34.	Paraffin oil	Ottawa sand	0.35			1.7	0.9	0.5 to 0.18
35.	Trichloroethene	medium sand	0.39	0.04	0.003	1.6	1.46	0.5 to 0.25
36.	Trichloroethene	fine sand	0.43	0.04	0.005	1.5	1.46	0.25 to 0.1
37.	Trichloroethene	loamy sand	0.41	0.06	0.005	1.4	1.46	
38.	Tertrachloroethene	fine to medium beach sand	0.41	0.04	0.005	1.6	1.62	0.5 to 0.1
39.	O-Xylene	Coarse sand	0.33	0.04	0.003	1.6	0.88	1 to 0.5
40.	Gasoline	Sandy loam	0.45			1.5	0.75	
41.	Tertrachloroethene	Sandy loam	0.45			1.5	1.62	
42.	Trichloroethene	Sandy loam	0.45			1.5	1.46	

Notes: Porosity data and particle size information (ranges) estimated from USEPA (1991); pore water data adapted from Carsel and Parrish, (1988); f_{oc} data adapted from Wiedemeier et al., (1999).

underpredicts measured values of $C_{res,soil}$ by a factor ranging from 5 to over 50,000. As was noted in Table 1, the difference between $C_{sat,soil}$ and $C_{res,soil}$ increases with decreasing NAPL volatility and decreasing aqueous solubility.

A comparison of the data in Table 2 for residual NAPL concentration in soil, $C_{res,soil}$ to the models of Eq. [4a], [4b], and [5] is shown in Figure 2. Within the applicable range of values in the original references, both models predict values of $C_{res,soil}$ which are, on average, biased high relative to the comparable values listed in Table 2. In all cases, excepting point 38 (tetrachloroethene) in Table 2, for Eq. [4a], the model to data ratio ranges from 0.7 to 69; for Eq. [4b], the ratio ranges from 0.3 to 27; for Eq. [5], the model to data ratio ranges from 0.3 to 11. Point 38 has an exceptionally broad range of measured $C_{res,soil}$ values in the same soil.

Both the models of Zytner *et. al.*, (1993) and Hoag and Marley (1986) are correlations based on measured data. The indicated bias between the models and data of Table 2 could be due to differences in data measurements methods, or may indicate the reasonable range in variability for this type of measurement.

SCREENING VALUES FOR RESIDUAL NAPL CONCENTRATION

Based on the model to data comparisons of the last section, it is possible to specify conservative screening values for NAPL mobility based on a range of qualifying information. In many cases the screening levels will be very conservative estimates of mobility. In such cases, site-specific measurements may be used to refine the estimate, if necessary. Such measurements, for example, could include observation (or lack thereof) of floating and migrating hydrocarbon in shallow groundwater wells surrounding a known NAPL source area.

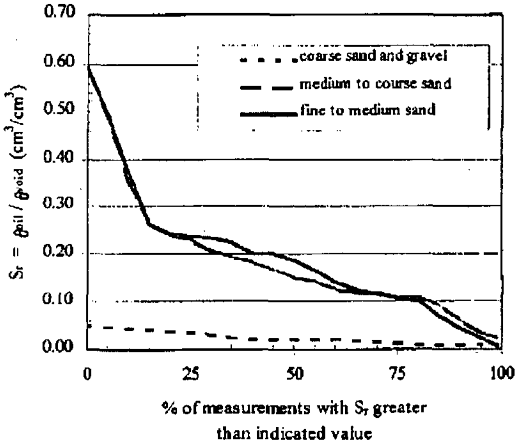


Figure 3. Cumulative distribution for measured residual NAPL void fraction, S_r, as a function of soil type. These cumulative histograms are based on the data in Table 2. Values for the "medium to course sand" and the "fine to medium sand" are very similar over the distribution. The "coarse sand and gravel" shows much lower values and narrower distribution of S_r over the range of different experiments. Tolerance limits for these distributions are given in Table 3.

Table 3. Screening values for residual phase void fraction as a function of soil type. The tabulated values are based on distributions of data from Table 2 for each soil type. The 95% statistical tolerance limit indicates that 5% of individual measurements showed lower values for S_r; the 50% tolerance limit is the median value for the soil type. The 90% tolerance limit is sufficiently conservative for most screening applications. The distribution of values is plotted in Figure 3.

Soil type	Indicated statistical tolerance limit 95%	90%	50%
	residual NAPL fraction in the voids, S_r, (cm³-res/cm³-void)		
coarse sand and gravel	0.01	0.01	0.02
medium to course sand	0.04	0.06	0.15
fine to medium sand	0.02	0.05	0.19

Table 4. Residual Saturation Screening Values. Values are tabulated for medium to coarse sand and represent lower limits from Table 2. If a tolerance limit is needed, or for chemicals not listed (but with densities in the range of 0.7 to 1.5 g/cm³, including petroleum products and crude oil), we suggest the use of the S_r parameters in Table 3 as screening values.

	Name	S_r residual NAPL fraction in the voids (cm³/cm³)	$C_{res,soil}$ residual NAPL concentration in soil (mg/kg)
(3.)	Gasoline	0.02	3,000
(8.)	Middle distillates	0.04	8,000
(13.)	Fuel oils	0.08	17,000
(39.)	O-xylene	0.01	2,000
(35.)	Trichloroethylene (TCE)	0.2	70,000

Note: Data row from Table 2 is indicated.

