FINAL REPORT

VOLUME I

Water Quality Impacts From Surfaces Treated with Dust Suppressants and Soil Stabilizers

September 2002

Prepared For:
Clark County Health District
Clark County Air Quality Management Agency
Las Vegas Valley Water District
Clark County Flood Control District
City of Las Vegas

Principal Investigators:

Thomas Piechota, Assistant Professor
Dept. of Civil & Environmental Engineering
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154-4015
P: 702-895-4412 F: 702-895-3936
piechota@unlv.edu

Jacimaria Batista, Assistant Professor
Dept. of Civil & Environmental Engineering
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154-4015
P: 702-895-1585 F: 702-895-3936
jaci@ce.unlv.edu

David James, Associate Professor
Dept. of Civil & Environmental Engineering
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154-4015
P: 702-895-1067 F: 702-895-3936
daveearl@ce.unlv.edu

Graduate Students
Daniela Loreto
Vivek Singh

DISCLAIMER

This report makes no representations that endorse or exclude the use of the products tested as part of this research project. The individual products were selected to include the major classes of suppressants (e.g., petroleum-based, ligninsulfonate products). The results do not necessarily reflect the water quality impacts for all the products in each class. Any interpretations beyond those presented in this report will not be supported by the authors or participating agencies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This research is supported under contracts with the Clark County Health District, Clark County Air Quality Management Agency, Las Vegas Valley Water District, Southern Nevada Water Authority, Clark County Flood Control District, the City of Las Vegas, and the University and Community College System of Nevada Applied Research Initiative. We would like to thank the following companies, agencies, and individuals for their cooperation in this research:

- Las Vegas Valley Water District (Alec Hart) for permitting the use of the West Charleston Reservoir Site.
- Envirocon (Troy Hildreth) for supplying and applying several of the dust suppressants.
- Stewart & Stewart Fine Grade, Inc. (Scott Stewart) for applying two of the dust suppressants.
- Las Vegas Paving (David Breault) for grading the site.
- The manufacturers of the dust suppressants listed in Table 1-1 for donating the supplies.

EXECUTIVE SUMMARY

Goals Of Research

This report presents the results of field experiments on the potential water quality impacts from the application of dust suppressants to disturbed lands in Clark County, Nevada. This is an important issue not only in the southwest, but in all of the U.S. since there are currently minimal guidelines for the use of dust suppressants. The use of dust suppressants is driven by the need of communities to comply with air quality standards of PM-10 (particulate matter less than 10 μm in diameter) emissions. There is, however, concern that the solution of this air pollution problem will have other unanticipated environmental and human health consequences. Dust suppressants include water, fiber mulches, water-absorbing materials (e.g., calcium chloride, magnesium chloride), petroleum based organics (e.g., asphalt emulsion), non-petroleum based organics (e.g., vegetable oil, molasses), synthetic polymer emulsions, and lignin products. These materials are generally effective in minimizing dust; however, little is known about the effects of the products on the environment and human health.

In Clark County, there is the potential for dust suppressants to be used on large areas to minimize the PM-10 emissions from lands that are disturbed from construction activities and on unpaved roads. Furthermore, all of the Las Vegas Valley drains to Lake Mead which is a drinking water source for many communities in the southwest. It is undesirable to allow the application of dust suppressants that could potentially contribute contaminated runoff to Lake Mead. The agencies sponsoring this research (Clark County Health District, Clark County Air Quality Management Agency, Las Vegas Valley Water District, Southern Nevada Water Authority, Clark County Flood Control District, and the City of Las Vegas) recognize that research on all the potential environmental impacts is important; however, impacts of dust suppressants on water quality were given the highest priority for this study. **Therefore, the overall objective of this research was to generate basic data for evaluating the water quality impacts of major categories of dust suppressants.** This information will serve as a scientific basis for proposed guidelines on the application of dust suppressants to disturbed lands.

Research Approach

For this study, rainfall events were simulated onto land plots to which different dust suppressants were applied. The field site was selected to represent soil characteristics typical of disturbed land surfaces in the Las Vegas Valley. A property owned by the Las Vegas Valley Water District (LVVWD) and located at the West Central Reservoir and Well Field site (7512, West Charleston Blvd.) was selected for application of the 11 different dust suppressants. The existing conditions of the land surface was typical of a desert landscape, and the soil is classified by the U.S. Department of Agriculture, Natural Resources Conservation Service as "Cave-Las Vegas-Goodsprings-Destazo-Tencee." This is a gravelly fine sandy loam soil that is representative of 35.6% of the Las Vegas Valley area based on general soil classifications. The central portion of the property was graded to create a surface similar to a construction site. This was accomplished with a construction blade that scraped the surface and removed all vegetation. A uniform surface with the same slope as the existing ground (approximately 3%) was created.

The site was divided into individual plots (10 meters x 10 meters) and different categories of dust suppressants were applied according to industry standards and by local dust suppressant applicators. A control plot (i.e., no dust suppressant applied) was also created for comparison purposes. The selection of the dust suppressants focused on products that represent different categories of dust suppressants. This research is not meant as an endorsement of any products, so the selection of individual products was based on input from the Clark County Dust Palliative Working Group which is comprised of local and state agencies, industry representatives, and academia. The following items were considered in making the product selection (See Table 1-1 for a list of products).

1. Types of dust suppressants currently used in Clark County
2. Types of dust suppressants that may be used in the future in Clark County
3. Representation of all major categories of dust suppressants
4. Use of the product in a previous study by James et al. (1999) for Clark County that evaluated the "effectiveness" of dust suppressants

The rainfall event which was simulated over the test plots was representative of natural rainfall occurring in the Las Vegas Valley. A rainfall intensity of 2.3 cm/hr (0.89 in/hr), which is between a 2 and 5 year – 1 hour storm at McCarran Airport was simulated. This event represents a reasonable sized storm that will result in sufficient runoff for the water quality experiments. It was necessary to construct a rainfall simulation system for the field experiments so all experiments had the same rainfall rate and comparisons could be made between the different plots.

The environmental impacts focused on the quality of the runoff emanating from the plots treated with dust suppressants and the residual contaminants remaining in the soil after rainfall events. The parameters to be analyzed in this research were chosen by contrasting federal and state regulations on water quality for aquatic life, regulations on hazardous waste pollutants, and priority pollutant regulations. All comparisons were made in reference to the control plot.

Results

The results of this study provide information for preliminary assessment of the water quality impacts from the application of dust suppressants to disturbed lands. The following is a summary of the results obtained for the major categories of dust suppressants.

Petroleum-based

The runoff and soil extracts from the plots treated with petroleum-based products (Coherex and Road Pro) contained the largest number of contaminants with concentrations above the control plot. Application of these suppressants is likely to contribute metals, volatile and semi-volatile compounds, sulfate, ammonia, nitrate, sulfide, coliform bacteria, hardness, TDS, and sulfide to runoff waters. A comparison of the runoff and soil extracts results show a significant difference between Coherex and Road Pro. The number of contaminants with concentrations above the control plot was higher in the runoff of Coherex while the concentrations in the soil extract were higher for Road Pro. This implies that Coherex washed out more easily from the soil than Road Pro. Both of the petroleum-based dust suppressants created runoff volumes that were higher than the control plot (by at least 200%) and an earlier timing of the initial runoff.

Acrylic Polymers

A large number of parameters with concentrations greater than those of the control plot were also found for all acrylic-polymers. Acrylic polymers are likely to contribute volatile and semi-volatile organic compounds, organic carbon, TDS, alkalinity, hardness sulfate, metals, and nitrate to the runoff. The iso-alkane (EK35) and acrylic polymer (Enviro-Tac) showed higher concentrations of contaminants than Poly-bond and Soil Sement. The acrylic polymer with the least number of contaminants is Soil Sement, but lead and selenium were detected in the runoff of the plots treated with this dust suppressant. The hydrologic impacts from plots treated with acrylic polymers was mixed. The runoff volume was increased for 3 of the 4 products and a surface was created with a similar runoff coefficient similar to that of a residential development (e.g., runoff coefficient of 0.40-0.50). All of the acrylic polymers had an earlier time to initial runoff (10 to 30 minutes earlier).

Ligninsulfonate

The ligninsulfonate dust suppressants (Dustac and Topein) also present a high number of components with concentrations above those of the control, but the concentrations of most contaminants found are smaller than those present in the petroleum-based and some of the acrylic products. A moderate number of metals were also found in the runoff of both dust suppressants. Use of these dust suppressants can potentially increase organic content, TDS, sulfate, nitrate, metals, and chloride to runoff waters. The soil extract from Topein shows a large number of contaminants at high concentrations. It appears that the contaminants from Dustac are more easily leached out than those of Topein. Plots treated with ligninsulfonate increased the runoff coefficient by 21 to 142%, and had a time to initial runoff of 5 to 25 minutes earlier than the control plot runoff. These hydrologic impacts are small compared to petroleum-based and acrylic polymer dust suppressants.

Organic Nonpetroleum-based (Tall Oil)

The organic nonpetroleum-based product (Road Oyl) had a moderate number of parameters with concentrations above that of the control plot. The soil extract of Road Oyl contains the highest number of contaminants with concentration above that of the control. The quality of the soil extract of this plot is comparable to those to which petroleum-based products where applied. Thus, the contaminants from Road Oyl adsorb to the soil and are not easily leached by rainfall. A high number of metals was detected in the runoff treated with this product. Application of tall oil will contribute to volatile organic compounds, organic carbon, TDS, hardness, sulfide, ammonia, and metals. The hydrologic impacts from plots treated with Road Oyl was a slight increase in runoff (42%) and an earlier time to initial runoff (15 minutes earlier). The hydrologic impacts from this product are relatively small compared to petroleum-based and acrylic polymers.

Fiber Mulch

The runoff from the plot treated with the fiber mulch (Plas-bond) presented a small number of components above that of the control. The major contributions of this suppressant to runoff are hardness, sulfate, organic carbon, TDS, and metals. However, the soil extract had a high number of contaminants (particularly metals) with concentrations greater than the control plot. These results imply that most contaminants present in Plas-bond are not easily leached out with rainfall, but they remain in the soil. The application of fiber mulch to the plots had a large impact on the hydrologic characteristics of the soil surface. All of the rainfall in the first hour of the simulation was absorbed by the fiber mulch. Surfaces that are treated with fiber mulch will receive lower runoff volume during the initial part of the storm; however, runoff rates will increase (still below the control plot) as the product becomes saturated.

Magnesium Chloride

The magnesium chloride (Dust Gard) contributes the smallest number of contaminants to the runoff. The major contributions to runoff from the application of this suppressant are ions that will result in increased salinity and conductivity. The soil extract from the magnesium chloride plot showed a relatively low number of contaminants at concentrations greater than the control. Both the runoff and soil extract had high concentrations of boron and chloride. The runoff volume was reduced for these plots and the time to runoff initiation was increased. The hydrologic impacts from surfaces treated with magnesium chloride will not adversely change the downstream flow in a watershed.

Final Observations

A preliminary evaluation of the potential loads from areas treated with dust suppressants was provided for the Las Vegas Valley watershed. Noteworthy observations are that chloride concentrations were increased for all of the dust suppressants, and phosphate and TSS loads were reduced for the majority of the dust suppressants. The extrapolation of the concentrations from the experimental plots to a large area implies many assumptions, but provides an integration of changes in water quality concentrations and hydrologic characteristics which results in the potential loading from the watershed.

All suppressants studied showed some effect on the quality of the runoff or soil extract as compared to the control. However, the significance of these effects can only be evaluated by considering jointly the effectiveness of the dust suppressant, the location of the application, and the runoff water quality. A dust suppressant that generates relatively good runoff quality may become undesirable if it has to be applied very often, resulting in a large pollutant load.

SECTION 1: INTRODUCTION AND RESEARCH GOALS

1.1. GENERAL OVERVIEW

The United States Environmental Protection Agency (USEPA) has established a health-based national air quality standard for PM-10 (particulate matter less than 10 µm in diameter) with an annual average of 50 $\mu g/m^3$ and a maximum daily concentration of 150 $\mu g/m^3$ (USEPA, 2002). The rapid growth in the southwestern United States, including the Las Vegas Valley, has resulted in the disturbance of several thousand acres of arid lands. This disturbance of the natural soil crust exacerbates the release of fine particular matter (PM-10) to the air (James et al., 1999) from unpaved roads and parking lots, vacant lots that have been graded, and construction sites. In response to the PM-10 regulations, dust suppressants are being used to stabilize disturbed lands and unpaved roads. There is, however, concern that the solution of this air pollution problem will have other unanticipated environmental and human health consequences.

Dust suppressants include water, fiber mulches, water-absorbing materials (e.g., calcium chloride, magnesium chloride), petroleum based organics (e.g., asphalt emulsion), non-petroleum based organics (e.g., vegetable oil, molasses), synthetic polymer emulsions, and lignin products. These materials are generally effective in minimizing dust; however, little is known about the effects of the products on the environment and human health (Hanes et al., 1970, Hanes et al., 1976). Impacts will depend upon their composition, application rates, and interactions with other environmental components. Potential environmental impacts include: surface and groundwater quality deterioration; soil contamination; toxicity to soil and water biota; toxicity to humans during and after application; unintentional air pollution; accumulation in soils; changes in hydrologic characteristics of the soils; and impacts on native flora and fauna populations. The majority of studies on dust suppressants have focused on their effectiveness to abate dust and not on their environmental impacts. Only a few studies have evaluated environmental impacts of dust suppressants (see the Literature Review in Appendix A). Furthermore, the majority of studies have focused on the application of dust suppressants to unpaved roads. An extensive literature review on the effectiveness of dust suppressants and some of their environmental impacts is provided in Appendix A.

In order to quantify the impacts of dust suppressant application to the environment, several local agencies (Clark County Health District, Clark County Air Quality Management Agency, Las Vegas Valley Water District, Southern Nevada Water Authority, Clark County Flood Control District, and the City of Las Vegas), made the decision to financially support this research on the effects of dust suppressants on the water quality of the Las Vegas Valley. The sponsoring agencies are part of the Clark County Dust Palliative Working Group which is comprised of local and state agencies, industry representatives, and academia. The objective of the working group was to evaluate the application of dust suppressants in the Las Vegas Valley. The agencies recognize that research on other environmental impacts is also important; however, impacts of dust suppressants on water quality were given the highest priority for this study.

1.2. STATEMENT OF PROJECT OBJECTIVES AND APPROACH

The objective of this research was to provide basic data for evaluating the water quality impacts of major categories of dust suppressants and soil stabilizers. The ultimate goal of this research was to generate preliminary data that can guide future studies and provide scientific basis for proposed guidelines on the application of dust suppressants to disturbed lands. Given the proximity of the Las Vegas Wash (end point of urban runoff from the Las Vegas Valley) to Lake Mead (drinking water source to the 1.2 million residents of the Las Vegas Valley), the application of any dust suppressant found to negatively impact chosen water quality criteria would likely be deemed undesirable.

For this study, rainfall events were simulated onto land plots to which different dust suppressants were applied. A site with soil characteristics representative of disturbed lands in the Las Vegas Valley was chosen. The site was divided into individual plots and different categories of dust suppressants were applied. The soils from each plot were evaluated to establish background characteristics. Rainfall events were simulated on the dust suppressant-treated plots, and the runoff from the plots was collected and analyzed for several parameters. Finally, the soils were sampled after the rainfall events to determine the remaining levels of the different suppressants' constituents . All comparisons were made in reference to a control plot that provides background concentrations.

1.3. PROJECT ORGANIZATION

This project involved the following researchers:

- **Dr. Thomas Piechota (PI)**, Assistant Professor, Department of Civil and Environmental Engineering, University of Nevada Las Vegas. Telephone: 702-895-4412 piechota@unlv.edu

- **Dr. Jacimaria Batista (Co-PI)**, Assistant Professor, Department of Civil and Environmental Engineering, University of Nevada Las Vegas. Telephone: 702-895-1585 jaci@ce.unlv.edu

- **Dr. David James (Co-PI)**, Associate Professor, Department of Civil and Environmental Engineering, University of Nevada Las Vegas. Telephone: 702-895-3701 daveearl@ce.unlv.edu

- **Daniela Loreto,** Graduate Student, Department of Civil and Environmental Engineering, University of Nevada Las Vegas. Telephone: 702-895-4339 daniela@unlv.edu

- **Vivek Singh,** Graduate Student, Department of Civil and Environmental Engineering, University of Nevada Las Vegas. Telephone: 702-895-2623 vivek@unlv.edu

1.4. SELECTION OF DUST SUPPRESSANTS

The selection of the dust suppressants focused on products that represent different categories of dust suppressants. This research is not meant as an endorsement of any products. Instead, the overall goal was to provide preliminary information on the major categories of dust suppressants. The selection of individual products was based on input from the Clark County Dust Palliative Working Group where the following items were considered in making the product selection (See Table 1-1 for a list of products).

1. Types of dust suppressants currently used in Clark County.
2. Types of dust suppressants that may be used in the future in Clark County.
3. Representation of all major categories of dust suppressants.
4. Use of the product in a previous study by James et al. (1999) for Clark County that evaluated the "effectiveness" of dust suppressants

Table 1-1: Summary of dust suppressants used in this study.

Trade Name	Category	Manufacturer
Poly-Bond	Acrylic Polymer	Soil Tech
Soil Sement	Acrylic Polymer	Midwest Industrial Supply
Enviro-tac	Acrylic Polymer	Environmental Product & Applications Inc.
EK35	Synthetic Iso-alkane	Midwest Industrial Supply
Plas-Bond	Fiber Mulch	Soil Solutions
Dust Gard	Magnesium Chloride	Dustchem
Road Pro	Petroleum-based	Midwest Industrial Supply
Coherex	Petroleum-based	Golden Bear Oil
Road Oyl	Organic Nonpetroleum (Tall Oil)	Soil Stabilization Products
Dustac	Ligninsulfonate	Georgia Pacific
Topein	Ligninsulfonate	Topein Emulsions

1.5. SELECTION OF RAINFALL EVENT FOR SIMULATION

The rainfall event which was simulated over the test plots was representative of natural rainfall occurring in the Las Vegas Valley. A rainfall intensity of 2.3 cm/hr (0.89 in/hr), which is between a 2 and 5 year – 1 hour storm at McCarran Airport as defined in the Clark County Hydrologic Design Manual (CCRFCD, 1999) (See Table 1-2) was simulated. This event represents a reasonable sized storm that will result in sufficient runoff for the water quality experiments.

Table 1-2: McCarran Airport rainfall – intensity (cm/hr) (from CCRFCD, 1999).

Length of Event (hours)	Recurrence Interval (yr)					
	2	**5**	**10**	**25**	**50**	**100**
0.08	4.57	8.23	10.67	14.02	16.46	19.20
0.17	3.81	6.71	8.69	11.28	13.56	15.54
0.25	3.35	5.79	7.52	9.86	11.68	13.41
0.5	2.24	3.96	5.13	6.65	7.87	9.09
1	1.32	2.26	2.92	3.81	4.52	5.23
2	0.76	1.30	1.65	2.16	2.57	2.92
3	0.53	0.91	1.17	1.55	1.83	2.11
6	0.30	0.51	0.66	0.86	1.02	1.17
24	0.13	0.18	0.20	0.25	0.28	0.30

1.6. SELECTION OF WATER QUALITY TESTS

In this research, parameters were evaluated to determine: (a) the quality of the runoff emanating from the plots treated with dust suppressants, and (b) the residual contaminants remaining in the soil extract after rainfall events. In Nevada, there are currently no regulations for the quality of runoff waters. However, Nevada has water quality standards for aquatic life and for surface waters contaminated by hazardous substances present in soils. The parameters to be analyzed in this research were chosen by contrasting federal and state regulations on water quality for aquatic life, regulations on hazardous waste pollutants, and priority pollutant regulations. The majority of the toxic substances regulated by the state of Nevada are included in the EPA National Recommended Water Quality Criteria for Priority Pollutants. The following regulations were compiled and contrasted to determine analyses to be performed in the runoff and soil extract from the plots to which suppressants were applied:

1. The EPA National Recommended Water Quality Criteria for freshwater for priority pollutants (Table B.2 - Appendix B).
2. The EPA National Recommended Water Quality Criteria for freshwater for non-priority pollutants (Table B.3 - Appendix B).
3. The Nevada NAC 445A.119 for beneficial uses (aquatic life) (Table B.4 – Appendix B).
4. The Nevada NAC 445A.144 for toxic substances (Table B.1 – Appendix B)
5. The Nevada NAC 445A.2272 for waters emanating from contaminated soil was consulted and it was learned that this regulation calls for the Toxicity Characteristic Leaching Procedure (TCLP) and for petroleum hydrocarbon concentration in soil (Table B.5 - Appendix B).
6. The Material Safety Data Sheets (MSDS) for the dust suppressants under consideration were examined and components, which reflect their composition, were added to the analysis.
7. The EPA Synthetic Precipitation Leaching Procedure, Method 1312 (Appendix C).

The EPA freshwater priority and non-priority pollutant lists, the Nevada beneficial use and toxic substances regulations for aquatic life (NAC 445A.119 and NAC 445A.144), regulations for waters from contaminated soils (TCLP - NAC 445A.2272), and the potential harmful substances based on the MSDS's were combined to create Table B.6 (Appendix B). These components were analyzed in the runoff emanating from the plots to which suppressants were applied.

For the analysis of the residual contaminants in the soil, samples were taken from the top two inches of the treated plots, after rainfall simulation, and leached using the EPA Synthetic Precipitation Leaching Procedure (Method 1312). All analyses were performed in duplicate samples and the values shown on the graphs are the average of the readings obtained. Table 1-3 presents all components analyzed in the runoff samples. The highlighted compounds were analyzed in the soil extract.

Table 1-3: Contaminants analyzed for in the runoff and soil extract from the plots treated with dust suppressants.

Compound	Compound
Organochlorine Pesticides and PCBs:	Chromium
Aldrin	Copper
Alpha-BHC	Iron
Beta-BHC	Lead
A-Chlordane	Manganese
B-Chlordane	Mercury
4,4'-DDD	Nickel
4,4'-DDE	Selenium
4,4'-DDT	Silver
Delta-BHC	Thallium
Dieldrin	Zinc
Endosulfan I	***Inorganic and Other Parameters:***
Endosulfan II	Chloride
Endosulfan Sulfate	pH
Endrin	Total Organic Carbon (TOC)
Endrin Aldehyde	Chemical Oxygen Demand (COD)
Gamma-BHC (Lindane)	Biochemical Oxygen Demand (BOD)
Heptachlor	Conductivity
Heptachlor Epoxide	Salinity
Malathion	Nitrate
Methoxychlor	Sulfate
Mirex	Ammonia-Nitrogen
Toxaphene	Cyanide
Aroclor-1016	Turbidity
Aroclor-1221	Hardness
Aroclor-1232	Phosphate
Aroclor-1242	Alkalinity
Aroclor-1248	Total Solids
Aroclor-1254	Total Dissolved Solids
Aroclor-1260	Total Volatile Solids
Metals:	Total Suspended Solids
Aluminum	Coliform
Arsenic	Sulfide
Barium	***Volatile Organic Compounds*** (Table 1-3A)
Boron	***Semi-Volatile Organic Compounds*** (Table 1-3B)
Cadmium	

Table 1-3A: Volatiles organic compounds analyzed for in the runoff from the plots treated with dust suppressants.

Compound	Compound
Acetone	1,3-Dichloropropane
Benzene	2,2-Dichloropropane
Bromobenzene (Phenyl bromide)	1,1-Dichloropropene
BROMOCHLOROMETHANE	cis-1,3-Dichloropropene
Bromodichloromethane	trans-1,3-Dichloropropene
Bromoform (Tribromomethane)	Ethylbenzene
Bromomethane (Methyl bromide)	Hexachlorobutadiene
2-Butanone (MEK, Methyl ethyl ketone)	2-Hexanone
n-Butylbenzene	Isoproprylbenzene
sec-Butylbenzene	p-Isopropyltoluene (4-Isopropyltoluene)
tert-Butylbenzene	MTBE
Carbon disulfide	4-Methyl-2-pentanone (MIBK)
Carbon tetrachloride (Tetrachloromethane)	Methylene chloride (Dichloromethane, DCM)
Chlorobenzene	Naphthalene
Chloroethane	n-Propylbenzene
2-Chloroethyl vinyl ether	Styrene
Chloroform (Trichloromethane)	1,1,1,2-Tetrachloroethane
Chloromethane (Methyl chloride)	1,1,2,2-Tetrachloroethane
2-Chlorotoluene (o- Chlorotoluene)	Tetrachloroethene (Tetrachloroethylene)
4-Chlorotoluene (p- Chlorotoluene)	Toluene (Methyl benzene)
Dibromochloromethane	1,2,3-Trichlorobenzene
1,2-Dibromo-3-chloropropane (DBCP)	1,2,4-Trichlorobenzene
1,2-Dibromoethane (EDB, Ethyl dibromide)	1,1,1-Trichloroethane
Dibromomethane	1,1,2-Trichloroethane
1,2-Dichlorobenzene (o-DCB)	Trichloroethene (Trichloroethylene)
1,3-Dichlorobenzene (m-DCB)	Trichlorofluoromethane
1,4-Dichlorobenzene (p-DCB)	1,2,3-Trichloropropane
Dichlorodifluoromethane (Freon 12)	1,2,4-Trimethylbenzene
1,1-Dichloroethane (1,1-DCA)	1,3,5-Trimethylbenzene
1,2- Dichloroethane (1,2-DCA)	Vinyl acetate
1,1- Dichloroethene (1,1-DCE)	Vinyl chloride (chloroethene)
cis-1,2-Dichloroethene	o-Xylene
trans-1,2-Dichloroethene	m,-& p-Xylenes
1,2-Dichloropropane	

Table 1-3B: Semi-volatile organic compounds analyzed for in the runoff and soil extract from the plots treated with dust suppressants.

