Technical Supplement to Accompany Environmental Assessment for ExxonMobil's Piceance Development Project

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Technical Supplement to Accompany Environmental Assessment for ExxonMobil's Piceance Development Project

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

Civil/Water Resource Engineering

- Pumps and pipelines
- Surface and groundwater modeling
- FEMA floodplain assessments
- Hydraulic and hydrologic analysis and design
- Dam design and rehabilitation
- Water supply, treatment and distribution
- Wastewater treatment and disposal
- Irrigation systems
- GPS and conventional surveying
- Civil engineering design, plans and specifications
- Construction engineering
- Water rights
- Computer-aided design and drafting (CADD)
- GIS mapping
- Stormwater management
- Geotechnical sampling
- 404 permits

Transportation Services

- Reconnaissance reports
- Surveys (right of way, ground control, construction)
- Bridge hydraulics, scour analysis, structure selection
- Design of urban streets, rural roadways and interstate reconstruction
- Streetscape enhancements
- Utility replacement
- Drainage design
- Bicycle/pedestrian pathways
- Parking facilities
- Construction administration

Mine Services

- NEPA compliance documents
- Baseline studies (climatology, geology, hydrology, wetlands and AVF assessments)
- GPS and conventional surveying
- Drilling and monitoring services
- Mining and reclamation design and permitting
- Hydrologic control plans
- Reservoir and dam design
- Haulroads and stream crossings
- Annual reports and bond calculations
- Blast monitoring and reporting
- Assessment of probable hydrologic consequences
- Mine simulation modeling
- Postmine topography design
- Reclaimed stream channels, AVF reclamation and wetland mitigation design
- Abandoned mine land reclamation

Environmental Services

- Environmental compliance and best management practices
- Environmental impact analysis and regulatory permitting
- Environmental site assessments
- Geomorphologic investigations
- Hydrocarbon product recovery system design
- Hydrologic and water quality monitoring
- Hazardous and non-hazardous waste management planning
- Site remediation planning and design
- Soil and groundwater cleanup plans
- Underground storage tanks investigation and removal plans
- NEPA compliance documents
- Environmental audits
- Wetland delineation and mitigation

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Technical Supplement to Accompany
Environmental Assessment for Piceance Development Project

1.0   INTRODUCTION

This document is a compilation of technical data regarding ExxonMobil's Proposed Water Evaporation Ponds (PWEP), a component of their Piceance Development Project. This technical supplement has been prepared to provide additional information to supplement the Bureau of Land Management's (BLM's) Environmental Assessment for ExxonMobil's Piceance Development Project. The technical aspects of the proposed ponds and the evaporation system are discussed below.

The PWEP for the Piceance Development Project is located in the SE/4 of Section 32, Township 2 South, Range 97 West, which is approximately 24 miles southwest of Meeker, Colorado. Figure 1 depicts the general location of the PWEP facility.

The PWEP will occupy 52 acres and will consist of three interconnected ponds with a common containment berm. The ponds will be double lined with a leak detection system so that no infiltration through the pond floor or bermed areas will occur. Each pond is approximately 800 x 500 feet in size and will have an available capacity of 1,160,000 barrels (149 acre-feet). Pond embankments will be at a slope of 2.5:1 with two feet of freeboard to accommodate storm rainfall. A figure showing the facility layout with cross-sections of each pond is included in Attachment 1 of this report.

This facility is designed to dispose of produced water through means of natural and mechanical evaporation. The evaporators will operate approximately eight months out of the year with little or no mechanical evaporation occurring during the remaining winter months. Importantly, natural evaporation volumes are excluded from analysis.

2.0   POND SITING

Site selection for the PWEP was based on several factors including environmental, safety, aesthetics, site-specific engineering properties of the foundation soil, ease of construction, and access. The ponds will be located on an elevated mesa,

Legend

Treating/Processing Facilities

- Central Treating Facility
- Fresh Water Pond & PWEP
- Proposed Pipelines

- water wells
- Proposed Access Road (New)
- Proposed Access Road (Upgrade)
- Primary Paved Roads
- County Roads

- Piceance Development Project Area
- BLM
- Private

N

1:70,000

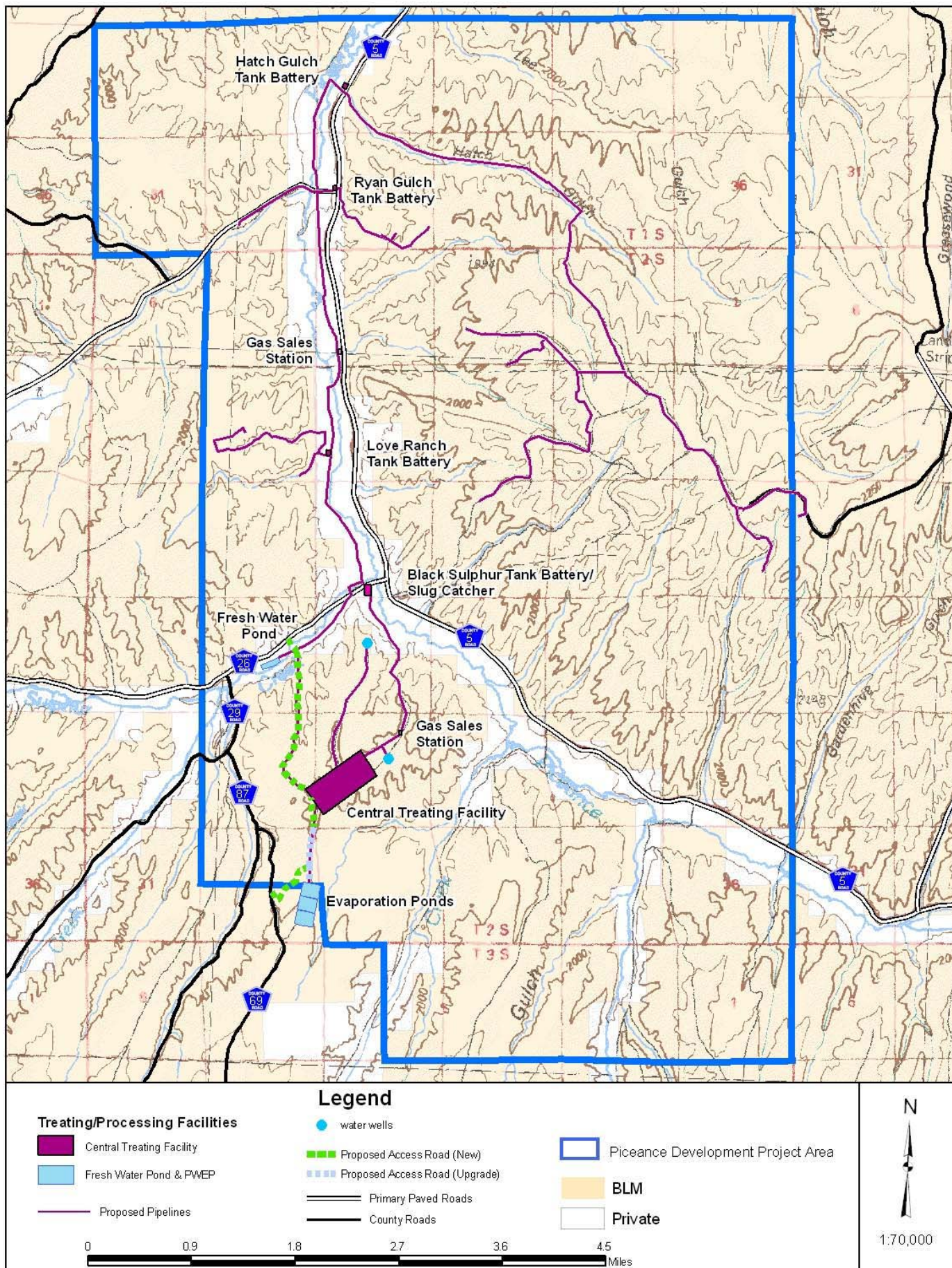0   0.9   1.8   2.7   3.6   4.5
Miles

Figure 1.   General Location Map

which is well outside of any floodplain. The mesa is relatively flat and in close proximity to the proposed Central Treating Facility (CTF). Figure 1 depicts the general location of the CTF. The PWEP will not be in view of any populated areas or paved highways. A diagram showing the PWEP facility and surrounding area is included in Attachment 2.

3.0   WATER BALANCE

A typical water balance for one year of operation for the PWEP is included in Table 1. This water balance takes into account all inflows and outflows to determine the amount of produced water that can be evaporated per month and the storage volumes required.   The facility may operate under several different scenarios because the number of evaporators may be increased or decreased from the amount shown. Therefore, the annual water balance included in Table 1 is presented only as a typical scenario. Even though minimal amounts of evaporation will occur throughout the winter months, evaporation volumes for November 1st through February 28th were excluded in order to make a conservative estimate of the necessary water storage needed.

Table 2 shows the solids accumulation over the life of this facility. ExxonMobil estimates that it will take three years for water within the ponds to concentrate sodium chloride to the point where it precipitates out of solution; therefore, no solids accumulation will occur during this period. As shown on Table 2, the ponds have an estimated service life of 30 years if no solids are removed while the PWEP facility is in operation. Variability in the Total Dissolved Solids (TDS) concentration of the produced water may extend or shorten the service life of the facility. However, at this time, ExxonMobil does not expect water quality to vary significantly from the initial estimates. The components of this water balance are discussed in greater depth as follows.

3.1   Inflows

The inflows to the ponds presented in the water balance consist of natural precipitation and produced water. Natural precipitation received directly to the pond surface is a comparatively small component of the inflow. Precipitation data for Little Hills and Meeker, Colorado found within the Western Regional Climate Center database

Table 1.   Annual Water Balance for ExxonMobil's PWEP Facility.

Month	% Evap.[1]	Constant Flowrate per Evaporator[2] (gpm)	Evap. Per Super Polecat (gpm)	Evap. per Super Polecat (gpd)	Number of Super Polecats Operating	Total Water Evap. per Day (bpd)	Days Per Month	Total Water Evap. per Month (bbl)	Monthly Precip.[3] (in)	Precip. Inflow per Month (bbl)	Produced Water Inflow per Month (bbl)	Total Inflow per Month (bbl)	Storage (bbl)	Available Pond Capacity (bbl)
Nov	10	0	0	0	0	0	30	0	0.91	16,238	360,000	376,238	376,238	3,123,762
Dec	0	0	0	0	0	0	31	0	0.91	16,149	372,000	388,149	764,387	2,735,613
Jan	0	0	0	0	0	0	31	0	1.28	22,841	372,000	394,841	1,159,228	2,340,772
Feb	0	0	0	0	0	0	28	0	1.60	28,462	336,000	364,462	1,523,690	1,976,310
Mar	24	65.9	15.82	22,775	25	13,557	31	420,254	1.43	25,428	372,000	397,428	1,500,864	1,999,136
Apr	51	65.9	33.61	48,397	20	23,046	30	691,385	1.16	20,610	360,000	380,610	1,190,089	2,309,911
May	58	65.9	38.22	55,040	16	20,967	31	649,992	1.32	23,465	372,000	395,465	935,562	2,564,438
Jun	67	65.9	44.15	63,580	16	24,221	30	726,632	1.67	29,800	360,000	389,800	598,729	2,901,271
Jul	72	65.9	47.45	68,325	16	26,029	31	806,887	1.36	24,268	372,000	396,268	188,110	3,311,890
Aug	60	65.9	39.54	56,938	14	18,979	31	588,355	1.35	24,090	372,000	396,090	0	3,500,000
Sep	54	65.9	35.59	51,244	11	13,421	30	402,630	1.08	19,183	360,000	379,183	0	3,500,000
Oct	49	65.9	32.29	46,499	12	13,285	31	411,849	1.05	18,647	372,000	390,647	0	3,500,000

[1]   Percent evaporation developed by SMI and presented in Section 4.1 of ExxonMobil's Piceance Development Project Report (Attachment 4).

[2]   Based upon an operating pressure of 100 psig.

[3]   Monthly precipitation from WRCC 2006, based on average of Meeker and Little Hills, Colorado sites (Attachment 3).

gpm = gallons per minute
gpd = gallons per day
bbl = barrels (42 gallons)
bpd = barrels per day
in = inch
psig = pounds per square inch gage

Table 2. Schedule of Sediment Storage to ExxonMobil's PWEP Facility.

Year	TDS Concentration (mg/L)	Percent Solids by Weight	Produced Water Flow Rate (bpd)	Solids Volume per Year (bbl)	Available Pond Capacity (bbl)
1	16,500	1.62	12,000	0	3,500,000
2	16,500	1.62	12,000	0	3,500,000
3	16,500	1.62	12,000	0	3,500,000
4	16,500	1.62	12,000	264,285	3,235,715
5	16,500	1.62	12,000	330,356	3,169,644
6	16,500	1.62	12,000	396,427	3,103,573
7	16,500	1.62	12,000	462,498	3,037,502
8	16,500	1.62	12,000	528,570	2,971,430
9	16,500	1.62	12,000	594,641	2,905,359
10	16,500	1.62	12,000	660,712	2,839,288
11	16,500	1.62	12,000	726,783	2,773,217
12	16,500	1.62	12,000	792,854	2,707,146
13	16,500	1.62	12,000	858,925	2,641,075
14	16,500	1.62	12,000	924,997	2,575,003
15	16,500	1.62	12,000	991,068	2,508,932
16	16,500	1.62	12,000	1,057,139	2,442,861
17	16,500	1.62	12,000	1,123,210	2,376,790
18	16,500	1.62	12,000	1,189,281	2,310,719
19	16,500	1.62	12,000	1,255,353	2,244,647
20	16,500	1.62	12,000	1,321,424	2,178,576
21	16,500	1.62	12,000	1,387,495	2,112,505
22	16,500	1.62	12,000	1,453,566	2,046,434
23	16,500	1.62	12,000	1,519,637	1,980,363
24	16,500	1.62	12,000	1,585,709	1,914,291
25	16,500	1.62	12,000	1,651,780	1,848,220
26	16,500	1.62	12,000	1,717,851	1,782,149
27	16,500	1.62	12,000	1,783,922	1,716,078
28	16,500	1.62	12,000	1,849,993	1,650,007
29	16,500	1.62	12,000	1,916,065	1,583,935
30	16,500	1.62	12,000	1,982,136	1,517,864

Note: Maximum predicted water storage is 1,523,700 bbl in February.
bpd = barrels per day
bbl = barrels
mg/L = milligrams per liter
TDS = total dissolved solids

(WRCC 2006) was used within the water balance. Measured precipitation rates at the Little Hills and Meeker sites were averaged to produce representative numbers for monthly precipitation at the PWEP site. The monthly inflow due to precipitation was calculated by multiplying the surface area of the ponds by the average monthly precipitation. Precipitation rates from the WRCC database are included in Attachment 3.

The expected flow rate of produced water is 12,000 barrels per day (bpd). This flow rate was calculated by multiplying the expected water to gas ratio by the estimated gas flow rate to the CTF. This calculation is included in Section 1.1 of ExxonMobil's Evaporation Pond Design Basis: Piceance Development Project Report, which is included in Attachment 4 of this report.

3.2 Outflows

Natural evaporation of produced water from the ponds' surface was not included in the water balance. The presence of waterfowl deterrent balls on the surface of the water will effectively negate direct surface evaporation. However, it is expected that the portion of the spray from the mechanical evaporators that does not evaporate will fall onto the waterfowl balls and a portion of that water will evaporate from the balls' surface. The bird balls will, in effect, increase the wetted surface area available for evaporation beyond the natural flat planer surface of the ponds. In addition, the non-reflective flat black color of the balls will be conducive to natural solar heating and increase evaporative effects. Based on data provided in ExxonMobil's Piceance Development Project Report (Attachment 4), pan evaporation rates at Montrose and Grand Junction, Colorado vary from a low of 3.3 and 4.3 inches per month to a high of approximately 9.5 and 13.0 inches per month, respectively. Assuming a pan coefficient of 0.75 (Pochop et al 1984) the average monthly evaporation would be approximately 5.7 inches per month. Using an evaporation rate of 5.7 inches per month, the evaporation from the surface of the waterfowl deterrent balls could be as much as 101,000 barrels of water per month. Importantly, this additional evaporation from the surface of the waterfowl deterrent ball was not considered in the water balance.

The Super Polecat, an evaporator developed by SMI Evaporative Solutions (SMI), will carry out mechanical evaporation of the produced water. Technical

specifications for the Super Polecat are included in Attachment 5. Forty evaporators will be installed at the PWEP, with less than half of them in operation at one time. With spare evaporators, the PWEP will be better equipped to handle changes in the wind direction thereby eliminating overspray. The proposed layout for the evaporators is shown in a figure included in Attachment 6. This figure was submitted to the Colorado Oil and Gas Conservation Commission as part of the permit application. ExxonMobil plans to operate the facility with an average of 16 evaporators operating most of the time. The evaporators will operate approximately eight months out of the year, with little or no mechanical evaporation occurring throughout the winter months. Evaporation volumes for the four months of November through February were excluded in the water balance to make a conservative estimate of total annual evaporation. ExxonMobil anticipates that throughout the spring months (March through May) it may be necessary to operate more than 16 evaporators in order to reduce stored volumes from winter. This is reflected in the water balance in Table 1.

Evaporative efficiencies were calculated by SMI for the Super Polecat Evaporator. SMI used climatic data such as maximum and minimum temperature, wind speed and direction, relative humidity, and pan evaporation from the surrounding area to estimate the evaporation efficiency by month. The evaporator flow rate used in the water balance was established from a table provided by SMI where flow rate is a function of feed pressure. The feed pressure for the Super Polecat is expected to be approximately 100 psig. The climatic data as well as the tables showing evaporative efficiency and feed pressure vs. flow rate are included in the Piceance Development Project Report (Attachment 4).

Based upon information presented below, high TDS concentrations in the produced water at the PWEP are not expected to impact evaporation rates significantly. Research done by the Office of Saline Water, U.S. Department of the Interior on the feasibility of seawater evaporators, has stated that the heat-transfer performance in these evaporators is comparable with that of pure water (Perry 1984). The Office of Saline Water did extensive research on this topic up to 1972, which is outlined in their Annual Saline Water Conversion Reports. A study on estimating pond evaporation rates in Wyoming for the Wyoming Water Research Center includes limited research on the effects of dissolved constitutes on evaporation rates. In this study, evaporation

7

rates of several different wastewaters including municipal, coal mining, oil shale, uranium, and trona were compared to evaporation rates of tap water in a series of field tests. The wastewaters had varying water qualities with TDS values ranging from 626 to 74,200 mg/L. The results of the field tests show that the wastewaters had evaporation rates both above and below that of the tap water, with no apparent connection to the concentration of TDS in the wastewater (Pochop et al 1985).

3.3 Excess Storage

The PWEP was designed to handle the excess storage of solids that will accumulate as well as the annual peak storage of produced water and precipitation. The design of the evaporation ponds was based upon having approximately 30 years of solids storage capacity while still being able to handle an inflow of 12,000 bpd. The solids volume per year was calculated using the flow rate discussed previously, an average TDS concentration of 16,500 mg/L and a solids density of 67lbs/ft^3. An example of this calculation is contained in Section 1.4 of ExxonMobil's Piceance Development Project Report (Attachment 4). This TDS concentration is based on a composite average of the produced water from existing wells within the Piceance Development Area. Laboratory analyses of the produced water, water from the Love Ranch pond, and from other locations are included in Attachment 7.

4.0 ENVIRONMENTAL

This section discusses the environmental and operator committed safety measures taken by ExxonMobil to ensure that the PWEP will have little or no impact on the surrounding environment.

4.1 Pond Liner

The evaporation ponds will be lined with dual 60 mil high-density polyethylene (HDPE) geomembranes. The geomembrane to be used is GSE HD, which is manufactured by GSE Lining Technology, Inc. Specifications for the liner are included in Attachment 8. This liner meets or exceeds all specifications stated in GRI GM13, which is a set of certification standards used by the Geosynthetic Institute to certify HDPE membranes.

A great deal of research has been done on the durability/lifespan of HDPE geomembranes. Attachment 9 includes a study of a 20-year old HDPE liner used in ponds that hold wastewater for a steam electric generation station located on the northeastern plains of Colorado. Samples of the liner were collected from five ponds that ranged in water quality and exposure characteristics. The study involved testing the old geomembrane using current standards. The results of this study showed that no significant reduction in the physical properties of the membrane had occurred over the 20-year life. The old geomembrane passed most of today's standards except for Oxidative Induction Time (OIT). OIT is a test used to assess the long-term oxidative stability of geomembranes. The OIT test effectively accelerates oxidation of the geomembrane by subjecting it to high temperatures in the presence of oxygen. The time it takes to see significant oxidation in the material is measured and is said to be the OIT. Current standards for oxidation time are 100 and 400 minutes for low-pressure and high-pressure tests, respectively. Oxidation of the geomembrane will result in embrittlement and eventually stress cracking. Resistance to oxidation is usually accomplished with the addition of anti-oxidants to the geomembrane.

The lower OIT values of the 20-year old geomembrane may be attributed to the fact that OIT values that could be expected at the time the membrane was manufactured were about half of today's standards. In addition, technology in this field has improved over the last 20 years, so it is therefore likely that modern geomembranes will last even longer. According to the Environmental Protection Agency's ad hoc committee on HDPE geomembranes, the expected life of similar liners is 100 years or more (Tisinger and Giroud 1993).

4.2   Leak Detection

In order to ensure that the liner has retained its integrity through installation, it will be spark tested prior to being commissioned. Spark testing is a test that uses electrical current to determine if any punctures, tears or holes are present in the geomembrane. In addition, the liner will be configured to incorporate an automatic leak detection system similar to the one shown in Figure 5 of the Onshore Oil and Gas Order No. 7. The top layer of the system will consist of a 60-mil HDPE geomembrane. Directly under

the geomembrane will be a permeable drainage net layer. This layer will provide support to the overlying geomembrane, and will also transmit any leachate down towards the collection pipes. Under the drainage net, two-inch diameter perforated pipes will be in place. These pipes will collect and convey any leachate that might penetrate the top layer of HDPE. The perforated pipes will be installed along the same slope as the pond floor and will drain into riser pipes located along the northeast embankment of each pond. The presence of any leachate in these riser pipes will signal an alarm at the CTF control room and leak investigation will begin immediately. Below the perforated pipes, a second layer of 60-mil HDPE will be used to ensure that no produced water will enter the underlying soil. Figures showing the leak detection system configuration, as well as the cross section of the liner system, are included in Attachment 10.

4.3   Containment Fence

A 9-foot high security fence topped with stranded barbwire will be constructed around the perimeter of the PWEP in order to provide for the safety of wildlife and unauthorized personnel. Entry into the facility will be via several locked gates. A mammal barrier will be an integral part of the fence system and will extend two feet below grade.

4.4   Waterfowl Deterrents

The use of waterfowl deterrent balls will be used at the site to camouflage the pond from passing waterfowl. The balls will be made of HDPE and will be 4 inches in diameter. The balls will cover the entire pond surface. In addition, information has been conveyed to ExxonMobil from other operators having experience with evaporation ponds that the mechanical evaporators themselves will also deter waterfowl.

4.5   Monitoring and Maintenance

A tentative maintenance schedule is shown in Tables 1 and 2 of Attachment 11. Actual monitoring and maintenance schedules will be issued closer to the date of

commissioning of the PWEP. This schedule will reflect the manufacturers' specifications, as well as ExxonMobil's equipment guidelines.

4.6   Overspray

Two automated weather stations will be employed at the site. The stations will record wind direction, wind speed, temperature, barometric pressure, and humidity. Wind direction and speed will dictate which evaporators are operating at any given time. If at any time, the wind speed becomes high enough to risk spray being blown outside of the pit, the weather station will automatically shut the mechanical evaporators down.

To minimize the potential for the evaporators to turn the produced water into snow, which may tend to drift away from the PWEP, the evaporators will not operate when the ambient temperature is below 32 degrees Fahrenheit. In effect, meteorological data collected by the weather stations at the PWEP will dictate the actual operating practices of the mechanical evaporators.

At this time, ExxonMobil does not have enough site-specific climatological data to give specific operating criteria for the evaporators. For example, at what wind speeds will the evaporators be shut down, and what direction or angle will the evaporators be set up to prevent blow over? That type of information will be compiled and analyzed by Exxon/Mobil after the PWEP is put into production, and will become the basis for adjustments to the mechanical evaporation system.