Several histograms of measured residual NAPL void fraction, S_r, as a function of soil type, are shown in Figure 3. These histograms are based on the relevant data in Table 2 and provide a basis for estimating conservative values of S_r within a specified statistical tolerance limit. Numerical values are given in Table 3. For example, with a medium to coarse sand, in specifying a screening level of $S_r = 0.06$, we would expect 90% of individual samples with equivalent NAPL concentrations below this level to be immobile in this soil type.

We expect that the tolerance limits in Table 3 and Figure 3 are biased conservatively, given that the Table 2 data showed lower residual NAPL concentration in soils than the empirical correlations of Eqs. [4] or [5]. The data in Table 2 is for NAPLs with densities ranging from about 0.7 to 1.5 g/cm³. The screening values for residual NAPL fraction in the voids, S_r, in Table 3, should be valid and reasonably conservative for this range in NAPL density.

Consolidated minimum values for S_r are shown in Table 4 for the various NAPL types in Table 2 listed as "medium sands". Again, these should be reasonably conservative screening values for NAPL mobility, for the indicated pure chemicals and hydrocarbon mixtures. No tolerance limits are specified for the Table 4 values, given the sparse data available when the screening values are qualified by both soil type and NAPL composition. If a tolerance limit is needed, or for chemicals not listed in Table 4 (with densities in the range of 0.7 to 1.5 g/cm³ including petroleum and crude oil), we suggest the use of the S_r parameters in Table 3 as screening values. A tolerance limit of 90% is reasonable in most cases.

These screening values are intended to be worst-case estimates for mobility. Higher values may be applicable on a site-specific basis. For example, with an adequate distance in unsaturated soil between the lower depth of a mobile NAPL and groundwater, it may also be reasonable to account for potential NAPL redistribution in the unsaturated soil layer. This redistribution would decrease the concentrations of mobile NAPL to concentrations in soil equivalent. to S_r. After this redistribution, an acceptable distance between the deepest expected NAPL penetration and the historical top boundary of the water table capillary fringe must still remain.

These screening values, as already discussed, are intended for use in estimating conservative limits of NAPL mobility. The data of Table 2 may be used for other purposes, such as relating a known released volume of NAPL to an equivalent soil volume at the residual concentration level. While it is not the purpose of this paper to detail this type of calculation, the variability of an estimated residual concentration level, as illustrated in Figure 3, clearly needed to be considered.

SUMMARY AND CONCLUSIONS

Screening values describing residual saturation of NAPLs in unconsolidated vadose zone soils have been tabulated. These values are proposed for use in estimating concentrations of immobile NAPL in soil. The values, in Tables 3 and 4, are based on measured, published values for residual NAPL concentrations in soil, $C_{res,soil}$, in the unsaturated soil zone.

Another value, the soil saturation limit, $C_{sat,soil}$, has already found use as a screening level for NAPL mobility. $C_{sat,soil}$ is a calculated value estimating the presence of a residual NAPL. Data in this paper shows $C_{sat,soil}$, is a factor up to 50,000 times less than the residual NAPL concentration in soil, $C_{res,soil}$. For screening immobile NAPL concentrations the soil saturation limit is exceptionally conservative. We would instead recommend use of the values in Tables 3 and 4.

A complete site assessment, in addition, would also include evaluation of other potential transport mechanisms, including soluble dissolution into mobile soil pore water, and volatilization into soil pore air. These transport mechanisms, as noted previously, are discussed elsewhere.

Use of residual NAPL concentration in soil values for screening immobile NAPL presumes homogenous soils and soil properties. Consolidated soil matrices, macropores, and fractures will greatly affect the flow and movement of NAPL and must be recognized when these screening values are applied. Further, we note that the values have been developed using a limited data set, from multiple authors, and no attempt has been made to judge bias or error in the individual measurement techniques.

ACKNOWLEDGEMENT

Support for preparing this document from American Petroleum and GRI (formerly the Gas Research Instutite) under GRI Contract No. 5097-210-3874 is gratefully acknowledged.

REFERENCES

API, 1996. A guide to the Assessment and Remediation of Underground Petroleum Releases, American Petroleum Institute, Publication No. 1628, third edition, Washington, D.C., July 1996.

ASTM E 1739-95: Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites, American Society for Testing and Materials, West Conshohocken, PA.

ASTM PS 104-98: Standard Provisional Guide for Risk-Based Corrective Action, American Society for Testing and Materials, West Conshohocken, PA.

Boley, Troy M. and Thomas J. Overcamp, 1998. Displacement of Non-wetting Liquids from Unsaturated Sands by Water Infiltration, Ground Water Journal of the Association of Groundwater Scientists and Engineers, September - October, 1998.

Carsel, R.F. and R.S. Parrish, 1988. Developing Joint Probability Distributions of Soil and Water Retention Characteristics, Water Resources Research, 24(5): 755-769.

Cary J.W., J.F. McBride and C.S. Simmons, 1989a. Trichlorethelene Residuals in the Capillary Fringe as Affected by Air-entry Pressure, Journal of Environmental Quality, 18:72-77.

Charbeneau, R.J., R.T. Johns, L.W. Lake and M.J. McAdams, Free-Product Recovery of Petroleum Hydrocarbon Liquids, American Petroleum Institute Publication No. 4682, Washington, D.C., June 1999.

Cohen, Robert M. and James W. Mercer, 1993. DNAPL Site Evaluation; CRC Press, Inc., Boca Raton, FL.

CONCAWE (*Conservation of Clean Air and Water - Europe*), DePastrovich, T.L., Baradat Y., Barthel R., Chiarelli A., and Fussell D.R., 1979. Protection of Groundwater from Oil Pollution, CONCAWE Report No. 3/79.