Compound	Compound
Acenaphthene	2,4-Dinitrotoluene
Acenaphthylene	2,6-Dinitrotoluene
Anthracene	Fluoranthene
Benzo (a) anthracene	Fluorene
Benzo (a) pyrene	Hexachlorobenzene
Benzo (b) fluoranthene	Hexachlorobutadiene
Benzo (g,h,i) perylene	Hexachlorocyclopentadiene
Benzo (k) fluoranthene	Hexachloroethane
Benzoic acid	Indeno (1,2,3-cd) pyrene
Benzyl alcohol	Isophorone
bis (2-chloroethoxy) methane	2-Methylnaphthalene
bis (2-chloroethyl) ether	2-Methylphenol
bis (2-chloroisopropyl) ether	4-Methylphenol
bis (2-ethylhexyl)phthalate	2-Methyl-4,6-dinitrophenol
4-Bromophenyl-phenylether	N-Nitroso-di-n-propylamine
Butylbenzylphthalate	N-Nitrosodiphenylamine
4-Chloro-3-methylphenol	Naphthalene
4-Chloroaniline	2-Nitroaniline
2-Chloronaphthalene	3-Nitroaniline
2-Chlorophenol	4-Nitroaniline
4-Chlorophenyl-phenylether	Nitrobenzene
Chrysene	2-Nitrophenol
Di-n-butylphthalate	4-Nitrophenol
Di-n-octylphthalate	Pentachlorophenol
Dibenz (a,h) anthracene	Phenanthrene
Dibenzofuran	Phenol
1,3-Dichlorobenzene	Pyrene
1,2-Dichlorobenzene	Pyridine
1,4-Dichlorobenzene	1,2,4-Trichlorobenzene
3,3'-Dichlorobenzidine	2,4,5-Trichlorophenol
2,4-Dichlorophenol	2,4,6-Trichlorophenol
Diethylphthalate	Aniline
2,4-Dimethylphenol	Azobenzene
Dimethyl phthalate	Benzidine
2,4-Dinitrophenol	Carbazole

SECTION 2: FIELD SITE PROCEDURES

2.1. SITE DESCRIPTION

The ideal experimental site for this research was representative of soils in Clark County, had safe and secure access, a water supply, minor grading requirements of the surface to simulate disturbed lands, and native soil. The field experiments took place at the West Central Reservoir and Well Field site (7512 West Charleston Blvd - Figure 2-1), which is currently owned by the Las Vegas Valley Water District (LVVWD). There is an above ground reservoir located in the southwest portion of the site and several pumping wells throughout the site (Figure 2-2).

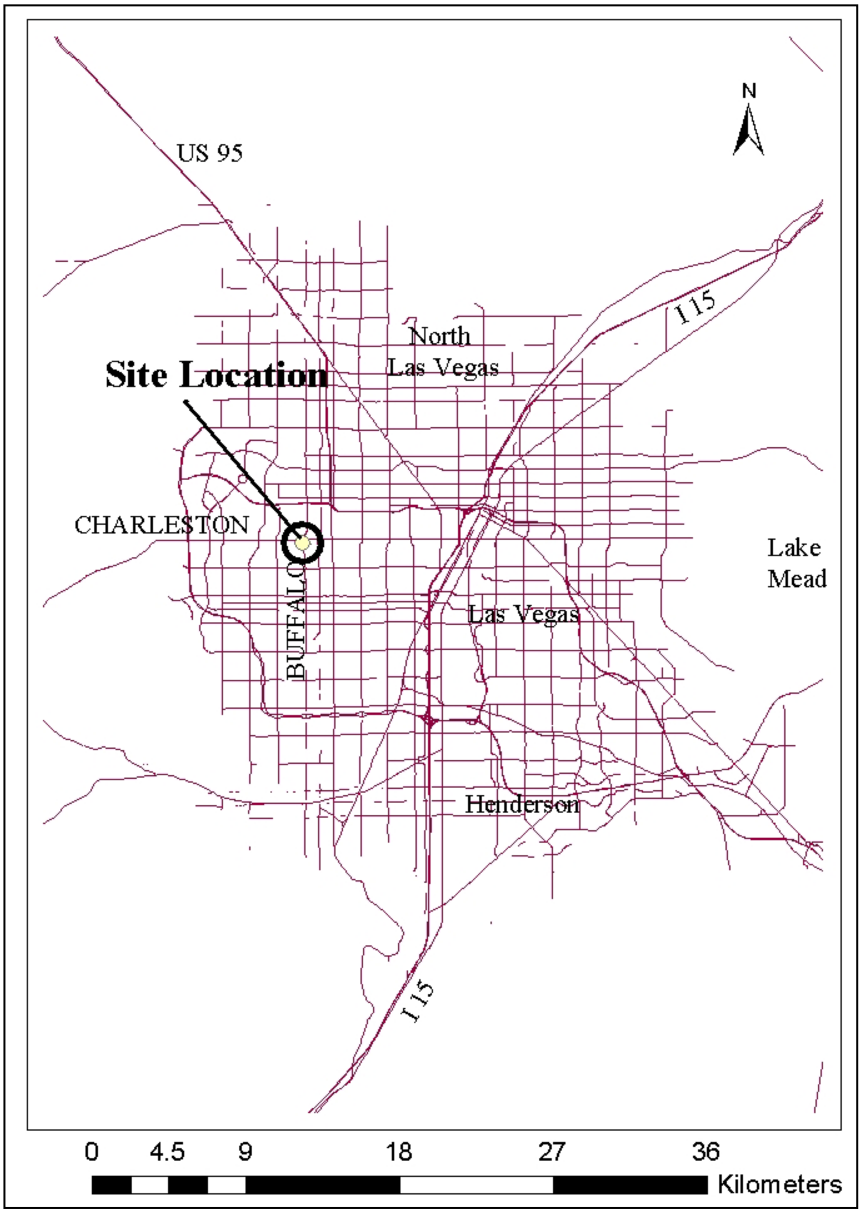


Figure 2-1: General location of the experimental site for dust suppressant application and testing in Clark County, Nevada.

Figure 2-2: Overview of experimental site owned by the Las Vegas Valley Water District (LVVWD).

The test plots for this study were located in the middle of the LVVWD property (Figure 2-2). The existing condition of the land surface was typical of a desert type landscape with small scrub brush and various rock piles (see Figure 2-3 and Figure 2-4). The U.S. Department of Agricultural (USDA) Natural Resources Conservation Service (formerly the Soil Conservation Service – USDA, 1985) has classified the general soil type for this site as "Cave-Las Vegas-Goodsprings-Destazo-Tencee." More specifically, the type of soil is "cave gravelly fine sandy loam". The USDA has identified 10 general soil types in the Las Vegas Valley area: Rock Outcrop-St. Thomas-Akela-Hobog, Cave-Las Vegas-Goodsprings-Destazo-Tencee, Jean-Arizo, Bluepoint-Knob Hill, Weiser-Dalian-Canutio-Casaga, Caliza-Aztec-Bracken-Nickel, McCarran-Badland-Grapevine, Glencarb-Skyhaven, Land-Spring-Paradise, Gravel Pits-Dumps-Slickens, and each soil type represents 15.2%, 35.6%, 7.3%, 2.3%, 15.1%, 8.1%, 5.7%, 5.5%, 2.6%, 2.7% of the Las Vegas Valley area, respectively (see Figure 2-3). Thus, the soil used in the study site is representative of the soils for 35.6% of the Las Vegas Valley area based on general soil classifications.

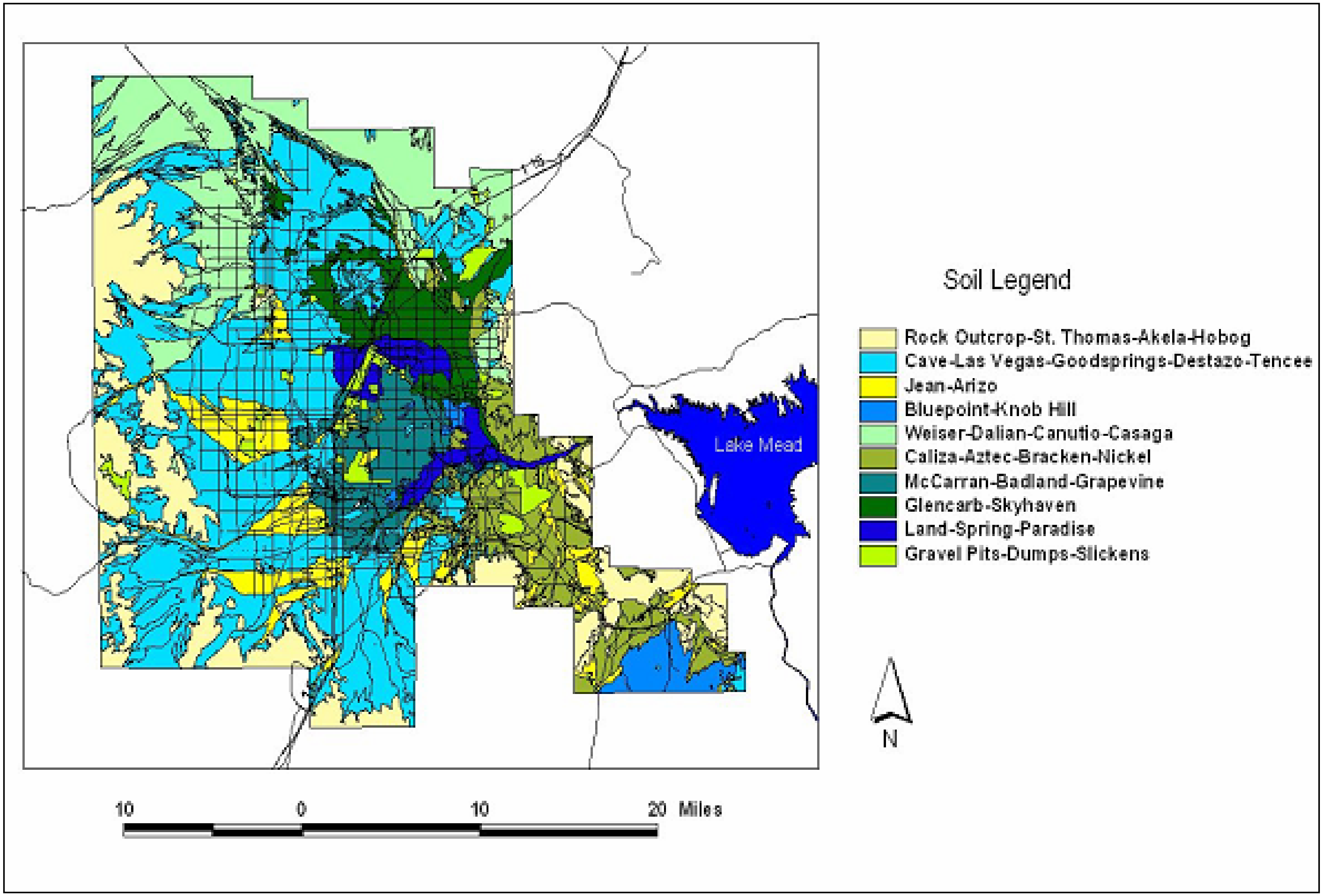


Figure 2-3: Soil types for the Las Vegas Valley based on NRCS-USDA classifications.

Figure 2-4: Experimental site before grading.

2.2. SITE PREPARATION

2.2.1. Grading

The study seeks to investigate the use of dust suppressants on disturbed lands; therefore, the central portion of the property was graded to create a surface similar to a construction site. This was accomplished with a construction blade (courtesy of Las Vegas Paving) that scraped the surface and removed all vegetation (Figure 2-5). This created a uniform surface with the same slope as the existing ground (approximately 3%).

Figure 2-5: Experimental site after grading.

2.2.2. Plot Preparation

After grading the site, twelve plots (1 control and 11 for dust suppressants) were created with overall dimensions of 10 meters x 10 meters (33 ft x 33 ft) (See Figure 2-6). Each individual dust suppressant was applied to the entire surface of a specific plot. Subplots that are 2.4 meters x 2.4 meters (8 ft x 8 ft) were created inside the larger plot and rainfall simulation was performed separately on each plot shown in Figure 2-7. These smaller plots were created to assist in the collection of surface water runoff.

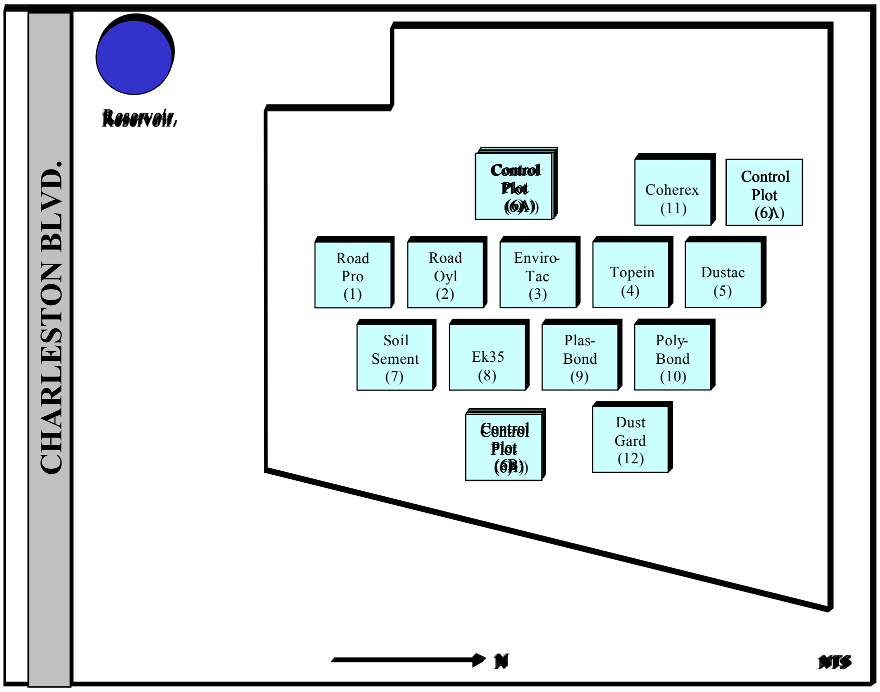


Figure 2-6: Individual plot location of applied dust suppressants. Control Plot 6 was used for water quality tests whereas Control Plots 6A and 6B were used for hydrologic impact calculations.

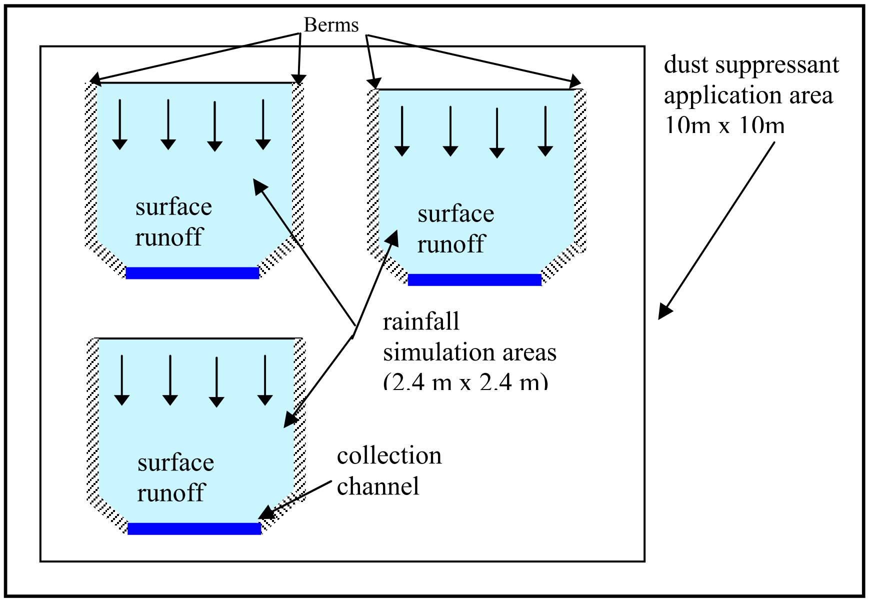


Figure 2-7: Typical layout for one dust suppressant plot with subplots used for rainfall simulation

2.3. SITE CHARACTERIZATION

2.3.1. Physical Properties of Soils

Soil samples were taken from each plot and analyzed at the UNLV Soils Laboratory prior to dust suppressant application. Approximately 5 Kg of soil were taken from each plot and placed into plastic bags. Sub-samples (about 2 Kg) were sealed in plastic bags and transported to the laboratory for soil properties testing. The tests that were used to physically characterize the soil properties from each plot are summarized in Table 2-1 and a summary of the results is provided in Table 2-2 and Appendix D. All soils are classified as “well-graded sand with gravel”. The soil properties for all the plots are uniform, with the exception of Plot No. 7. All the plots have very low moisture content (less than 1%), and permeability values are comparable to those for silty sand soils (Fetter, 1994).

Table 2-1: Summary of standard tests used to physically characterize soils from each test plot.

Soil Parameter	Test Method
Grain Size Analysis	Mechanical Method (ASTM D2487)
Weight- Volume Relationship	ASTM D4253-93, D4254-91, D4718-87, D243-90
Permeability	Falling Head Test (ASTM D2434)
Classification	USDA Classification
Classification	AASHTO Classification
Specific Gravity	ASTM D854-92

Table 2-2: Summary of the physical soil properties for all the test plots

Plot No.	Permeability (cm/s)	Porosity	Density (kg/m^3)	Moisture content (%)	Specific Gravity
1	2×10^{-4}	0.19	1458	0.38	2.75
2	3×10^{-4}	0.21	1424	0.62	2.39
3	4×10^{-4}	0.20	1450	0.67	2.64
4	3×10^{-4}	0.21	1450	0.65	2.90
5	5×10^{-4}	0.21	1514	0.53	2.73
6	1×10^{-4}	0.16	945	0.53	3.36
7	1×10^{-4}	0.19	887	0.75	2.52
8	3×10^{-4}	0.18	1457	0.74	2.64
9	3×10^{-4}	0.18	1478	0.52	2.56
10	2×10^{-4}	0.16	1668	0.49	2.39
11	3×10^{-4}	0.16	1752	0.38	2.75
12	2×10^{-4}	0.14	1026	0.62	2.39
Control Plot 6A	4×10^{-4}	0.20	1450	0.67	2.64
Control Plot 6B	3×10^{-4}	0.18	1457	0.74	2.64

2.4. APPLICATION OF DUST SUPPRESSANTS

The 11 different dust suppressants were applied to the test plots in the summer of 2001. The application of dust suppressants followed the manufacturer's specifications and was performed by local dust suppressant applicators (Soil Solutions Co., Inc. and Stewart & Stewart Fine Grade, Inc). The dust suppressants were topically applied at the rates specified by the manufacturers. Some dust suppressants can be windrowed into the soils; however, this study focused on the more common topical application method of dust suppressants. Topical application also represents the worst-case scenario for chemicals entering the surface water runoff. Table 2-3 provides the application date, application rates, and dilution for each dust suppressant. The plot numbers in Table 2-3 correspond to those in Figure 2-6. The application rates vary according to many factors such as, type of product, degree of dust control required, traffic surface, and climatic considerations. All of the dust suppressants were applied on the surface with a spray hose that received the dust suppressant from a mixing reservoir. A sample of each product applied was collected in a polypropylene bottle during the field application. It was necessary to apply Coherex through spray jets behind a truck with a reservoir that maintains the suppressant at 82^{o}C (180^{o}F). Figure 2-8 and Figure 2-9 present two examples of dust suppressant application in the field.

Table 2-3: Dust suppressant application rates and plot locations.

Trade Name	Type	Date Applied	Dilution / Mix	Application Rate *	Plot #
Road Pro	Petroleum-based	08/07/2001	No Dilution	0.25 gal/yd^2	1
Road Oyl	Organic Nonpetroleum	06/29/2001	1:5	0.20 gal/yd^2	2
Enviro-tac	Acrylic Polymer	06/29/2001	-	-	3
Topein	Ligninsulfonate	06/15/2001	1:7	0.50 gal/yd^2	4
Dustac	Ligninsulfonate	06/15/2001	0.25 lb/gal	0.75 gal/yd^2	5
Soil Sement	Acrylic Polymer	06/26/2001	1:4	0.25 gal/yd^2	7
EK35	Synthetic Iso-alkane	06/26/2001	No Dilution	0.25 gal/yd^2	8
Plas-Bond	Fiber Mulch	06/26/2001	water 500 lb gypsum 300 lb mulch 10-15 lb color	6000 lb/acre 1.24lb/yd^2 (Dry Product)	9
Poly-Bond	Acrylic Polymer	06/21/2001	1:4	0.50 gal/yd^2	10
Coherex	Petroleum-based	06/08/2001	1:4	0.35 gal/yd^2	11
Dust Gard	Magnesium Chloride	06/26/2001	No Dilution	0.5 gal/yd^2	12

* Application rates are for the diluted mixture

Figure 2-8: The application of Enviro-tac onto a test plot by Stewart & Stewart Fine Grade, Inc.

Figure 2-9: The application of Coherex to a test plot by Soil Solutions Co, Inc.

2.5. RAINFALL SIMULATION SYSTEM

A rainfall simulation system for the field experiments was constructed for several reasons. First, Las Vegas receives sporadic rainfall events and it would be problematic to collect runoff from these uncontrolled events. Secondly, the magnitude of these natural rainfall events may not be enough to generate sufficient runoff for water quality tests. Lastly, a rainfall simulation system permits a set of controlled experiments at a predefined rainfall rate. Following is a description of the rainfall simulation system.

2.5.1. Description of System

2.5.1.1. Configuration

A general layout of the rainfall simulator system is presented in Figure 2-10. The LVVWD tap water was treated using a Reverse-Osmosis (RO) system, stored in a 4,165 liters (1,100-gallon) plastic reservoir, and pumped to the rainfall simulator towers. The use of RO treated water ensured that any chemicals coming from the runoff would either be from the soils or dust suppressants. The pump was needed to provide enough pressure at each tower to maintain desired flow. Each rainfall simulation tower is composed of three legs made of aluminum poles that are 2.4 meters in height, and support a pressure gauge and nozzle. Gauges were incorporated into the rainfall simulator system to verify the pressure in each nozzle. The rainfall rate depends on the nozzle type and pressure in the system. The nozzle is a ¼ GG – SS 10W (Full Jet) nozzle, from the Spraying System Company (Wheaton, IL). A schematic of one rainfall simulator tower is provided in Figure 2-11 and an actual setup of the rainfall towers is shown in Figure 2-12.

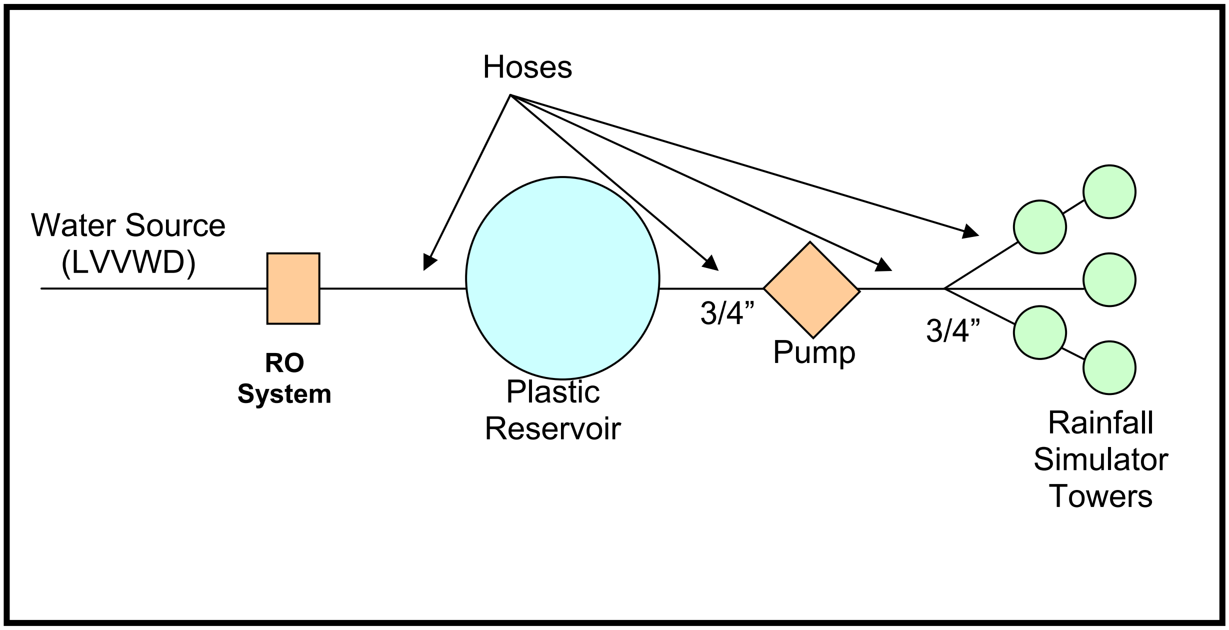


Figure 2-10: Layout of the rainfall simulator system.