Overspray is not anticipated to cause damage to soils located adjacent to the PWEP facility. As previously discussed, the facility will be managed to stop the mechanical evaporators once the wind velocity exceeds a level that could potentially result in overspray. However, there is a possibility that some degree of overspray onto the land surrounding the PWEP could occur; therefore, ExxonMobil has proposed a monitoring program. ExxonMobil's monitoring program will include the collection of baseline soil samples adjacent to the PWEP prior to construction, followed by periodic monitoring to determine impact. Permanent soil sampling points will be established around the PWEP. These sample locations will either be permanent brass survey caps or defined on record by latitude and longitude points. ExxonMobil plans to collect samples along four quadrant lines leading away from the PWEP as shown in Figure 2.

11

LEGEND

○ 200'	SOIL SAMPLE SITE LOCATION
●➤	PHOTO POINT AND DIRECTION
⊕ 2000'	CONTROL SAMPLE POINT
△	MONITOR WELL LOCATION

EVAPORATION PONDS

WIND DIRECTION FREQUENCY DISTRIBUTION FOR CATHEDRAL BLUFFS, CO.
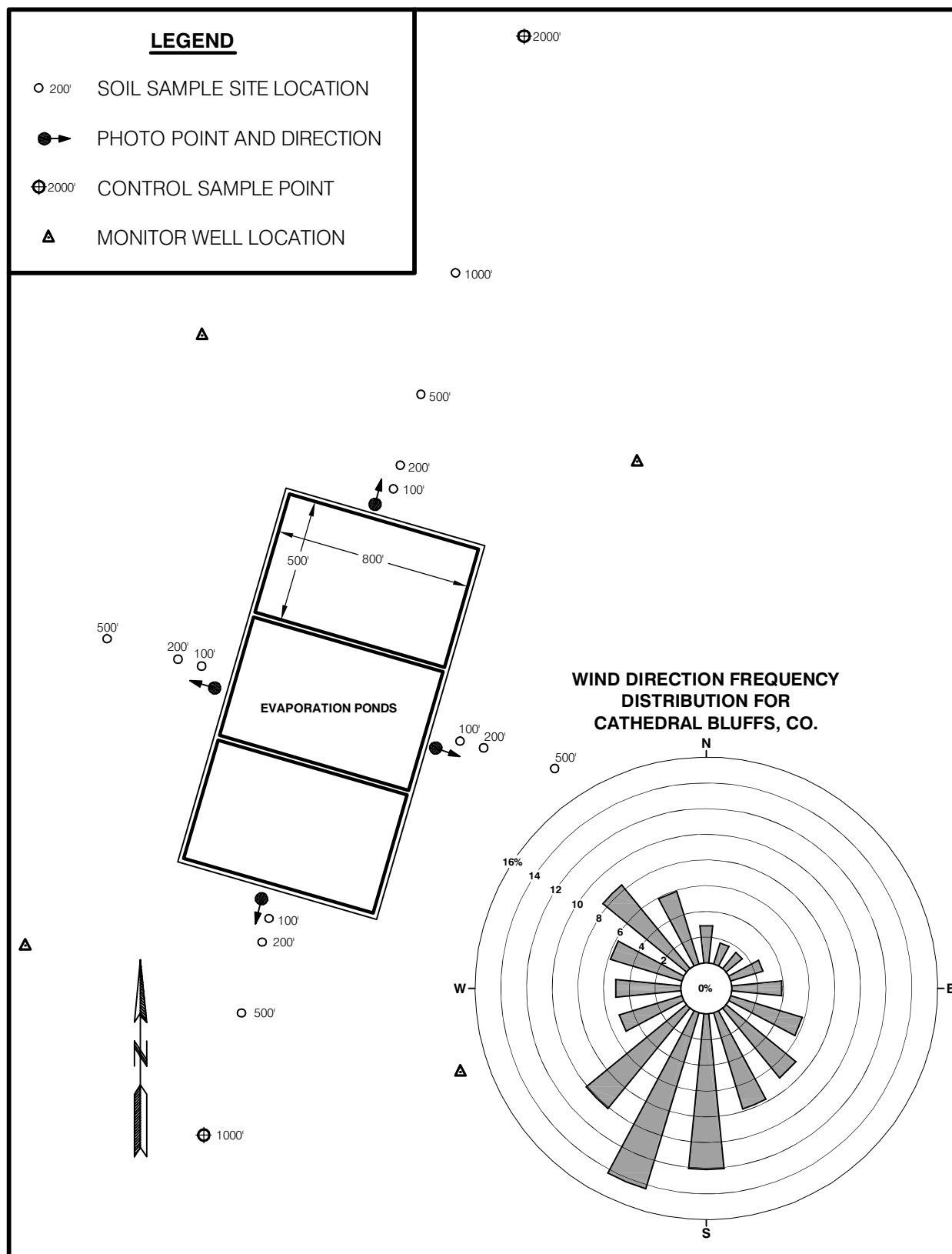
Figure 2. ExxonMobil's Proposed PWEP Monitoring Site Locations.

The quadrants will be oriented with the prevailing wind directions and in line with the pond dimensions. Soils will be sampled along the quadrant lines 100 feet, 200 feet, 500 feet, 1,000 feet, and 2,000 feet from the toe of the berm on the downwind side (the northeast side) of the ponds. Samples on the other three quadrants will be collected 100, 200, and 500 feet from the toe of the berm. An additional sample will be collected on the upwind side (the southwest side) of the ponds, 1,000 feet from the toe of the berm to act as a control point to monitor baseline conditions. The sample collected 2,000 feet from the toe of the berm on the downwind side of the ponds will also act as a control point. Samples will be collected in the vicinity of the established location with the exact locations based on a randomization process.

As described previously, soil samples will be collected to establish baseline conditions and on an annual basis thereafter. At each sampling point, subsamples will be collected from three adjacent sampling points by depth and composited for analysis. Samples will be collected using depth increments as follows: (1) 0 to 3 inches; (2) 3 to 6 inches; and (3) 6 to 12 inches. The composited samples will be thoroughly mixed prior to submittal to the laboratory for analysis.

The parameters analyzed for the baseline analysis are depicted in Table 3. The parameters selected for baseline analysis consist of the constituents identified from a produced water quality sample in addition to the eight metals of concern listed under the Resource Conservation and Recovery Act (RCRA). With the exception of Barium, none of the RCRA metals were detected in a water quality analysis of the produced water. However, the RCRA metals were included within the baseline analysis list because they are metals that are of particular concern under the RCRA and there is a chance, albeit relatively low, that some of these metals may be detected in the produced water at a later date. By including these metals in the baseline sampling list, ExxonMobil will be able to more fully assess any impacts from the proposed PWEP.

Most of the constituents listed on the baseline list either exist in very small concentrations or, in the case of most of the RCRA metals, are not even contained within the produced water. However, of all the constituents within the produced water, concentrations of sodium and chloride are highest. Therefore, sodium and chloride will be used as indicator elements to determine if the surrounding area is being impacted by blowover. As such, the ongoing monitoring program samples will include pH, EC

(indication of soluble salts), soluble calcium, soluble magnesium, soluble sodium, and chloride. Sodium adsorption ratios (SAR) will be calculated from the soluble calcium, soluble magnesium, and soluble sodium levels.

Table 3.   Parameters Within the Soils Sampled to Establish Baseline Conditions.

Parameter	Sampled to Establish Baseline Conditions	Sampled Annually	Parameter	Sampled to Establish Baseline Conditions	Sampled Annually
Sodium	Yes	Yes	Sulfur	Yes	No
Calcium	Yes	Yes	*Barium	Yes	No
Magnesium	Yes	Yes	*Arsenic	Yes	No
pH	Yes	Yes	*Cadmium	Yes	No
EC	Yes	Yes	*Chromium	Yes	No
Chloride	Yes	Yes	*Lead	Yes	No
Carbonates	Yes	No	*Mercury	Yes	No
Boron	Yes	No	*Selenium	Yes	No
Lithium	Yes	No	*Silver	Yes	No
Potassium	Yes	No	TPH	Yes	No
Strontium	Yes	No			

*RCRA metals.

In the event that the annual sampling program indicates that sodium and chloride levels are increasing due to blowover from the PWEP, additional constituents will be analyzed at the locations where increases were noted. The additional constituents analyzed will consist only of the constituents contained within the water being discharged to the PWEP.

The soil monitoring program will provide an indication of whether or not the PWEP is influencing adjacent soils. Soil testing will be conducted on a regular basis to monitor soil condition. If chemical changes occur, additional soil evaluations will be performed to determine whether or not increased SAR and EC levels of the impacted soil will potentially cause a problem. Additional parameters will include soil texture, saturated percentage, cation exchange capacity, and exchangeable sodium percentage. Increases in salt levels, sodium concentrations, or in SAR values do not necessarily indicate soil damage or damage to the plant community occupying the site as described in Attachment 12. Attachment 12 is a literature review that presents

several instances where increased levels of sodium or SAR did not result in soil or vegetation damage. The data collected from ExxonMobil's soil analyses will provide a basis to determine if changes in soil conditions have occurred and will guide adaptive management strategies, if necessary. Threshold limits (documented in the literature) based on the above parameters will be used to assess the suspected level of damage caused by the produced water.

In the event that the monitoring program indicates that overspray is impacting the adjacent soil and/or vegetation, ExxonMobil will adjust the mechanical evaporators to eliminate blow-over. In addition, an appropriate mitigation program will be developed to reclaim the impacted areas and to reduce the potential for future impact. For example, if sodic conditions develop as a result of sodium deposition, gypsum will be applied to the soil surface to provide a soluble source of calcium, which under natural climatic conditions would facilitate the removal of sodium from the soil cation exchange sites, thus eliminating the sodic soil character. Following mitigation, an application of gypsum will be applied to the surface at locations susceptible to overspray to protect soils from developing sodic soil characteristics. This treatment will result in the maintenance of good water movement characteristics of the soil facilitating salt leaching from the root zone. Gypsum of appropriate chemical and physical characteristics will be spread at a rate determined from soil sampling results.

Section 4.6 of this Technical Supplement provides the basis for the soil monitoring program. An appropriate QA/QC program will be developed in conformance with procedures and protocol recommended by the U.S. Department of Agriculture in their soil sampling handbook (NRCS 2005) for sampling and analyzing soil quality.

In conjunction with the soil monitoring program, ExxonMobil proposes to conduct photo monitoring at four separate locations at the PWEP. Photos will be taken at the permanently established photo points once a year, approximately in mid-June. The annual photographs will be used to provide visual documentation of any changes that may occur to the soils and vegetation during the operation of the PWEP. The proposed photo monitoring points are also depicted in Figure 2.

4.7   Monitor Wells

A review of the boring information submitted to the Colorado Oil and Gas Conservation Commission in conjunction with the permit application for the PWEP by ExxonMobil indicates that there is no shallow groundwater at the PWEP down to 30 feet. In addition, data from the wells ExxonMobil intends to use as supply wells to supply freshwater to the CTF indicates that the static water level is over 300 feet below the level of the PWEP. Therefore, it is unlikely that any shallow groundwater exists in the vicinity of the PWEP. However, the BLM was still concerned that there may be perched aquifers near the PWEP that could be impacted in the unlikely event that one of the ponds begins to leak. Therefore, at the request of the BLM, ExxonMobil plans to install monitor wells to assess impacts to any shallow groundwater that may exist within the area.

ExxonMobil is proposing to install four monitor wells approximately 500 feet diagonally from each corner of the PWEP site. The proposed monitor well sites are depicted on Figure 2. This layout was chosen because it maximizes the distance between the proposed monitor wells and the soil sampling locations, which will minimize contamination of the sample locations with drill cuttings. Each well will be drilled to a depth of 100 feet or to the first occurrence of groundwater, whichever is encountered first. If no groundwater is encountered to 100 feet, the well will be completed to a depth of 100 feet. If groundwater is encountered at depths less than 100 feet, the well will be completed within the zone in which groundwater was first encountered.

If groundwater is encountered, ExxonMobil will collect baseline water quality samples and analyze for the same baseline constituents presented in Table 3, as well as the TDS concentration. ExxonMobil will then collect groundwater samples once every five years thereafter and analyze for pH, EC, major anion and cation concentrations, and TDS concentration. Sodium adsorption ratios (SAR) will be calculated from the soluble calcium, magnesium, and sodium levels. In the event that the leak detection system under the PWEP detects a leak, ExxonMobil will collect a sample as soon as possible after the leak is detected. Additional samples will be collected on a yearly basis thereafter until it can shown that there have been no impacts to groundwater due to the leak.

16

If no groundwater is encountered at the time the groundwater monitor wells are drilled, the wells will be checked yearly to determine if there is groundwater present within the wells. In the event that water appears in the wells at a later time and there is adequate depth of water, the water will be sampled and baseline water quality will be established. After that time, the well will then be sampled on the same schedule as the wells in which groundwater was encountered, as described above. In the event that the leak detection system indicates there is a leak in the PWEP, adjacent monitor wells will checked for water as soon as possible after the leak is detected and then on a monthly basis for six months. If no groundwater is detected after six months, the wells will be checked for water on an annual basis again.

4.8   Reclamation

ExxonMobil will reclaim the PWEP facility at the end of its design life. The sediment that has accumulated will be characterized and disposed of in accordance with regulations at the time of decommissioning. The pond embankments will be re-graded and re-vegetated to match the surrounding area.

5.0   CONCLUSIONS

The results of this analysis show that the PWEP facility will be viable for disposal of anticipated produced water volumes from the Piceance Development Area. Considering an average TDS concentration of 16,500 mg/L, the capacity in the ponds will be exhausted in between 29 and 30 years. During the first 20 years, the ponds will operate nowhere near full capacity. The facility will be operated, monitored, and maintained to ensure that the PWEP facility does not adversely affect the surrounding environment. In addition, ExxonMobil has taken the necessary precautions to reduce impacts on wildlife to an acceptable level.

6.0 REFERENCES

Perry, Robert H., 1984, <u>Perry's Chemical Engineers' Handbook</u>. 6th ed. New York: McGraw-Hill, 1984.

Pochop, L., J. Borrelli, and V. Hasfurther, 1984, "Design characteristics for evaporation ponds in Wyoming". Prepared for the Wyoming Water Resource Center, University of Wyoming, Laramie, Wyoming.

Tisinger, L.G., J.P. Giroud, 1993, "The Durability of HDPE Geomembranes" Geotechnical Fabrics Report.

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), 2005, National Soil Survey Handbook, title 430-VI. Available online at website: http://soils.usda.gov/technical/handbook/ .

Western Regional Climate Center (WRCC), 2006, Historical precipitation summaries for the Little Hills (055048) and Meeker Field Stations (055484). Available online at website: http//www.wrcc.dri.edu.

ATTACHMENT 1

PWEP Layout and Cross-Section
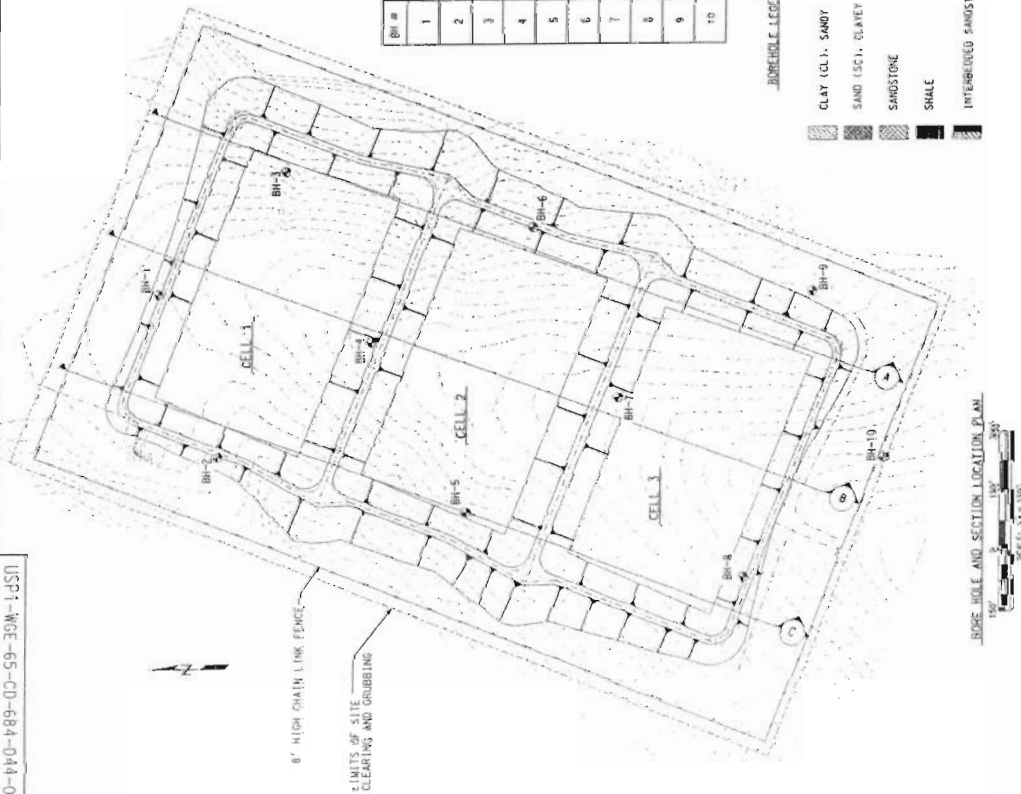
SECTION A
SCALE 1" = 150'
APPROXIMATE SCALE IN FEET (VERTICAL EXAGGERATION = 10)

SECTION B
SCALE 1" = 150'
APPROXIMATE SCALE IN FEET (VERTICAL EXAGGERATION = 10)

SECTION C
SCALE 1" = 150'
APPROXIMATE SCALE IN FEET (VERTICAL EXAGGERATION = 10)

BOREHOLE LEGEND

CLAY (CL), SANDY
SAND (SC), CLAYEY
SANDSTONE
SHALE
INTERBEDDED SANDSTONE / CLAYSTONE

BH #	COORDINATE	
1	N 1,194,471	E 2,214,609
2	N 1,194,383	E 2,214,192
3	N 1,194,153	E 2,214,916
4	N 1,193,940	E 2,214,484
5	N 1,193,764	E 2,214,048
6	N 1,193,535	E 2,214,772
7	N 1,193,322	E 2,214,339
8	N 1,193,004	E 2,213,883
9	N 1,192,834	E 2,214,610
10	N 1,192,653	E 2,214,184

BORE HOLE AND SECTION LOCATION PLAN
SCALE 1" = 500'

8' HIGH CHAIN LINK FENCE

LIMITS OF SITE CLEARING AND GRUBBING

ExxonMobil
Production
U.S. PRODUCTION
Houston, Texas

Washington Group International

EVAPORATION POND
EXPLORATION LOCATION PLAN AND
SUBSURFACE PROFILES

EXXONMOBIL PICEANCE DEVELOPMENT PROJECT

DWG. NO.
USP1-WGE-65-CD-684-044-0004

USP1-WGE-65-CD-684-044-0004

ATTACHMENT 2

Evaporation Pond Area Map
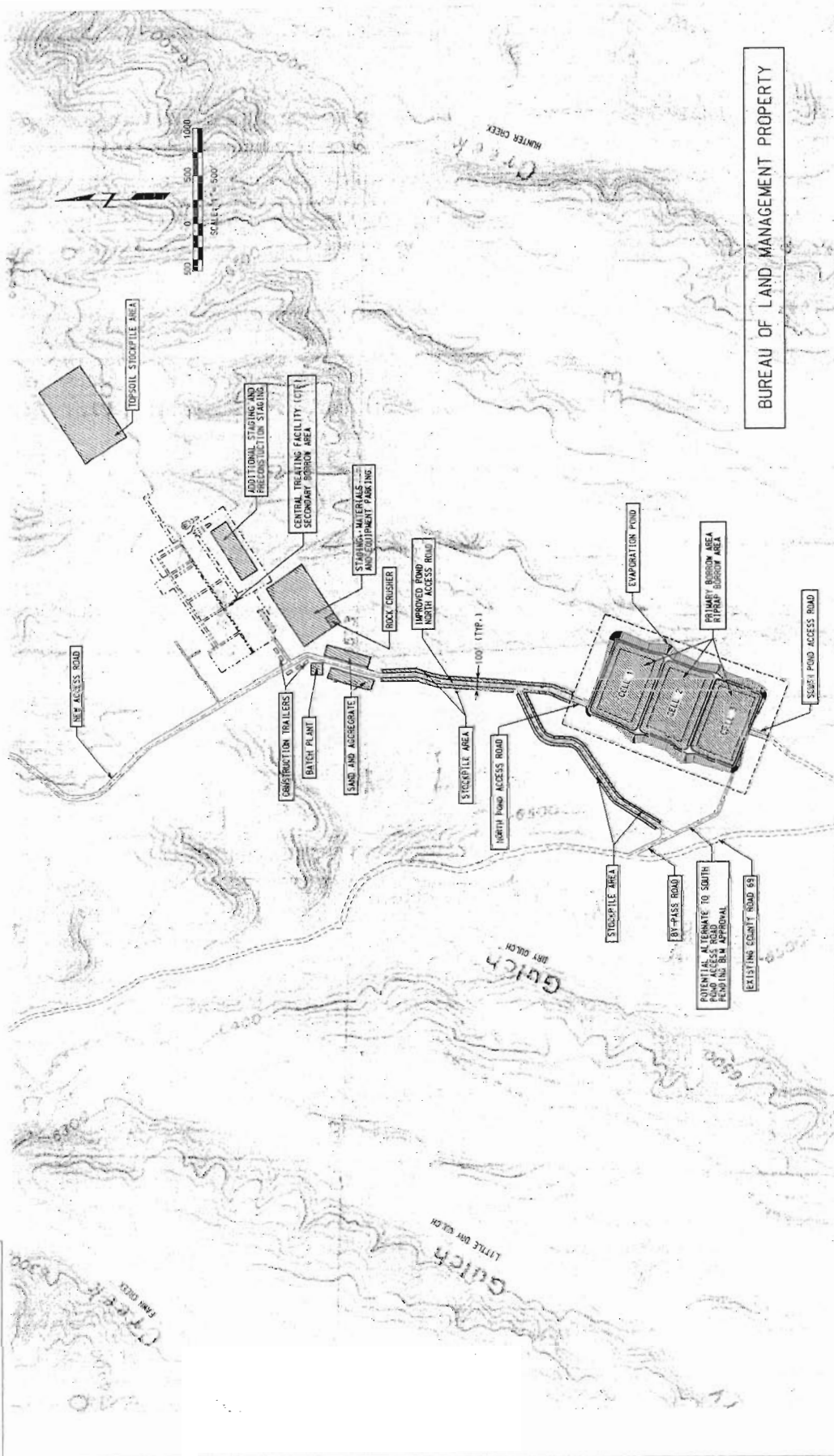
BUREAU OF LAND MANAGEMENT PROPERTY

HUNTER CREEK

GULCH
DRY GULCH

GULCH
LITTLE DRY GULCH

FENN CREEK

SCALE 1" = 500'
500   0   500   1000

TOPSOIL STOCKPILE AREA

ADDITIONAL STAGING AND PRECONSTRUCTION STAGING

CENTRAL TREATING FACILITY (CTF)
SECONDARY BORROW AREA

STAGING, MATERIALS AND EQUIPMENT PARKING

ROCK CRUSHER

IMPROVED POND NORTH ACCESS ROAD

100' (TYP.)

EVAPORATION POND

PRIMARY BORROW AREA
RIPRAP BORROW AREA

CELL 1
CELL 2
CELL 3

SOUTH POND ACCESS ROAD

NEW ACCESS ROAD

CONSTRUCTION TRAILERS

BATCH PLANT

SAND AND AGGREGATE

STOCKPILE AREA

NORTH POND ACCESS ROAD

STOCKPILE AREA

BY-PASS ROAD

POTENTIAL ALTERNATE TO SOUTH POND ACCESS ROAD PENDING BLM APPROVAL

EXISTING COUNTY ROAD 69

ExxonMobil
Production
U.S. PRODUCTION
Houston, Texas

Washington Group International
1800 E. Union Ave. - Denver, CO 80231 - (303) 843-2000

EXXONMOBIL PICEANCE DEVELOPMENT PROJECT

EVAPORATION POND
PROJECT AREA MAP

SHEET 3 OF 19

SEQ NO.