CONCAWE, Fussell, D.R., H. Godjen, P. Hayward, R.H. Lilie, A Macro and C. Panisi, 1981. Revised Inland Oil Spill Clean-up Manual, CONCAWE Report No. 7/81, Den Haag, 150 pp.

Converly, M.P., 1979. The Behavior and Movement of Petroleum Products in Un-consolidated Surficial Deposits, M.S. thesis, University of Minnesota.

Huntley D. and G. D. Beckett, 1999. Assessment of LNAPL Sources: Distribution, Mobility, Risk and Risk Reduction, (American Petroleum Institute, Review Draft).

DeVaull, G. E., G. M. Deeley, C. C. Stanley, and W. Hamilton, 1999. Development of Tier 1 Risk-Based Corrective Action (RBCA) Tools for Application at Exploration and Production Facilities, report prepared for Gas Research Institute under GRI Contract No. 5097-210-3874, Review Draft.

Hoag, G.E. and M.C. Marley, 1986. Gasoline Residual Saturation in Unsaturated Uniform Aquifer Materials, Journal of Environmental Engineering, ASCE, 112(3):586-604.

Johnson, P. C., Hertz, M.B., Byers, D. L., Estimates for Hydrocarbon Vapor Emissions Resulting from Service Station

Remediations and Buried Gasoline-Contaminated Soils, Petroleum Contaminated Soils, Vol 3, P.T. Kostecki and E.J. Calabrese, eds., (Lewis Publishers, MI), 1990, pp 295-326.

Lin, C., G.F. Pinder and E.F. Wood, 1982. Water Resources Program Report 83-WR-2, October, Water Resources Program, Princeton University, Princeton, New Jersey.

Mariner, P. E., M. Jin, and R. E. Jackson, 1997. An Algorithm for the Estimation of NAPL Saturation and Composition from Yypical Soil Chemical Analyses, Ground Water Monitoring and Remediation, 17, 1:122-129.

Mercer, James W., and Robert M. Cohen, 1990. A Review of Immiscible Fluids in the Subsurface: Properties, Models, Characterization and Remediation, Journal of Contaminant Hydrology, 6 107-163.

Mott, H.V., A Model for Determination of the Phase Distribution of Petroleum Hydrocarbon Release Sites, Ground Water Monitoring and Remediation, 15, 3, 1995, pp. 157-167.

Ohio Administrative Code 3745-300-08 Generic numerical Standards, State of Ohio. *http://www.epa.ohio.gov/derr/vap/rules/rule_8.pdf.*

Pfannkuch, H. O., 1983. Hydrocarbon Spills, Their Retention in the Subsurface and Propagation into Shallow Aquifers, Water Resources Research Center, United States Department of the Interior, NTIS Accession No. PB83-196477.

Pfannkuch, H., 1984. Mass-exchange Processes at the Petroleum-water Interface, Paper presented at the Toxic-Waste Technical Meeting, Tucson, AZ (March 20-22), M.F. Hult, ed., USGS Water-Resources Investigation Report 84-4188.

Poulsen, M.M. and B.H. Kueper, 1992. A Field Experiment to Study the Behavior of Tetrachloroethylene in Unsaturated Porous Media, Environmental Science and Technology, 26(5):889-895, ACS.

USEPA, 1991. Assessing UST Corrective Action Technology - A Scientific Evaluation of the Mobility and Degradability of Organic Contaminants in Subsurface Environments, United States Environmental Protection Agency, Office of Research and Development, Washington, DC, EPA/600/2-91/053, September, NTIS Accession No. PB92-114552.

USEPA, 1996. Soil Screening Guidance: Technical Background Document, United States Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C., EPA/540/R-95/128, NTIS Accession No. PB96963502.

Washington Administrative Code 173-340-747 Part VII Cleanup Standards, State of Washington. Proposed draft regulation *http://www.wa.gov/ECOLOGY/tcp/regs/rule/340vii.doc.*

Wiedemeier, T.H., Rifai, S.H., Newell, J.C., and Wilson, J.T., 1999. Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface, John Wiley and Sons, Inc., 617pp.

Zytner, R. G., N. Biswas and J. K. Bewtra, 1993. Retention Capacity of Dry Soils for NAPLS, Environmental Technology, 14, 1073-1080.

FOR MORE INFORMATION ON OTHER API

ENVIRONMENT, HEALTH & SAFETY

RESEARCH, CONTACT

THE EHS COMMUNICATIONS SPECIALIST,

(202) 682-8319; E-MAIL: EHS@API.ORG

OR

VISIT THE AMERICAN PETROLEUM INSTITUTE EHS WEB SITE

HTTP://WWW.API.ORG/EHS.

Summary Report

UArz #14m
Sec 10
T29N R10W

Wayne Price
OCD-Santa Fe
1220 S. Saint Francis Dr.
Santa Fe, NM, 87505

Report Date: June 22, 2007

Work Order: 7060415

Project Location: OCD Pit Sampling
Project Name: NM OCD Dist III

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
126204	DP3-01	Sludge	2007-05-30	12:10	2007-06-02

Sample - Field Code	TPH 418.1 TRPHC (mg/Kg)	TPH DRO DRO (mg/Kg)	TPH GRO GRO (mg/Kg)
126204 - DP3-01	<10.0	<50.0	**28.9**