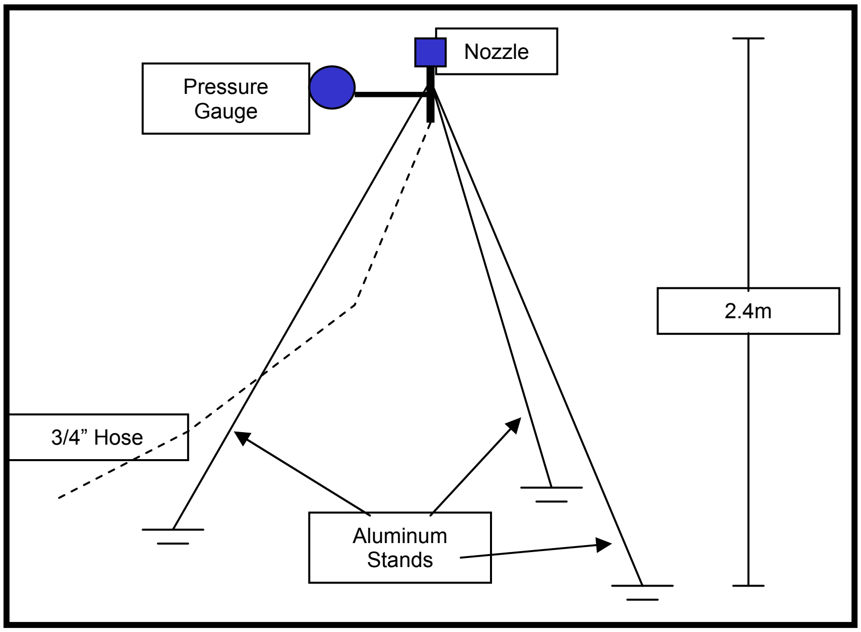


Figure 2-11: Typical rainfall simulator tower.

Figure 2-12: Actual layout of the rainfall simulation towers at a test plot.

2.5.1.2. Testing of Rainfall Towers

Two variables that control the rainfall rate and distribution are the pressure at the nozzle and the spacing between the rainfall towers. To determine the appropriate pressure and tower spacing, experiments were performed over an area equal to the size of each test plot (2.4 meters x 2.4 meters). The spacing between the towers was varied, and the pressure at the nozzle was varied using a flow valve. Experiments were performed using a tower spacing of 3 and 4 meters with pressures varying from 89 to 152 kPa (13.0 to 22.0 psi).

The actual rainfall depth during the rainfall simulation was determined with nine gages placed inside the plot and on the perimeter (Figure 2-13). A measure of how uniform the rainfall is spatially distributed over the control area (plot) is the coefficient of uniformity (CU) (Zoldoske, 1998):

$$\mathrm{CU} = 1 - \frac{\mathrm{D}}{\mathrm{M}} \qquad (1)$$

$$\mathrm{D} = \frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \left| \mathrm{X}_{\mathrm{i}} - \mathrm{M} \right| \qquad (2)$$

$$\mathrm{M} = \frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{X}_{\mathrm{i}} \qquad (3)$$

where M is the mean of the applied rainfall over the plot (as measured by the gages), D is the average absolute deviation from M, X_i is the individual rainfall value within the plot, and n is the number of individual points sampled in the plot. CU varies from 0 to 1 where a high CU value represents a uniform distribution of rainfall over the plot. The CU was determined for each experiment, and experiments that had a CU value greater than 0.80 were considered adequate for the field simulations (Zoldoske, 1998).

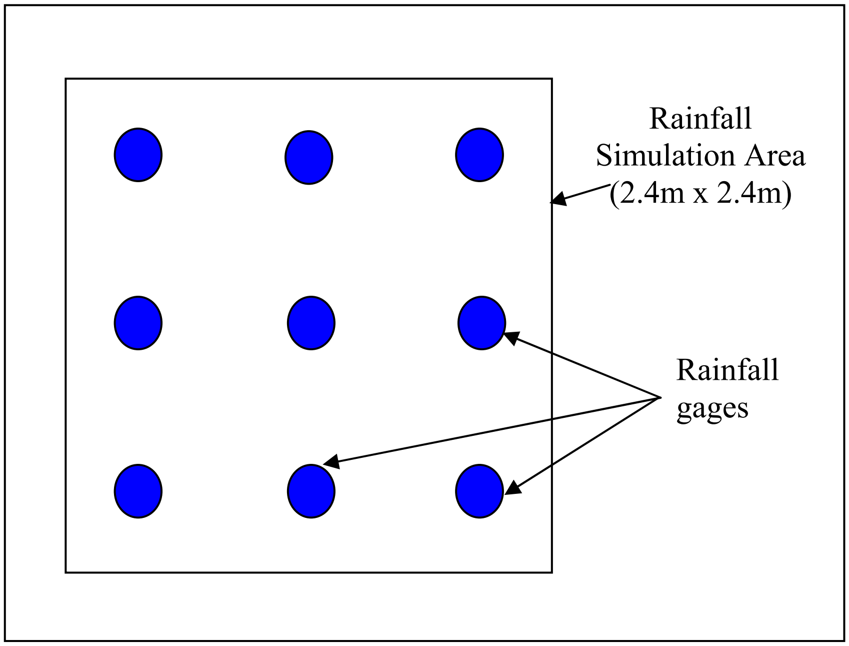


Figure 2-13: Spatial distribution of the rainfall gages. The location of the rainfall gages were selected to provide a uniform distribution throughout the plot.

Initially, the distance between the towers was 3 meters and the pressures varied from 89 to 152 kPa. In Figure 2-14, rainfall intensity increases with increasing pressure. The maximum intensity in these experiments was 33.3 mm/hr (1.31 in/hr) with a pressure of 152 kPa (22 psi) at the nozzle. The CU was also the highest at this point. Generally, the CU value increases with increasing pressure and rainfall intensity. A graphical representation of the CU value is provided in Figure 2-15 by plotting the spatial distribution of rainfall.

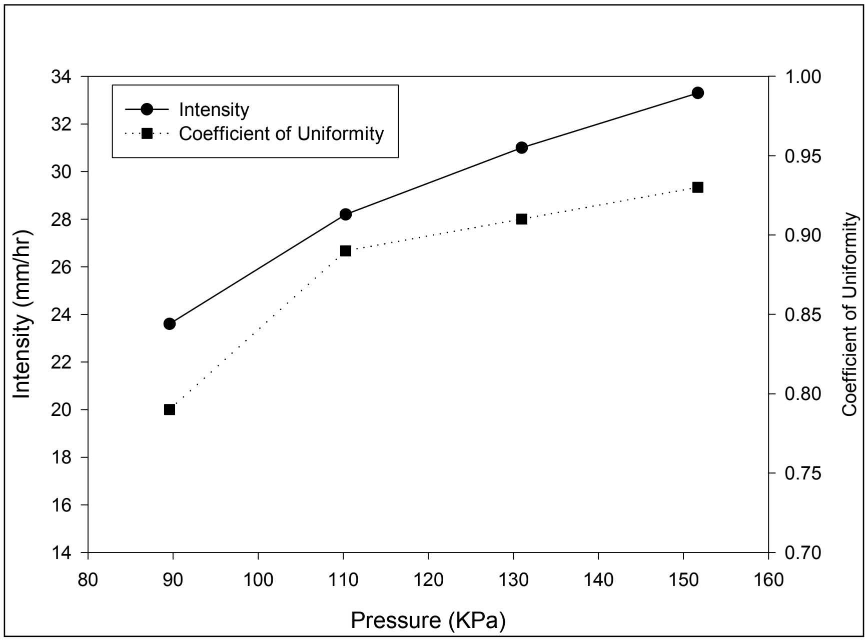


Figure 2-14: Summary of relationship between pressure, intensity, and coefficient of uniformity (CU) at a tower spacing of 3 meters.

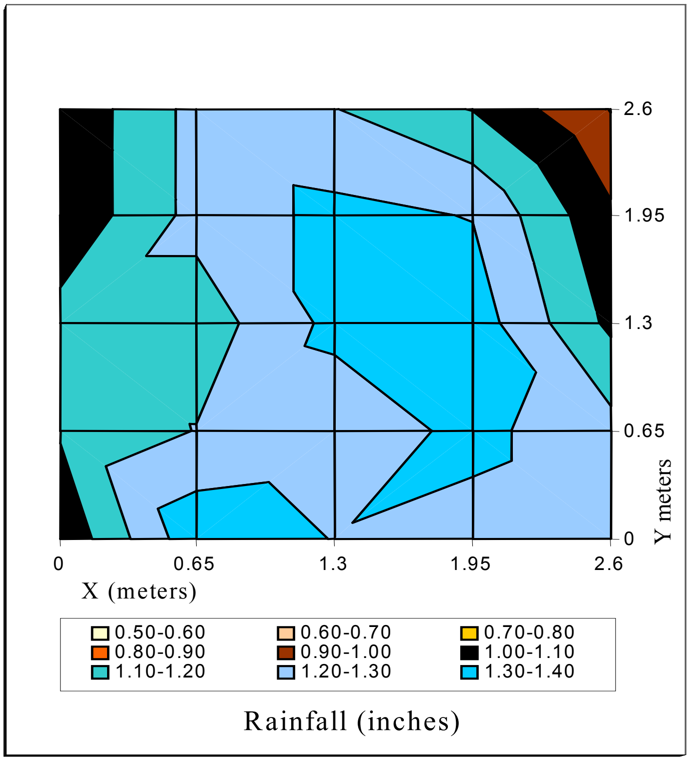


Figure 2-15: Spatial distribution of rainfall over the plot area for a pressure of 131 kPa (19 psi), and a 3 meter tower spacing (CU = 0.91).

The distance between the rainfall towers was increased to 4 meters and the pressures varied from 89 to 152 kPa (13 to 22 psi). Figure 2-16 and Figure 2-17 present the results of these experiments. Similar to the previous experiments at a 3-meter spacing, the experiments had an increasing CU value with increasing pressure and rainfall intensity. The rainfall intensities were lower for this set of experiments since the tower spacing was increased. An intensity as low as 0.61 in/hr was achieved with a pressure of 89 kPa (13 psi). The CU for all pressures and tower spacing was greater than 0.80. Figure 2-17 shows an example of the spatial distribution of rainfall for a pressure of 131 kPa (19 psi).

A tower spacing of 4 meters with a pressure of 131 kPa (19 psi) was selected based on the above tests. This operating point results in a rainfall intensity of 23 mm/hr (0.89 in/hr), which is between a 2 and 5 year – 1 hour storm at McCarran Airport as defined in the Clark County Hydrologic Design Manual (CCRFCD, 1999) (See Table 1-2). This event represents a reasonable sized storm that will result in sufficient runoff for the water quality experiments.

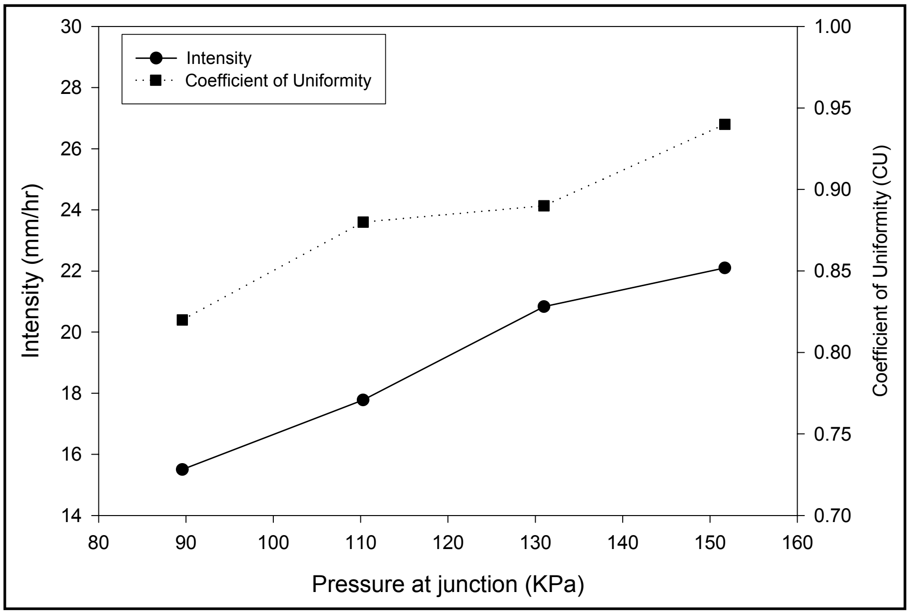


Figure 2-16: Summary of relationship between pressure, intensity, and coefficient of uniformity (CU) at a tower spacing of 4 meters.

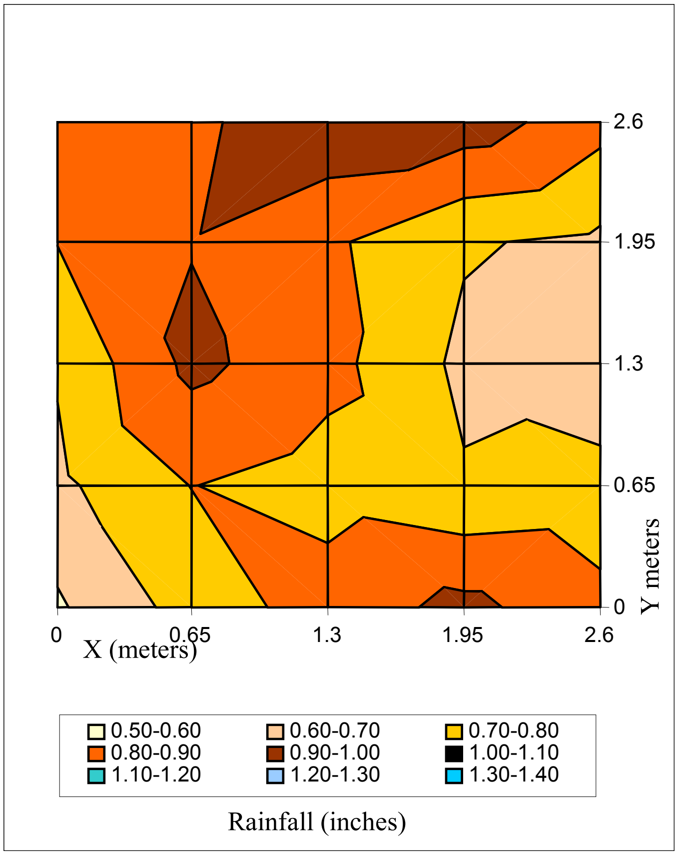


Figure 2-17: Spatial distribution of rainfall over the plot area for a pressure of 131 kPa (19 psi), and a 4 meter tower spacing (CU = 0.91).

2.5.1.3. Quality of Rainfall Water

Because of the many interactions of the soil components with the suppressants and the rainfall, it was important that the composition of the water used in the simulated rainfall events be as close as possible to that of the rainfall in the Las Vegas area. The average composition of the rainfall in the Las Vegas Valley, as reported by the National Atmospheric Deposition Program for a station located in Red Rock Canyon is summarized in Appendix E. The characteristics of the rainfall water in the Red Rock Canyon Station include an average pH of 5.4, an average conductivity of 9.52 μS/cm, and very low concentrations of cations and anions. Since the Las Vegas tap water has very high hardness (about 300 mg/L as $CaCO_3$), a RO system was used to generate a water quality similar to that of rainfall events. The RO system used is a Culligan B – 4L Plus RO system preceded by a Culligan MK-89 carbon filter to remove organics and chlorine. Las Vegas tap water was the input to the RO system to generate a water supply with characteristics similar to those of rainfall.

2.5.1.4. Weather Monitoring

Experiments were performed in the morning to minimize evaporation losses and during low wind conditions to ensure uniform rainfall distribution. The environmental conditions in the field were recorded using a Davis Wireless Weather Monitor II Station that records wind velocity, temperature, and relative humidity.

2.5.1.5. Runoff Collection System

The runoff generated from each test plot was collected in order to evaluate the runoff quantity and quality. The collection of the runoff was accomplished with a 3.81 cm (1½ in.) PVC pipe that was cut to form a semi-circular channel. The pipe was placed on the downstream side of the plot and it conveyed the runoff to a polypropylene bottle (Figure 2-18 and Figure 2-19). Berms were placed along the side of the plot to ensure that all runoff drained to the pipe. The rainfall simulation was performed on two of the sub plots of each dust suppressant plot shown in Figure 2-7 and the control plot. The composite runoff sample was then transported on ice to the UNLV environmental engineering laboratory for chemical analysis.

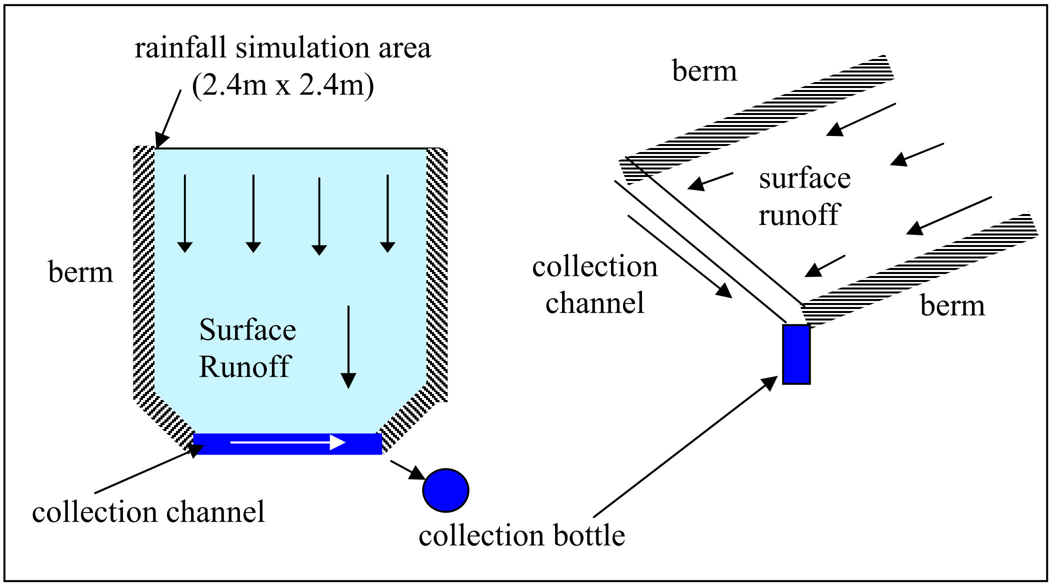


Figure 2-18: Runoff collection system created for each subplot.

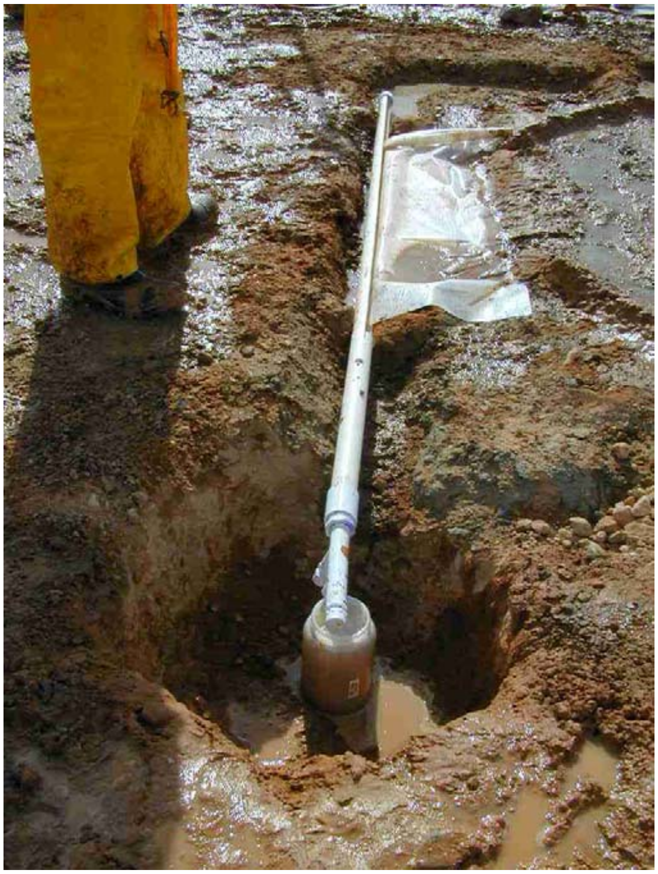


Figure 2-19: Runoff collection system in the field

2.6. SAMPLE HANDLING, STORAGE, PRESERVATION AND IDENTIFICATION

2.6.1. Handling, Storage and Preservation

During the rainfall simulations, composite runoff samples were collected in a clean 3.78 liter (1-gallon) cubitainer. In the field, 100 ml of sample was collected into acidified vola-vials for the analysis of volatile organic compounds. In addition, a sample was collected, in the field, into a sterile vial for coliform analysis. The remaining composite sample was transported on ice to UNLV environmental engineering laboratory, divided into aliquots, preserved and stored according to the standards procedures summarized in Appendix F.

2.6.2. Identification

Samples were identified with the project name, date, and name of the person taking the samples. A chain of custody system was used to track the samples from the field to the laboratory. Sampling procedures and results of all analyses were kept in hand-written, bound laboratory notebooks that were available for inspection. All analytical results were calculated using appropriate equations and reported in appropriate concentration units. Reduced data was transferred to spreadsheets, and was periodically reviewed by the research assistant and principal investigators. All data classified as outliners (data that does not satisfy QA objectives) were immediately examined in detail and corrective actions taken.

SECTION 3: ANALYTICAL METHODS USED FOR THE ANALYSIS OF THE RUNOFF AND SOIL EXTRACT

The following procedures were used in the analysis of the runoff and soil extract performed in this research.

pH

A Corning pH/ion meter 450 (New York, NY) with an Orion combination probe (Beverly, MA) and a Corning General Purpose Combo were used in the experiments. Calibration was performed with pH standards of 4.0, 7.0 and 10.0.

Chloride

Chloride was analyzed as per Standard Method 4110 using a DX-120 Ion Chromatograph (IC) equipped with an IonPac AS11 separation column, an IonPac AG-11 4-mm guard column (Sunnyvale, CA). A self-regeneration suppressor and external water mode were used. Five-mM NaOH (sodium hydroxide) was used as the eluent in the analysis. The sample injection volume was 25-μL, the flow rate for the eluent was 1.00 ml/min. The IC calibration curve achieved a R^2 (from linear least square analysis) value of 0.997 or greater. A quality control (QC) sample was analyzed every 20 samples.

Total Organic Carbon

Non-Purgable Organic Carbon (NPOC) was measured in all runoff and soil extraction samples using a total organic carbon analyzer, Shimadzu TOC-5000A (Moorpark, CA). An R^2 (from least square analysis) of 0.998 or greater was maintained in the calibration curves.

Chemical Oxygen Demand

Chemical Oxygen Demand (COD) test was performed using low and high range pre-mixed Hach (Loveland, CO) COD vials, a Hach COD reactor, and a Milton Roy Spectronic 20 spectrophotometer. A COD vial containing DI water was used as the blank to calibrate the spectrophotometer.

Biological Oxygen Demand

BOD testing was performed as per Standard Method 5210B. Samples were seeded with domestic wastewater in 300-ml BOD bottles to promote biological oxidation of the potential biodegradable organic matter in the samples. The Dissolved Oxygen (DO) of the samples was determined using a YSI 54 A Dissolved Oxygen meter (Yellow Springs, OH) with a YSI 5720 probe. BOD dilution water was used as the blank control. After seeding, samples were incubated at 20ºC for a period of five days. Dissolved Oxygen was measured before and after incubation and the BOD was calculated from the difference between the initial and the final DO measured in the bottles.