USP1-WGE-65-CO-6B4-044-0003

DISCIPLINE ENG
DISCIPLINE
ARCH.
CIVIL
ELECTRICAL
MECHANICAL
NUCLEAR
PIPING
PROCESS
I & C / IN
STRUCTURAL
GEN. ARRANG.
HVAC

REVISIONS

NOT APPROVED FOR CONSTRUCTION UNLESS SIGNED
ALL PRINTS WEARING CHECKER

ATTACHMENT 3

Monthly Precipitation Data for
Meeker and Little Hills, Colorado Stations

Table. 3   Monthly Precipitation at Meeker and Little Hills precipitation stations

Period of Record : 1/ 1/1900 to 12/31/2005													
Meeker (#055484-2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Total Precipitation (in.)	1.08	1.02	1.32	1.75	1.49	1.2	1.38	1.79	1.55	1.46	1.18	1.14	16.36
Period of Record : 8/ 1/1948 to 9/30/1991													
Little Hills (#055048-2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Total Precipitation (in.)	0.74	0.79	1.24	1.44	1.36	1.11	1.25	1.55	1.17	1.24	0.97	0.95	13.81
Average	0.91	0.905	1.28	1.595	1.425	1.155	1.315	1.67	1.36	1.35	1.075	1.045	15.085

ATTACHMENT 4

Piceance Development Project Report

PICEANCE DEVELOPMENT PROJECT

RIO BLANCO COUNTY, COLORADO

EVAPORATION POND DESIGN BASIS

					EM RVWD	
C	BLM Submittal	TM	MA	IJH		5/23/06
B	Revised for Extended Feed	MDA	BMF	IJH		12/16/05
A	Initial Issue	MDA	BMF	BMF		11/02/05
MARK	**DESCRIPTION**	**BY**	**CHKD**	**APVD**	**EM RVWD**	**DATE**
	REVISIONS					
CLIENT:	ExxonMobil U.S. Production					
PROJECT:	Piceance Development Project					
JOB NO.:	28175-001					
DOC. NO.:	USP1-WGE-00-PB-000-B01-2116					

ExxonMobil
Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	Doc. No.:USP1-WGE-00-PB-B01-2116	
Rev:	C		Page:	2 of 10

TABLE OF CONTENTS

ExxonMobil
Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	**Doc. No.:USP1-WGE-00-PB-B01-2116**	
Rev:	C		**Page:**	3 of 10

1. SCOPE OF WORK

Design an evaporation pond to store the dissolved solids for a period of 30 years. The pond will have minimal, if any, evaporation for 4 months from November 1st through February 28th.

The evaporation system is designed to evaporate the stored and continuously produced water over the remaining 8 months, March 1st through October 31st.

To minimize heat tracing, it is suggested that the piping system be buried or drained and evacuated from November 1st to February 28th. The evaporators would make snow during this period and evaporate some water by sublimation, but it would be a minimal amount.

1.1 Pond Capacity

The pond capacity is based on evaporating 12,000 BPD of produced water, using a water-gas-ratio (WGR) of 80 BBL/MSCF (80 BBL/MSCF x 150 MSCFD = 12,000 BPD).

1.2 Evaporation Efficiency

The evaporation efficiency is calculated at an average of 37%/year (12 month basis) or 55% over the 8 month viable evaporation period. See Section 4.1 for average monthly evaporation efficiency provided by Snow Makers Inc. (SMI), the manufacturer of the "Super Polecat" evaporator.

No additional evaporation has been included from Pan Evaporation. The use of bird deterrent balls, which will cover the water surface, will minimize any Pan Evaporation effects.

1.3 Water Storage Capacity

The water storage capacity was determined using the monthly average evaporation efficiency provided by SMI. Utilizing SMI's evaporation efficiency (see Section 4.1) and the minimum required pump capacity (see Section 6) an iterative calculation was performed.

Adding 12,000 BPD to the pond, circulating at the minimum required rate and using SMI's evaporation efficiencies resulted in a maximum accumulation of approximately 1,440,000 BBL or 8,100,000 ft^3.

Two (2) feet of freeboard is included in the pond design to accommodate rainfall and wave action.

1.4 Sediment Storage Capacity

Based on an average sediment content (TDS = 16,500 mg/l), which is approximately equal to 1.62 wt.% with an average density of 67 lbs./ft^3 then:

- 5 Years Requires – 1,900,000 ft^3 (12,000 BPD x 42 gal/bbl x 8.34 lbs/gal x 1.62 wt% x 365 days/yr x 5 yrs / 67 lbs/ft^3 = 1,900,000 ft^3)

- 15 Years Requires – 5,600,000 ft^3

- 30 Years Requires – 11,200,000 ft^3

ExxonMobil
Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	Doc. No.:USP1-WGE-00-PB-B01-2116
Rev:	C		Page:	4 of 10

Approximately 3 years after the start of the evaporation process the pond will reach saturation and sedimentation will begin to occur.

2. CLIMATIC CONDITIONS

The following climatic conditions were provided to the evaporator vendor (SMI). This information was obtained from the Western Regional Climatic Center located in Reno, NV.

2.1 Average Monthly Climate

The following average monthly conditions were provided to the evaporator vendor for his calculations of the average monthly evaporation rate. These sites are the closest available sites for the information requested.

All information is from Rifle, CO (35 miles SE, elevation 5345 ft) and Meeker, CO (22 miles NE, elevation 6239 ft), with the exception of relative humidity, which came from Grand Junction, CO (57 miles SSW, elevation 4579 ft) and Evaporation Pan Rate, which came from Grand Junction, CO and Montrose, CO (95 miles SSE, elevation 5811 ft).

The evaporation pond will be located at an elevation of approximately 6600 ft on a mesa adjacent to the Piceance Creek valley. The area is relatively flat and arid, no trees, covered in sage brush and not near any large body of water.

- Observations regarding climate data

  ➢ Meeker is colder and windier compared to Rifle

  ➢ Rifle (and Grand Junction) data and Meeker data can be skewed by the Colorado and White river respectively.

  ➢ Evaporation Pan Rate for Grand Junction correlate with relative humidity.

  ➢ The Evaporation Pan Rates at Montrose (800 ft below the plant site elevation) are quite a bit lower than Grand Junction (1300 ft below the plant site elevation).

  ➢ The wind direction in Rifle and Meeker are meaningless. They tend to follow their respective river valley.

ExonMobil
Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	Doc. No.:USP1-WGE-00-PB-B01-2116
Rev:	C		Page: 5 of 10

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Max. Temp, F												
Meeker, CO	36.5	40.4	48.1	58.4	69.1	79	85.6	83.1	75.2	63.7	48.9	37.4
Rifle, CO	36.8	43.8	53.7	64.2	74	84	90.2	87.6	79.4	67.3	51.4	39.4
Avg. Min. Temp, F												
Meeker, CO	6.9	11.6	20.1	28	34.6	40.6	46.9	45.9	37.6	28.1	18.5	9.4
Rifle, CO	9.4	16.5	24.2	31.4	38.7	45.2	52	50.4	41.4	31.1	21.3	12.4
Avg. Wind Speed, MPH												
Meeker, CO	4.2	4.9	5.9	7.3	7.5	7.5	6.5	6.1	6.0	5.4	4.0	3.4
Rifle, CO	3.5	4.5	5.8	7.5	7.3	7.3	6.2	5.5	5.6	5.3	3.8	3.2
Avg. Wind Dir.												
Meeker, CO	NE	NE	NE	NE	NE	NE	NE	ENE	ENE	NE	NE	NE
Rifle, CO	S	S	W	W	W	W	W	W	W	W	S	S

ExxonMobil
Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	Doc. No.:USP1-WGE-00-PB-B01-2116
Rev:	C		Page: 6 of 10

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Relative Humidity, % Grand Junction, CO												
5:00 AM	77	71	63	55	51	44	48	51	52	58	70	76
5:00 PM	50	47	36	27	24	19	22	24	26	33	46	59
Pan Evaporation, in.												
Grand Junction, CO	1.9	2.1	4.3	6.6	9.9	12.5	13.0	11.1	8.2	5.4	2.5	1.3
Montrose, CO	1.7	1.5	3.3	5.7	7.5	9.5	9.0	7.4	5.5	3.5	1.6	1.3

ExxonMobil
Piceance Development Project

Date:	5/23/2005	EVAPORATION POND DESIGN BASIS	Doc. No.:USP1-WGE-00-PB-B01-2116
Rev:	C		Page: 7 of 10

2.2 Average Temperature

The following graphs provide the average temperatures in Rifle, CO and Meeker, CO.
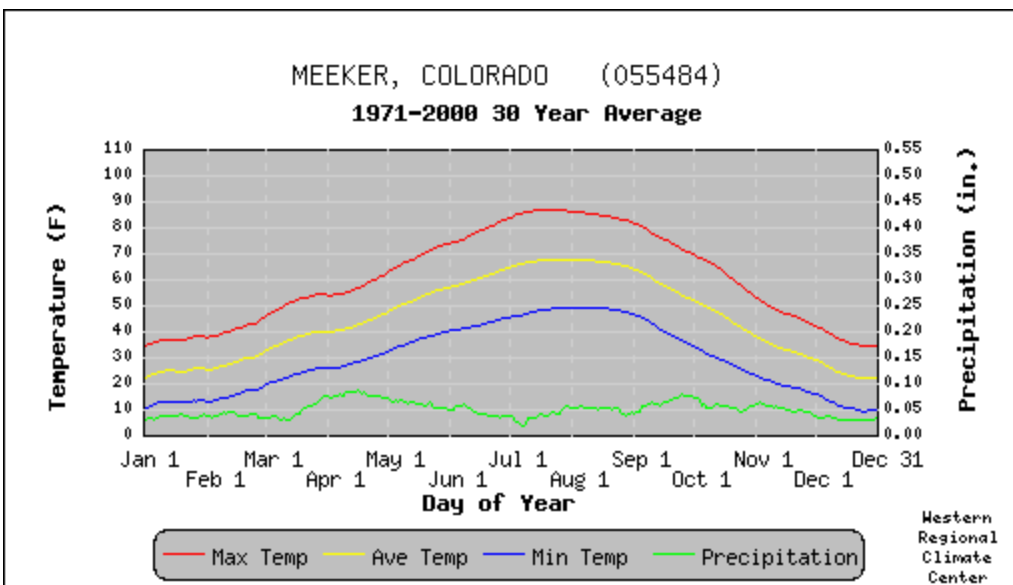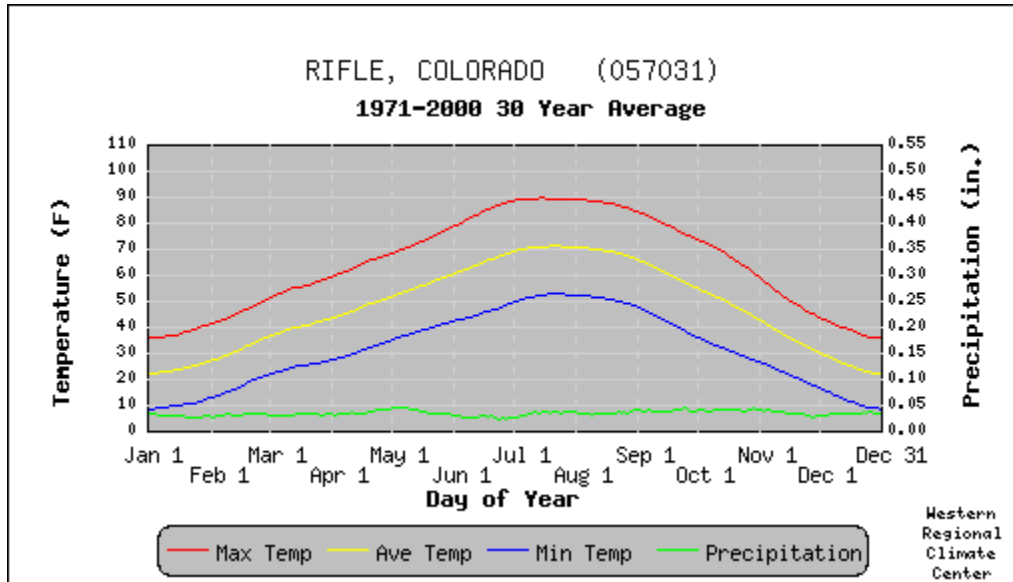
3. SITE CONDITIONS

Elevation: 6600 feet

Atmospheric Pressure: 11.5 psia

The site is flat, no trees and covered with sagebrush. No major bodies of water a near the site.

ExxonMobil
Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	Doc. No.:USP1-WGE-00-PB-B01-2116	
Rev:	C		Page:	8 of 10

4. EVAPORATOR DESIGN INFORMATION

Snow Makers, Inc. (SMI), the manufacturer of the Super Polecat evaporator, provided the following information (it is conservative) based on the supplied climatic conditions. Pan Evaporation Rate is the major component in the evaporation rate calculation.

4.1 Average Monthly Evaporation Efficiency

The average monthly evaporation efficiencies were calculated by SMI based on Climatic Conditions and Site Conditions in Section 2 and Section 3.

Month	Super Polecat Low Pressure (80 -100 psi)	
	% Evaporation	GPM Evaporation
Jan	0%	-
Feb	0%	-
Mar	24%	13.94
Apr	51%	30.25
May	58%	34.40
June	67%	39.74
July	72%	42.70
Aug	60%	35.59
Sept	54%	32.03
Oct	49%	29.06
Nov	0%	-
Dec	0%	-
Average	37%	21.98

If operations are continued through the winter months, some evaporation will occur. In the colder periods snow will be formed and some slight sublimation will occur.

The produced water freezes at approximately 30.5 °F. At the sodium chloride eutectic of 23.3 wt. %, the brine freezes at –6 °F. Mixing 600 gpm of eutectic brine with 350 gpm of produced water results in a solution of about 15 wt. % NaCl which freezes near 12 °F.

350 gpm corresponds to 12,000 BPD of produced water, the 600 gpm is the recycled eutectic solution required to make up the minimum required pumping capacity (see Section 6).

ExxonMobil
Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	Doc. No.:USP1-WGE-00-PB-B01-2116	
Rev:	C		Page:	9 of 10

4.2   Evaporator Spacing

SMI recommends that the spacing between evaporators of about 75 – 100 feet.

4.3   Evaporator Spraying Distance

At zero wind the Super Polecat will throw water droplets 170 to 200 feet from the machine. With an average wind speed of about 7.5 mph the spray will travel about 300 ft. The ponds are 800 ft. x 500 ft. so the particles will be contained.

4.4   Evaporator Water Capacity

The following table provides the water capacity of each Super Polecat evaporator versus the inlet water pressure.

Water Pressure, psig	Water Flow, GPM	
30	42	
40	45.7	
50	49.3	
60	52.8	
70	46.3	
80	59.6	Expected range of pressures and rates based on water supply piping run lengths and size.
90	62.8	
100	65.9	
110	68.9	
120	71.9	
130	74.7	
140	77.5	
150	80.2	
160	82.8	
170	85.4	
180	87.9	
190	90.3	
200	92.7	

ExxonMobil

Piceance Development Project

Date:	5/23/2005	**EVAPORATION POND DESIGN BASIS**	**Doc. No.:USP1-WGE-00-PB-B01-2116**	
Rev:	C		**Page:**	10 of 10

Utilizing fiberglass piping in lieu of HDPE will allow higher operating pressures and the potential reduction of 15 to 30 percent of the required evaporators.

5. POND SIZING

Based on the above calculated evaporation efficiencies the overall average annual efficiency is 37%. The evaporation efficiency from November through February is very low and therefore the pond sizing will be based on storing 4 months of produced water.

5.1 Pond Capacity

The following pond capacities were calculated based on 4 months storage of water during the low periods of evaporation.

Years of Salt Storage	Salt Volume, ft^3	Water Volume, ft^3	Total Volume, ft^3
5 Years	1,900,000	8,100,000	10,000,000
15 Years	5,600,000	8,100,000	13,700,000
30 Years	11,200,000	8,100,000	19,300,000

6. PUMP CAPACITY

Utilizing the monthly average evaporation efficiency provided by SMI it was determined that a constant pumping rate of 946 GPM ((12000 BPD x 42 gal/bbl)/(37% efficiency x 1440 min/day)) was required to evaporate the yearly production of produced water. A safety factor of 25% was added to this rate resulting in 1183 GPM. Three 750 GPM pumps will be provided.

7. EVAPORATORS

The minimum number of evaporators required to evaporate the 12,000 BPD of produced water is 16. This is based on the monthly average evaporation efficiency and an evaporator inlet pressure of 80 – 100 psig.

ATTACHMENT 5

SMI Super Polecat Specifications

Super Polecat Snowmaker

The SMI® Super PoleCat Snowmaker and Snowtower® are SMI's big throw simple nozzle fan snowmaking products that excel in all temperature conditions. The Super PoleCat is offered with a piston or vane compressor or hill air feed, in manual or automatic, and in a variety of custom tower and carriage mounts.
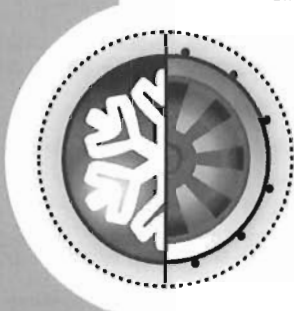
The PoleCats use a 20 or 25 HP (15 – 19 Kw) fan for a big throw and 30 nozzles that you can customize to achieve water flows specific to your climate. These 30 nozzles are nucleated with a single central six jet nucleator nozzle. Water adjustment is easy with four heated self draining valves.

The PoleCat is simple to operate and maintain and an excellent all around performer for all conditions. Another great snowmaking value from SMI.

POLECAT
SNOWMAKER

AUTOMATION ■ ENGINEERING ■ CONSTRUCTION ■ EQUIPMENT

PROJECTED WATER FLOW RATES

■ Gallons per minute

Bank	Nozzles	200 psi	300 psi	400 psi	500 psi
Always On	10x078	22.00	27.00	31.00	35.00
Valve 1	6x078	13.20	16.20	18.60	21.00
Valve 2	4x078	08.80	10.80	12.40	14.00
Valve 3	5x092	19.50	24.00	27.50	30.50
Valve 4	2x092	07.80	09.60	11.00	12.20
	3x125	15.90	19.50	22.50	25.20
Total		87.20	107.10	123.00	137.90

■ Liters per minute

Bank	Nozzles	14 Bar	20 Bar	28 Bar	34 Bar
Always On	10x078	83.30	102.20	117.30	132.50
Valve 1	6x078	50.00	61.30	70.40	79.50
Valve 2	4x078	33.30	40.90	46.90	53.00
Valve 3	5x092	73.80	90.80	104.10	115.40
Valve 4	2x092	29.50	36.30	41.60	46.20
	3x125	60.20	73.60	85.20	95.40
Total		330.10	405.50	465.50	522.00

Super Polecat Snowmaker

TECHNICAL SPECIFICATIONS

- Mount: 10.5' or 15.5' (3.2 m or 4.7 m) tower or 3 wheel painted A-frame carriage or 3 wheel galvanized steel carriage with Snowcat lifting brackets

- Electrical: Three Phase

- Fan: Horsepower: 20 or 25 HP (15 Kw or 19 Kw)
  Fan Speed: 1760 rpm or 1450 rpm
  Propeller: SMI 7 blade aluminum
  Screen: stainless steel

- Compressor: 5 or 10 HP (4 Kw or 7.5 Kw) Piston or Hill Air
  5 or 10 HP (4 Kw or 7.5 Kw) Vane or Hill Air
  20 or 40 cfm at 80 psi if on-board compressor
  60-100 cfm at 80 psi if Hill Air

- Heating: 285 watts
  Optional spray manifold heater 1300 watts
  900 watts additional if Hill Air

- Water Flow: 22-142 gpm (83 - 540 lpm)

- Water Pressure: 100 - 750 psi (7 - 50 Bar)

- Water Connection: Customer's choice

- Valves: Four self draining heated three-way valves

- Nozzles: Always on banks- 10 nozzles, Valve 1 - 6 nozzles, Valve 2 - 4 nozzles, Valve 3 - 5 nozzles, Valve 4 - 5 nozzles, Total - 30 nozzles

- Nucleators: Central Nozzle with six jets

- Filtration System: Stainless steel filter with washable 30 mesh screen

- Electrical Cord: Tower 40 feet (12 meters)
  Carriage 150 feet (46 meters)

- Rotation: 360° horizontal rotation -10° to 60° elevation adjustment

- Oscillator: Optional for tower and galvanized carriage
  70° arc of rotation

SMI Snow Makers
SMI COVERS THE WORLD

Snow Machines, Inc.
1512 Rockwell Drive
Midland, MI 48642
Phone: 989-631-6091
Toll-Free: 1-800-248-6600
Fax: 989-631-3162
Web Site: www.snowmakers.com

ATTACHMENT 6

Proposed Layout for Evaporators

NOTES:
1. SEE DWG. USP1-WGE-65-LD-684-D01-6502 FOR ENLARGED PLAN AT PUMPS, SECTION AT BERM AND TRENCHING & BEDDING DETAILS.

2. EACH POLECAT EVAPORATOR IS SUPPLIED INDEPENDENTLY FROM THE 10" SUPPLY HEADER WITH A 2" AUTOMATIC VALVE.

3. ALL ABOVEGROUND WATER PIPING IS HEAT TRACED AND INSULATED FOR FREEZE PROTECTION.

EVAPORATION POND

EVAPORATION POND

EVAPORATION POND

GRAPHICAL SCALE

SEQ NO.   SHEET P1 OF 2

EVAPORATION PONDS
PIPING PLAN

ExxonMobil
Production
U.S. PRODUCTION
Houston, Texas

Washington Group International
7800 E. Union Ave. - Denver, CO 80237 - (303) 843-2000

EXXONMOBIL PICEANCE DEVELOPMENT PROJECT

DWG. NO.   USP1-WGE-65-LD-D01-6501   REV   B

PROJECT NO.: 261725-001
DRAWN: CHH   DATE: 02/02/06
CHECKED: DATE:
SCALE: 1"=80'-0"

REVISIONS

DISCIPLINE
ARCH.
CIVIL
MECHANICAL
NUCLEAR
ELECTRICAL
PIPING
ENVIRON.
PROCESS
GEN. ARRANG.
QA / QC
STRUCTURAL
HVAC

ATTACHMENT 7

Produced Water Chemistry

Analysis of a Six Water Samples
From ExxonMobil Development Company

By:
J. A. Toups, Jr.

Work by:
J. Toups
I. Goldenberg
W. Vasquez

Intertek Westport Technology Center
6700 Portwest Drive
Houston, Texas 77024
(713) 479 8400
(713) 864-9357 (Fax)
www.westport1.com

Analysis of a Six Water Samples
From ExxonMobil Development Company

INTRODUCTION

At the request of Sabine. C. Zielinger (ExxonMobil Development Company, Houston, Texas), the Intertek Westport Technology Center Drilling Fluids Laboratory conducted an analysis on six submitted water samples. These water samples were submitted from a Colorado drilling operation for ExxonMobil.

CONCLUSIONS

Test results indicate that the submitted water samples are fairly clean. Extremely low levels of petroleum hydrocarbons were detected in all samples (0.002 to 0.007 wt%).

Please see test results in Tables #1 through #5.

Sample Identification

06-080 – one-quart glass jar of fluid, labeled "Sample I, 23-16", received by Westport 2-21-2006.

06-081 – one-quart glass jar of fluid, labeled "Sample II, 68-11, Downstream 23-16, injection pump", received by Westport 2-21-2006.

06-082 – one-quart glass jar of fluid, labeled "Sample IV, B&M Reservoir", received by Westport 2-21-2006.

06-083 – one-quart glass jar of fluid, labeled "Sample V, LR-1, (IDP 4" line, LR6, LR8 & 68-11, 35-11)", received by Westport 2-21-2006.

06-084 – one-quart glass jar of fluid, labeled "Sample VI, Evap. Pond", received by Westport 2-21-2006.

06-085 – one-quart glass jar of fluid, labeled "Sample VII, Little Hills Spring", received by Westport 2-21-2006.