Sample: 126204 - DP3-01

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/Kg as CaCo3	1.00
Carbonate Alkalinity		**544**	mg/Kg as CaCo3	1.00
Bicarbonate Alkalinity		**126**	mg/Kg as CaCo3	4.00
Total Alkalinity		**670**	mg/Kg as CaCo3	4.00
Bromide		<1.00	mg/Kg	0.200
Chloride		**704**	mg/Kg	1.00
Fluoride		**28.9**	mg/Kg	0.500
Sulfate		**205**	mg/Kg	2.00
Naphthalene		**1.14**	mg/Kg	0.170
Acenaphthylene		<0.170	mg/Kg	0.170
Acenaphthene		<0.170	mg/Kg	0.170
Dibenzofuran		<0.170	mg/Kg	0.170
Fluorene		**0.190**	mg/Kg	0.170
Anthracene		**0.405**	mg/Kg	0.170
Phenanthrene		<0.170	mg/Kg	0.170
Fluoranthene		<0.170	mg/Kg	0.170
Pyrene		<0.170	mg/Kg	0.170
Benzo(a)anthracene		<0.170	mg/Kg	0.170
Chrysene		<0.170	mg/Kg	0.170
Benzo(b)fluoranthene		<0.170	mg/Kg	0.170
Benzo(k)fluoranthene		<0.170	mg/Kg	0.170
Benzo(a)pyrene		<0.170	mg/Kg	0.170
Indeno(1,2,3-cd)pyrene		<0.170	mg/Kg	0.170
Dibenzo(a,h)anthracene		<0.170	mg/Kg	0.170
Benzo(g,h,i)perylene		<0.170	mg/Kg	0.170

continued . . .

sample 126204 continued ...

Param	Flag	Result	Units	RL
pH		**11.9**	s.u.	0.00
Total Calcium		**14200**	mg/Kg	100
Total Magnesium		**2790**	mg/Kg	100
Total Potassium		**1230**	mg/Kg	100
Total Sodium		**1570**	mg/Kg	100
Pyridine		<0.250	mg/Kg	0.250
N-Nitrosodimethylamine		<0.250	mg/Kg	0.250
2-Picoline		<0.250	mg/Kg	0.250
Methyl methanesulfonate		<0.250	mg/Kg	0.250
Ethyl methanesulfonate		<0.250	mg/Kg	0.250
Phenol		<0.250	mg/Kg	0.250
Aniline		<0.250	mg/Kg	0.250
bis(2-chloroethyl)ether		<0.250	mg/Kg	0.250
2-Chlorophenol		<0.250	mg/Kg	0.250
1,3-Dichlorobenzene (meta)		<0.250	mg/Kg	0.250
1,4-Dichlorobenzene (para)		<0.250	mg/Kg	0.250
Benzyl alcohol		<0.250	mg/Kg	0.250
1,2-Dichlorobenzene (ortho)		<0.250	mg/Kg	0.250
2-Methylphenol		<0.250	mg/Kg	0.250
bis(2-chloroisopropyl)ether		<0.250	mg/Kg	0.250
4-Methylphenol / 3-Methylphenol		<0.250	mg/Kg	0.250
Acetophenone		<0.250	mg/Kg	0.250
N-Nitrosodi-n-propylamine		<0.250	mg/Kg	0.250
Hexachloroethane		<0.250	mg/Kg	0.250
Nitrobenzene		<0.250	mg/Kg	0.250
N-Nitrosopiperidine		<0.250	mg/Kg	0.250
Isophorone		<0.250	mg/Kg	0.250
2-Nitrophenol		<0.250	mg/Kg	0.250
2,4-Dimethylphenol		<0.250	mg/Kg	0.250
bis(2-chloroethoxy)methane		<0.250	mg/Kg	0.250
Benzoic acid		<0.250	mg/Kg	0.250
2,4-Dichlorophenol		<0.250	mg/Kg	0.250
1,2,4-Trichlorobenzene		<0.250	mg/Kg	0.250
a,a-Dimethylphenethylamine		<0.250	mg/Kg	0.250
Naphthalene		**1.12**	mg/Kg	0.250
4-Chloroaniline		<0.250	mg/Kg	0.250
2,6-Dichlorophenol		<0.250	mg/Kg	0.250
Hexachlorobutadiene		<0.250	mg/Kg	0.250
N-Nitroso-di-n-butylamine		<0.250	mg/Kg	0.250
4-Chloro-3-methylphenol		<0.250	mg/Kg	0.250
1-Methylnaphthalene		**1.19**	mg/Kg	0.250
2-Methylnaphthalene		**1.92**	mg/Kg	0.250
1,2,4,5-Tetrachlorobenzene		<0.250	mg/Kg	0.250
Hexachlorocyclopentadiene		<0.250	mg/Kg	0.250
2,4,6-Trichlorophenol		<0.250	mg/Kg	0.250
2,4,5-Trichlorophenol		<0.250	mg/Kg	0.250
2-Chloronaphthalene		<0.250	mg/Kg	0.250
1-Chloronaphthalene		<0.250	mg/Kg	0.250
2-Nitroaniline		<0.250	mg/Kg	0.250
Dimethylphthalate		<0.250	mg/Kg	0.250
Acenaphthylene		<0.250	mg/Kg	0.250
2,6-Dinitrotoluene		<0.250	mg/Kg	0.250
3-Nitroaniline		<0.250	mg/Kg	0.250

continued ...

sample 126204 continued ...