Conductivity and Salinity

An YSI Model 30 salinity/conductivity meter (Yellow Springs, OH) was used to measure the conductivity of the runoff and soil extracts. Salinity was calculated from the conductivity measured in the filtered samples using the practical salinity scale that was modified for low salinity ranges as per Hill, *et al*. (1986). The calculation method used for the salinity is presented in Appendix G.

Nitrate, Sulfate, Sulfide, Ammonia-Nitrogen, Cyanide, and Turbidity
Nitrate, sulfate, ammonia-nitrogen, and cyanide were measured using a Hach DR/890 Colorimeter following the procedures suggested by the manufacturer (Hach, Loveland, CO). Turbidity was measured for runoff samples using the same equipment.

Hardness
Hardness testing was performed using a Hach Hardness Kit that uses the EDTA Titrimetric Method as described in Standards Methods 2340C (APHA, 1995) for both, runoff and soil samples.

Phosphate
Phosphate was measured using the Ascorbic Acid Method # 4500E (APHA, 1995). A Spectronic 20D spectrophotometer with infrared phototube for use at 880 nm, providing light path of 2.5 cm was used to measure the phosphorus concentration. To correct for color interference, present in most of the samples, a blank was prepared by adding sulfuric acid and ammonium molybdate to the samples. The blank absorbance was subtracted from each sample absorbance to obtain the final result.

Alkalinity
Alkalinity was measured using the Titration Method # 2320B (APHA, 1995). A Corning pH/ion meter 450 (New York, NY) was used to measure the initial and final pH values of the samples.

Gravimetric tests
Total Solids (TS), Total Volatile Solids (TVS), Total Suspended Solids (TSS), and Total Dissolved Solids (TDS) analyses were performed gravimetrically in the runoff from all the plots using Standard Method procedure #2540 (APHA, 1995). In addition, TDS was analyzed in the soil extract from the treated and control plots.

Coliform
Coliform was determined in the runoff samples using the Chromogenic Substrate Coliform Test # 9223B (APHA, 1995). Tests were performed using Colilert, a product from the Idexx Laboratories, Inc. (Westbrook, ME). A 100-ml of diluted sample was added to the reagent container provided by the manufacturer. The enzymatic substrate was added to the reagent container and mixed to dissolve. The mixture was then placed on Quanti-Trays®, and sealed using a Quanti-Tray/2000 sealer. The sealed trays were incubated at 35ºC for 24 hours. The Most Probable Number (MPN) of coliform was evaluated using the MPN table provided by Idexx Laboratories, Inc.

Iron
Iron was measured using a Perkin-Elmer AAnalyst 100 Atomic Absorption Spectrometer (Norwalk, CT). Calibration of the equipment was performed using two-point calibration. All samples and standards used to perform the calibration were acidified with HNO_3 prior to analysis.

Other Metals

Metals such as aluminum, arsenic, barium, boron, cadmium, chromium, copper, lead, manganese, nickel, selenium, silver, thallium, and zinc, were measured using a Perkin Elmer Elan 5000 (Norwalk, CT) Inductively Coupled Plasma–Mass Spectrometer (ICP-MS) at the Harry Reid Center for Environmental Studies at UNLV. Method 200.8 (External Standard Method by Ultrasonic Nebulizer) was followed.

Mercury

Mercury was determined according to USEPA Method 1631 "Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry" using a Tekran CVAFS Mercury System Model 2600 (Toronto, CA) at the Harry Reid Center for Environmental Studies at UNLV. Samples were preserved with bromine monochloride (BrCl).

Volatile Organic Compounds

Volatile organic compounds were measured in the runoff samples by American Scientific Laboratories, LLC (Los Angeles, CA) using EPA Method 8260B. Analyses were performed using a HP 5972 Mass Selective Detector (MSD) with a HP-624 capillary column.

Semi-Volatile Organic Compounds

Semi volatile organic compounds were analyzed by D-TEK Analytical Laboratories, Inc. (San Diego, CA) using EPA Method 3510 for extraction, and EPA Method 8270 for runoff and soil extract analyses. Analyses were performed using a HP 5890 Series II GC/MS with a DB-5 capillary column.

Organochlorine Pesticides and Polychlorinated Biphenyls (PCBs)

Organic pesticides and PCBs were measured by D-TEK Analytical Laboratories, Inc. (San Diego, CA) using EPA Methods 3510 and 3620 for extraction and EPA Methods 8081 and 8082 for runoff and soil extract analyses. Those compounds were measured using a HP 5890 Series II GC/MS with two capillary columns, DB-608 and DB-1701.

Table 3-1 summarizes all the analyses, analytical methods, equipment, and quality assurance/control procedures used in this study.

Table 3-1: Summary of methods, equipment, and QA/QC procedure used in the analyses.

Analysis	***Analytical Method***	***Equipment***	***QA/QC***	***Reference***
pH		Corning pH/ion meter 450, Orion combination probe.	Calibrated with pH standards of 4, 7, and 10.	
Chloride	Ion Chromatography	DX-120 Dionex AS11/AG11 columns, 25 µl sample loop, 0.5 mM NaOH eluent, self regeneration suppressor, and external water mode.	Calibration curve $R^2 \geq 0.997$. Calibrated with chloride standards - 1 to 50 mg/L. QC run after every 20 samples.	Standard Method 4110
TOC	Total Organic Carbon – Combustion-Infrared Method	Shimadzu TOC-5000A	Calibration curve $R^2 \geq 0.998$	Standard Method 5310B
COD	Chemical Oxygen Demand	Pre-mixed Hach COD vials, Hach COD reactor, Spectronic 20 Spectrophotometer		Standard Method 5220
BOD	Biochemical Oxygen Demand	YSI 54 A Dissolved Oxygen instrument, YSI 5720 probe		Standard Method 5210B
Conductivity		YSI Model 30 system.	QC after every 20 samples	
Salinity		Hill *et al.* (1986) equations		Hill *et al.*, 1986
Nitrate	Colorimetry	Hach DR/890 Colorimeter	QC after every 20 samples	Hach® Datalogging Colorimeter Handbook
Sulfate	Colorimetry	Hach DR/890 Colorimeter	QC after every 20 samples	Hach® Datalogging Colorimeter Handbook
Sulfide	Colorimetry	Hach DR/890 Colorimeter	QC after every 20 samples	Hach® Datalogging Colorimeter Handbook
Ammonia-N	Colorimetry	Hach DR/890 Colorimeter	QC after every 20 samples	Hach® Datalogging Colorimeter Handbook
Cyanide	Colorimetry	Hach DR/890 Colorimeter	QC after every 20 samples	Hach® Datalogging Colorimeter Handbook
Turbidity	Colorimetry	Hach DR/890 Colorimeter		Hach® Datalogging Colorimeter Handbook

Table 3-1: Summary of methods, equipment, and QA/QC procedure used in the analyses. (continued).

Analysis	*Analytical Method*	*Equipment*	*QA/QC*	*Reference*
Hardness	Colorimetry/Titration	Hach Hardness Test Kit		Standard Method 2340C
Phosphate	Ascorbic Acid Method	Spectronic 20D spectrophotometer	QC after every 20 samples	Standard Method 4500E
Alkalinity	Titration Method			Standard Method 2320B
Gravimetric	Solids			Standard Method 2540
Coliform	Chromogenic Substrate Test	Colilert formulation		Standard Method 9223
Iron	Atomic Absorption	Perkin-Elmer Aanalyst 100 Atomic Absorption Spectrophotometer	QC after every 5 samples	Standard Method 3500B and 3111B
Metals	Inductively Coupled Plasma – Mass Spectrophotometry	Perkin Elmer Elan 5000, S/N 114 ICP –MS		Method 200.8 - External Standard Method by Ultrasonic Nebulizer
Mercury	Cold Vapor Atomic Fluorescence Spectrometry	Tekran CVAFS Mercury System Model 2600		EPA Method 1631
Volatile	Gas Chromatography/Mass Spectrometry	GC/MS		EPA Method 8260B
Semi-volatile	Gas Chromatography/Mass Spectrometry	HP 5890 Series II - GC/MS, DB-5 column		EPA Methods 3510 for extraction EPA Method 8270 for analysis
Organic pesticides and PCBs	Gas Chromatography	HP 5890 Series II - GC/MS, DB-608 and DB-1701 columns		EPA Methods 3510 and 3620 for extraction EPA Methods 8081 and 8082 for analysis

SECTION 4: FIELD RESULTS OF HYDROLOGIC IMPACTS

4.1. RAINFALL SIMULATION

During the rainfall simulation experiments, a minimum runoff of 9.5 liters (2.5 gallons) was required to perform the desired water quality tests. Rainfall simulation was performed on two of the subplots (2.4 meters x 2.4 meters) on the same day. The first 4.75 liters (1.25 gallons) of runoff emanating from each subplot was collected and mixed together to obtain a combined sample of 9.5 liters (2.5 gallons) for the water quality analysis. The volume of the remaining runoff was measured, but was not used for water quality analysis. Due to the length of time required for setup, water quality analysis, and generation of RO water, simulations for each test plot were performed on separate days. Relevant data were recorded including the date and time of experiment, meteorological conditions, volume and depth of rainfall, and volume and timing of runoff.

Table 4-1: Date and duration of rainfall simulations.

Dust Suppressant	*Sub-Plot No.	Dates	Start Time	End Time	Duration
Road Pro	1B	11/21/2001	12:00	13:00	1 hr.
	1D	11/21/2001	10:25	11:25	1 hr.
Road Oyl	2B	11/28/2001	10:43	11:43	1 hr.
	2D	11/28/2001	9:05	10:05	1 hr.
Enviro-Tac	3B	11/17/2001	10:00	11:00	1 hr.
	3C	11/17/2001	8:13	9:13	1 hr.
Topein	4A	11/19/2001	9:38	10:55	**1 hr 17 min
	4C	11/19/2001	7:41	8:56	**1 hr 15 min
Dustac	5A	11/01/2001	7:40	8:40	1 hr.
	5C	11/01/2001	9:40	10:40	1 hr.
Soil Sement	7A	11/06/2001	7:33	8:33	1 hr.
	7B	11/06/2001	9:15	10:15	1 hr.
Ek35	8A	11/15/2001	8:51	9:51	1 hr.
	8C	11/15/2001	7:22	8:22	1 hr.
Plas-Bond	9A	11/09/2001	10:06	12:06	** 2 hrs
	9B	11/11/2001	8:33	10:33	** 2 hrs
Poly-Bond	10A	10/30/2001	9:17	10:17	1 hr.
	10D	10/30/2001	7:38	8:38	1 hr.
Coherex	11C	12/01/2001	10:50	11:50	1 hr.
	11D	12/01/2001	9:08	10:08	1 hr.
Dust Gard	12A	10/25/2001	8:05	9:05	1 hr.
	12B	10/23/2001	8:05	9:05	1 hr.
Control Plot	6A	03/12/2002	9:58	10:58	1 hr.
	6B	03/12/2002	11:50	12:50	1 hr.

* Sub-plot lettering refers to location of sub plot within the main plot.

** Experiment was performed until 9.5 liters (2.5 gallons) of runoff was collected

4.1.1. Start and End Times of Experiments

Rainfall simulations were performed in October and November of 2001, and generally in the mornings (See Table 4-1). The majority of experiments lasted for one hour except for those that did not generate sufficient runoff [9.5 liters (2.5 gallons)] in one hour. The test plot with Plot 4 (Topein) required an experiment run time of approximately 1 hour and 15 minutes to generate the required runoff volume. The experiment on the Plot 9 (Plas-Bond) was run for 2 hours to generate the required runoff volume.

4.1.2. Meteorological Data

The rainfall simulation experiments were performed in the mornings to minimize the effect of evaporation, which increases as the day becomes warmer. The experiments were only performed on days when the wind speed was less than 10 km/hr. Wind speeds greater than 10 km/hr resulted in a non-uniform distribution (low CU value) of rainfall over the test plot. The rainfall simulation system has been designed to counter small changes in wind speed by adjusting the locations of the towers and the pressure at the nozzle. Temperature and relative humidity values were provided to represent the weather conditions on the day of the experiment. Table 4-2 lists the starting meteorological conditions for each experiment.

Table 4-2: Starting meteorological conditions during simulations

Product	Plot No.	Outside Temperature(^oC)	Wind Speed (Km/s)	Wind Direction	Relative Humidity (%)
Road Pro	1B	17	5	E - SE	23
	1D	16	6	E - SE	26
Road Oyl	2B	7	8	S	28
	2D	5	5	SE - S	31
Enviro-Tac	3B	17	6		32
	3C	15	0	---	37
Topein	4A	15	2	SW	29
	4C	11	5	SW	39
Dustac	5A	15	2	E -SE	46
	5C	20	2	SW	38
Soil Sement	7A	17	0	---	55
	7B	20	5	S - SE	49
Ek35	8A	15	3	SE	37
	8C	13	0	---	43
Plas-Bond	9A	19	4	W - SW	25
	9B	17	2	N - NE	44
Poly-Bond	10A	21	3	NE - E	30
	10D	18	3	W	41
Coherex	11C	9	5	NE	54
	11D	8	5	SE - E	57
Dust Gard	12A	14	3	W	21
	12B	18	0	---	18
Control Plot	6A	16	3	E - SE	21
	6B	19	0	---	19

4.1.3. Volume and Depth of Simulated Rainfall

A summary of the rainfall data for each plot is provided in Table 4-3 and Figure 4-1. The rainfall volume and depth are based on an average of the nine point measurements made for each plot as described in Section 2.5.1.2. The rainfall distribution for each was fairly uniform as noted by CU values greater than 0.8 (see Table 4-3), which are considered adequate for field experiments. The high CU values achieved for the simulations demonstrate that the rainfall simulators were adequately designed to simulate defined rainfall events. Furthermore, the rates for all the plots were between rainfall rates that correspond to a 2 year 1-hr storm and a 5 year 1-hr storm (see Table 1-2) for the Las Vegas Valley with the exception of the plot treated with Dust Gard.

Table 4-3: Calculated volume, depth and rate of rainfall simulated over each plot. The volume is calculated using the average data obtained from nine gages. The depth is calculated by dividing the volume of rainfall by the area of each plot.

Product	Plot No.	Rainfall Volume (ml)	Rainfall Depth (cm)	Time (hr)	Rainfall Rate (cm/hr)	Coeff. of Uniformity
Road Pro	1B	76124	1.58	1.00	1.58	0.89
	1D	78092	1.62	1.00	1.62	0.92
Road Oyl	2B	91746	1.99	1.00	1.99	0.89
	2D	93224	1.83	1.00	1.83	0.96
Enviro- Tac	3B	85271	1.84	1.00	1.84	0.93
	3C	98306	2.05	1.00	2.05	0.91
Topein	4A	110324	2.41	1.28	1.89	0.96
	4C	105620	2.25	1.25	1.80	0.93
Dustac	5A	99331	1.91	1.00	1.91	0.94
	5C	79921	1.75	1.00	1.75	0.95
Soil Sement	7A	96045	2.05	1.00	2.05	0.94
	7B	72084	1.89	1.00	1.89	0.87
Ek35	8A	91379	1.70	1.00	1.70	0.88
	8C	105341	2.09	1.00	2.09	0.96
Plas-Bond	9A	160670	3.76	2.00	1.88	0.97
	9B	143275	3.78	2.00	1.89	0.96
Poly-Bond	10A	74451	1.67	1.00	1.67	0.86
	10D	84391	1.70	1.00	1.70	0.94
Coherex	11C	111547	1.84	1.00	1.84	0.83
	11D	88387	1.61	1.00	1.61	0.90
Dust Gard	12A	121665	2.14	1.00	2.14	0.92
	12B	131238	3.01	1.00	3.01	0.89
Control Plot	6A	77523	1.79	1.00	1.79	0.95
	6B	76622	1.72	1.00	1.72	0.95

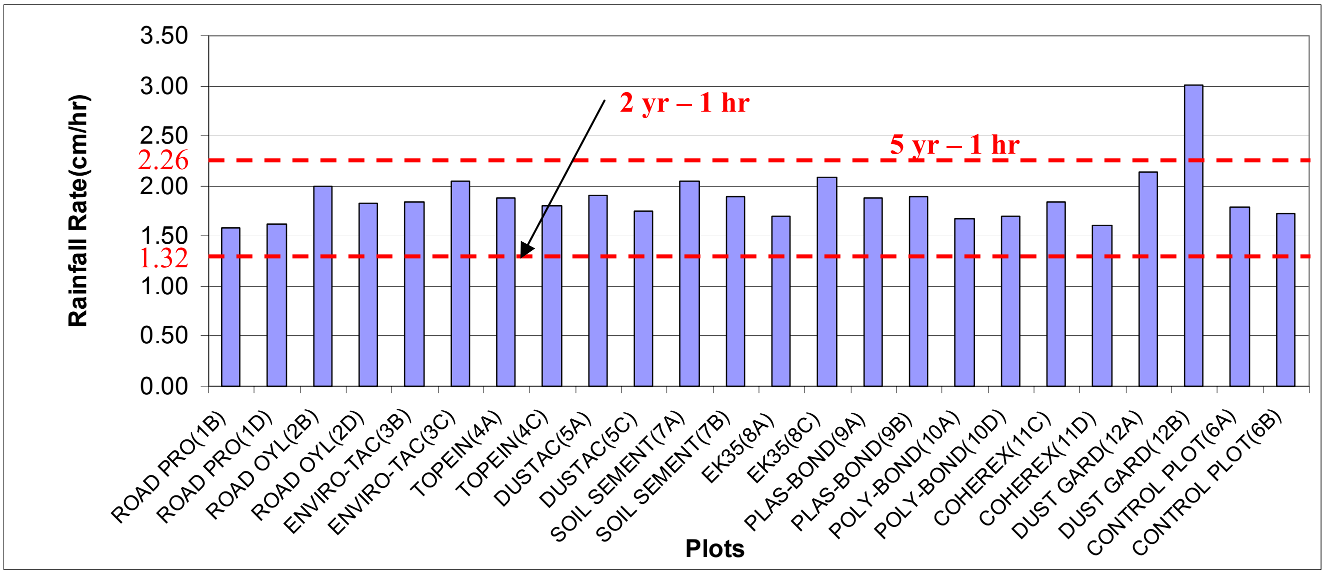


Figure 4-1: Rainfall rates simulated over each plot applied with different dust suppressants. The two dashed lines represent the 2 and 5 year 1 - hr storm for the McCarran Airport area.

4.2. RUNOFF

4.2.1. Runoff Coefficients

The total volume of runoff generated from each plot was measured and used for estimation of runoff coefficients. Using the rainfall and runoff volume, the runoff coefficient (C) was calculated for each plot as:

$$C = \frac{Q}{P} \tag{4}$$

where Q is the volumetric runoff and P is the volumetric rainfall applied to the plot.

Table 4-4 summarizes the runoff coefficients for all plots including the control plot. There is a large variation in the runoff coefficient with the type of dust suppressant applied. This variation is due to the different characteristics of the suppressant applied. In addition, minor variations in the plot physical properties could have affected the runoff coefficients. The experiments were designed to have surfaces with similar properties; however, there may be some minor variations in the plot physical soil characteristics that could impact the runoff coefficients. Figure 4-2 summarizes the runoff coefficients of the plots treated with dust suppressant compared to the control plot.

For all the plots, the runoff coefficient was equal or greater than the control plot with the exception of the plots treated with Poly-bond and Dust Gard. For instance, the petroleum-based products (Road Pro and Coherex) tend to produce an impermeable surface and a higher runoff coefficient (0.30 and 0.38, an increase of 215% and 294%, respectively) as compared to the control plot, which had a runoff coefficient of 0.10.

In the case of acrylic polymers, the runoff coefficients varied from 0.51 (431% increase) for Enviro-tac (it creates a very hard impermeable surface that is difficult to penetrate), to 0.04 (-57%) for Poly-Bond. There is not a consistent response of runoff to surfaces treated with acrylic polymers, and the changes will depend on the makeup of the dust suppressant. The formulation of a dust suppressant such as Poly-Bond can promote infiltration and reduce the amount of runoff. The application of the organic nonpetroleum based product (Road Oyl) and magnesium chloride (Dust Gard) had smaller changes in the runoff coefficient (see Table 4-4). The runoff coefficient for the plot treated with Dust Gard was reduced only by 15%, and the plot treated with Road Oyl was increased by 42%.

The fiber mulch product (Plas-Bond) had an overall runoff coefficient of 0.10 for the 2 hour rainfall simulation; however, it is noteworthy that there was no runoff in the first hour of the experiment. Thus, the runoff coefficient for this plot is reduced considerably for a one hour rainfall compared to the control plot. This is due to the large amount of paper material in the product that absorbs the rainfall water.

Table 4-4: Runoff coefficients of each test are plot calculated by dividing the volume of rainfall simulated by the volume of runoff. The last column shows the % change in runoff coefficient compared to the control plot.

Product	Plot No.	Runoff Volume (ml)	Rainfall Volume (ml)	Runoff Coefficient [C]	Average C	% Change
Road Pro	1B	23200	76123	0.30	0.30	215
	1D	23200	78092	0.30		
Road Oyl	2B	13050	91746	0.14	0.14	42
	2D	12250	93224	0.13		
Enviro-Tac	3B	44000	85270	0.51	0.51	431
	3C	48950	98305	0.50		
Topein	4A	11650	110323	0.11	0.12	21
	4C	12350	105620	0.12		
Dustac	5A	26540	99330	0.27	0.23	142
	5C	14950	79921	0.19		
Soil Sement	7A	23200	96045	0.24	0.25	163
	7B	18700	72083	0.26		
EK35	8A	30100	91379	0.33	0.41	326
	8C	50900	105340	0.48		
Plas-Bond	9A	18250	160670	0.11	0.10	5
	9B	12900	143275	0.09		
Poly-Bond	10A	2700	74451	0.04	0.04	-57
	10D	3000	84390	0.04		
Coherex	11C	46200	111546	0.41	0.38	294
	11D	30400	88387	0.34		
Dust Gard	12A	21267	252903	0.08	0.08	-15
Control Plot	6A	6500	77522	0.08	0.10	----
	6B	8550	76622	0.11		

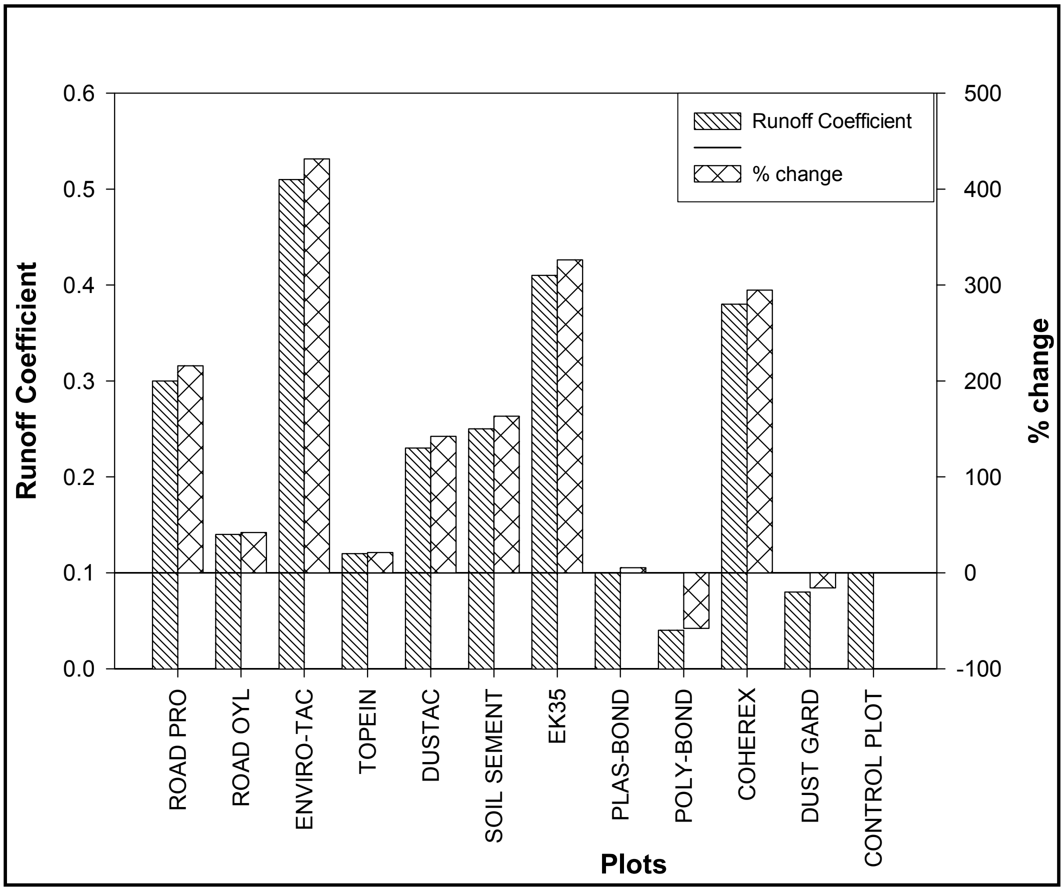


Figure 4-2: Summary of runoff coefficients for all plots and the % change as compared to the control plot.