Test Procedure

1. Drilling Fluid Lab water analysis
   a) Description of water samples submitted for testing.
   b) Physical properties of water samples (weight, pH, alkalinities, chlorides, calcium).
   c) Garrett Gas Train analysis for carbonates.
   d) Total Dissolved Solids Test.

2. Geochemistry Lab Analysis
   a) ICP AES Cation Analysis, ASTM D 5185 (concentration of thirty-three metals, 1 ppm detection level).
   b) Ion Chromatography Anion Analysis (concentration of eight anions, 1 ppm detection level).
   c) Total Petroleum Hydrocarbons, EPA 1664 (hexane extraction, gravimetric method).

TEST RESULTS

Table #1 – Drilling Fluid Laboratory Analysis of Submitted Water Samples

ExxonMobil Sample #	I	II	IV	V	VI	VII
Weight, lb/gal	8.40	8.40	8.33	8.43	8.42	8.33
pH	7.24	7.22	8.42	6.74	7.68	7.56
Pf/Mf	0.0/1.5	0.0/1.5	0.05/0.4	0.0/1.2	0.0/1.3	0.0/0.5
Chlorides, mg/L	6500	6500	150	8800	8700	200
Calcium, mg/L	200	200	200	320	240	160
GGT, Carbonates, mg/L	trace	750	trace	trace	1125	500

Description of water samples:

Sample I : slightly cloudy, sewage odor, dirty color.
Sample II: extremely cloudy (black), heavy sewage and hydrocarbon odor.
Sample IV: clear, no odor.
Sample V: light brown, cloudy, slight chemical odor.
Sample VI: dirty yellow-brown, cloudy, dirt odor.
Sample VII: clear, no odor.

Table #2 – Total Dissolved Solids Test of Water Samples

ExxonMobil Sample #	I	II	IV	V	VI	VII
Initial Beaker wt, g.	20.011	19.540	51.899	20.370	21.166	104.432
Beaker + sample, g.	23.945	22.562	112.622	23.273	23.890	152.637
Sample wt, g.	3.934	3.023	60.724	2.903	2.724	48.204
Sample vol, mL	3.901	2.998	60.724	2.871	2.696	48.204
Dried beaker wt, g.	20.063	19.578	51.960	20.419	21.210	104.469
Solids, g.	0.051	0.038	0.062	0.048	0.044	0.037
Solids, wt%	1.304%	1.260%	0.102%	1.667%	1.604%	0.077%

Table #3 – ICP AES Metals Analysis, 1 ppm Detection Level

Sample #	I	II	IV	V	VI	VII
Aluminum, ppm	< 1.0	2.6	< 1.0	1.5	< 1.0	< 1.0
Antimony, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Arsenic, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Barium, ppm	23.0	47.4	< 1.0	40.7	19.7	< 1.0
Berylium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Boron, ppm	13.3	12.2	< 1.0	6.7	9.5	< 1.0
Cadmium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Calcium, ppm	83.1	84.0	36.4	231.8	154.7	81.5
Chromium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cobalt, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Copper, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Iron, ppm	5.9	112.4	< 1.0	29.5	7.6	< 1.0
Lead, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Lithium, ppm	4.0	3.4	< 1.0	3.5	3.6	< 1.0
Magnesium, ppm	12.3	13.5	91.2	22.6	25.3	55.8
Manganese, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Mercury, ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Molybdenium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Nickel, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Phosphorous, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Platinum, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Potassium, ppm	158.2	156.6	5.1	1041	2142	3.3
Selenium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Silicon, ppm	35.4	29.6	< 1.0	64.9	48.5	9.8
Silver, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Sodium, ppm	4696	4920	199.6	6240	4650	< 1.0
Strontium, ppm	17.3	16.8	1.4	27.7	18.6	2.2
Sulfur, ppm	3.4	14.5	163.8	13.0	9.7	96.6
Thallium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Tin, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Titanium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Vanadium, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Zinc, ppm	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

Table #4 – Ion Chromatography Anion Analysis

ExxonMobil Sample #	I	II	IV	V	VI	VII
Bromides, ppm	not det.	not det.	1.0	not det.	not det.	1.8
Chlorides, ppm	9598	7774	22.7	9885	10591	15.9
Nitrates, ppm	not det.	not det.	not det.	not det.	not det.	3.1
Nitrites, ppm	not det.	not det.	not det.	not det.	not det.	not det.
Phosphates, ppm	not det.	not det.	not det.	not det.	not det.	not det.
Sulfates, ppm	not det.	not det.	543.4	not det.	not det.	305.8
Acetate, ppm	66.7	63.3	not det.	97.86	88.4	not det.
Formic Acid, ppm	not det.	not det.	not det.	not det.	not det.	not det.
Acetic Acid, ppm	not det.	not det.	not det.	not det.	not det.	not det.

Not det. = none detected

Table #5 – Total Petroleum Hydrocarbon Analysis

ExxonMobil Sample #	I	II	IV	V	VI	VII
TPH, wt%	0.005	0.005	0.004	0.007	0.004	0.002

Table #6 – Colorado Analysis Guidelines (from ExxonMobil)

Organics in Soil	
TPH Non-sensitive area	10,000 mg/kg
TPH sensitive area	1,000 mg/kg
Organics in Ground Water	
Benzene	5 mg/l
Toluene	1000 mg/l
Ethylbenzene	680 mg/l
Xylene	10,000 mg/l
Inorganics in Groundwater	
Total Dissolved Solids	1.25x background
Chlorides	1.25x background
Sulfates	1.25x background
Inorganics in Soil	
Electrical conductivity	<4 mmhos/cm or 2x background
Sodium adsorption ratio	<12
pH	6-9
Total Metals in Soils	
Arsenic	41 mg/kg
Barium	180,000 mg/kg
Boron	2 mg/l
Cadmium	26 mg/kg
Chromium	1,500 mg/kg
Copper	750 mg/kg
Lead	300 mg/kg
Molybdenum	17 mg/kg
Nickel	210 mg/kg
Silver	100 mg/kg
Zinc	1,400 mg/kg

ACZ Laboratories, Inc.

2773 Downhill Drive   Steamboat Springs, CO 80487   *(800) 334-5493*

August 17, 2006

Report to:

Kent Keller

Exxon Mobil Production Company

4743 County Rd 3

Rifle, CO 81650

Bill to:

Kent Keller

Exxon Mobil Production Company

4743 County Rd 3

Rifle, CO 81650

cc: Gary Holsan, Ray Moores, Steve More, Nate Dieterich, Fernando Blackgoat, Alex Correa

Project ID: 7199

ACZ Project ID: L58270

Kent Keller:

Enclosed are the analytical results for sample(s) submitted to ACZ Laboratories, Inc. (ACZ) on August 15, 2006. This project has been assigned to ACZ's project number, L58270. Please reference this number in all future inquiries.
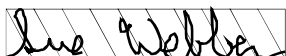
All analyses were performed according to ACZ's Quality Assurance Plan, version 11.0. The enclosed results relate only to the samples received under L58270. Each section of this report has been reviewed and approved by the appropriate Laboratory Supervisor, or a qualified substitute.

Except as noted, the test results for the methods and parameters listed on ACZ's current NELAC certificate letter (#ACZ) meet all requirements of NELAC.

This report shall be used or copied only in its entirety. ACZ is not responsible for the consequences arising from the use of a partial report.

All samples and sub-samples associated with this project will be disposed of after September 17, 2006. If the samples are determined to be hazardous, additional charges apply for disposal (typically less than $10/sample). If you would like the samples to be held longer than ACZ's stated policy or to be returned, please contact your Project Manager or Customer Service Representative for further details and associated costs. ACZ retains analytical reports for five years.

If you have any questions or other needs, please contact your Project Manager.

17/Aug/06

Sue Webber, Project Manager, has reviewed and approved this report in its entirety.

REPAD.01.06.05.01

Exxon Mobil Production Company

Project ID:	7199	
Sample ID:	INLET-A	

ACZ Sample ID: *L58270-01*
Date Sampled: *08/14/06 14:00*
Date Received: *08/15/06*
Sample Matrix: *Waste Water*

Benzene, Toluene, Ethylbenzene & Xylene

Analysis Method: **M8021B GC/PID**
Extract Method:

Workgroup: *WG211255*
Analyst: *ccp*
Extract Date:
Analysis Date: *08/16/06 11:08*

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
Benzene	71-43-2	5260		200	*	ug/L	60	200
Ethylbenzene	100-41-4	580		200	*	ug/L	40	200
m p Xylene	1330 20 7	8550		200	*	ug/L	80	400
o Xylene	95-47- 6	1340		200	*	ug/L	40	200
Toluene	108-88-3	12200		200	*	ug/L	40	200

Surrogate Recoveries	CAS	% Recovery		Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	102.4		200	*	%	83	117

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487   (800) 334-5493

Exxon Mobil Production Company

Project ID:	7199	ACZ Sample ID:	*L58270-01*
Sample ID:	INLET-A	Date Sampled:	*08/14/06 14:00*
		Date Received:	*08/15/06*
		Sample Matrix:	*Waste Water*

Volatile Organics by GC/MS

Analysis Method: **M8260B GC/MS**
Extract Method:

Workgroup: **WG211246**
Analyst: *jj*
Extract Date:
Analysis Date: **08/16/06 18:29**

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
1,1,1,2-Tetrachloroethane	630-20-6		U	200		ug/L	800	2000
1,1,1-Trichloroethane	71-55-6		U	200		ug/L	2000	5000
1,1,2,2-Tetrachloroethane	79-34-5		U	200		ug/L	600	2000
1,1,2-Trichloroethane	79-00-5		U	200		ug/L	800	2000
1,1-Dichloroethane	75-34-3		U	200		ug/L	800	2000
1,1-Dichloroethene	75-35-4		U	200		ug/L	800	2000
1,1-Dichloropropene	563-58-6		U	200		ug/L	800	2000
1,2,3-Trichlorobenzene	87-61-6		U	200		ug/L	800	2000
1,2,3-Trichloropropane	96-18-4		U	200		ug/L	800	2000
1,2,4-Trichlorobenzene	120-82-1		U	200		ug/L	600	2000
1,2,4-Trimethylbenzene	95-63-6	1200	J	200		ug/L	800	2000
1,2-Dibromo-3-chloropropane	96-12-8		U	200		ug/L	800	2000
1,2-Dibromoethane	106-93-4		U	200		ug/L	800	2000
1,2-Dichlorobenzene	95-50-1		U	200		ug/L	800	2000
1,2-Dichloroethane	107-06-2		U	200	*	ug/L	800	2000
1,2-Dichloropropane	78-87-5		U	200		ug/L	800	2000
1,3,5-Trimethylbenzene	108-67-8		U	200		ug/L	800	2000
1,3-Dichlorobenzene	541-73-1		U	200		ug/L	800	2000
1,3-Dichloropropane	142-28-9		U	200		ug/L	800	2000
1,4-Dichlorobenzene	106-46-7		U	200		ug/L	800	2000
2,2-Dichloropropane	594-20-7		U	200		ug/L	800	2000
2-Butanone	78-93-3		U	200	*	ug/L	2000	5000
2-Chloroethyl vinyl ether	110-75-8		U	200	*	ug/L	1000	5000
2-Chlorotoluene	95-49-8		U	200		ug/L	800	2000
2-Hexanone	591-78-6		U	200		ug/L	2000	5000
4-Chlorotoluene	106-43-4		U	200		ug/L	800	2000
4-Isopropyltoluene	99-87-9		U	200		ug/L	800	2000
4-Methyl-2-Pentanone	108-10-1		U	200		ug/L	2000	10000
Acetone	67-64-1		U	200	*	ug/L	2000	5000
Acrylonitrile	107-13-1		U	200	*	ug/L	3000	8000
Benzene	71-43-2	5000		200		ug/L	800	2000
Bromobenzene	108-86-1		U	200		ug/L	800	2000
Bromochloromethane	74-97-5		U	200		ug/L	800	2000
Bromodichloromethane	75-27-4		U	200		ug/L	800	2000
Bromoform	75-25-2		U	200		ug/L	800	2000
Bromomethane	74-83-9		U	200		ug/L	800	2000
Carbon Disulfide	75-15-0		U	200		ug/L	800	2000

REPOR.01.01.01.02   ** Please refer to Qualifier Reports for details*   L58270: Page 3 of 20

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487   (800) 334-5493

Organic Analytical Results

Exxon Mobil Production Company

Project ID:	7199
Sample ID:	INLET-A

ACZ Sample ID: *L58270-01*
Date Sampled: *08/14/06 14:00*
Date Received: *08/15/06*
Sample Matrix: *Waste Water*

Analyte	CAS	Result	Qual		Dilution	Units		
Carbon Tetrachloride	56-23-5		U		200	ug/L	2000	5000
Chlorobenzene	108-90-7		U		200	ug/L	800	2000
Chloroethane	75-00-3		U	*	200	ug/L	800	2000
Chloroform	67-66-3		U		200	ug/L	800	2000
Chloromethane	74-87-3		U		200	ug/L	800	2000
cis-1,2-Dichloroethene	156-59-2		U		200	ug/L	800	2000
cis-1,3-Dichloropropene	10061-01-5		U		200	ug/L	800	2000
Dibromochloromethane	124-48-1		U		200	ug/L	800	2000
Dibromomethane	74-95-3		U		200	ug/L	800	2000
Dichlorodifluoromethane	75-71-8		U		200	ug/L	1000	3000
Ethylbenzene	100-41-4		U		200	ug/L	800	2000
Hexachlorobutadiene	87-68-3		U		200	ug/L	800	2000
Isopropylbenzene	98-82-8	900	J		200	ug/L	800	2000
m,p-Xylene	1330 20 7	7000			200	ug/L	2000	5000
Methyl Tert Butyl Ether	1634-04-4		U		200	ug/L	800	2000
Methylene Chloride	75-09-2		U		200	ug/L	800	2000
Naphthalene	91-20-3		U		200	ug/L	600	2000
n-Butylbenzene	104-51-8		U		200	ug/L	800	2000
n-Propylbenzene	103-65-1		U		200	ug/L	800	2000
o-Xylene	95-47-6	1100	J		200	ug/L	800	2000
sec-Butylbenzene	135-98-8		U		200	ug/L	800	2000
Styrene	100-42-5		U		200	ug/L	800	2000
tert-Butylbenzene	98-06-6		U		200	ug/L	800	2000
Tetrachloroethene	127-18-4		U		200	ug/L	800	2000
Toluene	108-88-3	11600			200	ug/L	800	2000
trans-1,2-Dichloroethene	156-60-5		U		200	ug/L	800	2000
trans-1,3-Dichloropropene	10061-02-6		U		200	ug/L	600	2000
Trichloroethene	79-01-6		U		200	ug/L	1000	3000
Trichlorofluoromethane	75-69-4		U		200	ug/L	800	2000
Vinyl Acetate	108-05-4		U		200	ug/L	800	2000
Vinyl Chloride	75-01-4		U		200	ug/L	800	2000

Surrogate Recoveries	CAS	% Recovery	Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	88.2	200		%	70	130
Dibromofluoromethane	1868-53-7	75.6	200		%	70	130
Toluene-d8	2037-26-5	108.1	200		%	70	130

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487   (800) 334-5493

Exxon Mobil Production Company

Project ID:	7199	ACZ Sample ID:	*L58270-02*
Sample ID:	POND-A	Date Sampled:	*08/14/06 14:30*
		Date Received:	*08/15/06*
		Sample Matrix:	*Waste Water*

Benzene, Toluene, Ethylbenzene & Xylene

Analysis Method: **M8021B GC/PID**
Extract Method:

Workgroup: **WG211164**
Analyst: *ccp*
Extract Date:
Analysis Date: **08/16/06 0:04**

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
Benzene	71-43-2	47.6		1	*	ug/L	0.3	1
Ethylbenzene	100-41-4	7.1		1	*	ug/L	0.2	1
m p Xylene	1330 20 7	107		1	*	ug/L	0.4	2
o Xylene	95-47- 6	18		1	*	ug/L	0.2	1
Toluene	108-88-3	113		1	*	ug/L	0.2	1

Surrogate Recoveries	CAS	% Recovery		Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	116.2		1	*	%	83	117

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487   (800) 334-5493

Organic Analytical Results

Exxon Mobil Production Company

Project ID:	7199
Sample ID:	POND-A

ACZ Sample ID: *L58270-02*
Date Sampled: *08/14/06 14:30*
Date Received: *08/15/06*
Sample Matrix: *Waste Water*

Volatile Organics by GC/MS

Analysis Method: **M8260B GC/MS**
Extract Method:

Workgroup: **WG211246**
Analyst: *jj*
Extract Date:
Analysis Date: **08/16/06 17:17**

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
1,1,1,2-Tetrachloroethane	630-20-6		U	1		ug/L	4	10
1,1,1-Trichloroethane	71-55-6		U	1		ug/L	10	30
1,1,2,2-Tetrachloroethane	79-34-5		U	1		ug/L	3	10
1,1,2-Trichloroethane	79-00-5		U	1		ug/L	4	10
1,1-Dichloroethane	75-34-3		U	1		ug/L	4	10
1,1-Dichloroethene	75-35-4		U	1		ug/L	4	10
1,1-Dichloropropene	563-58-6		U	1		ug/L	4	10
1,2,3-Trichlorobenzene	87-61-6		U	1		ug/L	4	10
1,2,3-Trichloropropane	96-18-4		U	1		ug/L	4	10
1,2,4-Trichlorobenzene	120-82-1		U	1		ug/L	3	10
1,2,4-Trimethylbenzene	95-63-6	27		1		ug/L	4	10
1,2-Dibromo-3-chloropropane	96-12-8		U	1		ug/L	4	10
1,2-Dibromoethane	106-93-4		U	1		ug/L	4	10
1,2-Dichlorobenzene	95-50-1		U	1		ug/L	4	10
1,2-Dichloroethane	107-06-2		U	1	*	ug/L	4	10
1,2-Dichloropropane	78-87-5		U	1		ug/L	4	10
1,3,5-Trimethylbenzene	108-67-8		U	1		ug/L	4	10
1,3-Dichlorobenzene	541-73-1		U	1		ug/L	4	10
1,3-Dichloropropane	142-28-9		U	1		ug/L	4	10
1,4-Dichlorobenzene	106-46-7		U	1		ug/L	4	10
2,2-Dichloropropane	594-20-7		U	1		ug/L	4	10
2-Butanone	78-93-3	20	J	1	*	ug/L	10	30
2-Chloroethyl vinyl ether	110-75-8		U	1	*	ug/L	5	30
2-Chlorotoluene	95-49-8		U	1		ug/L	4	10
2-Hexanone	591-78-6		U	1		ug/L	10	30
4-Chlorotoluene	106-43-4		U	1		ug/L	4	10
4-Isopropyltoluene	99-87-9		U	1		ug/L	4	10
4-Methyl-2-Pentanone	108-10-1		U	1		ug/L	10	50
Acetone	67-64-1	370		1	*	ug/L	10	30
Acrylonitrile	107-13-1		U	1	*	ug/L	20	40
Benzene	71-43-2	45		1		ug/L	4	10
Bromobenzene	108-86-1		U	1		ug/L	4	10
Bromochloromethane	74-97-5		U	1		ug/L	4	10
Bromodichloromethane	75-27-4		U	1		ug/L	4	10
Bromoform	75-25-2		U	1		ug/L	4	10
Bromomethane	74-83-9		U	1		ug/L	4	10
Carbon Disulfide	75-15-0		U	1		ug/L	4	10

REPOR.01.01.01.02   ** Please refer to Qualifier Reports for details*

L58270: Page 6 of 20

Exxon Mobil Production Company

Project ID:	7199	
Sample ID:	POND-A	

ACZ Sample ID: *L58270-02*
Date Sampled: *08/14/06 14:30*
Date Received: *08/15/06*
Sample Matrix: *Waste Water*

Analyte	CAS	Result		XQ	Dil	Units		
Carbon Tetrachloride	56-23-5		U	1		ug/L	10	30
Chlorobenzene	108-90-7		U	1		ug/L	4	10
Chloroethane	75-00-3		U	1	*	ug/L	4	10
Chloroform	67-66-3		U	1		ug/L	4	10
Chloromethane	74-87-3		U	1		ug/L	4	10
cis-1,2-Dichloroethene	156-59-2		U	1		ug/L	4	10
cis-1,3-Dichloropropene	10061-01-5		U	1		ug/L	4	10
Dibromochloromethane	124-48-1		U	1		ug/L	4	10
Dibromomethane	74-95-3		U	1		ug/L	4	10
Dichlorodifluoromethane	75-71-8		U	1		ug/L	5	20
Ethylbenzene	100-41-4	5	J	1		ug/L	4	10
Hexachlorobutadiene	87-68-3		U	1		ug/L	4	10
Isopropylbenzene	98-82-8	18		1		ug/L	4	10
m,p-Xylene	1330 20 7	90		1		ug/L	10	30
Methyl Tert Butyl Ether	1634-04-4		U	1		ug/L	4	10
Methylene Chloride	75-09-2		U	1		ug/L	4	10
Naphthalene	91-20-3	11		1		ug/L	3	10
n-Butylbenzene	104-51-8		U	1		ug/L	4	10
n-Propylbenzene	103-65-1		U	1		ug/L	4	10
o-Xylene	95-47-6	15		1		ug/L	4	10
sec-Butylbenzene	135-98-8		U	1		ug/L	4	10
Styrene	100-42-5		U	1		ug/L	4	10
tert-Butylbenzene	98-06-6		U	1		ug/L	4	10
Tetrachloroethene	127-18-4		U	1		ug/L	4	10
Toluene	108-88-3	114		1		ug/L	4	10
trans-1,2-Dichloroethene	156-60-5		U	1		ug/L	4	10
trans-1,3-Dichloropropene	10061-02-6		U	1		ug/L	3	10
Trichloroethene	79-01-6		U	1		ug/L	5	20
Trichlorofluoromethane	75-69-4		U	1		ug/L	4	10
Vinyl Acetate	108-05-4		U	1		ug/L	4	10
Vinyl Chloride	75-01-4		U	1		ug/L	4	10

Surrogate Recoveries	CAS	% Recovery	Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	98.4	1		%	70	130
Dibromofluoromethane	1868-53-7	110.1	1		%	70	130
Toluene-d8	2037-26-5	104.4	1		%	70	130

Exxon Mobil Production Company

Project ID: 7199
Sample ID: LITTLE HILLS-A

ACZ Sample ID: *L58270-03*
Date Sampled: *08/14/06 15:00*
Date Received: *08/15/06*
Sample Matrix: *Surface Water*

Benzene, Toluene, Ethylbenzene & Xylene

Analysis Method: **M8021B GC/PID**
Extract Method:

Workgroup: **WG211164**
Analyst: *ccp*
Extract Date:
Analysis Date: **08/16/06 1:29**

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
Benzene	71-43-2		U	1		ug/L	0.3	1
Ethylbenzene	100-41-4		U	1		ug/L	0.2	1
m p Xylene	1330 20 7		U	1		ug/L	0.4	2
o Xylene	95-47- 6		U	1		ug/L	0.2	1
Toluene	108-88-3		U	1		ug/L	0.2	1

Surrogate Recoveries	CAS	% Recovery		Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	99		1		%	83	117

Exxon Mobil Production Company

		ACZ Sample ID:	*L58270-03*
Project ID:	7199	Date Sampled:	*08/14/06 15:00*
Sample ID:	LITTLE HILLS-A	Date Received:	*08/15/06*
		Sample Matrix:	*Surface Water*

Volatile Organics by GC/MS

Analysis Method: **M8260B GC/MS**
Extract Method:

Workgroup: **WG211246**
Analyst: *jj*
Extract Date:
Analysis Date: **08/16/06 17:53**