Param	Flag	Result	Units	RL
Acenaphthene		<0.250	mg/Kg	0.250
2,4-Dinitrophenol		<0.250	mg/Kg	0.250
Dibenzofuran		<0.250	mg/Kg	0.250
Pentachlorobenzene		<0.250	mg/Kg	0.250
4-Nitrophenol		<0.250	mg/Kg	0.250
1-Naphthylamine		<0.250	mg/Kg	0.250
2,4-Dinitrotoluene		<0.250	mg/Kg	0.250
2-Naphthylamine		<0.250	mg/Kg	0.250
2,3,4,6-Tetrachlorophenol		<0.250	mg/Kg	0.250
Fluorene		<0.250	mg/Kg	0.250
Diethylphthalate		<0.250	mg/Kg	0.250
4-Chlorophenyl-phenylether		<0.250	mg/Kg	0.250
4-Nitroaniline		<0.250	mg/Kg	0.250
4,6-Dinitro-2-methylphenol		<0.250	mg/Kg	0.250
Diphenylamine		<0.250	mg/Kg	0.250
Diphenylhydrazine		<0.250	mg/Kg	0.250
4-Bromophenyl-phenylether		<0.250	mg/Kg	0.250
Phenacetin		<0.250	mg/Kg	0.250
Hexachlorobenzene		<0.250	mg/Kg	0.250
4-Aminobiphenyl		<0.250	mg/Kg	0.250
Pentachlorophenol		<0.250	mg/Kg	0.250
Pentachloronitrobenzene		<0.250	mg/Kg	0.250
Pronamide		<0.250	mg/Kg	0.250
Phenanthrene		<0.250	mg/Kg	0.250
Anthracene		**0.402**	mg/Kg	0.250
Di-n-butylphthalate		<0.250	mg/Kg	0.250
Fluoranthene		<0.250	mg/Kg	0.250
Benzidine		<0.250	mg/Kg	0.250
Pyrene		<0.250	mg/Kg	0.250
p-Dimethylaminoazobenzene		<0.250	mg/Kg	0.250
Butylbenzylphthalate		<0.250	mg/Kg	0.250
Benzo(a)anthracene		<0.250	mg/Kg	0.250
3,3-Dichlorobenzidine		<0.250	mg/Kg	0.250
Chrysene		<0.250	mg/Kg	0.250
bis(2-ethylhexyl)phthalate		<0.250	mg/Kg	0.250
Di-n-octylphthalate		<0.250	mg/Kg	0.250
Benzo(b)fluoranthene		<0.250	mg/Kg	0.250
7,12-Dimethylbenz(a)anthracene		<0.250	mg/Kg	0.250
Benzo(k)fluoranthene		<0.250	mg/Kg	0.250
Benzo(a)pyrene		<0.250	mg/Kg	0.250
3-Methylcholanthrene		<0.250	mg/Kg	0.250
Dibenzo(a,j)acridine		<0.250	mg/Kg	0.250
Indeno(1,2,3-cd)pyrene		<0.250	mg/Kg	0.250
Dibenzo(a,h)anthracene		<0.250	mg/Kg	0.250
Benzo(g,h,i)perylene		<0.250	mg/Kg	0.250
Total Arsenic		<2.00	mg/Kg	2.00
Total Barium		**66.4**	mg/Kg	1.00
Total Cadmium		<0.200	mg/Kg	0.200
Total Chromium		**6.59**	mg/Kg	0.500
Total Mercury		<0.0400	mg/Kg	0.0400
Total Lead		**14.3**	mg/Kg	1.00
Total Selenium		<2.00	mg/Kg	2.00

continued ...

sample 126204 continued ...

Param	Flag	Result	Units	RL
Bromochloromethane	1	<20.0	μg/Kg	10.0
Dichlorodifluoromethane		<20.0	μg/Kg	10.0
Chloromethane (methyl chloride)		<20.0	μg/Kg	10.0
Vinyl Chloride		<20.0	μg/Kg	10.0
Bromomethane (methyl bromide)		<100	μg/Kg	50.0
Chloroethane		<20.0	μg/Kg	10.0
Trichlorofluoromethane		<20.0	μg/Kg	10.0
Acetone		<200	μg/Kg	100
Iodomethane (methyl iodide)		<100	μg/Kg	50.0
Carbon Disulfide		<20.0	μg/Kg	10.0
Acrylonitrile		<20.0	μg/Kg	10.0
2-Butanone (MEK)		<100	μg/Kg	50.0
4-Methyl-2-pentanone (MIBK)		<100	μg/Kg	50.0
2-Hexanone		<100	μg/Kg	50.0
trans 1,4-Dichloro-2-butene		<200	μg/Kg	100
1,1-Dichloroethene		<20.0	μg/Kg	10.0
Methylene chloride		<100	μg/Kg	50.0
MTBE		<20.0	μg/Kg	10.0
trans-1,2-Dichloroethene		<20.0	μg/Kg	10.0
1,1-Dichloroethane		<20.0	μg/Kg	10.0
cis-1,2-Dichloroethene		<20.0	μg/Kg	10.0
2,2-Dichloropropane		<20.0	μg/Kg	10.0
1,2-Dichloroethane (EDC)		<20.0	μg/Kg	10.0
Chloroform		<20.0	μg/Kg	10.0
1,1,1-Trichloroethane		<20.0	μg/Kg	10.0
1,1-Dichloropropene		<20.0	μg/Kg	10.0
Benzene		<20.0	μg/Kg	10.0
Carbon Tetrachloride		<20.0	μg/Kg	10.0
1,2-Dichloropropane		<20.0	μg/Kg	10.0
Trichloroethene (TCE)		<20.0	μg/Kg	10.0
Dibromomethane (methylene bromide)		<20.0	μg/Kg	10.0
Bromodichloromethane		<20.0	μg/Kg	10.0
2-Chloroethyl vinyl ether		<100	μg/Kg	50.0
cis-1,3-Dichloropropene		<20.0	μg/Kg	10.0
trans-1,3-Dichloropropene		<20.0	μg/Kg	10.0
Toluene		**70.8**	μg/Kg	10.0
1,1,2-Trichloroethane		<20.0	μg/Kg	10.0
1,3-Dichloropropane		<20.0	μg/Kg	10.0
Dibromochloromethane		<20.0	μg/Kg	10.0
1,2-Dibromoethane (EDB)		<20.0	μg/Kg	10.0
Tetrachloroethene (PCE)		<20.0	μg/Kg	10.0
Chlorobenzene		<20.0	μg/Kg	10.0
1,1,1,2-Tetrachloroethane		<20.0	μg/Kg	10.0
Ethylbenzene		**26.5**	μg/Kg	10.0
m,p-Xylene		**118**	μg/Kg	10.0
Bromoform		<20.0	μg/Kg	10.0
Styrene		<20.0	μg/Kg	10.0
o-Xylene		**49.5**	μg/Kg	10.0
1,1,2,2-Tetrachloroethane		<20.0	μg/Kg	10.0
2-Chlorotoluene		<20.0	μg/Kg	10.0
1,2,3-Trichloropropane		<20.0	μg/Kg	10.0
Isopropylbenzene		<20.0	μg/Kg	10.0