4.2.2. Comparison to other land uses (published literature)

Runoff coefficients are well documented for different land surfaces. These coefficients are used for design purposes by engineers. Typical runoff coefficients for undeveloped desert areas are on the order of 0.20 – 0.25 (McCuen, 1998). A list of the runoff coefficients for different land uses is provided in **Table 4-5**. Runoff coefficients typically vary according to the magnitude of the rainfall event (i.e., the higher the rainfall event, the higher the runoff coefficient). The values shown in **Table 4-5** are typically used for return periods of 10 years or less.

It is noteworthy that the runoff coefficient from the control plot (0.10) is not consistent with published data that suggest the coefficient should be approximately 0.25 for natural desert areas. The difference between these values could be due to the type of soil present in this study, the slope of the land surface, and/or the magnitude of rainfall event. For some of the plots treated with the dust suppressants, a surface was created that exhibits a runoff coefficient similar to a residential area. For instance, Road Oyl, EK35, and Coherex all had runoff coefficients that are greater than 0.40. The runoff coefficient for residential areas is between 0.45 and 0.62.

Table 4-5: Typical runoff coefficients (CCRFCD, Hydrologic Criteria and Drainage Design Manual, 1999)

Character of Surface	Runoff Coefficient (10 yr)	
	Grass	Desert
Business and Commercial		
NEIGHBORHOOD AREAS	0.70	0.75
Residential		
¼ Acre	0.55	0.62
2 Acres	0.35	0.45
Industrial	0.72	0.76
Open Space(Lawns, Parks, Golf courses)	0.10	
UNDEVELOPED AREAS(NATURAL VEGETATION)		0.25
Streets and Roads		
Paved	0.90	
Gravel	0.40	

4.2.3. Runoff timing

The timing of runoff from the individual plots treated with dust suppressants was highly variable. Figure 4-3 compares the cumulative volume of runoff versus time for the different categories of dust suppressants as well as the control plot. The runoff from the control plot was initiated approximately 40 minutes after the start of the rainfall simulation, and then continued at a constant rate (Figure 4-3). The control plot runoff is used for comparative purposes in Figure 4-3. For the majority of the plots treated with dust suppressants, the runoff occurred earlier than the control plot. Furthermore, the runoff rate (as indicated by the slope of the line) is higher for the majority of dust suppressant treated plots except for Poly-Bond, which has a lower runoff rate of runoff.

Most petroleum-based products and acrylic polymers [see Figure 4-3(a and b)] create an impermeable surface with high runoff volumes and runoff initiation approximately 30 minutes earlier than the control plot. Conversely, the fiber mulch (Plas-Bond) plot and one of the ligninsulfonate plots (Topein) had runoff that occurred much later than the control plot. Lower runoff volumes were obtained from these plots in the first hour.

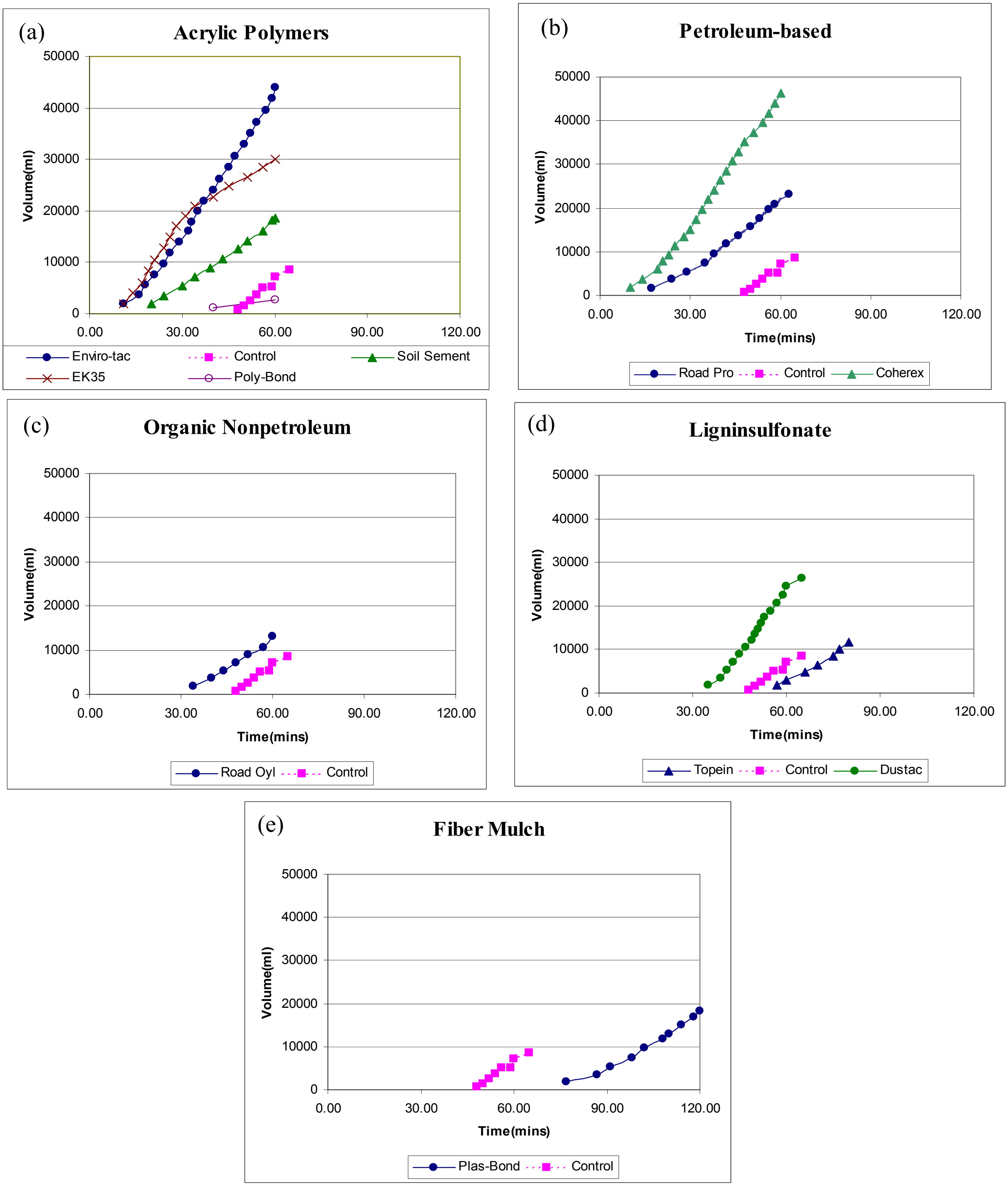


Figure 4-3: Cumulative runoff volume (ml) versus time for (a) acrylic polymers, (b) Petroleum products, (c) organic nonpetroleum products, (d) ligninsulfonate products, and (e) fiber mulch products. The control plot has been plotted in each of the graphs.

4.2.4. Estimated infiltration depth

Based on the soil properties and the amount of infiltration (P-Q), the infiltration depth for each the plot was calculated. The depth of infiltration represents the depth that the rainfall water infiltrates into the ground. It is assumed that the dust suppressant mixes with the rainfall water and leaches into the ground. Thus, the infiltration depth represents how far the dust suppressant may infiltrate. It is important to note that the infiltration depths here are based on a single rainfall event. The potential of leachate reaching the groundwater table can only be determined by evaluating rainfall over extended time periods and with a sufficient vadose zone transport model.

The infiltration depth is a function of the porosity of each plot, where the plots with a high porosity will have a high infiltration depth. The porosity for each plot is summarized in Table 2-2. Infiltration depth is calculated from the following (Mays, 2001):

$$I = \frac{P - Q}{A * n} \tag{5}$$

where, I is the infiltration depth, P is the volumetric rainfall applied to the plot (see Table 4-3), Q is the volumetric runoff (see Table 4-4), A is the area of the plot, and n is the porosity of the plot. The infiltration depths are summarized in Table 4-6.

Table 4-6: Infiltration depths for each plot

Product	Plot No.	Infiltration Depth (cm)
Road Pro	1B	5.81
	1D	6.01
Road Oyl	2B	7.95
	2D	7.38
Enviro-Tac	3B	4.31
	3C	5.03
Topein	4A	10.32
	4C	9.48
Dustac	5A	6.78
	5C	6.88
Soil Sement	7A	8.05
	7B	7.25
Ek35	8A	6.42
	8C	6.07
Plas-Bond	9A	----
	9B	----
Poly-Bond	10A	9.99
	10D	10.20
Coherex	11C	7.10
	11D	6.95
Dust Gard	12A	16.87
Control Plot	6A	8.19
	6B	8.51

The characteristics of the infiltration depth are opposite to runoff coefficients. For instance, Poly-Bond had a low runoff coefficient (0.04), but a high infiltration depth (approximately 10 cm). In comparison, the control plot had an infiltration depth of approximately 8 cm. For plots with high runoff coefficients, the infiltration depth was lower than the control plot (e.g., Road Pro, Envirotac, Dustac, EK35).

The relationship between runoff coefficient and infiltration will also depend on the porosity of the soil. For instance, Road Oyl and Coherex have similar infiltration depths of approximately 7 cm, but the runoff coefficients are 0.14 and 0.38, respectively. The difference in runoff coefficient is due to the different porosities for each test plot. The infiltration depth for the Plasbond plot is not shown since it is unclear how much water is absorbed by the paper product in the dust suppressant (fiber mulch).

SECTION 5: WATER QUALITY ANALYSIS

There are no specific standards for runoff waters generated from dust suppressants treated surfaces. As explained in Section 1.6, several federal and state regulations were combined to compile the list of parameters to be analyzed for in the runoff and in the soil extract from the suppressant treated plots. However, the specific concentrations of the contaminants set in the regulations cannot be used to establish the effects of suppressants on runoff water quality because they were not meant to be used for runoff waters. The approach adopted in this research, to evaluate the impact of dust suppressants, is to compare the water quality of the runoff and soil extracts of a control plot with that of plots treated with suppressants. For reference, the chemical composition and chemical formulations of the suppressants as reported in the MSDS are shown in Appendix H.

5.1. RUNOFF WATER QUALITY

The composition of the runoff water originated from each individual plot treated with dust suppressant was compared with that of the control plot, to which no dust suppressant was applied. The results are presented below.

5.1.1. Volatile and semi-volatile organics, and pesticides

Analysis of sixty-seven toxic volatile organic compounds (Table 1-3A) revealed the presence of acetone, 2-butanone, and 2-hexanone in the runoff of some of the plots (Figure 5-1). Acetone concentration in the control plot and in the majority of the other plots was below 30 μg/L. However, acetone concentrations of 196 μg/L, 133 μg/L, and 60.2 μg/L were found in the plots treated with EK-35 (synthetic iso-alkane), Enviro-tac (acrylic polymer), and Coherex (petroleum-based), respectively. Only the runoff of the plots treated with acrylic polymer (Poly-Bond) and synthetic iso-alkane (EK-35) showed detectable levels of 2-butanone, 18.9 μg/L and 45.4 μg/L, respectively. 2-Hexanone (8.2 μg/L) was detected only in the runoff sample collected from the plot treated with EK-35. The presence of higher concentrations of ketones (e.g. acetone) in EK-35, Enviro-tac, Coherex, and Road Oyl is not unexpected since volatile organic compounds are used in the manufacturing of these products.

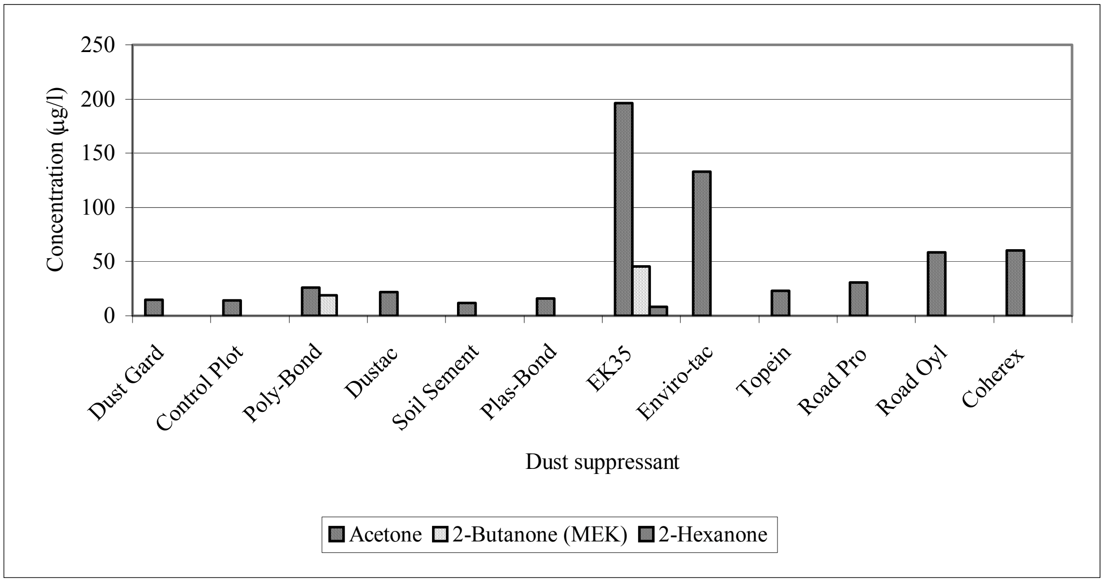


Figure 5-1: Volatile organic compounds detected in the runoff of plots treated with dust suppressants.

Analysis of sixty-nine semi-volatile organic compounds (Table 1-3B) revealed the presence of benzoic acid, di-n-butylphthalate, and pentachlorophenol (Figure 5-2). Benzoic acid concentrations ranged from 320 µg/L to 160 µg/L. The highest benzoic acid concentration was detected in runoff samples collected from the plots treated with Poly-Bond (320 µg/L), Enviro-tac (235 µg/L), and Coherex (225 µg/L). Benzoic acid was detected in concentrations higher than 200 µg/L only in the runoff from the plots to which acrylic polymer and petroleum-based products were applied. Benzoic acid is likely to be associated with the composition of these products. Di-n-butylphthalate was present in the runoff of the plot treated with Poly-Bond (3.08 µg/L), Soil Sement (7.45 µg/L), and Enviro-tac (3.29 µg/L) all of which are acrylic polymers. The presence of di-n-butylphthalate in acrylic polymer products can be expected since it is present in the adhesive products used to manufacture acrylic polymers. The plot treated with EK-35 presented pentachlorophenol (15.6 µg/L), the only pesticide detected in the runoff samples. The presence of pentachlorophenol in EK-35 may be associated with the use of tall oil in the manufacturing of this product. Tall oil is a by-product of the paper making industry and pentachlorophenol, used as an insecticide or pre-harvest defoliant in the wood industry, could end-up in the tall oils. No other organochlorine pesticide or polychlorinated biphenyls (PCBs) were found, above detection limits, in the runoff samples from the suppressant-treated or control plots. The pesticides and PCBs analyzed for in this research are listed in Table 1-3.

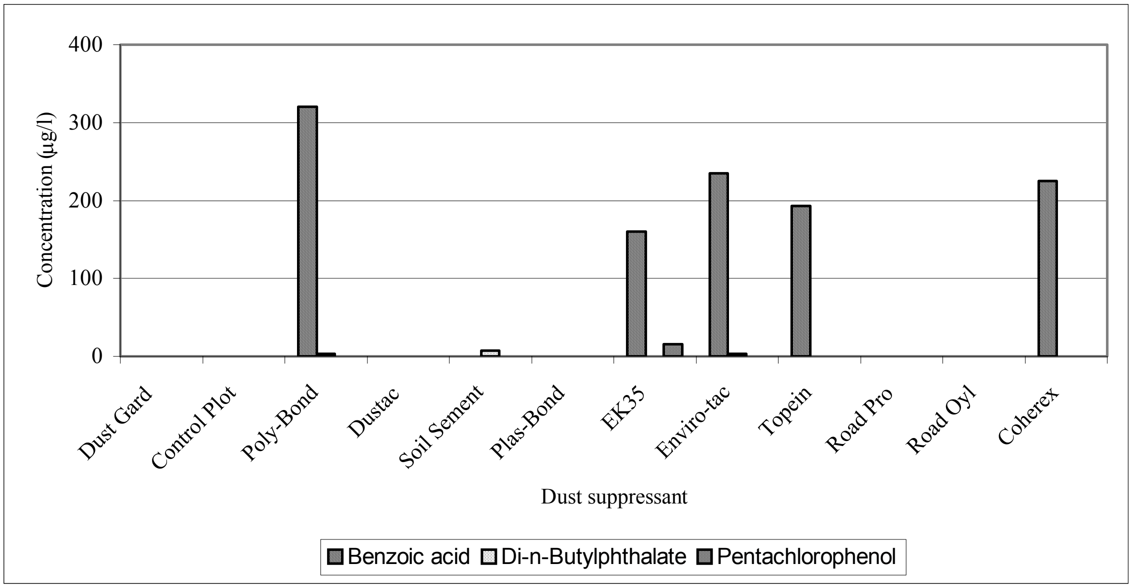


Figure 5-2: Semi-volatile organic compounds detected in the runoff samples of plots with dust suppressants.

5.1.2. Solids and Turbidity

Concentrations of Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Solids (TS), Total Volatile Solids (TVS), and turbidity (Figure 5-3) were evaluated in the runoff samples from all plots. TDS values ranged between 245 and 1,333 mg/L. The highest TDS concentrations were detected in the runoff samples collected from the plots where the fiber mulch (Plas-Bond), synthetic iso-alkane (EK-35), and petroleum-based (Coherex) suppressants were applied. TDS concentrations detected in the runoff samples from the other plots were relatively constant ranging from 497 to 245 mg/L. Total suspended solids concentrations varied between 1,043 and 9,678 mg/L. The highest TSS values were found in the runoff sample from the plots treated with Dust Gard, Poly-Bond, EK-35, Topein, and the control plot. All the dust suppressants, except for Dust Gard (magnesium chloride) acted to decrease the amount of suspend solids emanating from the plots, as compared to the control. Magnesium chloride application promoted the release of more particles from the soil resulting in higher TSS. The same observations can be made by evaluating TS and TVS. Turbidity values varied from 1,494 to 8,100 FAU (Formazin Attenuation Units). Most of the turbidity values were below 3,000 FAU. The highest turbidity value was encountered in the runoff sample collected from the control plot. As expected, the turbidity values found (Figure 5-3) correlate well with the TSS concentrations and with the runoff coefficients (Table 4-4), except for EK-35. Although the EK-35 plot presented a high runoff coefficient (0.41) the concentrations of solids was relatively high compared to the other plots. Thus, EK-35 behaves differently from the other acrylic polymer investigated.

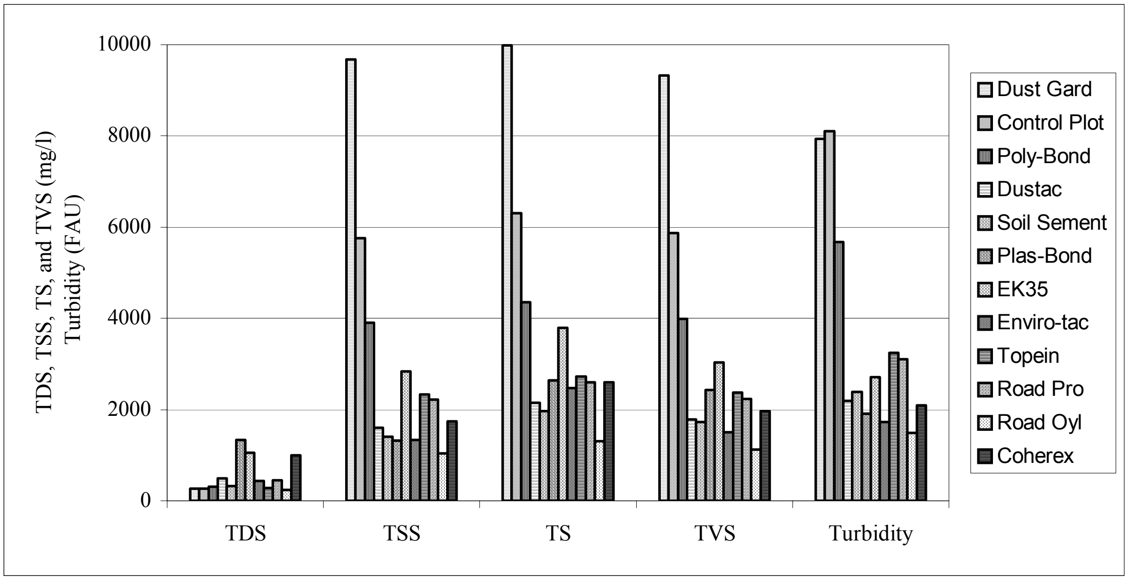


Figure 5-3: TDS, TSS, TS, TVS, and turbidity concentrations found in the runoff samples.

5.1.3. Inorganic Constituents

The inorganic constituents analyzed in this study were nitrate, ammonia-nitrogen, pH, chloride, sulfate, phosphate, cyanide, and sulfide. Nitrate concentrations ranged from 0.0 to 5.1 mg/L as N. The highest nitrate concentrations were detected in the runoff samples from Road Pro (5.1 mg/L as N), Dustac (4.5 mg/L as N), Soil Sement (3.4 mg/L as N), and Topein (3.35 mg/L as N). The control plot presented a nitrate concentration (1.6 mg/L as N) approximately three times lower than the highest concentration found in the runoff samples (Figure 5-4). The origin of nitrate in these suppressants is not evident from their reported chemical composition. No nitrate was detected in the runoff sample collected in the organic non-petroleum based plot (Road Oyl). Interestingly, the nitrate concentration in the runoff of Coherex, a petroleum-based suppressant, was 0.05 mg/L compared to 5.1 mg/L for Road Pro, the other tested petroleum-based suppressant. Ammonia-nitrogen concentrations varied from 0.0 to 8.5 mg/L as N (Figure 5-4). Runoff from the plots to which petroleum-based (Coherex) and the non-petroleum based tall oil (Road Oyl) suppressants were applied presented the highest ammonia concentrations, 8.50 mg/L as N and 6.5 mg/L as N, respectively. All other plots presented ammonia concentrations less than 0.75 mg/L. pH values of the runoff varied from 6.8 to 8.8 units (Figure 5-4). The highest pH value (8.8) was found in the runoff from the plot that received magnesium chloride treatment (Dust Gard) and the lowest pH was found in the plot treated with EK-35.

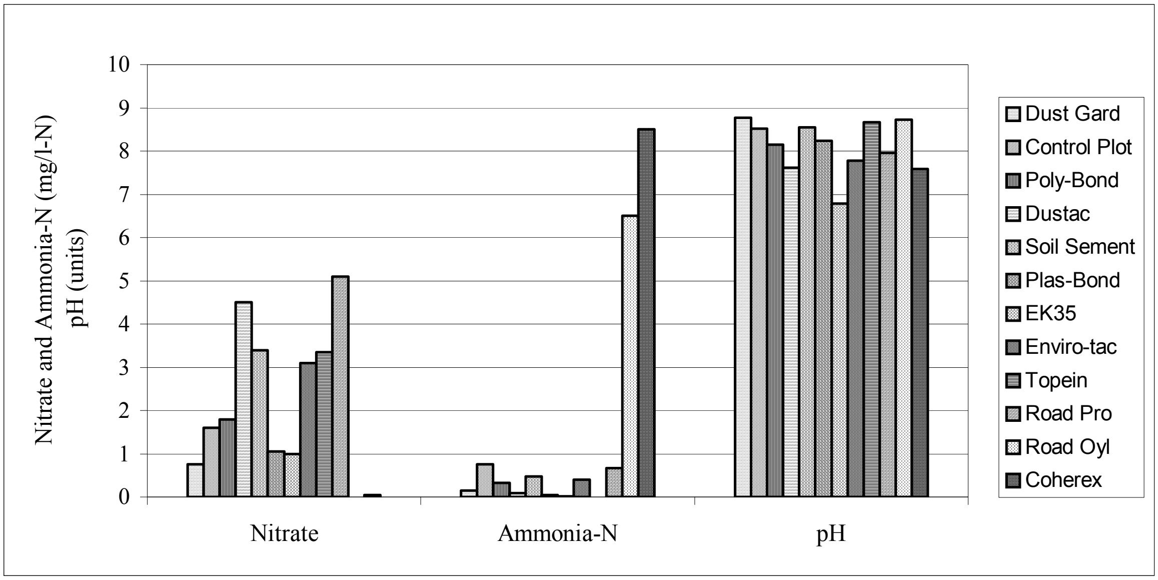


Figure 5-4: Nitrate, ammonia-nitrogen, and pH results.