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
1,1,1,2-Tetrachloroethane	630-20-6		U	1		ug/L	4	10
1,1,1-Trichloroethane	71-55-6		U	1		ug/L	10	30
1,1,2,2-Tetrachloroethane	79-34-5		U	1		ug/L	3	10
1,1,2-Trichloroethane	79-00-5		U	1		ug/L	4	10
1,1-Dichloroethane	75-34-3		U	1		ug/L	4	10
1,1-Dichloroethene	75-35-4		U	1		ug/L	4	10
1,1-Dichloropropene	563-58-6		U	1		ug/L	4	10
1,2,3-Trichlorobenzene	87-61-6		U	1		ug/L	4	10
1,2,3-Trichloropropane	96-18-4		U	1		ug/L	4	10
1,2,4-Trichlorobenzene	120-82-1		U	1		ug/L	3	10
1,2,4-Trimethylbenzene	95-63-6		U	1		ug/L	4	10
1,2-Dibromo-3-chloropropane	96-12-8		U	1		ug/L	4	10
1,2-Dibromoethane	106-93-4		U	1		ug/L	4	10
1,2-Dichlorobenzene	95-50-1		U	1		ug/L	4	10
1,2-Dichloroethane	107-06-2		U	1	*	ug/L	4	10
1,2-Dichloropropane	78-87-5		U	1		ug/L	4	10
1,3,5-Trimethylbenzene	108-67-8		U	1		ug/L	4	10
1,3-Dichlorobenzene	541-73-1		U	1		ug/L	4	10
1,3-Dichloropropane	142-28-9		U	1		ug/L	4	10
1,4-Dichlorobenzene	106-46-7		U	1		ug/L	4	10
2,2-Dichloropropane	594-20-7		U	1		ug/L	4	10
2-Butanone	78-93-3		U	1	*	ug/L	10	30
2-Chloroethyl vinyl ether	110-75-8		U	1	*	ug/L	5	30
2-Chlorotoluene	95-49-8		U	1		ug/L	4	10
2-Hexanone	591-78-6		U	1		ug/L	10	30
4-Chlorotoluene	106-43-4		U	1		ug/L	4	10
4-Isopropyltoluene	99-87-9		U	1		ug/L	4	10
4-Methyl-2-Pentanone	108-10-1		U	1		ug/L	10	50
Acetone	67-64-1		U	1	*	ug/L	10	30
Acrylonitrile	107-13-1		U	1	*	ug/L	20	40
Benzene	71-43-2		U	1		ug/L	4	10
Bromobenzene	108-86-1		U	1		ug/L	4	10
Bromochloromethane	74-97-5		U	1		ug/L	4	10
Bromodichloromethane	75-27-4		U	1		ug/L	4	10
Bromoform	75-25-2		U	1		ug/L	4	10
Bromomethane	74-83-9		U	1		ug/L	4	10
Carbon Disulfide	75-15-0		U	1		ug/L	4	10

Exxon Mobil Production Company

Project ID:	7199				ACZ Sample ID:	*L58270-03*	
Sample ID:	LITTLE HILLS-A				Date Sampled:	*08/14/06 15:00*	
					Date Received:	*08/15/06*	
					Sample Matrix:	*Surface Water*	

Carbon Tetrachloride	56-23-5	U	1		ug/L	10	30
Chlorobenzene	108-90-7	U	1		ug/L	4	10
Chloroethane	75-00-3	U	1	*	ug/L	4	10
Chloroform	67-66-3	U	1		ug/L	4	10
Chloromethane	74-87-3	U	1		ug/L	4	10
cis-1,2-Dichloroethene	156-59-2	U	1		ug/L	4	10
cis-1,3-Dichloropropene	10061-01-5	U	1		ug/L	4	10
Dibromochloromethane	124-48-1	U	1		ug/L	4	10
Dibromomethane	74-95-3	U	1		ug/L	4	10
Dichlorodifluoromethane	75-71-8	U	1		ug/L	5	20
Ethylbenzene	100-41-4	U	1		ug/L	4	10
Hexachlorobutadiene	87-68-3	U	1		ug/L	4	10
Isopropylbenzene	98-82-8	U	1		ug/L	4	10
m,p-Xylene	1330 20 7	U	1		ug/L	10	30
Methyl Tert Butyl Ether	1634-04-4	U	1		ug/L	4	10
Methylene Chloride	75-09-2	U	1		ug/L	4	10
Naphthalene	91-20-3	U	1		ug/L	3	10
n-Butylbenzene	104-51-8	U	1		ug/L	4	10
n-Propylbenzene	103-65-1	U	1		ug/L	4	10
o-Xylene	95-47-6	U	1		ug/L	4	10
sec-Butylbenzene	135-98-8	U	1		ug/L	4	10
Styrene	100-42-5	U	1		ug/L	4	10
tert-Butylbenzene	98-06-6	U	1		ug/L	4	10
Tetrachloroethene	127-18-4	U	1		ug/L	4	10
Toluene	108-88-3	U	1		ug/L	4	10
trans-1,2-Dichloroethene	156-60-5	U	1		ug/L	4	10
trans-1,3-Dichloropropene	10061-02-6	U	1		ug/L	3	10
Trichloroethene	79-01-6	U	1		ug/L	5	20
Trichlorofluoromethane	75-69-4	U	1		ug/L	4	10
Vinyl Acetate	108-05-4	U	1		ug/L	4	10
Vinyl Chloride	75-01-4	U	1		ug/L	4	10

Surrogate Recoveries	CAS	% Recovery	Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	103.2	1		%	70	130
Dibromofluoromethane	1868-53-7	91.4	1		%	70	130
Toluene-d8	2037-26-5	98.7	1		%	70	130

ACZ Laboratories, Inc.
2773 Downhill Drive Steamboat Springs, CO 80487   (800) 334-5493

Exxon Mobil Production Company

Project ID:	7199	ACZ Sample ID:	*L58270-04*
Sample ID:	TB081406-01	Date Sampled:	*08/14/06 0:00*
		Date Received:	*08/15/06*
		Sample Matrix:	*Waste Water*

Benzene, Toluene, Ethylbenzene & Xylene

Analysis Method: **M8021B GC/PID**
Extract Method:

Workgroup: **WG211164**
Analyst: *ccp*
Extract Date:
Analysis Date: **08/16/06 2:12**

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
Benzene	71-43-2		U	1		ug/L	0.3	1
Ethylbenzene	100-41-4		U	1		ug/L	0.2	1
m p Xylene	1330 20 7		U	1		ug/L	0.4	2
o Xylene	95-47- 6		U	1		ug/L	0.2	1
Toluene	108-88-3	0.5	J	1		ug/L	0.2	1

Surrogate Recoveries	CAS	% Recovery		Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	102.4		1		%	83	117

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ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487   (800) 334-5493

Exxon Mobil Production Company

Project ID:	7199	ACZ Sample ID:	*L58270-04*
Sample ID:	TB081406-01	Date Sampled:	*08/14/06 0:00*
		Date Received:	*08/15/06*
		Sample Matrix:	*Waste Water*

Volatile Organics by GC/MS

Analysis Method: **M8260B GC/MS**
Extract Method:

Workgroup: **WG211246**
Analyst: *jj*
Extract Date:
Analysis Date: **08/16/06 16:41**

Compound	CAS	Result	QUAL	Dilution	XQ	Units	MDL	PQL
1,1,1,2-Tetrachloroethane	630-20-6		U	1		ug/L	4	10
1,1,1-Trichloroethane	71-55-6		U	1		ug/L	10	30
1,1,2,2-Tetrachloroethane	79-34-5		U	1		ug/L	3	10
1,1,2-Trichloroethane	79-00-5		U	1		ug/L	4	10
1,1-Dichloroethane	75-34-3		U	1		ug/L	4	10
1,1-Dichloroethene	75-35-4		U	1		ug/L	4	10
1,1-Dichloropropene	563-58-6		U	1		ug/L	4	10
1,2,3-Trichlorobenzene	87-61-6		U	1		ug/L	4	10
1,2,3-Trichloropropane	96-18-4		U	1		ug/L	4	10
1,2,4-Trichlorobenzene	120-82-1		U	1		ug/L	3	10
1,2,4-Trimethylbenzene	95-63-6		U	1		ug/L	4	10
1,2-Dibromo-3-chloropropane	96-12-8		U	1		ug/L	4	10
1,2-Dibromoethane	106-93-4		U	1		ug/L	4	10
1,2-Dichlorobenzene	95-50-1		U	1		ug/L	4	10
1,2-Dichloroethane	107-06-2		U	1	*	ug/L	4	10
1,2-Dichloropropane	78-87-5		U	1		ug/L	4	10
1,3,5-Trimethylbenzene	108-67-8		U	1		ug/L	4	10
1,3-Dichlorobenzene	541-73-1		U	1		ug/L	4	10
1,3-Dichloropropane	142-28-9		U	1		ug/L	4	10
1,4-Dichlorobenzene	106-46-7		U	1		ug/L	4	10
2,2-Dichloropropane	594-20-7		U	1		ug/L	4	10
2-Butanone	78-93-3		U	1	*	ug/L	10	30
2-Chloroethyl vinyl ether	110-75-8		U	1	*	ug/L	5	30
2-Chlorotoluene	95-49-8		U	1		ug/L	4	10
2-Hexanone	591-78-6		U	1		ug/L	10	30
4-Chlorotoluene	106-43-4		U	1		ug/L	4	10
4-Isopropyltoluene	99-87-9		U	1		ug/L	4	10
4-Methyl-2-Pentanone	108-10-1		U	1		ug/L	10	50
Acetone	67-64-1		U	1	*	ug/L	10	30
Acrylonitrile	107-13-1		U	1	*	ug/L	20	40
Benzene	71-43-2		U	1		ug/L	4	10
Bromobenzene	108-86-1		U	1		ug/L	4	10
Bromochloromethane	74-97-5		U	1		ug/L	4	10
Bromodichloromethane	75-27-4		U	1		ug/L	4	10
Bromoform	75-25-2		U	1		ug/L	4	10
Bromomethane	74-83-9		U	1		ug/L	4	10
Carbon Disulfide	75-15-0		U	1		ug/L	4	10

REPOR.01.01.01.02   * Please refer to Qualifier Reports for details

Exxon Mobil Production Company

Project ID:	7199				ACZ Sample ID:	*L58270-04*		
Sample ID:	TB081406-01				Date Sampled:	*08/14/06 0:00*		
					Date Received:	*08/15/06*		
					Sample Matrix:	*Waste Water*		

Carbon Tetrachloride	56-23-5		U	1		ug/L	10	30
Chlorobenzene	108-90-7		U	1		ug/L	4	10
Chloroethane	75-00-3		U	1	*	ug/L	4	10
Chloroform	67-66-3		U	1		ug/L	4	10
Chloromethane	74-87-3		U	1		ug/L	4	10
cis-1,2-Dichloroethene	156-59-2		U	1		ug/L	4	10
cis-1,3-Dichloropropene	10061-01-5		U	1		ug/L	4	10
Dibromochloromethane	124-48-1		U	1		ug/L	4	10
Dibromomethane	74-95-3		U	1		ug/L	4	10
Dichlorodifluoromethane	75-71-8		U	1		ug/L	5	20
Ethylbenzene	100-41-4		U	1		ug/L	4	10
Hexachlorobutadiene	87-68-3		U	1		ug/L	4	10
Isopropylbenzene	98-82-8		U	1		ug/L	4	10
m,p-Xylene	1330 20 7		U	1		ug/L	10	30
Methyl Tert Butyl Ether	1634-04-4		U	1		ug/L	4	10
Methylene Chloride	75-09-2		U	1		ug/L	4	10
Naphthalene	91-20-3		U	1		ug/L	3	10
n-Butylbenzene	104-51-8		U	1		ug/L	4	10
n-Propylbenzene	103-65-1		U	1		ug/L	4	10
o-Xylene	95-47-6		U	1		ug/L	4	10
sec-Butylbenzene	135-98-8		U	1		ug/L	4	10
Styrene	100-42-5		U	1		ug/L	4	10
tert-Butylbenzene	98-06-6		U	1		ug/L	4	10
Tetrachloroethene	127-18-4		U	1		ug/L	4	10
Toluene	108-88-3		U	1		ug/L	4	10
trans-1,2-Dichloroethene	156-60-5		U	1		ug/L	4	10
trans-1,3-Dichloropropene	10061-02-6		U	1		ug/L	3	10
Trichloroethene	79-01-6		U	1		ug/L	5	20
Trichlorofluoromethane	75-69-4		U	1		ug/L	4	10
Vinyl Acetate	108-05-4		U	1		ug/L	4	10
Vinyl Chloride	75-01-4		U	1		ug/L	4	10

Surrogate Recoveries	CAS	% Recovery	Dilution	XQ	Units	LCL	UCL
Bromofluorobenzene	460-00-4	93.7	1		%	70	130
Dibromofluoromethane	1868-53-7	106.3	1		%	70	130
Toluene-d8	2037-26-5	108.4	1		%	70	130

REPOR.01.01.01.02   *Please refer to Qualifier Reports for details*

Report Header Explanations

Batch	A distinct set of samples analyzed at a specific time
Found	Value of the QC Type of interest
Limit	Upper limit for RPD, in %.
Lower	Lower Recovery Limit, in % (except for LCSS, mg/Kg)
LCL	Lower Control Limit
MDL	Method Detection Limit. Same as Minimum Reporting Limit. Allows for instrument and annual fluctuations.
PCN/SCN	A number assigned to reagents/standards to trace to the manufacturer's certificate of analysis
PQL	Practical Quantitation Limit
QC	True Value of the Control Sample or the amount added to the Spike
Rec	Amount of the true value or spike added recovered, in % (except for LCSS, mg/Kg)
RPD	Relative Percent Difference, calculation used for Duplicate QC Types
Upper	Upper Recovery Limit, in % (except for LCSS, mg/Kg)
UCL	Upper Control Limit
Sample	Value of the Sample of interest

QC Sample Types

SURR	Surrogate		*LFM*	Laboratory Fortified Matrix
INTS	Internal Standard		*LFMD*	Laboratory Fortified Matrix Duplicate
DUP	Sample Duplicate		*LRB*	Laboratory Reagent Blank
LCSS	Laboratory Control Sample - Soil		*MS/MSD*	Matrix Spike/Matrix Spike Duplicate
LCSW	Laboratory Control Sample - Water		*PBS*	Prep Blank - Soil
LFB	Laboratory Fortified Blank		*PBW*	Prep Blank - Water

QC Sample Type Explanations

Blanks	Verifies that there is no or minimal contamination in the prep method procedure.
Control Samples	Verifies the accuracy of the method, including the prep procedure.
Duplicates	Verifies the precision of the instrument and/or method.
Spikes/Fortified Matrix	Determines sample matrix interferences, if any.

ACZ Qualifiers (Qual)

B	Analyte detected in daily blank
H	Analysis exceeded method hold time.
J	Analyte concentration detected at a value between MDL and PQL
R	Poor spike recovery accepted because the other spike in the set fell within the given limits.
T	High Relative Percent Difference (RPD) accepted because sample concentrations are less than 10x the MDL.
U	Analyte was analyzed for but not detected at the indicated MDL
V	High blank data accepted because sample concentration is 10 times higher than blank concentration
W	Poor recovery for Silver quality control is accepted because Silver often precipitates with Chloride.
X	Quality contreol sample is out of control.
Z	Poor spike recovery is accepted because sample concentration is four times greater than spike concentration.
P	Analyte concentration differs from second detector by more than 40%.
E	Analyte concentration is estimated due to result exceeding calibration range.
M	Analyte concentration is estimated due to matrix interferences.

Method References

(1)	EPA 600/4-83-020. Methods for Chemical Analysis of Water and Wastes, March 1983.
(2)	EPA 600/4-90/020. Methods for the Determination of Organic Compounds in Drinking Water (I), July 1990.
(3)	EPA 600/R-92/129. Methods for the Determination of Organic Compounds in Drinking Water (II), July 1990.
(5)	EPA SW-846. Test Methods for Evaluating Solid Waste, Third Edition with Update III, December, 1996.
(6)	Standard Methods for the Examination of Water and Wastewater, 19th edition, 1995.

Comments

(1)	QC results calculated from raw data. Results may vary slightly if the rounded values are used in the calculations.
(2)	Organic analyses are reported on an "as received" basis.

REPIN03.11.00.01

Exxon Mobil Production Company   ACZ Project ID: *L58270*

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L58270-01	WG211255	*All Compounds*	M8021B GC/PID	Q3	Sample received with improper chemical preservation.
	WG211246	1,2-Dichloroethane	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		2-Butanone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		2-Chloroethyl vinyl ether	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		Acetone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		Acrylonitrile	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		Chloroethane	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
L58270-02	WG211164	*All Compounds*	M8021B GC/PID	Q3	Sample received with improper chemical preservation.
	WG211246	1,2-Dichloroethane	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		2-Butanone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		2-Chloroethyl vinyl ether	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		Acetone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		Acrylonitrile	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		Chloroethane	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
L58270-03	WG211246	1,2-Dichloroethane	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		2-Butanone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		2-Chloroethyl vinyl ether	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		Acetone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		Acrylonitrile	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		Chloroethane	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
L58270-04	WG211246	1,2-Dichloroethane	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		2-Butanone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		2-Chloroethyl vinyl ether	M8260B GC/MS	M2	Matrix spike recovery was low, the method control sample recovery was acceptable.
		Acetone	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.
		Acrylonitrile	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.

REPAD.15.06.05.01

Exxon Mobil Production Company

ACZ Project ID: *L58270*

ACZ ID	WORKNUM	PARAMETER	METHOD	QUAL	DESCRIPTION
L58270-04	WG211246	Chloroethane	M8260B GC/MS	W2	The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8260B / 8270C.

No certification qualifiers associated with this analysis

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487 (800) 334-5493

Exxon Mobil Production Company

7199

ACZ Project ID:	L58270
Date Received:	8/15/2006
Received By:	
Date Printed:	8/15/2006

Receipt Verification

	YES	NO	NA
1) Does this project require special handling procedures such as CLP protocol?			X
2) Are the custody seals on the cooler intact?			X
3) Are the custody seals on the sample containers intact?			X
4) Is there a Chain of Custody or other directive shipping papers present?	X		
5) Is the Chain of Custody complete?	X		
6) Is the Chain of Custody in agreement with the samples received?	X		
7) Is there enough sample for all requested analyses?	X		
8) Are all samples within holding times for requested analyses?	X		
9) Were all sample containers received intact?	X		
10) Are the temperature blanks present?			X
11) Are the trip blanks (VOA and/or Cyanide) present?			X
12) Are samples requiring no headspace, headspace free?		X	
13) Do the samples that require a Foreign Soils Permit have one?			X

Exceptions: If you answered no to any of the above questions, please describe

All of the vials for sample #1 contain headspace.

Contact (For any discrepancies, the client must be contacted)

The client was not contacted.

Shipping Containers

Cooler Id		Temp (°C)	Rad (µR/hr)
walkin		11.8	14

Client must contact ACZ Project Manager if analysis should not proceed for samples received outside of thermal preservation acceptance criteria.

Notes

Samples were hand delivered on ice.

REPAD.03.11.00.01

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487 (800) 334-5493

Sample Receipt

Exxon Mobil Production Company
7199

Sample Container Preservation

SAMPLE	CLIENT ID	R < 2	G < 2	BK < 2	Y < 2	YG< 2	B< 2	O < 2	T >12	N/A	RAD	ID
L58270-01	INLET-A									X		☐
L58270-02	POND-A									X		☐
L58270-03	LITTLE HILLS-A									X		☐
L58270-04	TB081406-01									X		☐

Sample Container Preservation Legend

Abbreviation	Description	Container Type	Preservative/Limits
R	Raw/Nitric	RED	pH must be < 2
B	Filtered/Sulfuric	BLUE	pH must be < 2
BK	Filtered/Nitric	BLACK	pH must be < 2
G	Filtered/Nitric	GREEN	pH must be < 2
O	Raw/Sulfuric	ORANGE	pH must be < 2
P	Raw/NaOH	PURPLE	pH must be > 12 *
T	Raw/NaOH Zinc Acetate	TAN	pH must be > 12
Y	Raw/Sulfuric	YELLOW	pH must be < 2
YG	Raw/Sulfuric	YELLOW GLASS	pH must be < 2
N/A	No preservative needed	Not applicable	
RAD	Gamma/Beta dose rate	Not applicable	must be < 250 µR/hr

* pH check performed by analyst prior to sample preparation

Sample IDs Reviewed By: _____

REPAD.03.11.00.01

ACZ Laboratories, Inc.

2773 Downhill Drive Steamboat Springs, CO 80487 (800) 334-5493

CHAIN of CUSTODY

Report to:

Name: Fernando	Address:
Company: Exxon Mobil	
E-mail:	Telephone:

Copy of Report to:

| Name: | E-mail: |
| Company: | Telephone: |

Invoice to:

Name: Fernando –	Address:
Company: Exxon Mobil	
E-mail:	Telephone:

If sample(s) received past holding time (HT), or if insufficient HT remains to complete   **YES** ☐
analysis before expiration, shall ACZ proceed with requested short HT analyses?   **NO** ☐
If "NO" then ACZ will contact client for further instruction. If neither "YES" nor "NO"
is indicated, ACZ will proceed with the requested analyses, even if HT is expired, and data will be qualified.

PROJECT INFORMATION

ANALYSES REQUESTED *(attach list or use quote number)*

| Quote #: |
| Project/PO #: 7199 |
| Reporting state for compliance testing: — |
| Sampler's Name: Bob |
| Are any samples NRC licensable material? |

SAMPLE IDENTIFICATION	DATE:TIME	Matrix	# of Containers	BTEX	8260	See Tim					
Inlet-A	8/14/06 2:00	WW	6	X	X	⟲					
Pond-A	2:30	WW	6	X	X						
Little Hills-A	7:00	SW	6	X	X						
Inlet-B	2:00	WW	4								
Pond-B	2:30	WW	4	HOLD							
Little Hills-B	7:00	SW	4								

Matrix   SW (Surface Water) · GW (Ground Water) · WW (Waste Water) · DW (Drinking Water) · SL (Sludge) · SO (Soil) · OL (Oil) · Other (Specify)

REMARKS

"A" Samples – Super Rush – See Tim

Please refer to ACZ's terms & conditions located on the reverse side of this COC.

RELINQUISHED BY:	DATE:TIME	RECEIVED BY:	DATE:TIME
(Robert) Return	8/15/06 8:12	LEG	8.15.06 8:30

FRMAD050.03.05.02   White - Return with sample.   Yellow - Retain for your records.

ATTACHMENT 8

Liner Specifications

GSE HD is a smooth, high quality, high density polyethylene (HDPE) geomembrane produced from specially formulated, virgin polyethylene resin. This polyethylene resin is designed specifically for flexible geomembrane applications. It contains approximately 97.5% polyethylene, 2.5% carbon black and trace amounts of antioxidants and heat stabilizers; no other additives, fillers or extenders are used. GSE HD has outstanding chemical resistance, mechanical properties, environmental stress crack resistance, dimensional stability and thermal aging characteristics. GSE HD has excellent resistance to UV radiation and is suitable for exposed conditions. *These product specifications meet or exceed GRI GM13.*

Product Specifications

TESTED PROPERTY	TEST METHOD	FREQUENCY	MINIMUM VALUE				
Product Code			HDE 030A000	HDE 040A000	HDE 060A000	HDE 080A000	HDE 100A000
Thickness, mil (mm) or per project specs	ASTM D 5199	every roll	27 (0.69)	36 (0.91)	54 (1.4)	72 (1.8)	90 (2.3)
Density, g/cm³	ASTM D 1505	200,000 lb	0.94	0.94	0.94	0.94	0.94
Tensile Properties (each direction)	ASTM D 6693, Type IV	20,000 lb					
Strength at Break, lb/in-width (N/mm)	Dumbell, 2 ipm		122 (21)	162 (28)	243 (43)	324 (57)	405 (71)
Strength at Yield, lb/in-width (N/mm)			63 (11)	84 (15)	130 (23)	173 (30)	216 (38)
Elongation at Break, %	G.L. 2.0 in (51 mm)		700	700	700	700	700
Elongation at Yield, %	G.L. 1.3 in (33 mm)		13	13	13	13	13
Tear Resistance, lb (N)	ASTM D 1004	45,000 lb	21 (93)	28 (125)	42 (187)	56 (249)	70 (311)
Puncture Resistance, lb (N)	ASTM D 4833	45,000 lb	59 (263)	79 (352)	119 (530)	158 (703)	180 (800)
Carbon Black Content, %	ASTM D 1603	20,000 lb	2.0	2.0	2.0	2.0	2.0
Carbon Black Dispersion	ASTM D 5596	45,000 lb	+Note 1	+Note 1	+Note 1	+Note 1	+Note 1
Notched Constant Tensile Load, hrs	ASTM D 5397, Appendix	200,000 lb	400	400	400	400	400
REFERENCE PROPERTY	**TEST METHOD**	**FREQUENCY**	**NOMINAL VALUE**				
Oxidative Induction Time, minutes	ASTM D 3895, 200° C; O₂, 1 atm	200,000 lb	>100	>100	>100	>100	>100
Roll Length (approximate), ft (m)			1,120 (341)	870 (265)	560 (171)	430 (131)	340 (104)
Roll Width, ft (m)			22.5 (6.9)	22.5 (6.9)	22.5 (6.9)	22.5 (6.9)	22.5 (6.9)
Roll Area, ft² (m²)			25,200 (2,341)	19,575 (1,819)	12,600 (1,171)	9,675 (899)	7,650 (711)

NOTES:

- +Note 1: Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.