continued ...

---

[1] Elevated reporting limit due to surfactants.

sample 126204 continued ...

Param	Flag	Result	Units	RL
Bromobenzene		<20.0	µg/Kg	10.0
n-Propylbenzene		**20.7**	µg/Kg	10.0
1,3,5-Trimethylbenzene		**35.5**	µg/Kg	10.0
tert-Butylbenzene		<20.0	µg/Kg	10.0
1,2,4-Trimethylbenzene		**112**	µg/Kg	10.0
1,4-Dichlorobenzene (para)		<20.0	µg/Kg	10.0
sec-Butylbenzene		**20.0**	µg/Kg	10.0
1,3-Dichlorobenzene (meta)		<20.0	µg/Kg	10.0
p-Isopropyltoluene		<20.0	µg/Kg	10.0
4-Chlorotoluene		<20.0	µg/Kg	10.0
1,2-Dichlorobenzene (ortho)		<20.0	µg/Kg	10.0
n-Butylbenzene		**27.6**	µg/Kg	10.0
1,2-Dibromo-3-chloropropane		<100	µg/Kg	50.0
1,2,3-Trichlorobenzene		<100	µg/Kg	50.0
1,2,4-Trichlorobenzene		<100	µg/Kg	50.0
Naphthalene		**170**	µg/Kg	50.0
Hexachlorobutadiene		<100	µg/Kg	50.0

BH GR

MANY CANYONS
29-4-11 #34-H

Summary Report

Wayne Price
OCD-Santa Fe
1220 S. Saint Francis Dr.
Santa Fe, NM, 87505

Report Date: June 28, 2007

Work Order: 7060432

Project Location: San Juan Basin
Project Name: Pits

Sample	Description	Matrix	Date Taken	Time Taken	Date Received
126262	T3-01	water	2007-05-31	00:00	2007-06-04

Sample - Field Code	TPH 418.1 TRPHC (mg/L)	TPH DRO DRO (mg/L)	TPH GRO GRO (mg/L)
126262 - T3-01	**385**	**18.6**	**0.713**

Sample: 126262 - T3-01

Param	Flag	Result	Units	RL
Hydroxide Alkalinity		<1.00	mg/L as CaCo3	1.00
Carbonate Alkalinity		**352**	mg/L as CaCo3	1.00
Bicarbonate Alkalinity		**674**	mg/L as CaCo3	4.00
Total Alkalinity		**1030**	mg/L as CaCo3	4.00
Bromide		**39.8**	mg/L	0.200
Chloride		**2050**	mg/L	0.500
Fluoride		**49.3**	mg/L	0.200
Sulfate		**757**	mg/L	0.500
Naphthalene	1	**0.0466**	mg/L	0.000200
Acenaphthylene		<0.00100	mg/L	0.000200
Acenaphthene		<0.00100	mg/L	0.000200
Dibenzofuran		**0.00224**	mg/L	0.000200
Fluorene		**0.00207**	mg/L	0.000200
Anthracene		**0.00458**	mg/L	0.000200
Phenanthrene		<0.00100	mg/L	0.000200
Fluoranthene		<0.00100	mg/L	0.000200
Pyrene		<0.00100	mg/L	0.000200
Benzo(a)anthracene		<0.00100	mg/L	0.000200
Chrysene		<0.00100	mg/L	0.000200
Benzo(b)fluoranthene		<0.00100	mg/L	0.000200
Benzo(k)fluoranthene		<0.00200	mg/L	0.000400
Benzo(a)pyrene		<0.00100	mg/L	0.000200
Indeno(1,2,3-cd)pyrene		<0.00200	mg/L	0.000400

continued ...

---

[1] Sample ran at a dilution due to matrix difficulties.

sample 126262 continued ...