Chloride values ranged from 3.1 to 42.8 mg/L (Figure 5-5). As expected, the highest concentration of chloride (42.8 mg/L) was detected in the sample collected from the plot treated with magnesium chloride. The ligninsulfonate (Topein) presented the second highest concentration of chloride, 39.7 mg/L, followed by the synthetic iso-alkane (EK-35), 34.4 mg/L. All other plots, including the control (3.7 mg/L), presented chloride concentrations below 20 mg/L. Sulfate concentrations in the runoff ranged from 2 to 134 mg/L (Figure 5-5), and the highest values were measured in the runoff sample from the plots treated with Coherex (134 mg/L), Dust Gard (52.5 mg/L), Enviro-tac (52 mg/L), and Plas Bond (38 mg/L). The high sulfate concentration in Coherex is the result of its origin from petroleum products. The presence of sulfate in Plas-Bond is associated with the presence calcium sulfate ($CaSO_4$) in its composition. One cannot infer the origin of sulfate in Dust Gard and Enviro-tac based on their known chemical composition. The control plot presented a sulfate concentration of 9 mg/L.

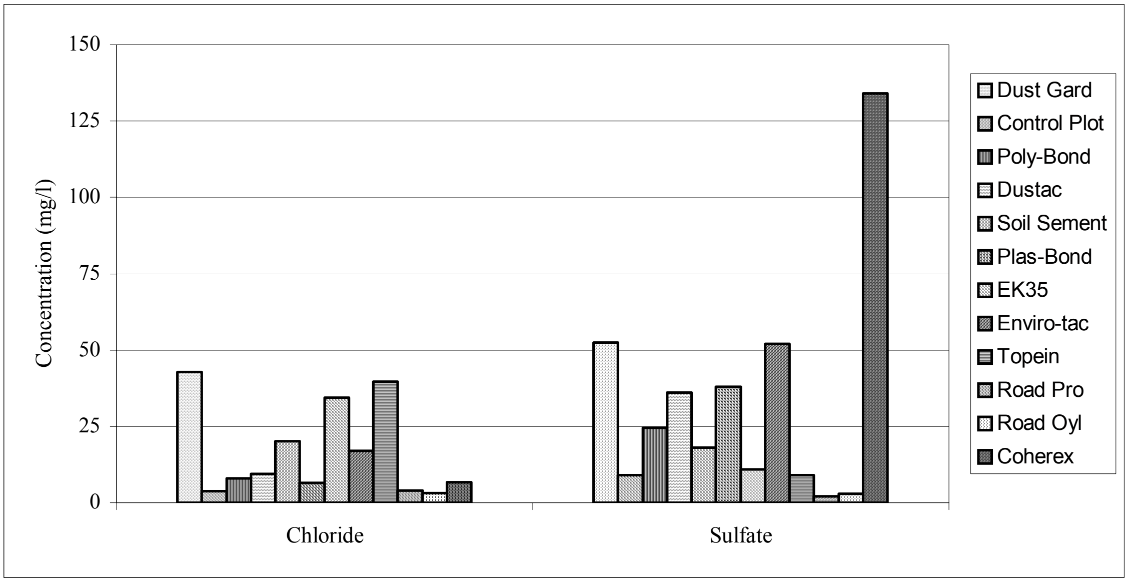


Figure 5-5: Chloride and sulfate concentrations in the runoff samples.

Phosphate values ranged from 1.86 to 29.36 µg/L as P (Figure 5-6). The highest phosphate value was found in the control plot (29.36 µg/L as P). Soil Sement, Dust Gard, and Poly-Bond had the highest phosphate concentrations after the control. Those are also plots with low runoff coefficients (Table 4-4). It appears that the application of dust suppressants had a binding effect on phosphate concentrations in the runoff. Only insignificant amounts of cyanide (<0.003 mg/L) were found in most of the plots (Figure 5-6).

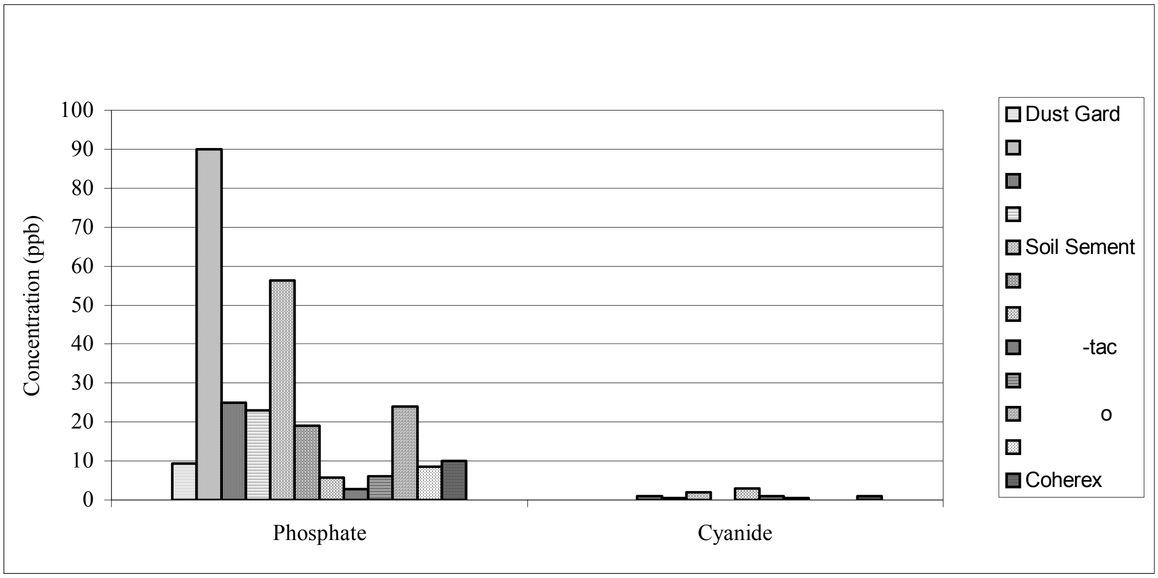


Figure 5-6: Phosphate and cyanide concentrations in the runoff samples.

Sulfide concentrations of 0.115 mg/L, 0.195 mg/L, and 0.165 mg/L were found in the runoff samples from the EK-35, Road Oyl, and Coherex plots, respectively. Sulfide concentrations in all other plots, including the control plot (0.04 mg/L), were below 0.08 mg/L (Figure 5-7).

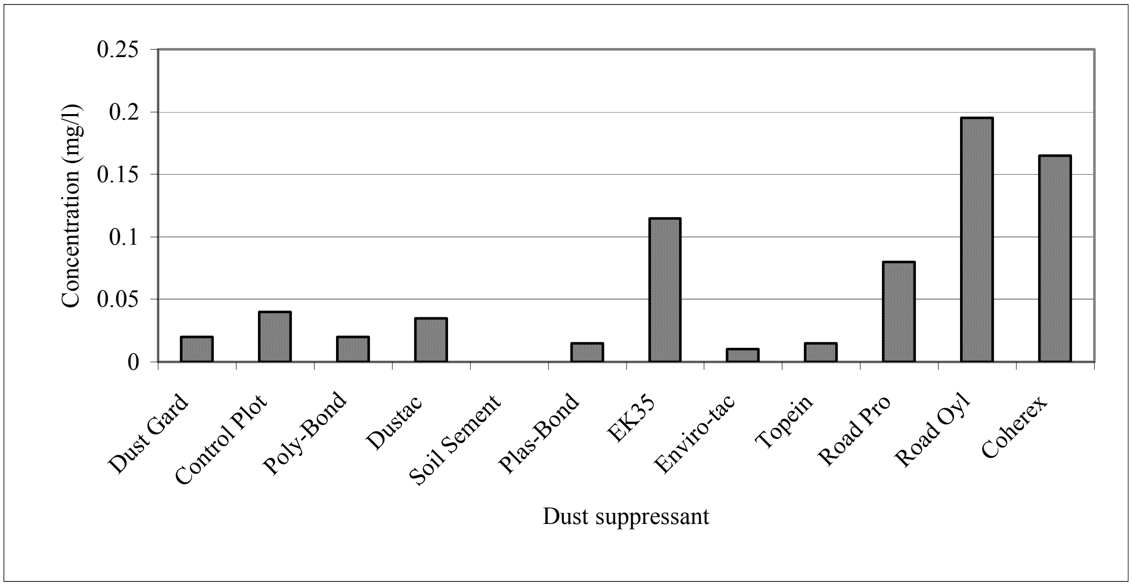


Figure 5-7: Sulfide concentrations in the runoff samples.

5.1.4. Other Parameters

Other parameters analyzed include alkalinity, hardness, conductivity, and salinity. Alkalinity values greater than the control, were detected only from the plots treated with Enviro-tac (232 mg/L as $CaCO_3$), Coherex (146 mg/L as $CaCO_3$), and EK-35 (124 mg/L as $CaCO_3$). Hardness values ranged from 40 to 860 mg/L as $CaCO_3$. The maximum hardness value, 860 mg/L as $CaCO_3$, was measured in the plot treated with fiber mulch (Plas-Bond). This is expected since calcium sulfate is the major component of this product. The control plot presented the lowest hardness concentration, 40 mg/L as $CaCO_3$. The other samples presented hardness values below 350 mg/L as $CaCO_3$. Figure 5-8 presents the alkalinity and hardness concentrations found in the runoff samples.

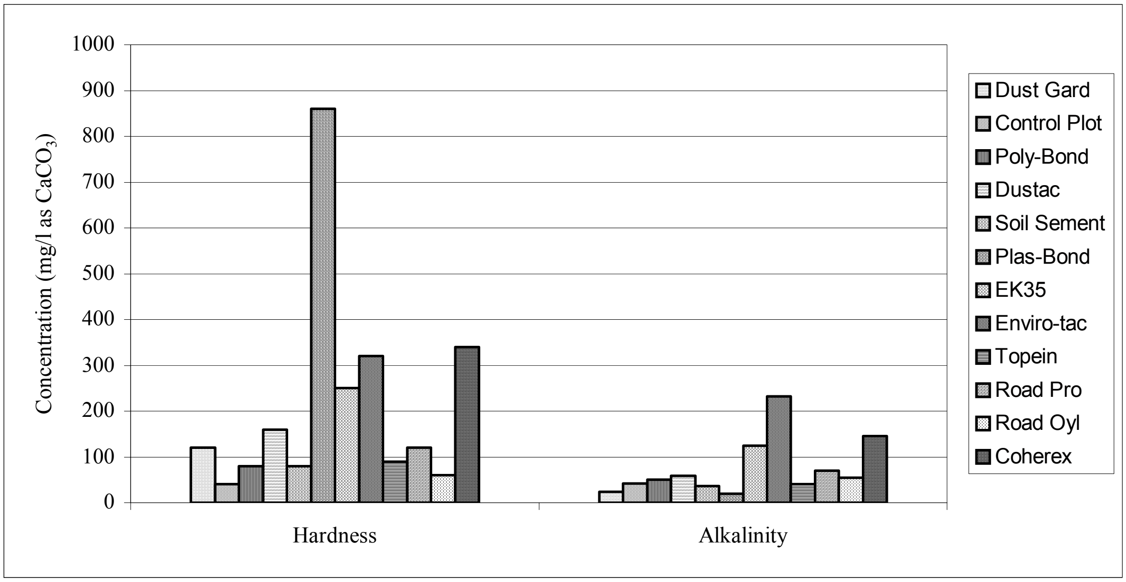


Figure 5-8: Hardness and alkalinity concentrations in the runoff samples.

Conductivity measurements and salinity calculations varied from 157 to 1,349 μS and from 0.09 to 0.84 ppt (Figure 5-9 and Figure 5-10), respectively. The highest conductivity and salinity were found in the runoff of the plot treated with fiber mulch (Plas-Bond). As expected, this is also the runoff with the highest TDS value. The lowest values were encountered in the samples from the control plot. Thus, all the suppressants applied contributed to increasing the conductivity and salinity of the runoff.

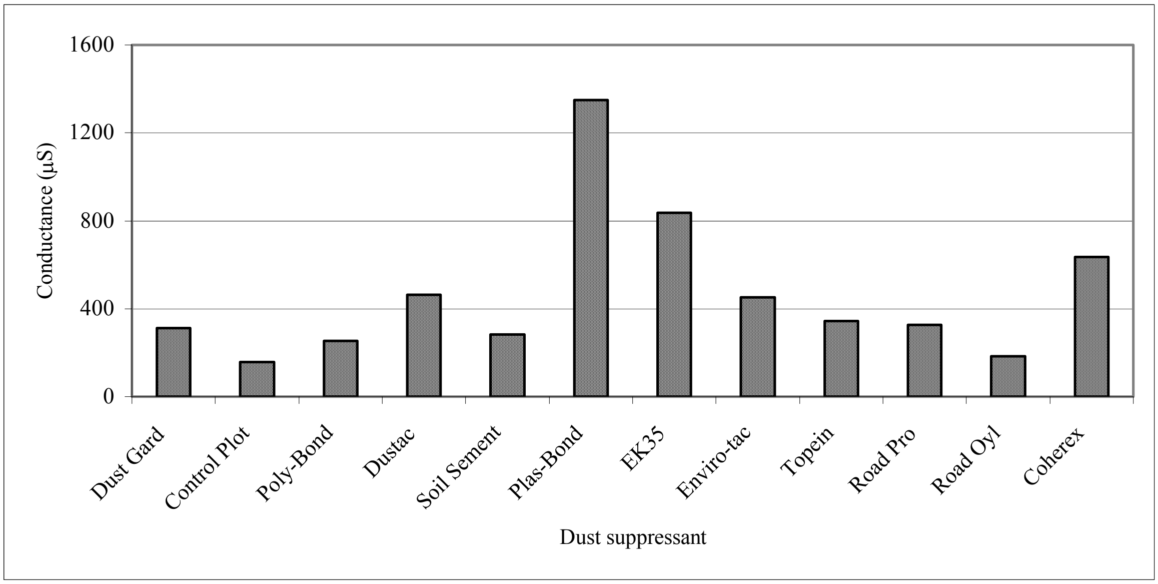


Figure 5-9: Conductivity concentrations in the runoff samples.

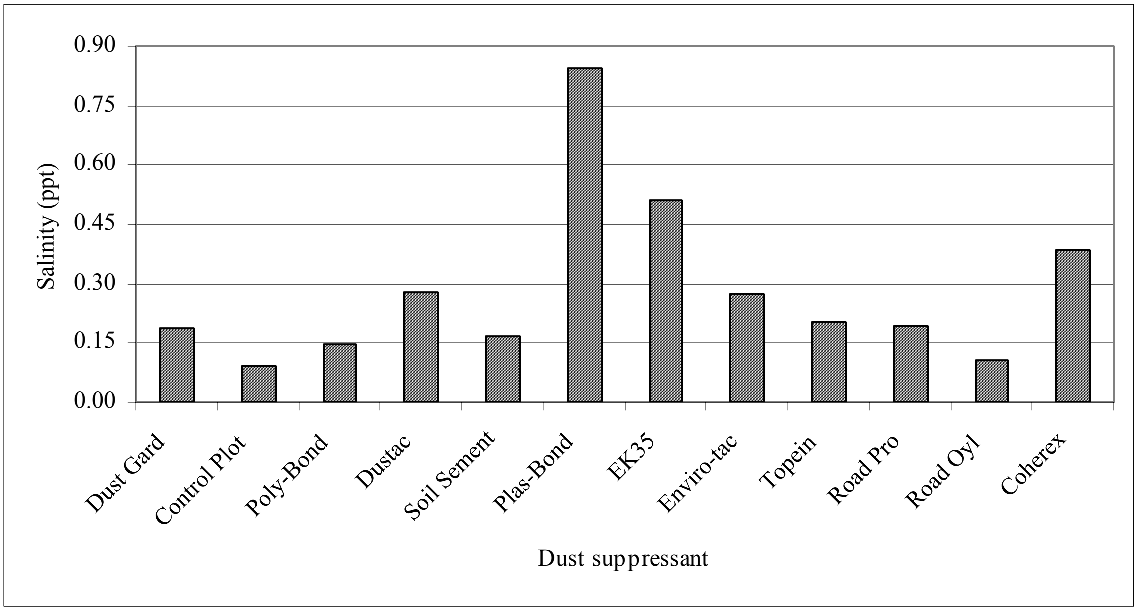


Figure 5-10: Salinity concentrations in the runoff samples.

5.1.5. Organic Constituents

The organic character of the samples was evaluated using biochemical oxygen demand (BOD), soluble chemical oxygen demand (soluble COD), and Total Organic Carbon (TOC) measurements (Figure 5-11). The BOD values found were very low and varied from 0 to 42 mg/L indicating that most suppressants investigated exert a small readily biodegradable oxygen demand. However, the BOD values for the plots treated with EK-35, Coherex, and Enviro-tac are relatively higher than that of the control plot.

The soluble COD values ranged from 7.5 mg/L (control plot) to 1,290 mg/L (Enviro-tac). The highest soluble COD values were found for Dustac, EK-35, Enviro-tac, and Coherex. The concentrations of TOC in the studied runoff samples were between 3 and 303 mg/L and the highest values were detected in the samples from the ligninsulfonate (Dustac), acrylic polymer (EK-35), and petroleum-based (Coherex) plots. For all the other samples the TOC concentrations were smaller than 75 mg/L. The petroleum-based and acrylic polymer suppressants, except for Poly Bond and Soil Sement, show higher TOC and COD concentrations. One would expect high COD valued for Poly Bond and Soil Sement, but this is not observed.

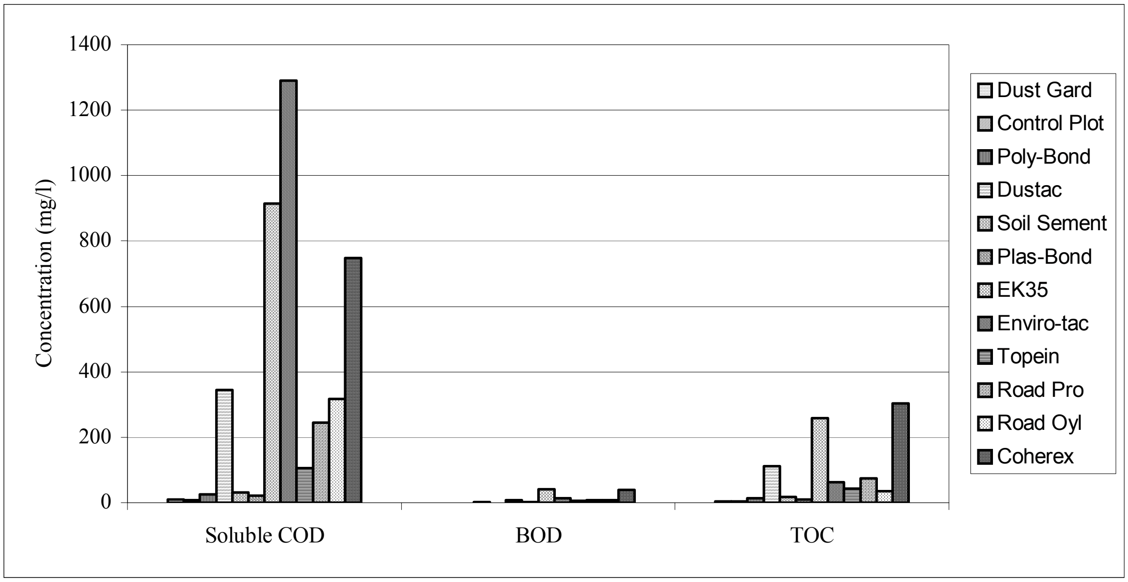


Figure 5-11: Soluble COD, BOD, and TOC concentrations in the runoff samples.

5.1.6. Microbial analysis

The concentrations of coliform bacteria in the runoff from most plots were found to be very small, except in that of the Coherex plot (Figure 5-12). For that, coliform count of 2,500 MPN/100 ml was found. We cannot explain the presence of coliform bacteria in the runoff of this plot.

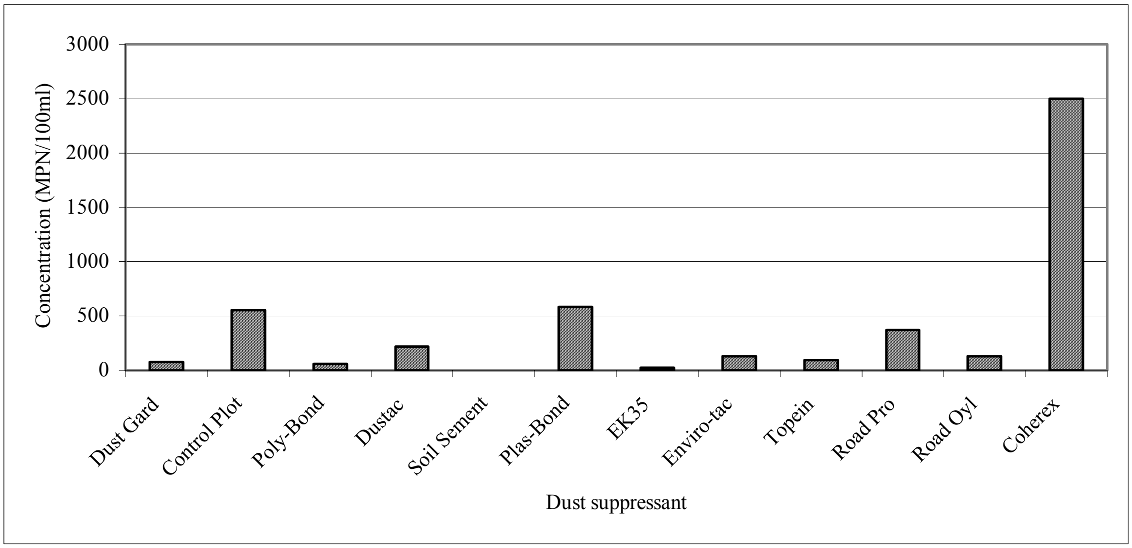


Figure 5-12: Coliform bacteria concentrations in the runoff samples.

5.1.7. Metals

Metal concentrations measured in this study include boron, aluminum, chromium, manganese, nickel, copper, zinc, arsenic, selenium, silver, cadmium, barium, thallium, and lead. Figure 5-13 presents boron, manganese, and barium concentrations found in the runoff samples. A high concentration of boron (466 µg/L) was observed in the runoff sample from the plot treated with magnesium chloride (Dust Gard). All other plots presented boron concentration slightly higher or less than that found in the control plot (89.18 µg/L). Thus, the runoff from the Dust Gard plot had boron concentrations approximately four times higher than that of the control (Figure 5-13). The runoff from the plot treated with Coherex, EK-35, Road Oyl, Enviro-tac, and Dustac showed manganese concentration greater that that of the control (13.22 µg/L). The runoff from the Coherex plot had manganese concentration about twenty-four times higher than that of the control (Figure 5-13). Barium concentrations in the plots treated with Coherex, EK-35, and Enviro-tac were about 3-5 times that of the control plot (20.25 µg/L).

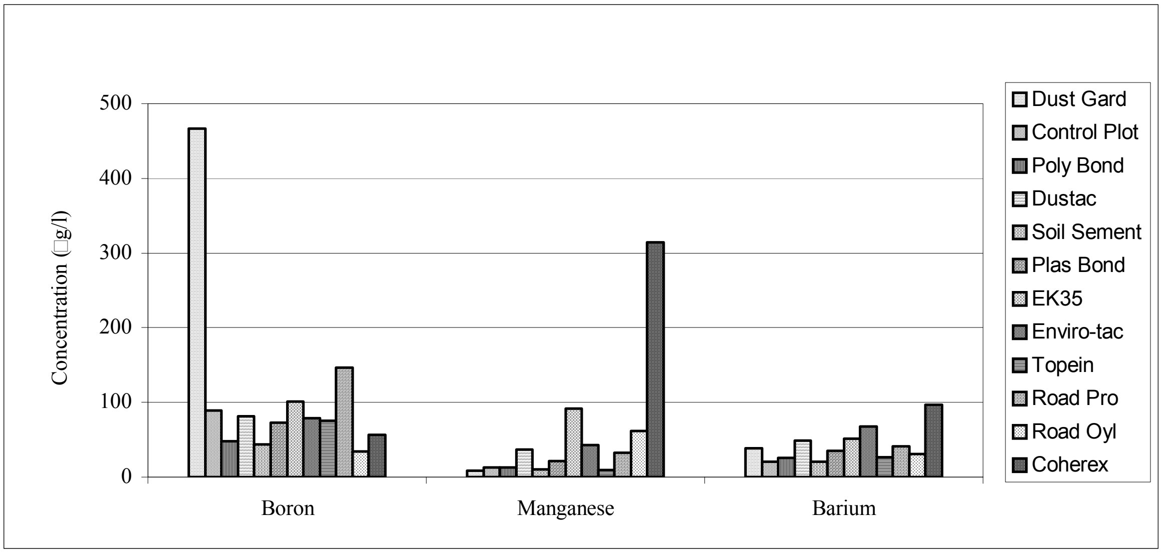


Figure 5-13: Boron, manganese, and barium concentrations detected in the runoff samples.