- GSE HD is available in rolls weighing about 3,900 lb (1,769 kg).

- All GSE geomembranes have dimensional stability of ±2% when tested with ASTM D 1204 and LTB of <-77° C when tested with ASTM D 746.

DS005 R12/08/04

This product data sheet is also available on our website at:

www.gseworld.com

ATTACHMENT 9

Study of 20-Year-Old Pond Liner

HDPE geomembrane
after 20 years of service

Testing reveals that most physical properties of 20-year-old pond liner pass today's requirements.

The following is a study of high-density polyethylene (HDPE) geomembrane lining material that was installed in Colorado, United States. Specifically, the geomembrane is a 100-mil (2.5-mm) HDPE smooth geomembrane. This geomembrane was produced using a non-continuous indexing roller manufacturing process. The continuous extrusion process widely available today was not in widespread use at the time the material was manufactured. The material was installed by SLT North America Inc., now GSE Lining Technology.

This material was used to line eight containment ponds at a steam electric generating station on the northeastern plains of Colorado, elevation 4,300 ft. (1,311 m). Currently plans are being developed to re-

furbish these ponds. Testing was performed to determine the effect of 20 years of service life. Remarkably, the testing showed that with very few exceptions such as Oxidative Induction Time (OIT) and some individual NCTL specimens, all other physical properties pass today's requirements.

Background

An HDPE geomembrane was chosen to line each of eight containment ponds at a 500 MW steam electric generating station. Two of these ponds contain high quality water for recycling back into the plant systems. They are 21 ft. (6.4 m) deep and relatively small (0.75 and 1.5 acres). Three of the ponds are intermediate quality (IQ) ponds that contain cooling tower blow-down water.

One of these ponds is 21 ft. (6.4 m) deep with top dimensions of 430 x 380 ft. (131.1 x 115.8 m) with 3:1 side slopes. Water level in this pond varies from 5 to 18 ft. (1.5 to 5.5 m). The water has a pH of 8^{10}. Total dissolved solids are about 25,000 mg/l and are comprised of sodium (5000 mg/l), chlorides (1,000 mg/l), calcium (700 mg/l) and sulfates (15,000 mg/l) among other elements. This is the pond that was sampled for the study. The other two ponds are used for bottom ash recovery. The first of these ponds is 1015 x 877 ft. (309.4 x 267.3 m) with a depth of 23 ft. (7 m). The second of these ponds is 410 x 100 ft. (125 x 30.5 m) with a depth of 12 ft. (3.6 m). Sample material was removed at the area of a weld in each of three different locations. By removing the

Table 1. Physical property comparison of current GRI-GM13 requirements vs. aged samples.

Property	Test Method	Units	GM 13	IQ Ponds		Evaporation Ponds	
				Exposed	Unexposed	Exposed	Unexposed
Density	ASTM D 1505	g/cc	0.940	0.947	0.947	0.947	0.945
Tensile Properties	ASTM D 638						
Yield Strength	Type IV	ppi	210	240	248	229	263
Break Strength	2 in./min	ppi	280	399	428	349	400
Yield Elongation		%	12	17	16	18	18
Break Elongation		%	700	962	1011	865	866
Tear	ASTM D 1004	b_r	70	81	79	84	*
Puncture	ASTM D 4833	b_c	180	196	216	207	*
Carbon Black	ASTM D 1603	%	2	2.3	2.3	2.2	2.1
OIT (low pressure)	ASTM D 3895	minutes	100	37	38	36	35
OIT (high pressure)	ASTM D 5885	minutes	400	242	289	263	249
SP NCTL	ASTM D 5397	hours	200	448	318	>469	*

Individuals for SP NCTL	Exposed (hours)	Unexposed (hours)
IQ 1W	352, 419	116, 172, 385, 406, 418
IQ 1E	405, 369, 421, 541, 515	142, 261, 243, 552, 487
IQ 2E	508, 508	*
EP C1	267, 451	*
EP C2	320, 249, >667, >667, >667	*

Individual Specimens for OIT (minutes)	Exposed		Unexposed	
	High Pressure	Low Pressure	High Pressure	Low Pressure
IQ 1W	313	27	283	27
IQ 1E	276	49	293	47
IQ 2E	137	36	151	39
EP C1	269	33	232	33
EP C2	257	38	265	37

By Nathan Ivy

material at the site of a weld, one can test properties of both the exposed and the unexposed geomembrane, i.e., the material that comprises the overlap for the bottom of the weld has not been exposed to UV radiation. Material was sampled from the side slopes and labeled as follows:

- IQ-1E – East above water level
- IQ-2E – East intermittent water coverage
- IQ-1W – West above water level

The other three ponds are evaporation ponds. These ponds take all waste from the plant, mostly brine waste from the brine concentrators. As expected, dissolved solids are very high in these ponds. Two of these are 14-acre (5.67-ha) ponds and the other is 10 acres (4 ha) (the one that was sampled). The 10-acre (4-ha) pond and one of the 14-acre (5.67-ha) ponds are 10 ft. (3 m) deep from the bottom of the liner to the top of the dike. They have 1 ft. (0.3 m) of sand on the bottom that was placed when the liner was installed. Both now have 4 ft. (1.2 m) of salt sludge in them. Raising the sides of the pond recently expanded the third pond by 6 ft. (1.8 m). Samples were taken as from the 10-acre (4-ha) evaporation pond 'C' and labeled as follows:

- EP-C1 – South side above water level
- EP-C2 – West side above water level

Performance

The geomembrane was manufactured in 1980. At that time, the following tests were performed:

- Density — ASTM D 792
- Tensile strength — ASTM D 638, Type IV, 2 ipm (51 mm/min.)
- Tensile elongation — ASTM D 638, Type IV
- Carbon black content — ASTM D 1603

In June 2000, samples of this material were removed and the testing above was performed. The specimens from the three intermediate quality ponds have been averaged together, as have the two specimens from the evaporation ponds for simplification of reporting. For the more critical durability tests such as OIT and NCTL, the individual data are also presented. Unfortunately, the QA/QC certs for this ma-

terial have been lost throughout the years so the original 1980 test data are not included in the tables. Additional testing, not yet part of routine QA/QC testing some 20 years ago was also performed on this geomembrane. This testing includes:

- Oxidative induction time — ASTM D 3895 (low pressure)
- Oxidative induction time — ASTM D 5885 (high pressure)
- NCTL – ASTM D 5397
- Puncture resistance — ASTM D 4833
- Tear resistance — ASTM D 1004

Table 1 contains the actual test values for exposed material, unexposed material and the current GRI-GM 13 requirements for the above tests. For each of the specimens mentioned previously, samples were tested from two areas for each of the 5 specimens. These samples were taken at the site of a fusion weld, including about 1 ft. of exposed material and at least 6 in. of unexposed material. As part of routine fusion welding for this project, the geomembrane was overlapped at least 6 in. The flap that is on bottom as the two pieces are overlain and welded is not exposed to either the solution in the pond or to UV radiation from the sun. The flap that is on top as the pieces are welded is exposed to both the pond solution and UV radiation (when the water level is down). These

samples are labeled in the table as simply exposed and unexposed. The testing for the exposed portion was tested using five replicates for machine and cross direction (where applicable). For the unexposed portion, two specimens were tested. The reason for the variability is that the unexposed flap was narrower in many instances and thus there was less material to test. In order to test as many aspects as possible, the number of specimens per test was reduced.

Analysis

Density

There is no apparent change in density. The colored density of 0.945–0.947 g/cc is

Photo 1. Three of the eight lined containment ponds: An evaporation pond is pictured on the left side of the photo, while two intermediate quality ponds are visible on the right.

Photo 2. Desiccated soil can be seen beneath a liner sample taken above the water line (an exposed sample).

Photo 3. A sample taken from an area with intermediate water coverage. The soil is more supple (not desiccated) as can be seen by the footprints.
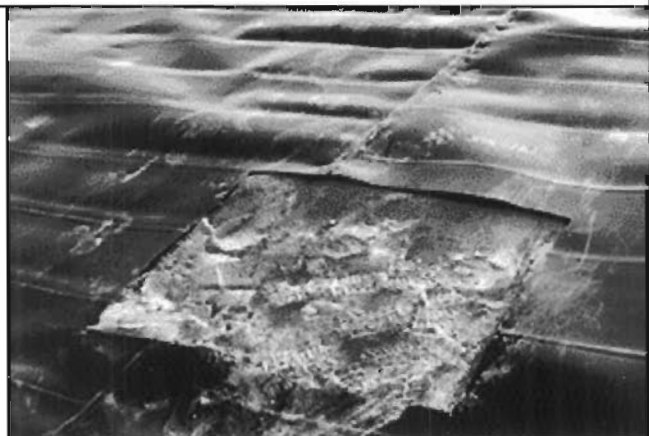
Photo 4. One of the intermediate quality ponds, drained in preparation for cleaning and sampling.

what would be expected for HDPE geomembranes in production at the time this material was produced and installed.

Tensile values

The specimens that were received for testing contained surface scratches. These abrasions likely reduced the tensile properties somewhat. Even with this being considered, all tensile properties are above what is commonly specified for this industry today. This is to be expected because the geomembrane was not subjected to any chemicals that could be absorbed, affecting tensile properties. Likewise, the individual ponds had similar tensile properties within pond type—no one pond performed especially well or especially poorly.

Carbon black content

Again, these values are likely the same as when the material was first produced. Carbon black cannot leach out of polyethylene over time.

Carbon black dispersion

All specimens had very good (A1 classification) dispersion.

Oxidative induction time

Both high- and low-pressure oxidative induction tests were performed on the exposed and the unexposed material. The average OIT values are contained in **Table** 1. The OIT values seem to be independent of the type of pond or whether the material was exposed or not. The one exception to this, as can be seen from the individual data below, is IQ 2E. The only apparent difference between IQ 2E and the other ponds is intermittent water coverage.

The current requirement for OIT is 100 and 400 minutes for low-pressure and high-pressure OIT, respectively. However, these numbers are the result of 20 years of improvements in antioxidants and resins. At the time of the manufacture of this material, the typical low-pressure OIT values that could be expected were 50 minutes. Taking this into consideration, it is obvious that the stabilizers are still present and are still doing their job.

SP NCTL

This test was not even conceived when this material was produced. This is currently thought to be one of the best indicators of long-term performance. The average values achieved by this 20-year-old material are still above the common industry requirement of 200 hours. Of the 26 specimens that

were tested, only three failed (11.5%) the current industry specification of 200 hours. While some individual specimens broke before 200 hours, others were removed at 667 hours without failure. The variability is wider than would be expected in current-day production. However, surface effects such as oxidation and scratches likely contributed to the variability of the failure times. The average of the five specimens includes the time at which the specimens were removed.

One interesting thing to note about NCTL performance is that both the average and individual readings indicate better NCTL performance for the exposed specimens than for the unexposed specimens. While many of the unexposed specimens were too small to perform SP NCTL, the two specimens for which a comparison is available, IQ 1W and IQ 1E, indicate this. Furthermore, of the exposed specimens, the material in the evaporation ponds demonstrated superior NCTL performance to the material in the intermediate quality ponds. Three of the five evaporation pond specimens did not fail after 667 hours.

Summary

Rigorous modern day testing was performed on 100-mil HDPE exposed for 20 years to wastewater from a steam electric generating station in Colorado. No significant reduction in the primary physical properties was observed (tensile, tear, puncture, carbon black or density). The only testing that indicates some reduction in original properties is OIT testing. Considering how much lower these values were at the time of manufacture as compared to modern day geomembranes, it is obvious that low amounts of antioxidant are still present in this geomembrane. While not at the levels required by current-day standards to ensure protection, they are still at more than half the likely level at the time of manufacture.

This study demonstrates that after 20 years, a geomembrane, depending on the conditions to which it is exposed, can still perform its desired function. Because today's resins, resin stabilizers and manufacturing techniques have improved significantly over the last 20 years, logic would dictate that today's geomembranes will last even longer. ∎

Nathan Ivy is the geomembrane manager for GSE Lining Technology Inc.

ATTACHMENT 10

Leak Detection Layout and Liner Configuration Profile

CELL 1

CELL 2

CELL 3

NOMINAL ROCK SURFACE

POND DOUBLE LINER SYSTEM WITH LEAK DETECTION

STRIPPED SURFACE

EXISTING GROUND

2.5:1

HORIZONTAL SCALE

100   0   100   200

SECTION A 0017

USP1-WCE-65-CD-684-D44-0005
USP1-WCE-65-CD-684-D44-0006

SCALE: HORIZ. 1"= 100'
VERT. 1"= 20'

STRIPPED SURFACE

PRIMARY LINER

2.5H:1V

2" PERFORATED LEAK DETECTION PIPE

SECONDARY LINER

PERFORATED LEAK DETECTION PIPE

2.5H:1V

DETAIL 3 0017
NTS

PRIMARY LINER

SECONDARY LINER

DRAINAGE NET

NONWOVEN GEOTEXTILE

2" PERFORATED LEAK DETECTION PIPE

3"(±) 3/4" MINUS (IMPORTED SAND MATERIAL) (SEE NOTE 2 THIS DWG)

DETAIL 2 0017
NTS

NOTES:

1. FOR LINER AND PVC SPECIFICATIONS. SEE SPECIFICATION NO. USP1-WGE-00-CS-0000-510-1206 PONDS AND RESERVOIR LINERS.

2. FOR IMPORTED SAND MATERIAL SEE SPECIFICATION NO. 312323 - FILL AND BACKFILL.

3. THE GEOCOMPOSITE SHALL BE PLACED IN THE LINER TRENCH AND DRAPED A MINIMUM OF 1' OVER EXPOSED LINER PRIOR TO PLACING ASPHALT PAVING. THE GEOCOMPOSITE SHALL BE CUT BACK EVEN WITH THE PAVEMENT SURFACE AFTER PAVING OPERATIONS ARE COMPLETE. A WATER RESISTANT SEALER SHALL BE PLACED AT THE JUNCTION OF THE LINER AND THE PAVEMENT.

NUMERIC MARKINGS WILL BE 12" HIGH AT 5.0' INTERVALS

MAIN MARKINGS AT 1.0' INTERVALS PAINTED WITH WHITE STENCIL

INTERMEDIATE MARKINGS LINE THICKNESS 1/4"

MAIN MARKINGS LINE THICKNESS 1/2"

BOTTOM OF CELL

TYPICAL ELEVATION

DETAIL 4 0017
NTS

DEPTH GAGE MARKING ON LINER

EDGE OF LINER

BUTYL TAPE BETWEEN PIPE AND BOOT

2" STAINLESS STEEL BAND CLAMP (TYP)

PIPE BOOT

WELDED AREA

REMOTE PROBE JUNCTION BOX

2" LEAK DETECTION PIPE

PIPE BOOT

EDGE OF BERM

PIPE BOOT

WELDED AREA

BUTYL TAPE BETWEEN PIPE AND BOOT

2" STAINLESS STEEL BAND CLAMP (TYP)

TOP VIEW

CONDUIT

JUNCTION BOX

PVC CAP

SIKA-FLEX 1-A

BUTYL TAPE BETWEEN PIPE AND BOOT

2" STAINLESS STEEL CLAMP (TYP)

PIPE BOOT

WELD TO LINER

LINER

REMOTE PROBE JUNCTION BOX

LEAK DETECTION PROBE

PIPE

CONDUIT

JUNCTION BOX

PVC CAP

SIKA-FLEX 1-A

BUTYL TAPE BETWEEN PIPE AND BOOT

WELD TO LINER

SIDE VIEW

TYPICAL 90 DEGREE PIPE BOOT

DETAIL 1 0017
NTS

BOTTOM OF CELL (TYP)

INTERMEDIATE MARKINGS AT 0.1' INTERVALS

0.25' (TYP)

0.1' (TYP)

1.0'

TYPICAL SECTION

GEOCOMPOSITE (SEE NOTE 3 THIS DWG)

CREST OF SLOPE

PRIMARY LINER

DRAINAGE NET

SECONDARY LINER

NONWOVEN GEOTEXTILE

3"(±) 3/4" MINUS (IMPORTED SAND MATERIAL) (SEE NOTE 2)

4" ASPHALT PAVEMENT

2.5:1

1.0'

1.0'

2.0'

2.0'

2.0'

ANCHOR TRENCH DETAIL AT TOP OF BERM
NTS

USP1-WGE-65-CD-684-044-0016

SHEET LEGEND

—— xx ——	CHAIN LINK FENCE
	EDGE OF BERM
	WELDED SEAM
– – –	2" PERFORATED PVC PIPE
o	LEAK DETECTION RISER
– · –	TOP EDGE OF LINER
▼▼▼	TEXTURIZED HDPE
▲▲▲	EARTH SLOPE
▦	LINER
▥	DEPTH GAGE MARKING

NOTES:

1. FOR LINER AND LEAK DETECTION DETAILS, SEE SHEET USP1-WGE-65-CD-684-044-0017.

2. FOR LAYOUT AND GRADING PLANS SEE SHEETS USP1-WGE-65-CD-684-044-0006 THROUGH 0010.

NORTH POND ACCESS ROAD

E 2,214,200
E 2,214,400
E 2,214,600
E 2,214,800
E 2,215,000
E 2,215,200

N 1,194,800
N 1,194,600
N 1,194,400
N 1,194,200
N 1,194,000
N 1,193,800
N 1,193,600
N 1,193,400
N 1,193,200
N 1,193,000
N 1,192,800

USP1-WGE-65-CD-684-044-0017

TEXTURIZED HDPE 11 FT. WIDE AT 50 FT INTERVAL AROUND ALL CELLS (TYP.) FUSE TO PRIMARY LINER

8' HIGH CHAIN LINK FENCE

2' PERFORATED PVC (TYP.)

SLOPE (TYP.)

CELL 1

CELL 2

CELL 3

LIMIT OF SITE CLEARING AND GRUBBING

SOUTH POND ACCESS ROAD

LEAK DETECTION AND LINER LAYOUT

SCALE: 1" = 100'

SCALE: 1" = 100'

REVISIONS

DISCIPLINE	RECORD
ARCH.	
CIVIL	
MECHANICAL	
NUCLEAR	
PIPING	
PROCESS	
ELECTRICAL	
ENVIRON.	
QA / QC	
GEN. ARRANG.	
HVAC	
STRUCTURAL	

REVISION APPROVAL

ATTACHMENT 11

Tentative Monitoring and Maintenance Schedule

Total Dissolved Solids (TDS) will be collected quarterly and a record will be kept at the Central Treating Facility (CTF) Control Room.

TABLE 1	
Parameter	Frequency
Charge pump discharge	Daily
Recirculation rate	Daily
Evaporator Run-time	Daily
Pond level	Weekly
Sediment Accumulation	Annually
Pond TDS Concentration	Quarterly

3.9 Inspection/Maintenance

Routine inspection will be conducted for a number of items in the system. Plant operations personnel will perform the inspection. In the event an inspection leads to a finding, then a work order will be prepared for correction of the problem. Table 2 lists the inspection and their frequency.

TABLE 2	
Inspection Item	Frequency
Fence integrity (visual)	Daily
Liner integrity (visual)	Daily
Oil accumulation (pond)	Daily
Spills/Release	Daily
Wildlife within Perimeter fence	Daily
Weather monitor station operation	Weekly

Maintenance items will be tracked, scheduled, and recorded through the Systems, Applications and Processing (SAP) system. Maintenance frequency will be determined by liner vendor specifications or ExxonMobil equipment guidelines. ExxonMobil plant personnel or an ExxonMobil approved service provider will perform all maintenance items. Once the work item is completed, it will be tracked in the system and rescheduled based on the predetermined frequency.

3.10 Environmental/Safety Considerations

3.10.1 Environmental

The pond will be fenced and gated to protect entrance of wildlife and unauthorized personnel. "Bird Balls" manufactured by Euro-Matic Plastics, Inc. will be distributed over the pond surface to camouflage the pond from waterfowl. The balls will also aid in lowering the rate of ice formation in freezing conditions.

ATTACHMENT 12

Literature Review: Sodic/Saline Soils

The literature review contained within this section is intended to give the reader background information on sodic/saline soils. It is a review of present research and current practices in this field of study. While this literature review presents findings and results from various studies and reclamation projects, this document is not meant to commit ExxonMobil to any specific reclamation plan or mitigation procedure. The enclosed literature review is only meant to educate the reader on sodic/saline soils and provide the reader with background information to more fully understand the information presented in Section 4.7.

ATTACHMENT 12

Title: Literature Review: Sodic/Saline Soils

Terry H. Brown, Ph.D.

January 2, 2003

Table of Contents

Introduction

Excessive levels of salts impact extensive areas of soils throughout the world. The primary effects of these salts on soil quality are associated with saline and sodic conditions. Saline soil conditions are related to excess salts usually consisting of chlorides (Cl^{-1}) and sulfates (SO_4^{-2}) of sodium (Na^{+1}), calcium (Ca^{+2}), and magnesium (Mg^{+2}) (Sumner et al., 1998a). Saline conditions often have a deleterious effect on plant growth because salts decrease the osmotic potential of soil water making it difficult for plants to extract water. Sodic conditions result from elevated levels of Na on the exchange complex, which often cause the development of poor physical conditions in a soil. Thus the impacts of Na result in an inadequate balance between water and air regimes in the soil. This imbalance is created by restricted water infiltration and transmission properties causing the soil to be too wet or dry for much of the time

1

resulting in poor root development and plant growth. In addition, sodic soils often are difficult to cultivate and have low load bearing properties. Poor structural stability promotes the sealing of soil pores and crust formation at the soil surface, leading to soil erosion and pollution of surface water resources. An important aspect of sodic soil behavior is associated with the interaction between sodicity and salinity. A soil can be characterized with high exchangeable sodium percentages (ESP) and not develop instability of structure if the electrolyte levels in solution are above a threshold electrolyte concentration (TEC). As a result, a given ESP or sodium adsorption ratio (SAR) level means nothing relative to land management unless the salt levels of the system are understood.

Currently, many States use SAR or ESP levels for reclamation standards without adequate concern for electrical conductivity (EC), clay mineralogy, soil weathering and other important soil characteristics that determine now a soil will react or function under land use. This misconception has resulted in high reclamation costs that are more than likely unfounded.

Objectives

The objective of this work is to describe in some detail the chemistry of sodic/saline soil systems. The information will provide a basis for reclamation plans that can result in sound reclamation/management plans leading to the successful establishment and long-term stability of vegetation communities on sodic/saline soils.

Chemistry of Sodic/Saline Materials

High levels of sodium often trigger significant deterioration in the physical conditions of soils causing imbalances in the water and air regimes. The physical changes result from the flocculation and dispersion reactions impacted by the amount of Na that occupies cation exchange sites. The major factors responsible for these reactions include the type of soil colloid materials present and the charge distribution associated with the surfaces

2

of these materials. The flocculation and dispersion reactions are governed by the attractive and repulsive forces associated with the electron double layer resulting from the surface charge of soil colloids.