Param	Flag	Result	Units	RL
Dibenzo(a,h)anthracene		<0.00100	mg/L	0.000200
Benzo(g,h,i)perylene		<0.00100	mg/L	0.000200
pH		**11.0**	s.u.	0.00
Dissolved Calcium		**670**	mg/L	0.500
Dissolved Magnesium		**23.3**	mg/L	0.500
Dissolved Potassium		**64.1**	mg/L	0.500
Dissolved Sodium		**2330**	mg/L	0.500
Pyridine		<0.0250	mg/L	0.00500
N-Nitrosodimethylamine		<0.0250	mg/L	0.00500
2-Picoline		<0.0250	mg/L	0.00500
Methyl methanesulfonate		<0.0250	mg/L	0.00500
Ethyl methanesulfonate		<0.0250	mg/L	0.00500
Phenol		**0.0255**	mg/L	0.00500
Aniline		<0.0250	mg/L	0.00500
bis(2-chloroethyl)ether		<0.0250	mg/L	0.00500
2-Chlorophenol		<0.0250	mg/L	0.00500
1,3-Dichlorobenzene (meta)		<0.0250	mg/L	0.00500
1,4-Dichlorobenzene (para)		<0.0250	mg/L	0.00500
Benzyl alcohol		<0.0250	mg/L	0.00500
1,2-Dichlorobenzene (ortho)		<0.0250	mg/L	0.00500
2-Methylphenol		<0.0250	mg/L	0.00500
bis(2-chloroisopropyl)ether		<0.0250	mg/L	0.00500
4-Methylphenol / 3-Methylphenol		**0.0545**	mg/L	0.00500
N-Nitrosodi-n-propylamine		<0.0250	mg/L	0.00500
Hexachloroethane		<0.0250	mg/L	0.00500
Acetophenone		<0.0250	mg/L	0.00500
Nitrobenzene		<0.0250	mg/L	0.00500
N-Nitrosopiperidine		<0.0250	mg/L	0.00500
Isophorone		<0.0250	mg/L	0.00500
2-Nitrophenol		<0.0250	mg/L	0.00500
2,4-Dimethylphenol		<0.0250	mg/L	0.00500
bis(2-chloroethoxy)methane		<0.0250	mg/L	0.00500
2,4-Dichlorophenol		<0.0250	mg/L	0.00500
1,2,4-Trichlorobenzene		<0.0250	mg/L	0.00500
Benzoic acid		**0.388**	mg/L	0.00500
Naphthalene		**0.0402**	mg/L	0.00500
a,a-Dimethylphenethylamine		<0.0250	mg/L	0.00500
4-Chloroaniline		<0.0250	mg/L	0.00500
2,6-Dichlorophenol		<0.0500	mg/L	0.0100
Hexachlorobutadiene		<0.0250	mg/L	0.00500
N-Nitroso-di-n-butylamine		<0.0250	mg/L	0.00500
4-Chloro-3-methylphenol		<0.0250	mg/L	0.00500
2-Methylnaphthalene		**0.0299**	mg/L	0.00500
1-Methylnaphthalene		<0.0250	mg/L	0.00500
1,2,4,5-Tetrachlorobenzene		<0.0250	mg/L	0.00500
Hexachlorocyclopentadiene		<0.0250	mg/L	0.00500
2,4,6-Trichlorophenol		<0.0500	mg/L	0.0100
2,4,5-Trichlorophenol		<0.0250	mg/L	0.00500
2-Chloronaphthalene		<0.0250	mg/L	0.00500
1-Chloronaphthalene		<0.0250	mg/L	0.00500
2-Nitroaniline		<0.0250	mg/L	0.00500
Dimethylphthalate		<0.0250	mg/L	0.00500
Acenaphthylene		<0.0250	mg/L	0.00500

continued ...

sample 126262 continued ...

Param	Flag	Result	Units	RL
2,6-Dinitrotoluene		<0.0250	mg/L	0.00500
3-Nitroaniline		<0.0250	mg/L	0.00500
Acenaphthene		<0.0250	mg/L	0.00500
2,4-Dinitrophenol		<0.0250	mg/L	0.00500
Dibenzofuran		<0.0250	mg/L	0.00500
Pentachlorobenzene		<0.0250	mg/L	0.00500
4-Nitrophenol		<0.125	mg/L	0.0250
2,4-Dinitrotoluene		<0.0250	mg/L	0.00500
1-Naphthylamine		<0.0250	mg/L	0.00500
2,3,4,6-Tetrachlorophenol		<0.0500	mg/L	0.0100
2-Naphthylamine		<0.0250	mg/L	0.00500
Fluorene		<0.0250	mg/L	0.00500
4-Chlorophenyl-phenylether		<0.0250	mg/L	0.00500
Diethylphthalate		<0.0250	mg/L	0.00500
4-Nitroaniline		<0.0250	mg/L	0.00500
Diphenylhydrazine		<0.0250	mg/L	0.00500
4,6-Dinitro-2-methylphenol		<0.0250	mg/L	0.00500
Diphenylamine		<0.0250	mg/L	0.00500
4-Bromophenyl-phenylether		<0.0250	mg/L	0.00500
Phenacetin		<0.0250	mg/L	0.00500
Hexachlorobenzene		<0.0250	mg/L	0.00500
4-Aminobiphenyl		<0.0250	mg/L	0.00500
Pentachlorophenol		<0.0500	mg/L	0.0100
Anthracene		<0.0250	mg/L	0.00500
Pentachloronitrobenzene		<0.0250	mg/L	0.00500
Pronamide		<0.0250	mg/L	0.00500
Phenanthrene		<0.0250	mg/L	0.00500
Di-n-butylphthalate		<0.0250	mg/L	0.00500
Fluoranthene		<0.0250	mg/L	0.00500
Benzidine		<0.125	mg/L	0.0250
Pyrene		<0.0250	mg/L	0.00500
p-Dimethylaminoazobenzene		<0.0250	mg/L	0.00500
Butylbenzylphthalate		<0.0250	mg/L	0.00500
Benzo(a)anthracene		<0.0250	mg/L	0.00500
3,3-Dichlorobenzidine		<0.0250	mg/L	0.00500
Chrysene		<0.0250	mg/L	0.00500
bis(2-ethylhexyl)phthalate		<0.0250	mg/L	0.00500
Di-n-octylphthalate		<0.0250	mg/L	0.00500
Benzo(b)fluoranthene		<0.0250	mg/L	0.00500
Benzo(k)fluoranthene		<0.0250	mg/L	0.00500
7,12-Dimethylbenz(a)anthracene		<0.0250	mg/L	0.00500
Benzo(a)pyrene		<0.0250	mg/L	0.00500
3-Methylcholanthrene		<0.0250	mg/L	0.00500
Dibenzo(a,j)acridine		<0.0250	mg/L	0.00500
Indeno(1,2,3-cd)pyrene		<0.0250	mg/L	0.00500
Dibenzo(a,h)anthracene		<0.0250	mg/L	0.00500
Benzo(g,h,i)perylene		<0.0250	mg/L	0.00500
Total Dissolved Solids	2	**17200**	mg/L	10.00
Total Arsenic		<0.100	mg/L	0.0100
Total Barium		**18.6**	mg/L	0.0100
Total Cadmium		<0.0100	mg/L	0.00100
Total Chromium		**1.48**	mg/L	0.00500