Chromium concentration (Figure 5-14) in the runoff from the plot treated with Dustac (33.50 µg/L) was about thirty times greater than that of the control plot (1.07 µg/L). The plot treated with Coherex also showed chromium concentration about three times that of the control. Nickel concentrations were 18-36 times higher in the runoff of the Coherex and Road Pro plots, respectively, as compared to the control (Figure 5-14). All other plots had nickel concentrations smaller than the control (0.47 µg/L). Copper concentrations were found to be higher than the control (2.16 µg/L) in the runoff of the plots treated with Coherex (9 times higher), EK-35 (4 times higher), and Dustac (4 times higher) (Figure 5-14).

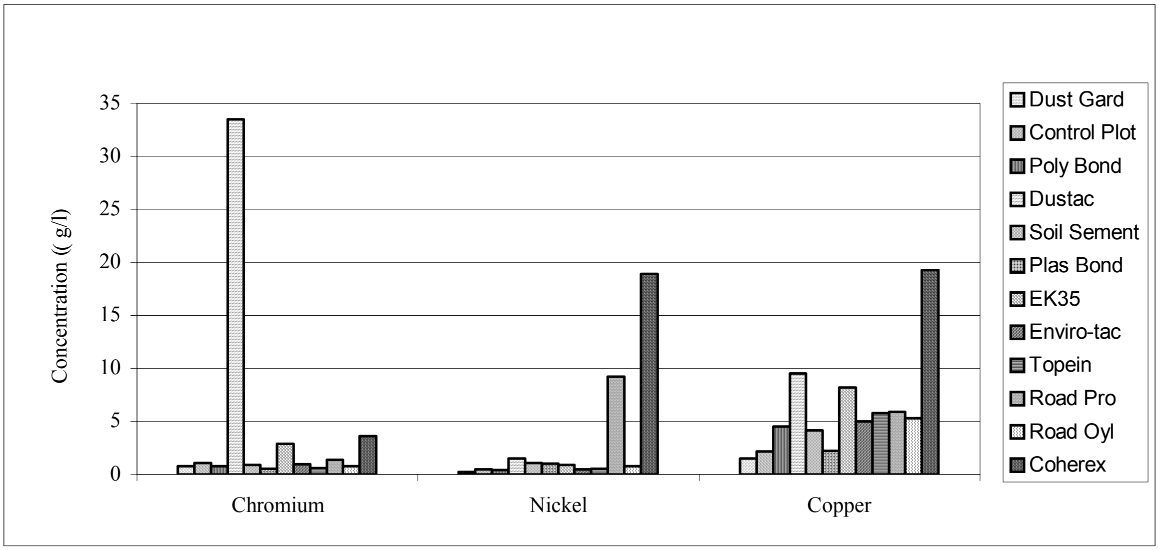


Figure 5-14: Chromium, nickel, and copper concentrations detected in the runoff samples.

Figure 5-15 shows zinc, lead, arsenic, and selenium concentrations in the runoff. Zinc concentrations 2-3 times greater than those of the control (4.38 µg/L) were found in the plots treated with Plas-Bond, Road Oyl, and Coherex. Lead concentrations 3-6 times greater that that of the control (1.09 µg/L) were found in the runoff of the plots treated with Soil Sement and Topein. The highest arsenic concentration was found in the runoff from the control plot (2.07 µg/L) and it may reflect the presence of naturally occurring arsenic in the local Las Vegas soils (Figure 5-15). Selenium concentration 7-18 times higher than that of the control (0.12 µg/L) were found in the runoff of the plots treated with Coherex (2.17 µg/L), Dustac (0.84 µg/L), and Topein (0.93 µg/L).

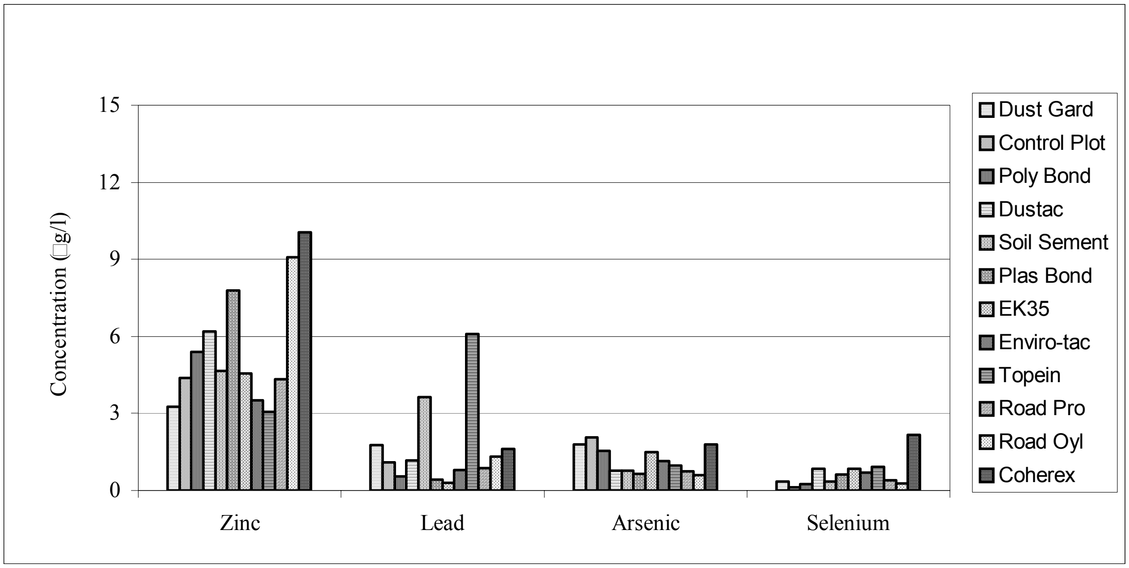


Figure 5-15: Zinc, lead, arsenic, and selenium concentrations detected in the runoff samples.

Most plots presented low iron concentrations (Figure 5-16), except for the plots treated with Road Oyl and Coherex for which iron concentrations were about two times higher than the control (400 µg/L). The runoff from the plots treated with Road Oyl and Coherex were found to have aluminum concentrations 3-6 times greater than that of the control plot (Figure 5-16). The runoff of all other plots had aluminum concentrations smaller than that of the control (577.70 µg/L).

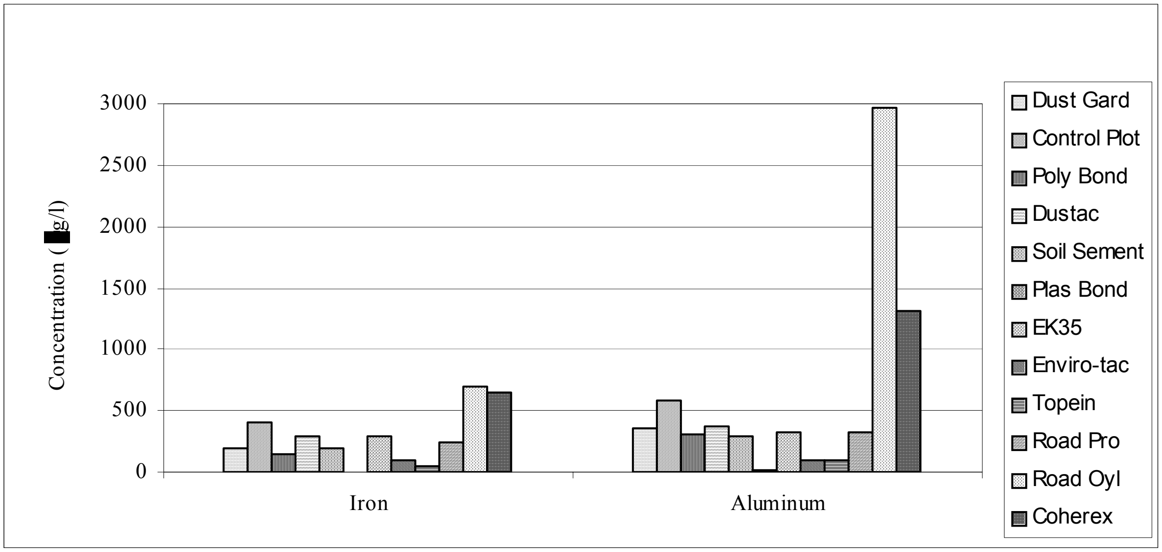


Figure 5-16: Iron and aluminum concentrations detected in the runoff samples.

Silver, cadmium, and Thallium concentrations are depicted in Figure 5-17. Silver concentrations in the runoff from the plots treated with Dustac and Soil Sement were 13-5 times greater than that of the control plot (0.01 µg/L). Cadmium concentrations 4-8 times greater than the control (0.03 µg/L) were found in the runoff of plots treated with Enviro-tac, Road Oyl, and Coherex. Thallium concentrations in the runoff from the Coherex and Dust Gard treated plots were about two times that of the control (0.11 µg/L).

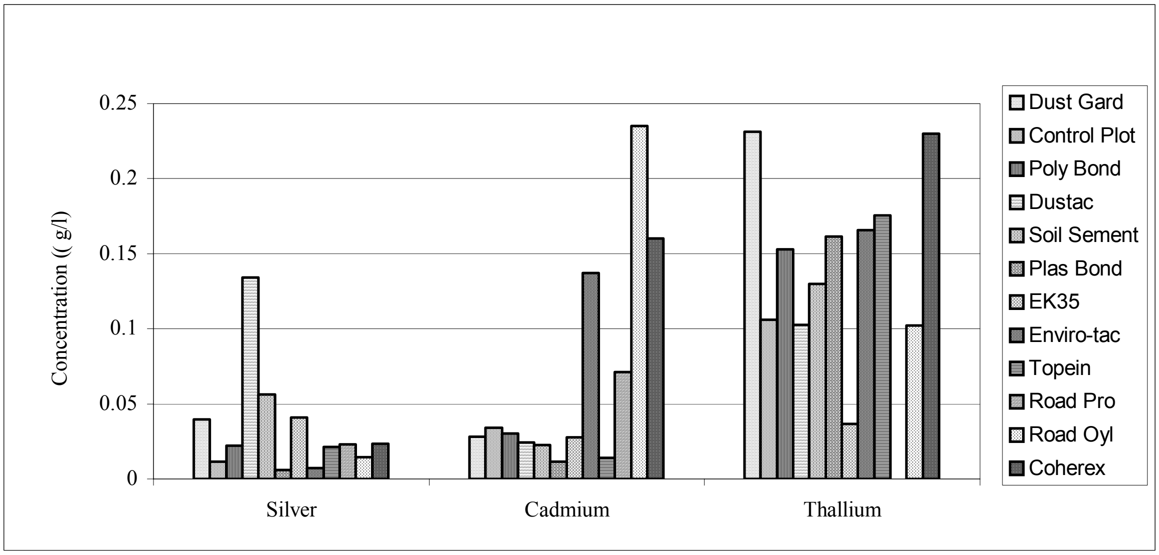


Figure 5-17: Silver, cadmium, and thallium concentrations detected in the runoff samples.

Mercury concentrations in the runoff of most plots was smaller than that of the control except for Road Oyl and Soil Sement (Figure 5-18). The runoff of the plot treated with Road Oyl had mercury concentrations three times greater than that of the control.

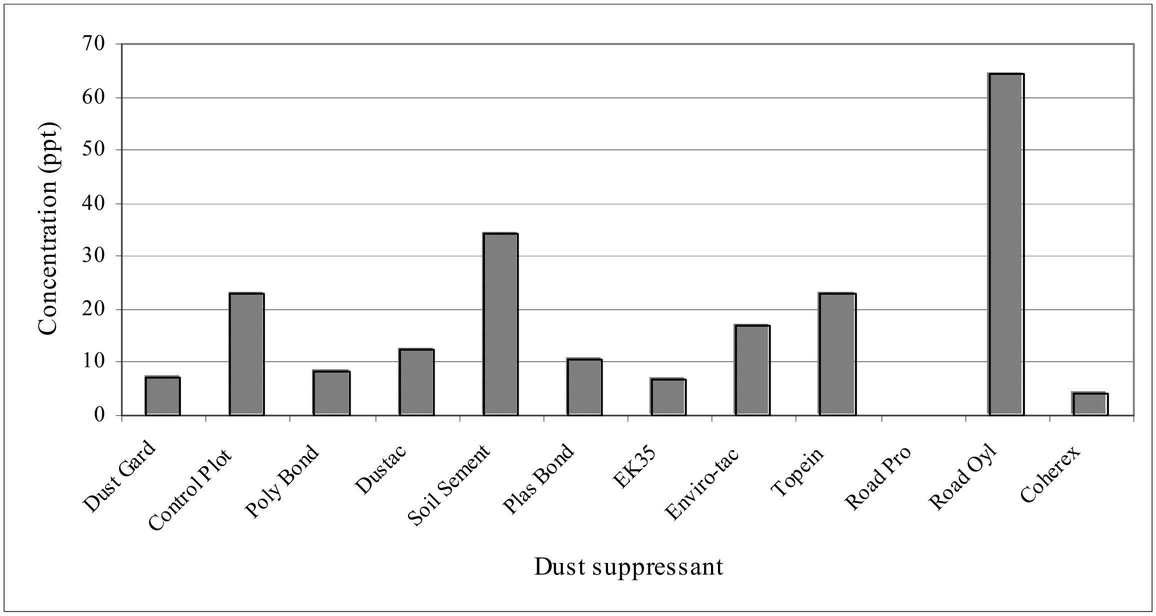


Figure 5-18: Mercury concentrations detected in the runoff samples.

The suppressants with the highest number of metals with concentrations higher than the control are the petroleum-based (Coherex and Road Pro), tall oil (Road Oyl), ligninsulfonate (Dustac), and synthetic iso-alkane (EK-35).

A summary of the runoff water quality data for all suppressants investigated is found in Section 7.

5.2. SOIL LEACHING ANALYSIS

The EPA Method 1312 (USEPA, 1994), Synthetic Precipitation Leaching Procedure (Appendix C), was used to determine residual contaminants, if any, remaining in the suppressant treated plots after the rainfall simulation. This test is designed to determine the mobility of both organic and inorganic compounds from soils and wastes. The test is very similar to the TCLP, except that the extraction fluid is a mixture of H_2SO_4 and HNO_3 instead of the acetic acid extraction mixture used in the TCLP. Method 1312 calls for a pH of 5±0.05, for soils west of the Mississippi River and 4.20±0.05 for soils east of the Mississippi River. Leaching was performed using 6-place rotary agitator with 2.2-L wide mouth glass bottles (Associated Design and Manufacturing Company, Alexandria, VA). Prior to leaching the soil was mixed well and ground using a mortar and pestle. One hundred grams of soil was then transferred to 2-L of the extraction fluid (60/40 weight percent mixture of H_2SO_4/HNO_3) and the closed bottles were agitated at 30 rpm for 18 hours. The extract solution was analyzed for the same semi-volatile organic compounds, PCBs, pesticides, and metals analyzed for in the runoff samples. Analyses of other desired parameters that would be affected by the acidity of the extraction fluid were performed by leaching soil samples with DI water, after mixing for 18±2 hours. A liquid to solid weight ratio of 20:1 was used. The following experiments were performed in the soil samples.

5.2.1. Semi-volatile and pesticides

The concentrations of all semi-volatile, pesticides, and PCBs encountered in the extract solution were below the detection limits of the methods. Although small amounts of some volatile, semi-volatile, and pesticides were found in the runoff from the plots treated with suppressants, basically none of these compounds remained in the soils after rainfall simulation. This implies that these compounds are present in the dust suppressants only in very small amounts.

5.2.2. Total Dissolved Solids Concentrations

Total Dissolved Solids concentrations ranged from 117 to 2,345 mg/L (Figure 5-19). The lowest TDS value was detected in the control plot and the highest was found in the plot treated with fiber mulch (Plas-Bond). When compared to the TDS values found for the runoff samples, the TDS of the plots treated with Dust Gard (magnesium chloride), Plas Bond (fiber mulch), and Topein (ligninsulfonate) were higher while the TDS of the plots treated with Dustac (ligninsulfonate), EK-35 (iso-alkane), and Coherex (petroleum-based) were lower than those found in the runoff. TDS was the only solid test performed because the soil leaching procedure requires the filtration of the extraction in a 0.7 μm filter.

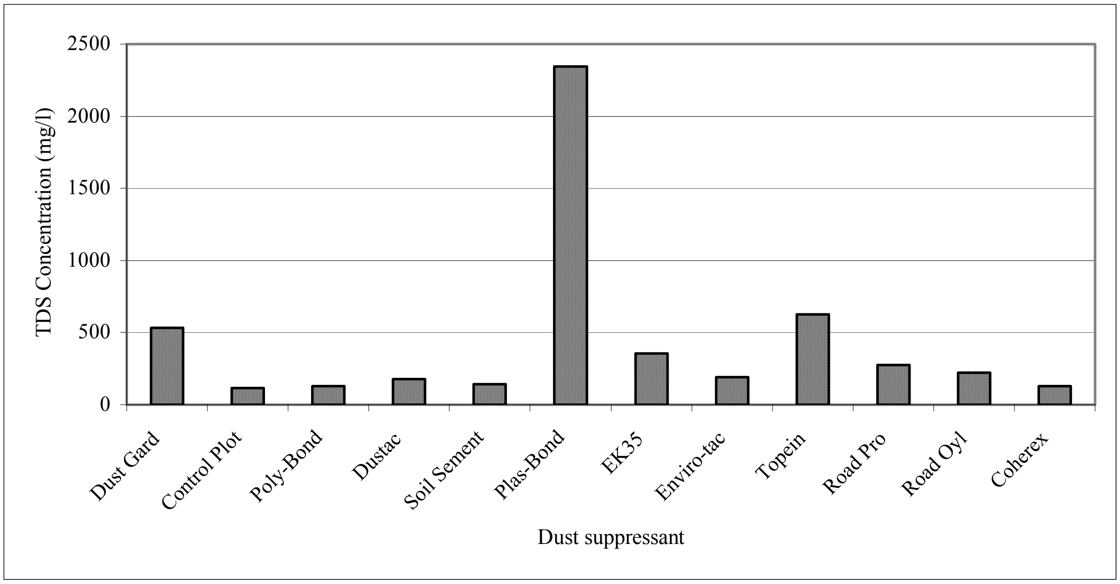


Figure 5-19: Total dissolved solids concentrations in the soil extract.

5.2.3. Inorganic Constituents

Inorganic constituents investigated include phosphate, cyanide, pH, nitrate, sulfide, ammonia-nitrogen, chloride, and sulfate. Phosphate values varied from 2.86 µg/L to 82.86 µg/L (Figure 5-20). The maximum phosphate concentration was found in the control plot. Similar to what was observed in the runoff samples, application of dust suppressants seem to decrease the mobility of phosphate. From all suppressants applied, Soil Sement has the weakest effect on phosphate mobility. Phosphate concentrations in both, the runoff and the soil extract, from the Soil Sement plot were closer to those in the control plot. Cyanide was not detected in eight of the twelve plots (Figure 5-20). The concentrations of cyanide found were very low and were highest in the extracts from the Soil Sement, Dustac, and Road Oyl plots. Cyanide was also detected in the runoff samples from the Dustac and Soil Sement. However, the runoff from the Road Oyl plot contained no cyanide.

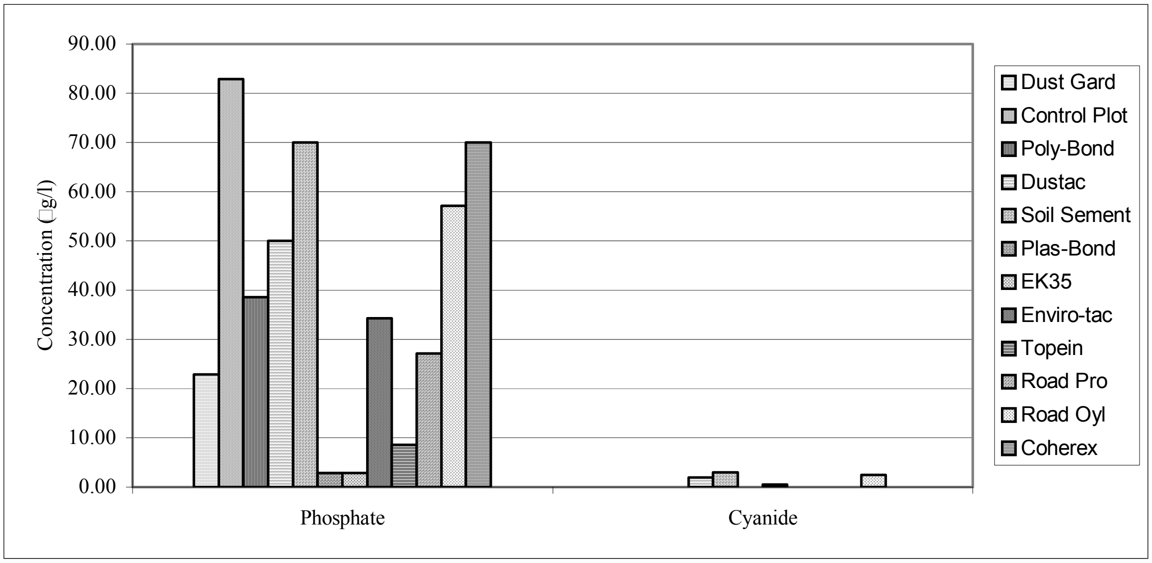


Figure 5-20: Phosphate and cyanide concentrations detected in the soil extract.

Nitrate concentrations ranged from 0.2 to 16.2 mg/L as N in the soil extract (Figure 5-21). The highest values were measure in the soil extract from the plots treated with Topein, Road Pro, and EK-35. The runoff from plots treated with Topein and Road Pro also presented high concentrations of nitrate. However, the high nitrate concentrations seen on the runoff from the Dustac and Soil Sement plots, is not observed in the soil extract. It can be inferred that the amount of nitrate present in Topein and Road Pro is larger than that present in Dustac and Soil Sement. pH values in the soil analysis ranged from 7.36 to 9.28 units (Figure 5-21). The control plot presented the highest pH value (9.28). All suppressants applied promoted the decrease in the pH of the soil, in some cases, the pH decreased by almost two units. Some decrease in the pH was also observed in the runoff samples emanating from some plots (Figure 5-4).

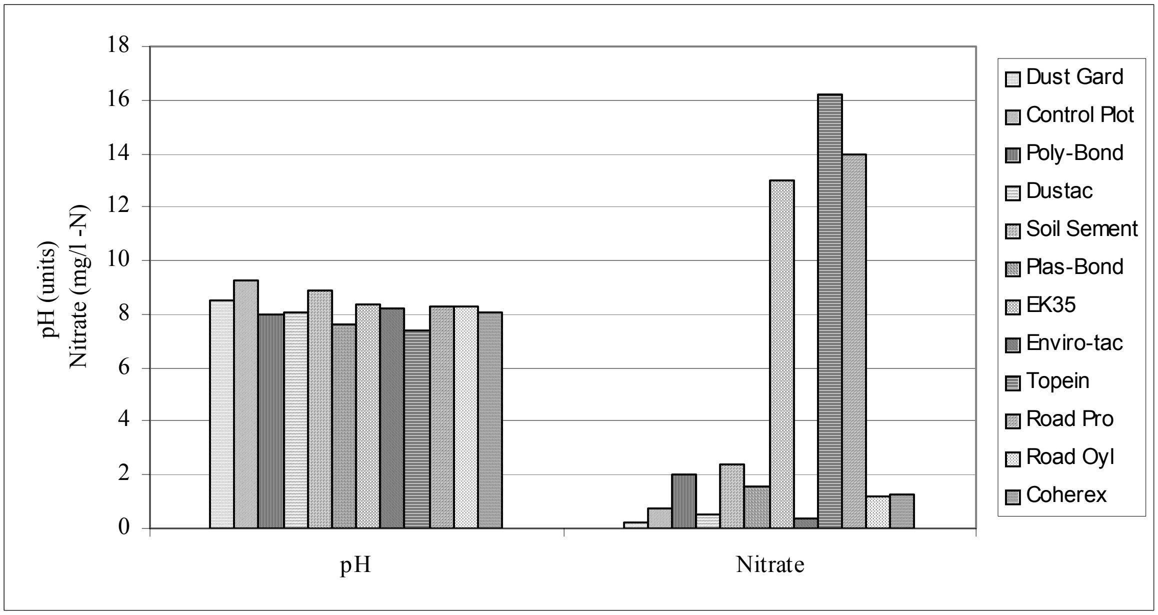


Figure 5-21: pH and nitrate values in the soil extract.

The only extract with sulfide concentration higher than the control was that of the Enviro-tac plot (Figure 5-22). The higher sulfide concentrations observed in the runoff from Road Oyl and Coherex are not seen in the soil. Ammonia-nitrogen concentrations varied from 0.0 to 1.0 mg/L as N (Figure 5-22). Ammonia-nitrogen concentration higher than the control was found in the extract from the Coherex and Road Oyl plots. In the runoff sample these were also the plots with the highest ammonia concentrations.