The basic theory of the diffuse double layer was developed separately by Gouy and Chapman and is now referred to as the Gouy-Chapman theory (DVLO) (Overbeek 1952). Bolt (1955) has shown that the Poisson-Boltzmann differential equation describes the exchange equilibrium of a Na-Ca illite in mixed solutions of NaCl and CaCl$_2$ and thereafter was referred to as the double-layer equation. The concept is based on the idea that the permanent charge of clay minerals results from two types of charge at the surface: 1) permanent charge due to the replacement of higher valence cations in the mineral structure with lower valence cations resulting in a net negative charge; and 2) variable charge, which is caused by dissociation of mineral-edge hydroxyls. The electrical force acting on the cations present in solution pulls them to the surface while the force of diffusion pulls the cations away from the surface. The opposite interaction occurs for the anions. The anions are repulsed from the surface and approach the concentration of the bulk solution at an exponential rate. The net interaction between the attractive and repulsive forces allows the adsorbed ions to extend outward to a point where the forces are equal. This layer of cations and anions is labeled as the electronic diffuse double layer. The double layer is characterized by an excess of cations near the surface due to the attraction by the negatively charged surface and a deficit of anions close to the surface due to the repulsion by the negative charge associated with the surface. Therefore, the concentrations of cations and anions asymptotically approach the bulk solution concentrations with increasing distance from the surface.

The distribution of cations in the liquid phase of soils grades from high concentrations near the particle surface to lower concentrations in the bulk solution. It is convenient to think of the diffuse double layer as having a thickness, although the thickness cannot be precisely defined. As noted in various texts, the thickness of the double layers are small compared to the diameter of soil pores but are of the same magnitude of water film thicknesses in a dry soil (Bohn et al. 1979). The thickness of the diffuse double layer decreases as the square root of the salt concentration in the bulk solution increases, and

3

directly with an increase in the valence of the exchangeable cations. The effect of increased salt concentration results from the reduction in cation diffusion from the surface to the bulk solution. Exchangeable Cations such as Na^{+1} with a large hydrated radius tend to promote the development of thick double layers while cations such as Ca^{+2} tend to promote a collapsed or thin double layer. The development of a thick diffuse double layer results in swelling especially with the expanding clay minerals. As the double layers associated with adjacent clay surfaces interact, excess cations exist at the mid plane. The excess of cations at the midplane compared to the bulk solution forms an osmotic gradient, which causes swelling and/or clay dispersion due to water inbibition. Water inbibition continues until the osmotic potential at the midplane between clay particles equals the osmotic potential in the solution or until swelling is reduced by the lack of water. Swelling is most pronounced in soils containing large amounts of montmorillonite. The dispersion of clays results as the clay particles are pushed apart when the attractive forces holding the clay tactoids together are over come by repulsive forces causing the clay particles to fall apart or disperse.

The basic theory of diffuse double layer formation assumes that exchangeable cations exist as point charges, colloid surfaces are planar and infinite in extent, and surface charge is distributed uniformly over the entire colloid surface. These assumptions obviously do not describe the actual soil system, however, the theory seems to describe the system well for soil colloids. Note that this system describes the pure colloid systems in aqueous solutions clearly, but probably does not come close to describing a real soil system that is not water saturated. This point of discussion will be addressed later in this review.

The Interactions between Salinity on Sodicity

The definition of a sodic soil in simple terms is a soil that has been adversely impacted physically by the presence of Na adsorbed to the cation exchange sites. The presence of Na in a soil promotes the slaking of aggregates and the dispersion of clay particles. At the same time the impact of Na, as characterized by ESP or estimated by SAR, on the physical character of a soil is greatly dependent on the salinity of the soil. It is

4

impossible to estimate the impact of low or high SAR values on the physical state of a soil or spoil material without evaluating the EC or electrolyte concentration of the system (Shanmuganathan and Oades, 1983). Any attempt to set critical ESP or SAR values for land management would be arbitrary unless total cation concentration or EC is taken into consideration simultaneously (Sumner, et. al., 1998a). Research has shown that extremely high SAR values do not cause physical degradation of soil materials if the system also contains high levels of salts. This fact was first demonstrated by research done by Quirk and Schofield (1955). Their work showed that soil materials with an ESP of 40 maintained a stable permeability with an electrolyte concentration of about 30 mmol/L (about EC = 2.9 dS/m). McNeal and Coleman (1966) pointed out that typical arid land soils (having clay mineralogy dominated by 2:1 layer silicates with only moderate amount of montmorillonite) can tolerate ESP values of 15 or greater before serious reductions in hydraulic conductivity (K) occur, if the salt concentration of the percolating solution exceeds 3 mmol/L (0.2 dS/m). Gardner et al. (1959) came to the same conclusion dealing with unsaturated soils. Similar results were found by Amezketa and Aragues (1995) for calcareous soils from arid environments. These researchers also found that large reductions in K occurred in sand clay mixtures where steep concentration gradients developed between the micropores and macropores. They concluded that an "osmotic explosion" effect was responsible for the reduction in K. Although interesting, this finding was associated with an artificial system of sand mixed with clay and may not represent conditions occurring in soils.

Many studies have shown the relationship between clay mineralogy and the relationship between salinity and sodicity (Velasco-Molina, et al., 1971; Frenkel et al., 1978). In general, the research indicates that clay dispersion becomes very important for soil management decisions when electrolyte concentrations are low even at low SAR values. This was found for the 2:1 clay minerals and to a lesser degree in the 1:1 kaolinitic clays (Velasco-Molina, et al., 1971; Miller et al. 1990). Sumner et al. (1998a) provides a thorough discussion of the SAR/EC relationship in their publication titled "Sodic Soils: Distribution, Properties, Management, and Environmental Consequences."

As noted, the literature indicates that high sodium adsorption rations and/or low electrolyte concentrations can cause soil structural problems. However, we still do not have reliable criteria and standards for predicting how these parameters quantitatively affect structural stability and K of soils (Rhoades, 1972). The mechanisms that cause these problems have been postulated to be: (1) swelling of soils; (2) clay dispersion and subsequent plugging of conducting pores by dispersed clay; and (3) failure or slaking of soil aggregates. However, many of the researchers have made diverging conclusions relative to the importance of these mechanisms. McNeal and Coleman (1966) and Jayawardane (1979) found that clay swelling was the dominant mechanism reducing K in sodic soils. Research by Rhoades and Ingvalson (1969), Frenkel et al. (1978), Pupisky and Shainberg (1979), Shainberg et al. (1981a) and Yousaf et al. (1987) has shown that clay dispersion was the dominant mechanism responsible for the reduction in K. Other scientists such as Waldron and Constantin (1968; 1970) and Cass and Sumner (1982) concluded that the reduction in K was primarily related to the slaking of aggregates caused by internal swelling pressure or from shearing stresses.

As noted previously, the impact of sodicity on the physical properties of soils is dependent on the electrolyte concentration associated with the system. If salt is added to a dispersed clay in a suspension, the increased electrolyte concentration causes the clay particles to stick together forming flocs that settle. The minimum electrolyte concentration required to cause flocculation is referred to as the threshold electrolyte concentration (TEC) or flocculation value (FV). This value is dependent on counter-ion valency and clay type. The TEC values for a sodium-montmorillonite were shown to be about 12 mol/m^3 NaCl or 0.86 dS/m and 0.25 mol/m^3 CaCl$_2$ or 0.02 dS/m for calcium-montmorillonite (van Olphen, 1977). Corresponding values for sodium and calcium illites were found to be 40 mol/m^3 to 50 mol/m^3 NaCl and 0.25 mol/m^3, respectively (Arora and Coleman, 1979). These data show that a sodium montmorillonite can be maintained in a flocculated condition if the salt levels of the same ion (Na) are about 1 dS/m and sodium illites will tend to remain flocculated if salt levels with the same ion (Na) are about 3.6 dS/m. Sposito (1989) indicated through his discussion of the literature that a fully Na-saturated smectite suspension will flocculate if the electrolyte

6

concentration is > 8 mol/m^3 (0.6 dS/m) and a suspension of Na-illite will do the same if the electrolyte concentration reaches about 50 mol/m^3 (3.6 dS/m) His conclusion is that soil salinity tends to counteract the effect of exchangeable sodium on soil structure. The presence of divalent ions such as Ca would lower the TEC to lower salt concentrations.

Abu-Sharar et al. (1987) found some interesting results with respect to aggregate slaking at various electrolyte concentrations. The stability of soil aggregates under various electrolyte/SAR combinations has provided some insight into the relationship between aggregate slaking and clay dispersion. SAR values of 0, 10, and 20 with corresponding electrolyte concentrations above 3.2, 15.9, and 19.4 mol/m^3 resulted in the slaking of aggregates as small as 5 μm with very little clay dispersion. Clay dispersion occurred only after electrolyte concentrations were reduced below these levels. They found that aggregate slaking preceded clay dispersion and that slaking occurred at electrolyte levels below the TEC. This finding is different from the previous findings that aggregates originated from the periphery of larger aggregates.

Goldberg and Forster (1990) found that the TEC for reference clays was much lower than those for soil clays. This indicates that studies evaluating reference clays to simulate the reactions expected in soils are not valid. Other factors such as organic matter content and the presence of Al- and Fe-oxide content may influence the dispersion of soil clays. Kaolinitic soils were also found to disperse under conditions of high ESP or SAR and low salt concentrations. However, such soils were usually impacted to a lesser degree as compared to the montmorillonitic and vermiculitic soils (Frenkel et al. 1978). Miller et al. (1990) found similar results for soils containing kaolinitic clays. This study demonstrates that TEC for these highly weathered soils ranged from 1 to 8 mol/m^3 for Ca clays with SAR <1 and from 10 to 40 mol/m^3 for SAR 16.

The data show that if salinity is maintained at or above the TEC value for a specific material, the physical condition of the material will be maintained in a flocculated state no matter how high the SAR. The only caveat to this situation is that some materials that have high SAR and EC character can become dispersed at the surface if impacted with

water containing low levels of electrolytes from irrigation or rainfall. However, the dissolution of unstable minerals due to weathering often results in solution salt levels above the TEC and therefore swelling and/or dispersion are not experienced. This is especially true for the unstable minerals usually found in soils of arid to sub arid regions. In addition, mechanical forces resulting from raindrop impact, the flow of water at the surface or the use of farm equipment could cause clay dispersion. However, if measures are taken to eliminate these potential impacts to the system, the high SAR, low EC soil/spoil material will usually be maintained in good physical condition. One method of doing this is to treat the surface with an amendment such as gypsum. The application of gypsum at the surface would result in electrolyte concentrations from 5 to 15 mol Ca/m^3 would be sufficient to ensure flocculation of the soil clays, reducing dispersion-induced sealing and erosion. Another method of protecting the surface against the mechanical forces that can initiate slaking and dispersion is to cover such materials with topdressing material.

Misconceptions Associated with the Diagnosis of Sodicity Problems

An understanding of our current misconceptions relative to the diagnosis of problems associated with Na is easily found with a brief examination of the history of soil chemistry specifically with regard to sodic and saline interactions. As noted by Sumner et al. (1998a), several major issues have caused undo complexity to the understanding of the sodic/saline character of soils and other materials. One interesting observation is that in the United States and much of the rest of the world, a value of ESP > 15 was used as the level for separating sodic soils while in Australia and Asia a value of ESP > 6 was used as the separation value. This explains why North America has much less area determined to be sodic. Why does this discrepancy exist? Sumner et al. (1998a) have developed the argument that the quality of the water used during the experimentation is the most probable reason for the differences. Much of the early research done in the United States was accomplished at the U.S.D.A. Salinity Laboratory in Riverside California. These experiments were usually completed using tap water as the infiltrating solution. The tap water used in southern California contained relatively high levels of

electrolytes (varying from 4 to 10 mmol/L) while tap waters used in Australia and South Africa ranged from 0.4 to 0.7 mmol/L. Textural differences were also identified as having an impact on the separation level identified above, as the soils tested in the United States were generally sandy in texture as compared to those tested in Australia and Asia. In addition, weathering differences associated with the stability of the mineral fraction were also different between the soils found in California compared to those found in Australia. The arid soils studied in California were much more unstable than the more weathered soils studied in Australasia.

The major issue that has caused many misunderstandings in diagnosing sodic soils is the interaction between salinity and sodicity. The information promoted for use in the management of sodic soils by the USDA Salinity Laboratory during the 1960s and 1970s did not mention to any great extent interactions with salinity. The reason for this seemingly deletion was discussed by Sumner et al. (1998a) with regard to a personal communication these authors had with Dr. Bower the head of the Soil Salinity Laboratory at that time. Dr. Bower indicated the data collected by Quirk and Schofield that demonstrated the relationship between sodicity and salinity were associated with laboratory evaluations using disturbed samples. Under these conditions dispersion is often greater when compared to field samples. In addition, Dr. Bower assumed that the salt concentrations of the soil solution are too transient to use as a factor in a classification system for sodic soils. The relevancy of Dr. Bower's arguments does have justification. However, the use of ESP without consideration for the electrolyte levels found in the corresponding soil solutions has resulted in inappropriate management of sodic soil conditions. The discussion provided by Sumner et al. (1998a) addresses the fact that the USDA Soil Salinity Laboratory did not address this topic in their recommendations for the management of sodic soils even though they were well aware of it. In fact, the definition of sodic soils was published by Bower et al. (1958) without mention of electrolyte concentration in the definition. It was apparent at the time that people were well aware of the impact of salinity on the behavior of sodic conditions, however apparently these scientists elected to down-play the relationships because of the apparent transient nature of salinity. Sumner et al. (1998a) noted that if the work of

9

Quirk and Schofield (1955) had been adopted in the United States at that time, a much clearer understanding of sodicity would have resulted. Instead of using electrolyte concentration as an important component of the definition of sodic soils, Handbook 60 (Richards, 1954), which was published in 1954 and reprinted in 1969 without emphasizing the importance of salinity and its impact on sodicity, has been and continues to be used as an authority addressing salinity and sodicity issues. In more recent times, Hanson et al (1999) have provided clarity to the issues dealing with salinity/sodicity relationships with a handbook that describes the relationships albeit for California conditions.

Model for Sodic Soil Behavior

Most research addressing soil sodicity has used a model evaluating the forces generated between colloidal clay minerals suspended in saturated systems to explain sodic soil behavior. Two major problems are apparent with this model. First, natural soils usually are complex heterogeneous aggregates made up of many clay types, silt and sand, intimately associated with inorganic and organic polymers. These aggregates do not resemble pure clay systems as was described by Abu-Sharar et al. (1987). In addition, the aggregates are not suspended in water. As a result, forces other than those that operate in saturated systems must be overcome during aggregate slaking and clay dispersion. Therefore, it is important to use a natural soil model that shows how sodicity and salinity impact the physical conditions of soil and/or spoil materials not suspended in aqueous solutions. The models described by Rengasamy and Sumner (1998) and Rengasamy and Olsson (1991) will be used to address this important concept. The fact is that aggregate slaking and clay dispersion decrease in an unsaturated system. This theory is further supported by the work of Russo and Bresler (1977) showing that unsaturated flow is not impacted compared to saturated flow at given soil ESP/EC levels. In other works, a soil will maintain more stability under unsaturated conditions than saturated conditions. It happens that soils very rarely experience saturated conditions in the field environment.

10

The impact of ESP often estimated using SAR on the physical character of a soil is greatly dependent on the salinity of the soil. It is impossible to estimate the impact of low or high SAR values on the physical state of a soil or spoil material without knowing the EC or electrolyte concentration of the system (Shanmuganathan and Oades, 1983; Sumner et al., 1998a). Any attempt to set critical ESP or SAR values for land management would be arbitrary unless electrolyte levels are taken into consideration simultaneously (Sumner et al., 1998a). Research has shown that extremely high SAR values do not cause physical degradation of soil materials if the system also contains high levels of salts.

A system of classification based on soil behavior rather than on a threshold ESP or SAR level without consideration for electrolyte concentrations should be developed for land management purposes. As noted by Sumner et al. (1998a) it makes more sense to use the behavior of soils such as spontaneous and mechanical dispersibility as a basis for threshold limits rather than chemical composition of the soil. In fact, Rengasamy et al. (1991) described sodic soil behavior using dispersive potential in lieu of setting arbitrary limits of ESP (SAR) and EC. The definition of dispersive potential is the difference in osmotic pressures in the diffuse double layer between the critical flocculation concentration (CFC) of electrolyte and the existing soil solution concentration. This concept sounds good, however, a significant amount of work needs to be done to fully develop the idea, and to account for various field conditions including mechanical energy inputs.

As noted in a previous section of this review, in the past, soil scientists have used a model involving electrical diffuse double layer theory to explain sodic soil behavior. This explanation was usually conducted using pure clay minerals in saturated systems. However, in natural systems, complex clay systems are bound together into aggregates with silt and sand particles by inorganic and organic compounds and are usually not suspended in water. The slaking of aggregates and the dispersion of clays requires forces other than those that operate in colloidal clay suspensions. Rengasamy and Sumner (1998) have developed a model that describes the processes that take place during the

wetting of a dry soil aggregate. Their model will be presented in this paper as a realistic approach describing the influences of sodicity and salinity on the physical nature of natural soil systems.

The model consists of four (4) stages as shown in Figure 1. Dry soil aggregates are held together by inorganic and organic compounds and associated bonds that produce very strong attractive forces. The forces involved include Lifshitz-van der Waals forces, ionic bonds, hydrogen bonds, hydrophobic interactions, and hard-soft acid-base reactions. As dry aggregates are wetted, solvation or hydration forces become important. The stability of aggregates, and hence the pore systems, depends upon attractive and repulsive forces resulting from intermolecular and electrostatic interactions between soil solution and soil particles (Rengasamy and Olsson, 1991). When an aggregate is placed in contact with water, the interactive forces lower the potential energy of water molecules; thus releasing energy for structural changes and as heat. Aggregate slaking, clay swelling, and clay dispersion are the major mechanisms that occur during these transformations.

Thus, as an aggregate is hydrated, the initial attractive forces between clay particles decrease. As hydration increases, the distance between particles increases. In general, if the clay particles are saturated with Ca or Mg, additional hydration does not increase the inter-particle distance beyond a few nanometers, resulting in a net force that is attractive and the aggregates are held together by hydrated cations. The swelling resulting from these reactions will occur even with high electrolyte concentrations. Slade and Quirk (1991) found that the change in separation to 1.5 nm is not affected by electrolyte solution (crystalline swelling) and that the separation from 1.5 to 1.9 nm is an osmotic process that includes electrolyte concentrations, charge density, and the location of the charge in the clay minerals. If the clays are saturated by monovalent cations such as Na, the clay particles are separated beyond 7 nm dependent on the ionic strength and the existence of soft-hard acid-base reactions. This results in clay dispersion shown as Stage 3 in Figure 1. Stage 3 can also be reached when a source of mechanical energy is applied to the clay domains that have undergone limited separation. Mechanical energy resulting

12
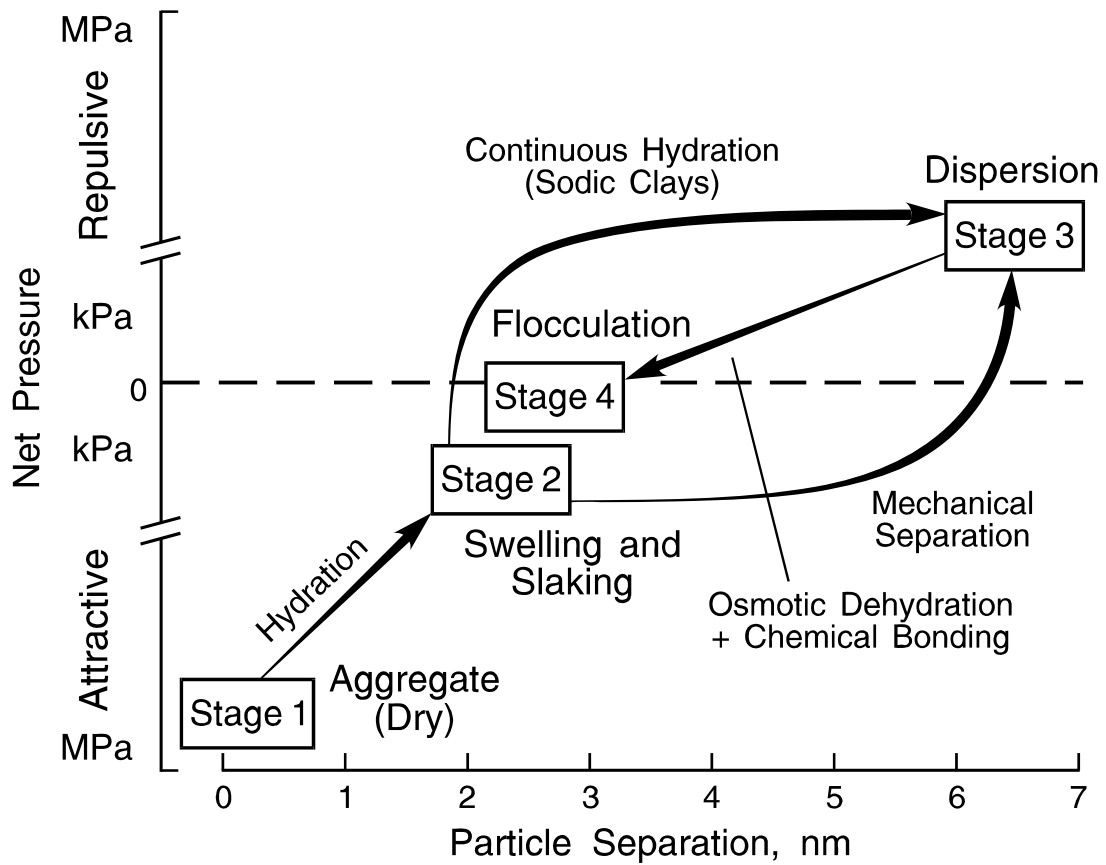
Source: P. Rengasamy and M.E. Sumner, 1998

Figure 1. Stages that take place during the wetting of a dry aggregate.

from raindrop impact and surface water flow can overcome the attractive forces causing the clay domains to separate or disperse. Once the system is completely dispersed, the electrostatic repulsive forces as predicted by the electrical double layer theory become important to the physical nature of the system. A dispersed clay system will become flocculated as the difference in the electrical potentials in the inner and outer solutions approach zero and as the clay particles approach each other. The repulsive pressure is balanced by osmotic pressure, and the van der Waals attractive forces become dominate. At this point, the clays become flocculated as identified in Figure 1 as Stage 4 of the model.

13

Parameters Associated with Sodic Behavior in Natural Soil Systems

The basic problem associated with sodic soils is the development of very poor physical conditions that result in imbalances between water and air regimes that greatly impact the development of vegetation. The imbalance in air and water regimes results from poor infiltration and transmission of water and air in the soil, which usually causes either wet or dry conditions for much of the time. In addition, the instability of soil structure often causes soil crusting, which results in erosion causing poor soil conditions and water pollution. The presence of relatively high levels of electrolytes will promote the maintenance of good physical conditions that maintain good plant growth. The impact of various conditions including electrolyte concentration, pH, water content, soil weathering and organic matter on the basic principals of the chemistry of sodicity will be briefly presented in this section.

Impact of Sodicity/Salinity on Hydraulic Conductivity (K) and Infiltration Rate

The impact of sodicity on the hydraulic properties of soils is dependent on the electrolyte concentration associated with the system (Malik et al., 1992; Lima et al., 1990; Mace and Amrhein, 2001; McNeal et al., 1968; Quirk and Shofield, 1955; Frenkel et al., 1978; Shainberg et al., 1981a; Abu-Sharar et al., 1987; Curtin et al., 1994a; Curtin et al., 1994b; Chiang et al., 1987). In general, the greater the SAR or ESP associated with a soil and the lower the EC, the greater for the potential for aggregate slaking, soil swelling and clay dispersion, which will reduce the K of a soil. As noted previously in this review (Section titled - The Interactions between Salinity on Sodicity), researchers have proposed different views on the primary mechanism responsible for the degradation of the physical structure of soils, which are responsible for changes in K. Sumner (1993) attributed the primary reduction in K to pore plugging due to aggregate slaking and clay dispersion. This author also suggested that clay swelling only impacted K at relatively high ESP values (ESP> 15%). However, high electrolyte concentrations either in the form of amendment applications to the surface or high salt levels of applied water would reduce the impacts. The fact is that all three mechanisms occur in a soil system with

14

varying impact from each dependent on the characteristics of the soil. Mace and Amrhein (2001) voiced this opinion in their study that showed substantial reduction in hydraulic conductivity with increasing SAR and decreasing EC. Results of their research using water with SAR values of 5 and 8 showed that the three mechanisms interact with each other. Clay swelling tends to reduce the size of the large pores enhancing the amount of pore clogging due to aggregate slaking and clay dispersion. The change in water holding capacity at –22 kPa suction was a good indication of the changes in pore geometry. As the electrolyte concentration of the water applied to the soils decreased the quantity of dispersed clay present in the leachate increased. This study demonstrated that both clay dispersion and clay swelling had major roles in the structural changes and the resulting decreasing K of the soil materials. The use of gypsum as an amendment was shown to reduce or eliminate clay dispersion due to the ionic strength effect. With subsequent leaching the EC of the solution in the soil materials decreased (less gypsum) and swelling again increased. The researchers found that the soils originally leached with the higher SAR water had the lowest K values and the most internal swelling after reclamation, suggesting that pore plugging initially resulted in a decreased K that was irreversible. This reaction may be associated with the fact that about 23% of the exchangeable Na remained in the soil after reclamation using gypsum and H_2SO_4. This research effort demonstrates that irrigation water with SAR values of 5 and 8 result in both temporary and longterm reductions in K dependent on the electrolyte concentrations in the water/soil system.