continued ...

---

[2] Sample ran out of hold time at different dilutions for accuracy. Filtrate colored possibly due to particles passing though filter.

sample 126262 continued ...

Param	Flag	Result	Units	RL
Total Mercury		**0.000230**	mg/L	0.000200
Total Lead		**1.87**	mg/L	0.00500
Total Selenium		<0.100	mg/L	0.0100
Bromochloromethane	3	<100	µg/L	1.00
Dichlorodifluoromethane		<100	µg/L	1.00
Chloromethane (methyl chloride)		<100	µg/L	1.00
Vinyl Chloride		<100	µg/L	1.00
Bromomethane (methyl bromide)		<500	µg/L	5.00
Chloroethane		<100	µg/L	1.00
Trichlorofluoromethane		<100	µg/L	1.00
Acetone		<1000	µg/L	10.0
Iodomethane (methyl iodide)		<500	µg/L	5.00
Carbon Disulfide		<100	µg/L	1.00
Acrylonitrile		<100	µg/L	1.00
2-Butanone (MEK)		<500	µg/L	5.00
4-Methyl-2-pentanone (MIBK)		<500	µg/L	5.00
2-Hexanone		<500	µg/L	5.00
trans 1,4-Dichloro-2-butene		<1000	µg/L	10.0
1,1-Dichloroethene		<100	µg/L	1.00
Methylene chloride		<500	µg/L	5.00
MTBE		<100	µg/L	1.00
trans-1,2-Dichloroethene		<100	µg/L	1.00
1,1-Dichloroethane		<100	µg/L	1.00
cis-1,2-Dichloroethene		<100	µg/L	1.00
2,2-Dichloropropane		<100	µg/L	1.00
1,2-Dichloroethane (EDC)		<100	µg/L	1.00
Chloroform		<100	µg/L	1.00
1,1,1-Trichloroethane		<100	µg/L	1.00
1,1-Dichloropropene		<100	µg/L	1.00
Benzene		<100	µg/L	1.00
Carbon Tetrachloride		<100	µg/L	1.00
1,2-Dichloropropane		<100	µg/L	1.00
Trichloroethene (TCE)		<100	µg/L	1.00
Dibromomethane (methylene bromide)		<100	µg/L	1.00
Bromodichloromethane		<100	µg/L	1.00
2-Chloroethyl vinyl ether		<500	µg/L	5.00
cis-1,3-Dichloropropene		<100	µg/L	1.00
trans-1,3-Dichloropropene		<100	µg/L	1.00
Toluene		**139**	µg/L	1.00
1,1,2-Trichloroethane		<100	µg/L	1.00
1,3-Dichloropropane		<100	µg/L	1.00
Dibromochloromethane		<100	µg/L	1.00
1,2-Dibromoethane (EDB)		<100	µg/L	1.00
Tetrachloroethene (PCE)		<100	µg/L	1.00
Chlorobenzene		<100	µg/L	1.00
1,1,1,2-Tetrachloroethane		<100	µg/L	1.00
Ethylbenzene		<100	µg/L	1.00
m,p-Xylene		**118**	µg/L	1.00
Bromoform		<100	µg/L	1.00
Styrene		<100	µg/L	1.00
o-Xylene		<100	µg/L	1.00
1,1,2,2-Tetrachloroethane		<100	µg/L	1.00

continued ...

---

[3] Sample ran at a dilution due to surfactants.

sample 126262 continued ...

Param	Flag	Result	Units	RL
2-Chlorotoluene		<100	μg/L	1.00
1,2,3-Trichloropropane		<100	μg/L	1.00
Isopropylbenzene		<100	μg/L	1.00
Bromobenzene		<100	μg/L	1.00
n-Propylbenzene		<100	μg/L	1.00
1,3,5-Trimethylbenzene		<100	μg/L	1.00
tert-Butylbenzene		<100	μg/L	1.00
1,2,4-Trimethylbenzene		<100	μg/L	1.00
1,4-Dichlorobenzene (para)		<100	μg/L	1.00
sec-Butylbenzene		<100	μg/L	1.00
1,3-Dichlorobenzene (meta)		<100	μg/L	1.00
p-Isopropyltoluene		<100	μg/L	1.00
4-Chlorotoluene		<100	μg/L	1.00
1,2-Dichlorobenzene (ortho)		<100	μg/L	1.00
n-Butylbenzene		<100	μg/L	1.00
1,2-Dibromo-3-chloropropane		<500	μg/L	5.00
1,2,3-Trichlorobenzene		<500	μg/L	5.00
1,2,4-Trichlorobenzene		<500	μg/L	5.00
Naphthalene		<500	μg/L	5.00
Hexachlorobutadiene		<500	μg/L	5.00