Hydraulic conductivity (K) is less sensitive to sodic conditions as compared to infiltration rate (IR). The primary factor responsible for these differences is the influence of mechanical energy caused by the impact of raindrops at the surface. This mechanical energy promotes the disintegration of aggregates and the dispersion of clays resulting in the formation of a structural crust. Crusts are formed due to the physical disintegration of aggregates, while compaction is caused by the impact of the water droplets and chemical dispersion of clays near the surface. Smectitic soils are very sensitive to reduced IR even at very low ESP levels (ESP<3). An important factor in the degradation of IR is that rainfall contains very low levels of salts. Therefore, rainfall is responsible for leaching

electrolytes from the surface, leaving the surface materials more susceptible to dispersion. K is much less susceptible to degradation, except at the surface, mainly because of the reduced impact of mechanical forces and the electrolyte levels that often occur (Shainberg et al., 1992). The mineral phase associated with arid land materials, usually readily weathers, providing electrolytes to the system, enhancing its ability to maintain structure.

This discussion supports the fact that suitable topdressing placed over sodic materials will alleviate the development of poor physical conditions in the sodic materials. The surface layer of material (topdressing) eliminates the mechanical energy input from raindrop impact and/or surface water flow on the sodic material and the low electrolyte rainwater that would promote aggregate slaking and clay dispersion. In addition, weathering of the surface layer and the underlying sodic materials result in increased electrolyte levels in solution. This prevents dispersion and the Ca^{+2} present in the solution therefore tends to self-remediate the sodic condition.

The Effect of Exchangeable Magnesium on the Physical Properties of Soils

Richards (1954) grouped Ca and Mg together as similar ions beneficial in developing and maintaining soil structure. However, evidence now exists that indicates that Mg can cause the deterioration of soil structure under certain conditions. Studies have shown that Na-Mg soils developed lower K characteristics than Na-Ca soils under similar conditions (McNeal et al., 1968). Research has also demonstrated that Mg can impact K through direct effects (specific effects) and through the ability of Mg^{+2} to cause higher exchangeable Na^{+1} levels to develop in the soils as compared to Ca^{+2} (Chi et al., 1977; Emerson and Chi, 1977).

Alperocitch et al. (1981) found that well-weathered soils that do not contain $CaCO_3$, are impacted by the specific effect of Mg^{+2}. Reduction in K and enhanced clay dispersion resulted when Na/Mg soils were leached with distilled water (simulated rain water). The theory behind this finding was that clays saturated with Mg^{+2} are chemically more stable

16

and do not release electrolytes into solution. As a result, the lack of weathering products will allow the system to disperse more easily when leached with water that contains low concentrations of electrolytes. In the same study, exchangeable Mg^{+2} was found not to have a specific effect on the K and clay dispersion in calcareous soils. In these soils, Mg^{+2} enhances the dissolution of $CaCO_3$ increasing the solution electrolyte concentrations, which prevent the dispersion of clays and the reduction of K.

Weathering

Dispersion is important in reducing the permeability of sodic soils, however, no adequate hypothesis is available that explains why some soils are more susceptible to clay dispersion than others when leached with distilled water. This is an important problem since the irrigation season is followed by the rainy season or snowmelt. Salt is usually built up in the soil during the irrigation season, thus the EC is high enough to prevent deterioration of the physical properties. However, when these soils are exposed to rainwater or spring runoff, the salts are leached from the surface portion of the soil and the physical conditions at the surface are very susceptible to degradation.

The TEC of the Ca-montmorillonite clays has been reported by van Olphen (1977) to be 0.17 to 0.23 meq/L and that the TEC for Na-montmorillonite is 12 to 16 meq/L. Oster et al. (1980) found that the TEC of montmorillonitic clays saturated with mixtures of two cations increase rapidly with the initial increments of exchangeable Na to values of 3 and 6 meq/L for ESP values of 10 and 20, respectively. It is very apparent that soils capable of releasing salt through weathering processes at rates sufficient to maintain salt levels above the TEC values for specific clay materials should maintain their physical condition. These soils will not disperse and their hydraulic conductivity should not be affected significantly by rainfall or spring runoff. Rhoades et al. (1968) showed that arid land soils increased the levels of Ca and Mg by 3 to 5 meq/L and determined that the dissolution of plagioclase, feldspars, hornblende, and other common mafic minerals accounted for the release.

In their evaluation of the dissolution of three arid zone soils, Oster and Shainberg (1979) observed that the release of Ca^{+2}, Mg^{+2} and K^{+1} from silicate minerals and the hydrolysis of exchangeable Na^{+1} and Ca^{+2} varied greatly. These researchers demonstrated that when salt-free soils were mixed with distilled water at a 1:5 ratio, the release of salts was fast enough to increase solution concentrations from 0.5 to 4.0 meq/L within 4 hours.

Shainberg et al. (1981a) has shown that low salt concentrations (2 to 3 meq/L) in leaching water prevented clay dispersion and reductions in K for ESP values below 30. These observations led to the idea that mineral dissolution is a major factor causing differences in susceptibility to sodic conditions when leached with low electrolyte water. These scientists hypothesized that sodic soils containing minerals that readily release soluble electrolytes such as $CaCO_3$ and minerals such as plagioclase, feldspars and hornblende will provide electrolytes levels high enough to prevent dispersion if leached with distilled water, which simulates rainfall and runoff. Shainberg et al. (1981b) showed that soils containing minerals that readily release soluble electrolytes will not disperse when leached with distilled water (simulated rainwater). This study was conducted using three soils; the Gila soil containing $CaCO_3$ with montmorillonite and mica, the Pachappa soil is a relatively unweathered soil containing montmorillonite and mica and a third, the Fallbrook soil, a soil characterized by increased weathering that contained montmorillonite and kaolinite clays. The salt release rates for these soils were initially greatest for the Gila soil. However, after about 100 hours the salt levels for the Gila and Pachappa soils were very similar. The levels of salts found in the Fallbrook were much lower since this soil had been weathered and was quite stable. The Fallbrook soil was found to be the most sensitive to sodicity impacts on clay dispersion and resulting impacts on K even though it contains sesquioxides and kaolinite in its clay fraction. The differences in capacity to release salts and to disperse are undoubtedly important relative to the formation of crusts under rainfall conditions. This capacity is essential for materials that have moderate ESP levels that are able to maintain physical conditions through the soil profile but are susceptible to dispersion near the surface. Electrolytes resulting from weathering, especially soils in arid or semiarid environments, can maintain the physical structure of the surface materials. Rhoades et al. (1968) found similar results

studying arid soils treated with irrigation water characterized by SAR values varying from 5 to 20. The total salt content of the displaced soil solutions was much greater than the salt levels applied in the irrigation water. The effluent solutions contained from 3 to 5 meq/L higher salt levels than present in the irrigation water. Much of the increase in salt levels resulted from weathering of the soil materials, which released significant amounts of Ca and Mg and HCO_3^{-1} ions. The net effect of the weathering processes was a 30 to 90% reduction in the SAR of the soil solutions. SAR reductions were largest for the waters containing lower salt concentrations, but were significant for waters containing as much as 15 to 20 meq/L of salt. Evaluations of the mineral fraction of these soils showed that unstable Ca-silicates, Mg-silicates such as plagioclase, feldspars, hornblende along with some common mafic minerals in the various size fractions of the soil were the contributing components to the soil solutions. This research determined that the weathering phenomenon reduces the Na hazard and therefore should be considered in water quality evaluations. Their findings imply that irrigation water containing relatively high levels of Na may be used successfully for irrigation of soils that have similar characteristics to those evaluated in this study.

In view of the above discussion concerning mineral weathering, Rhoades (1968) developed a modification to the Na hazard equation developed by Bower et al. (1963) for HCO_3^{-1} containing irrigation waters. This modification was based on the results of research, which evaluated the impact of mineral weathering on soils containing lime. The evaluation was complicated by the fact that the presence of Ca^{+2} and HCO_3^{-1} in solution tends to precipitate at the same time mineral weathering is releasinf Ca and Mg into the solution at relatively high rates. This study showed that the increases in Ca + Mg content produced by mineral weathering processes were greater than the decreases produced by lime precipitation processes. These data show that the evaluation of the Na hazard of HCO_3^{-1} containing irrigation water based on the assumption of $CaCO_3$ precipitation is inaccurate for soil water contents near saturation. It also demonstrates that mineral weathering must be considered in evaluating the Na hazard of irrigation waters in semiarid and arid soils.

Another important aspect of weathering is associated with the influence of CO_2 on the weathering of soils containing $CaCO_3$. The presence of CO_2 enhances the dissolution of $CaCO_3$ significantly (Nadler, et al., 1996). As a result, the development of a good plant cover on a soil containing calcite will result in significant levels of Ca in solution and on the exchange sites. Nadler et al. (1996) determined that solutions containing CO_2 will dissolve larger amounts of $CaCO_3$ as the contact time increases. If Nadler et al (1996) are correct, topdressing materials overlying sodic spoil materials would be expected to provide significant levels of Ca to the soil solution, which could easily leach to lower levels in the profile reducing the ESP values of the impacted spoil materials.

Unsaturated Flow

As is apparent from the literature, most investigations concerning the effect of salts on the transport of water and solutes in soil have been described under steady-state saturated conditions. However, in field conditions the transport of solutes and water almost always occurs under unsaturated flow conditions. Information is limited on the impact of sodic/saline conditions on the hydraulic properties of soils, however several very good studies have been completed. Russo and Bresler (1977) found that low soil water contents compensated for the negative effects of high ESP and low salt levels. This work was done in a laboratory study using the Gilat loam soil with various combinations of salt concentrations, compositions, and soil water contents. This study showed that maintaining the soil under unsaturated conditions allows a higher ratio of Na to Ca for any given EC without impacting the physical condition of the soil. These relationships are directly dependent on the degree of soil saturation. Since low water contents result in low repulsion forces, unsaturated systems would be expected to have higher attractive forces between clays and soil particles as compared to saturated systems. Rengasamy and Sumner (1998) have indicated that spontaneous dispersion takes place when sodic clay is impacted with water of very low electrolyte concentration. However, soil water content below saturation can result in limited swelling and incomplete separation of clay particles due to low electrolyte levels with the interparticle distance depending upon the water content. Therefore, aggregate slaking and clay dispersion in unsaturated systems

would be limited as compared to saturated systems for specific SAR/EC conditions. Russo and Bresler (1977) demonstrated this fact in their study evaluating K with regard to cationic ratio $(Na^{+1}/(Ca^{+2})^{1/2}$ (R), electrolyte concentrations (C), and volumetric water content (θ). This study has shown that under specific combinations of these variables, the value of the cationic ratio can be estimated for a given K. For example, under saturated conditions with C = 0.02 N (approximate irrigation field soil) it is possible to maintain K $\geq$ 0.5 cm/s as long as R $\leq$ 14. Under the same conditions (C and K), but in unsaturated soils the corresponding value for R is 20. This research has demonstrated that water of poorer quality (higher sodicity) can be applied when unsaturated conditions are maintained during irrigation. However, soils impacted by increased Na levels and low salinity levels will be negatively affected whether under saturated or unsaturated conditions. In similar research, Malik et al. (1992) found reductions in unsaturated flow when water containing high levels of Na was applied to montmorillonitic soil samples. The reductions in flow were attributed to changes in microstructure. This research illustrated that the negative effect of high SAR and low solution electrolyte levels decreases in unsaturated soils.

Menneer et al. (2001) has shown that saturated and unsaturated K measurements associated with Na impacted soils did not change until a pressure head of –120 mm was applied. These results indicate that some structural deterioration in the soil matrix resulted, however, the macropore flow at high moisture contents in the field were sufficient to overcome the effects. Weinhold and Trooien (1998) found similar results in a study of several sulfatic soils located in the semiarid Northern Great Plains. Tension infiltrometers were used to compare infiltration rates at various applied tensions. Infiltration into fine textured soils was found to be greatly impacted

Crust Formation

Soil surface crusting has been discussed in the literature for a long time, however, its serious consequences have not been fully appreciated. The influence of soil crusts on soils and eventually on vegetation and environment is of great importance. Processes

beginning with soil crust formation proceed to water and soil loss through erosion, followed by reduced plant cover and reduced yields. Other influences such as increased pressure from animal and human use intensify the impacts.

The susceptibility of soils to rainfall induced surface crusting is dependent on a combination of soil, physical, chemical and biological processes. The climate and soil conditions existing at a site will reflect the tendency for the formation of crusts. Flocculation and dispersion are important in determining the physical behavior of the colloidal fraction of soils and have a major bearing on the physical properties, which soils exhibit. There is strong evidence that dispersion of clay at the soil surface under the influence of impacting raindrops plays a major role in the formation of crusts. The formation of soil crusts begins with the breakdown of surface clods and aggregates by physical and chemical dispersive forces. The physical processes are controlled by the magnitude of the mechanical forces produced by water flow and rainfall impact and by air escaping from soil aggregates in relation to the internal resistance of the aggregates. The extent of chemical dispersion is determined by the chemistry of the pore water and the eroding or runoff water.

Soil crusting forms as a result of either structural deterioration as previously discussed or with the deposition of layers at the soil surface. Structural deterioration is usually associated with the impact of raindrops. The energy released from the impact of raindrops changes a structurally stable soil surface into a nonstructured reorientation of soil particles. Depositional crusts are formed by the deposition of particles on the surface from water. The formation of depositional crusts is also related to factors influencing soil erosion. The more soil erosion that occurs results in the formation of more extensive depositional crusting. Warrington et al. (1989) observed that erosion from an unstable and dispersive soil depended on water quality. In this study, a soil treated with gypsum experienced twice the soil loss when the slope angle changed from 5 to 25% while the untreated control plot had a sevenfold increase in erosion when treated with distilled water as an approximation for rainfall for the 5 to 25% slope angle change. Soil dispersion has been implicated in reduced permeability and crusting of soils by a number

of researchers (Agassi et al., 1981; Kazman et al., 1983; Shainberg and Letey, 1984; Shainberg and Singer, 1986; Ben-Hur et al., 1985). The permeability of a soil to water depends on the exchangeable sodium percentage of the soil and on the salt concentration of the percolating solution. Permeability tends to decrease with increasing ESP and decreasing salt concentration (Quirk and Schofield, 1955, McNeal et al., 1968). Further more, soil K can be maintained at a high level as long as the EC of the infiltrating water is above a critical threshold level termed in this report the TEC (Quirk and Schofield, 1955). Work completed by Shainberg et al. (1981b) has illustrated that relatively unweathered soils released high levels of electrolytes into solution due to mineral dissolution reducing clay dispersion and the resulting crust formation.

The Influence of pH on Sodicity

The role of pH on clay mineral dispersion is an area not often considered when making management decisions relative to sodic soils. The flocculation behavior of clay mineral has been found to depend on pH (Arora and Coleman, 1979; Suarez et al., 1984; Swartzen-Allen and Matijevic, 1974). Swartzen-Allen and Matijevic (1974) found that the TEC for Na-montmorillonite in a $NaNO_3$ solution increased with pH from 1 meq/L at pH 3.8 to 10 meq/L at pH 10. These authors also found an increase in TEC of kaolinite from 2 meq/L at pH 4.1 to 40 meq/L at pH 10.1. Suarez et al. (1984) found that the K of soils containing predominantly kaolinite and montmorillonite decreased with changes in pH from 6 to 9. These authors have suggested that the pH effect is due to the presence of variable charge associated with the clays and organic matter. Goldberg and Glaubig (1987) found that TEC's are much more pH dependent for kaolinitic clays compared to montmorillonites. These authors have shown that 50:50 mixtures of kaolinite with montmorillonite were not significantly impacted by kaolinite. The presence of kaolinite was expected to decreased the TEC. However, since the charge density of kaolinite per gram is much less that the montmorillonite, this decrease did not occur. This study also showed that small amounts of montmorillonite can disperse kaolinite. In addition, they found that small amounts of noncrystalline Al or Fe oxides improve the flocculation of

clay systems. This work also demonstrated that Al oxide is more effective in promoting flocculation over a larger pH range compared to the Fe oxide .

The Relationships between Organic Matter and Physical Structure

The impact of Na on the nature of organic matter is an interesting and complex interaction. Sodicity influences plant production and the amount of organic matter available to influence the soil, and the loss of organic matter to mineralization, erosion and leaching. The amount of organic matter that a soil usually contains is directly dependent on the growth of plants occupying such soils. Sodic conditions usually have a direct effect on plant growth through its influence on soil structure and nutrient availability. Plant growth is limited by the high soil strengths, which directly impact seedling emergence and root penetration. However, organic matter present in the system will improve the physical condition of the soil materials.

The role of the various components of organic matter in the stabilization of soil structure varies with scales of structure. Macroaggregates are largely stabilized by plant roots, mycorrhizal hyphae and saprophytic fungal hyphae. These binding agents are transient in that these components are only present when plants are growing and supplying fresh organic matter to the system continuously. At smaller scales, colloidal organomineral complexes that are more persistent in nature, are important to the stabilization of microaggregates with a variety of mechanisms.

As previously dicussed, the bonding agents for the macroaggregates are usually transient in nature. The bonding mechanisms result from the decomposition of the light fraction and the influence that plant roots have on the rhizosphere. Living roots slough off plant cells and exude mucilages consisting of polysaccharides. Microorganisms and fauna colonize the area in the surrounding soil. These organisms metabolize the more readily decomposable materials and excrete various organic compounds and mucilages. The plant roots and complex organic materials, surrounded by microbial colonies and resulting mucilages become the core for stabile aggregation. As the readily

24

decomposable substrates are mineralized, the aggregates become less stable, and the clay particles become more easily detached. Finally, when the readily decomposable materials are decomposed, only the resistant organic materials with no inorganic particles attached are present.

The more persistent organic bonding agents are the polyanionic colloidal material referred to as humic substances. This material consists of plant remains and microbial materials that are persistent in soils due to their chemical recalcitrance and association with inorganic materials. The formation of the stable structure results from the interaction of these molecules with negatively charged inorganic colloids via cation bridges. These linkages are relatively persistent in the presence of polyvalent cations resulting a resistance to microbial decomposition, chemical extraction and physical disintegration. At the same time, humic materials can also result in a tendency to promote clay dispersion. These anionic materials can easily sorb to clay surfaces by attraction to the positive charged materials (usually oxides and clay edges). This results in a reduction of the point of zero charge (PZC) of the soil raising the TEC and the tendency for dispersion at a given pH. Also, anionic organics sorb to negatively charged inorganic colloids via cation bridges as previously noted. In this case, the high CEC associated with the organic matter enhances the stability of the soil structure. However, the high negative charge densities can lead to increased clay dispersion. Barzegar et al. (1997) showed a similar characteristic of soils when they measured clay dispersion with varying degrees of mechanical disturbance. The addition of organic matter to a soil in the form of pea straw after a 7-day incubation period had little or a negative effect on spontaneously dispersible clay but had a positive effect on mechanically dispersible clays. Barzegar et al. (1997) attributes this difference to the organic matter having stabilizing and dispersing components and the fact that the stabilizing components were susceptible to disturbance and the dispersive components were not. The dispersive components were possibly anionic materials that enhance dispersion by complexing polyvalent cations and increasing the negative charge on colloids. This study also evaluated the impact of adding organic matter on the development of soil aggregates in sodic materials. This study has shown that the addition of organic materials to sodic soils

could be expected to improve their structural stability without prior treatment to remove sodium from the system. Again, they found that minimal disturbance after the application of organic matter further reduced the tendency for clay to disperse. Scanning electron microscopy showed that fungal hyphae were involved in the stabilization process forming aggregates no matter the clay type or the sodicity of the material.

Another study by Nelson et al. (1999) looked at the correlation between dispersibility and organic matter content. This study found that the dispersibility of clay fractions was a function of the amount and type of organic matter, CEC, selectivity for cations and particle size. The less dispersive clay had smaller particle size and higher CEC than easily dispersed clay, which may indicate that high surface area and charge enhance interactions between particles decreasing dispersion. In general, easily dispersed clay also had less organic C compared to more stabile clays. The organic matter associated with easily dispersed clay contained a high proportion of amino acids and proteins while the more stable clays contained a high proportion of aliphatic materials in the topsoils and carbohydrate in the subsoil. These data suggest that the amino acid and proteins acted as dispersants and the aliphatic and carbohydrate organic materials acted as water stable glues holding the clays together. Nelson et al. (1999) showed that the interactions between clay and organic matter have an important influence on clay dispersion in sodic and non-sodic soils.

Upward Sodium Migration

A major issue associated with mined land reclamation is whether or not sodium will migrate from a sodic spoil material into the overlying topsoil or topdressing material. A number of studies were undertaken in the Northern Great Plains (semiarid climate) during the 1970s using wedge plots to determine how much topsoil was needed over sodic materials to assure successful reclamation. These plots were also used by various researchers to assess the movement of Na from the spoil into the overlying topsoil material. Dollhopf et al. (1980) found no upward movement of Na in soils constructed 2 years prior with a sandy loam topsoil (70-cm in depth) overlying a spoil material

characterized by kaolinitic clay mineralogy. These findings differ from those found in reconstructed soil profiles at sites in the northern Great Plains by Bailey (2001), which found an accumulation of Na in the 15 cm of topdressing material directly above the spoil interface 16 years after soil profile construction. The constructed profiles consisted of 15 cm of a clay loam topsoil over either 0.55 m or 0.95 meters of subsoil above the sodic spoil material. These studies were associated with topsoil materials overlying spodic spoils containing smectitic clays. The researchers found that there tended to be less influence from upward Na migration in the 0.95 m subsoil profile compared to the 0.55 m subsoil profile. Similar findings were demonstrated by Merrill et al. (1983) using reconstructed profiles consisting of 30-cm of topsoil materials over sodic spoils (SAR = 25, EC = 3.3 dS/m) with about 30% smectitic clays (sandy clay loam texture) that had been reclaimed for 4 years. This study noted that the greatest upward migration of Na occurred during the first two years of the study. Barth and Martin (1984) found similar results in their study of wedge plots located in Wyoming, Montana and North Dakota where 152 cm of topsoil was placed over sodic spoil material. After 5 years, these sites showed Na migration from 7 to 14 cm into the topsoil overlying sodic spoil materials. These studies were all conducted where topsoil was placed over sodic spoil materials that were massive in structure and therefore represent similar conditons. It is interesting that in each of the studies the upward Na migration apparently reaches an "equilibrium" state of about 15 cm under the conditions studied. In addition, the upward diffusion of Na into the topsoil material is associated with an underlying spoil material that is characterized by a low saturated K, which promotes Na diffusion upward.

Conclusions

The impact of SAR on soil physical properties is highly dependent upon soil salinity. Any attempt to set standards for sodic conditions using SAR values must also consider total cation concentration. Sodic soils will remain flocculated when salinity is maintained at or above the threshold electrolyte concentration.

27

Spoil materials found in arid and semiarid environments are usually relatively unweathered, therefore, exposure to weathering readily provides salts to the soil solution maintaining the system in a flocculated condition. In addition, many of the soluble minerals contain Ca, thus providing a source for self-remediation. Where solution levels of Ca, Mg, and Na are low in CBNG produced water, contributions of Ca and Mg, through weathering of spoil and topdressing materials, will significantly reduce the SAR.

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28

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