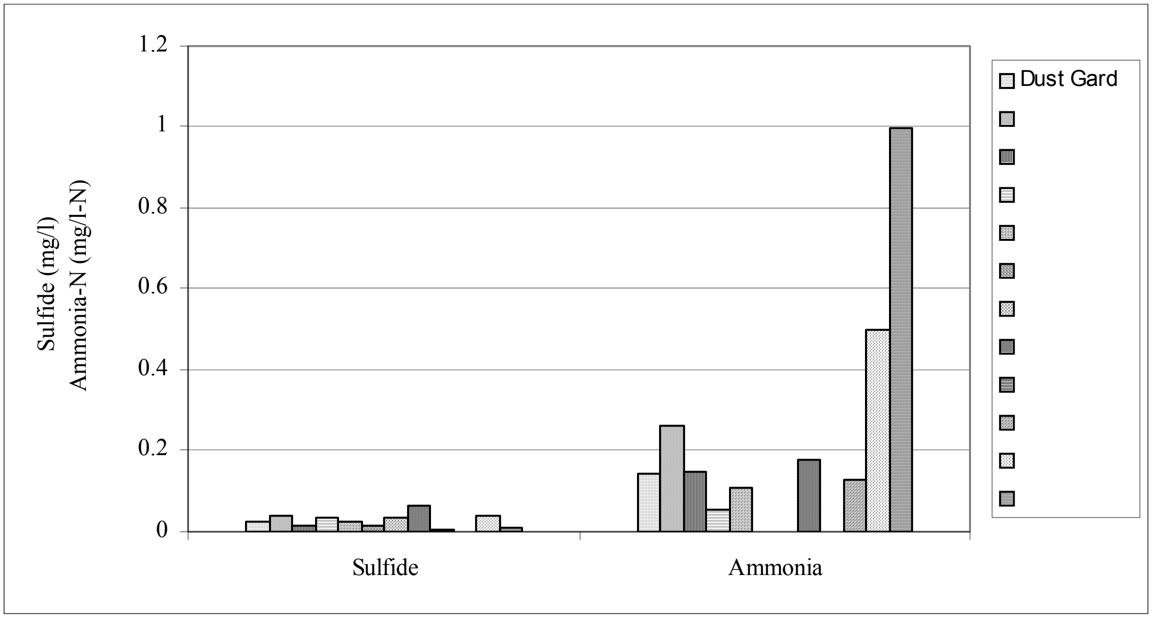


Figure 5-22: Sulfide and ammonia concentrations present in the soil extract.

As expected, the results show that the soil from the plot treated with Dust Gard (magnesium chloride) has the highest chloride concentration (221.6 mg/L as compared to 2.4 mg/L in the control). Higher chloride concentrations were also found in the plots treated with EK-35, Topein, and Road Pro (Figure 5-23). In the runoff samples, higher chloride concentrations were found for the same plots.

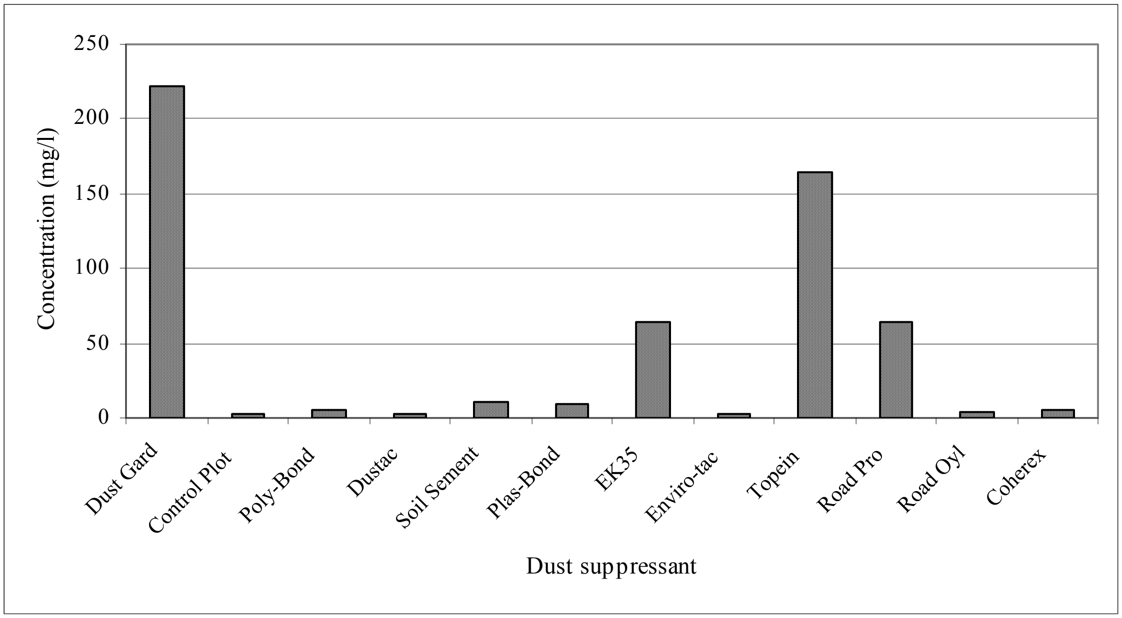


Figure 5-23: Chloride concentrations detected in the soil extract.

A very high concentration of sulfate, 1,000 mg/L, was measured in the sample collected in the fiber mulch plot (Plas-Bond). This is expected because gypsum ($CaSO_4$) is one of the components of Plas Bond. All other analyses presented sulfate concentration equal or below that of the control (Figure 5-24).

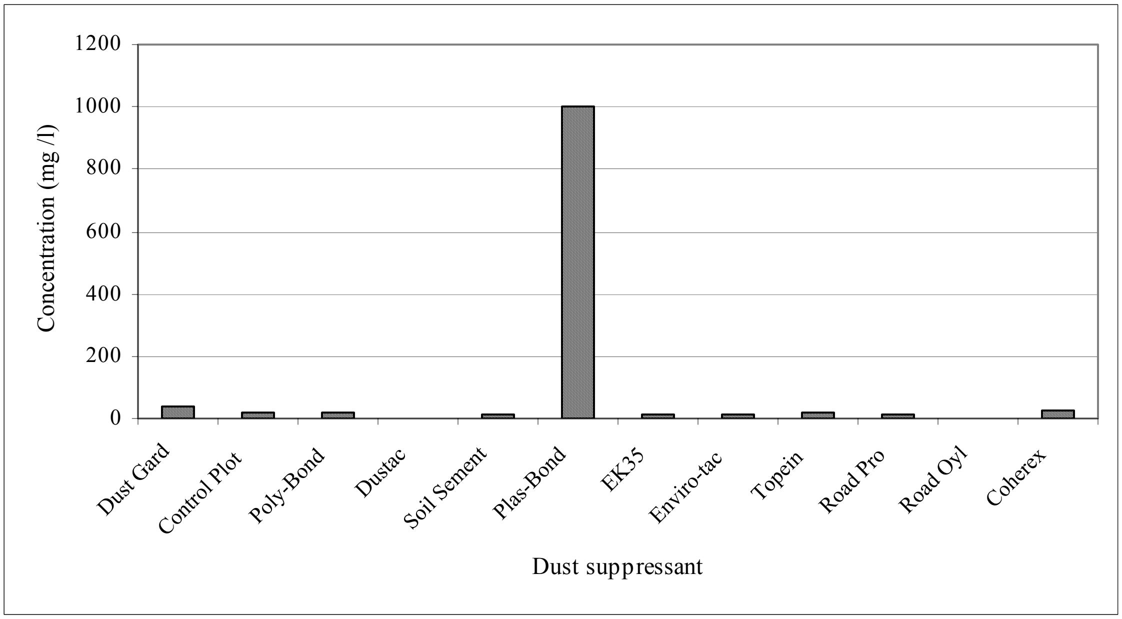


Figure 5-24: Sulfate concentrations present in the soil extract.

5.2.4. Physical Parameters

Alkalinity, hardness, conductivity, and salinity were the physical parameters analyzed. The highest alkalinity concentrations detected were found in the sample from the plot to which the acrylic polymer (Enviro-tac) and EK-35 were applied. Alkalinity values in the extract of these samples were twice as that of the control plot. Alkalinity values of the runoff emanating from these plots were also the highest (Figure 5-25). The soil extract from the plot where Plas Bond (fiber mulch) was applied presented an extremely high hardness, 1,600 mg/L as $CaCO_3$ (Figure 5-25). This is expected because of the $CaSO_4$ present in this suppressant. Both the soil extract and the runoff results revealed that the application of suppressants result in an increase of hardness, as compared to the control.

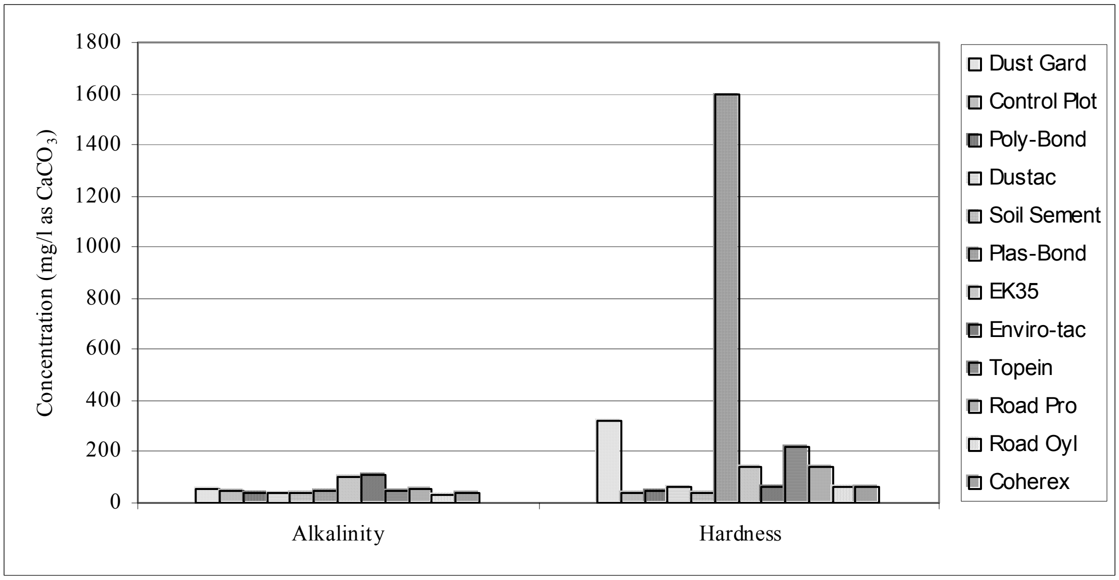


Figure 5-25: Alkalinity and hardness present in the soil extract.

The highest conductivity and salinity values were found in the extract from the plot that received fiber mulch as the dust suppressant treatment (Figure 5-26 and Figure 5-27). The same was found in the runoff analysis. It is interesting that the salinity of both, the soil extract and the runoff from this plot are higher than that from the magnesium chloride plot (Dust Gard).

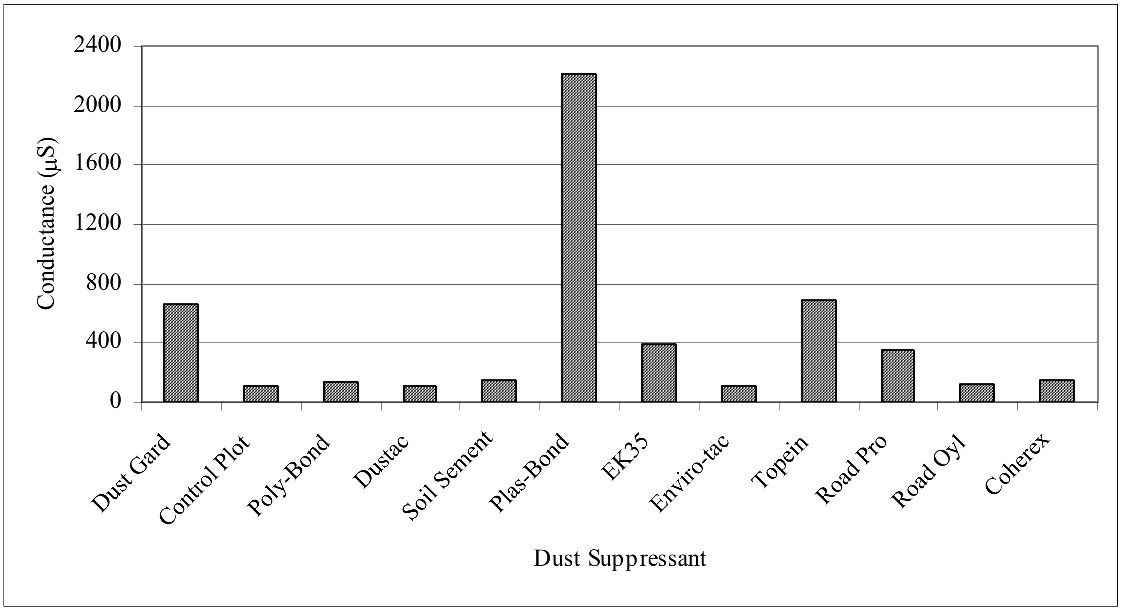


Figure 5-26: Conductivity measured in the soil extract.

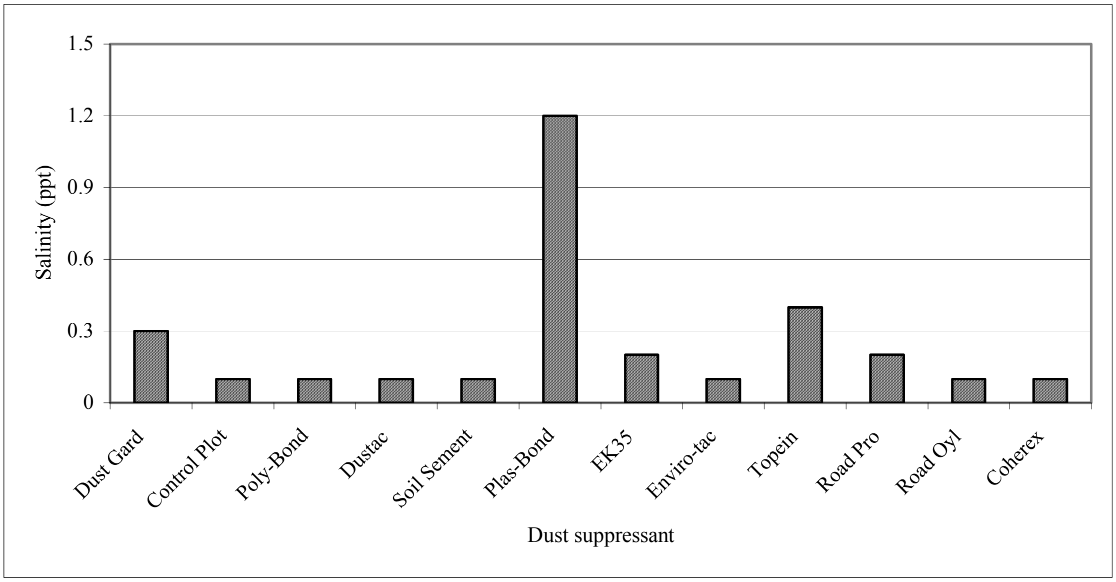


Figure 5-27: Salinity calculated in for the soil extract.

5.2.5. Organic Constituents

Soluble COD and TOC concentrations were evaluated in the soil extract from all plots, including the control (Figure 5-28). The soluble COD concentrations in the soil extract ranged from 15 mg/L to 153 mg/L. The highest soluble COD values were measured in the sample collected from the plot treated with the acrylic polymer (Enviro-tac) and the iso-alkane (EK-35). The same was also observed in the runoff from these plots. The soluble COD and TOC value found in the runoff and in the soil extract show the same trend. However, concentrations of TOC and soluble COD in the runoff were significantly higher than those in the soil extract. This indicates that organics present in the suppressants leach out with rainfall instead of attaching.

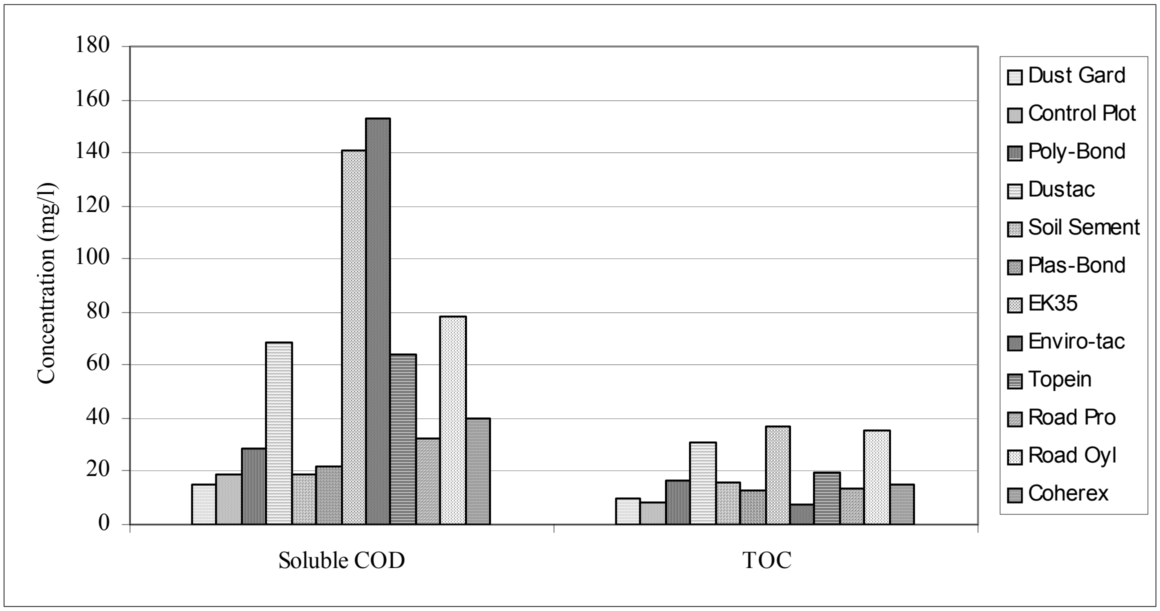


Figure 5-28: Soluble COD and TOC concentrations in the soil extract.

5.2.6. Metals

Figure 5-29 shows manganese, nickel, copper, and zinc concentrations in the soil extract. Manganese concentration in the plots treated with Dustac, Plas-Bond, Enviro-tac, and Topein were found to be only about twice as large as those of the control plot (13.09 μg/L). Only the Plas-Bond plot showed nickel concentration significantly higher (16.98 μg/L) than that of the control (0.53 μg/L) in the soil extract. Copper concentrations about 1.5-2 times greater than the control (4.58 μg/L) were found in the soil extracts from the plots treated with Dustac, Enviro-tac, Topein, and Road Oyl. Zinc concentrations 2-3 times greater than the control (7.80 μg/L) were found in the soil extracts from the Plas-Bond and EK-35 plots.

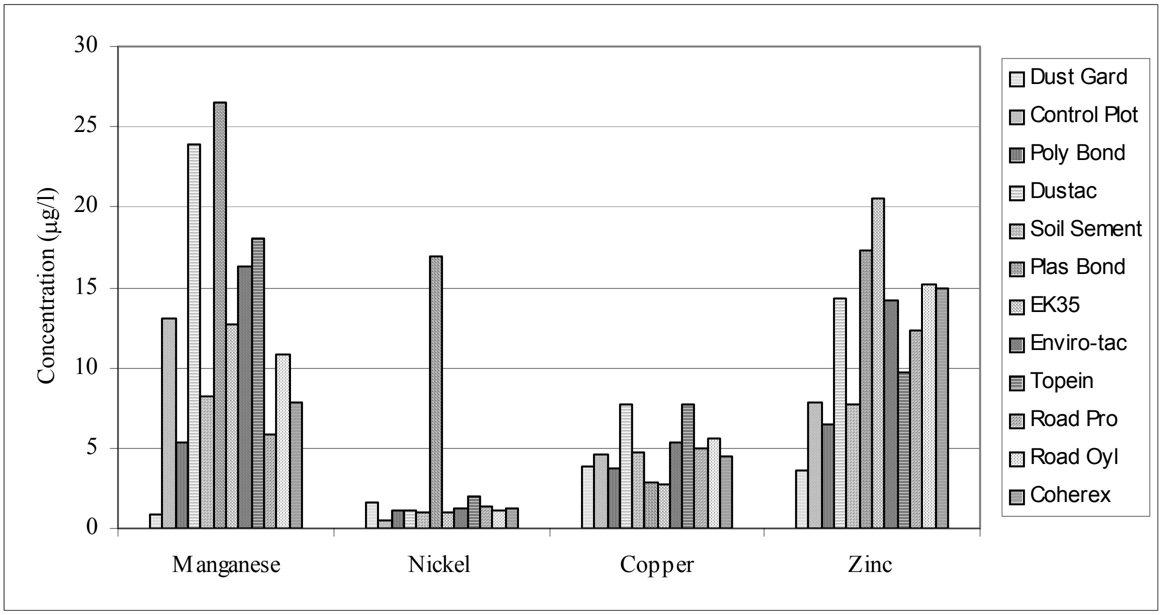


Figure 5-29: Manganese, nickel, copper, and zinc concentrations detected in soil extract.

Only very small silver concentrations were detected in the soil extracts (Figure 5-30). Silver concentrations 2-3 times greater than that of the control (0.03 µg/L) were found in the plots treated with Road Pro and Road Oyl. Cadmium concentrations (Figure 5-30) in the runoff of the plots treated with Enviro-tac and Road Oyl were about two times greater than that found in the control (0.01 µg/L). Thallium concentration 1000 times greater than that of the control (0.00008 µg/L) were found in the soil extract of the plots to which Topein, Road Pro, and Road Oyl have been applied (Figure 5-30).

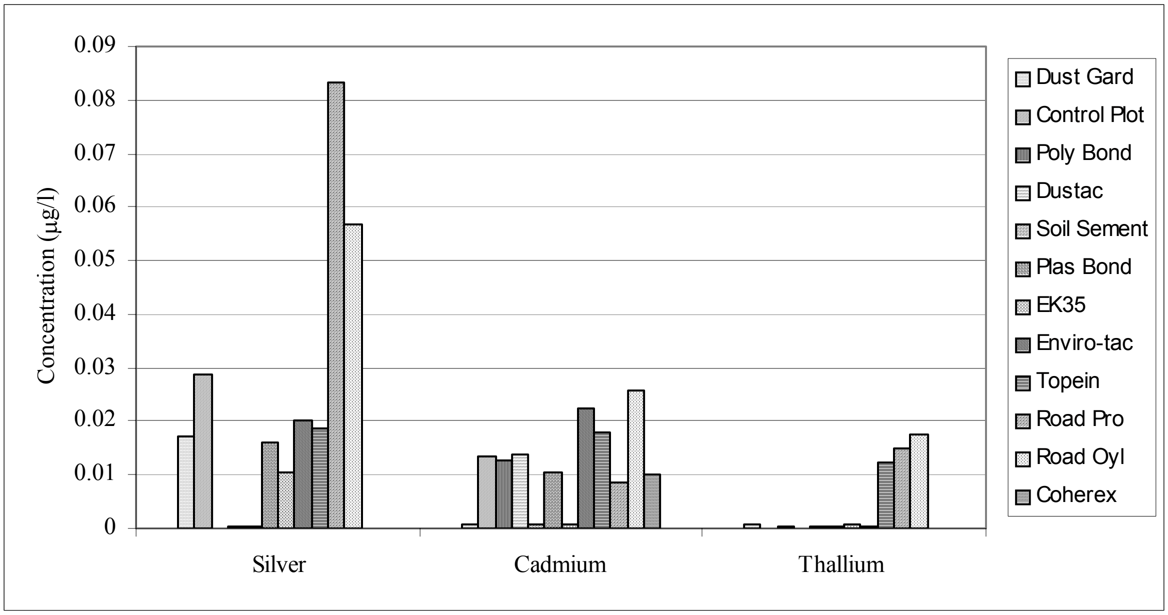


Figure 5-30: Silver, cadmium, and thallium concentrations detected in the soil extract samples.

Similar to that found for the runoff samples, boron concentrations in the soil extract from the Dust Gard plot was the highest (904 μg/L) from all plots (Figure 5-31). The extract from all other plots had boron concentrations slightly higher or less than that of the control plot (107 μg/L). In the soil extract analysis, the control plot presented the highest aluminum concentration (1533 μg/L). It is interesting that the extract from Road Oyl and Coherex plots did not show high aluminum concentrations given the high concentrations found in the runoff of these plots (Figure 5-31). This may indicate that aluminum present in these suppressants was easily leached out with rainfall.

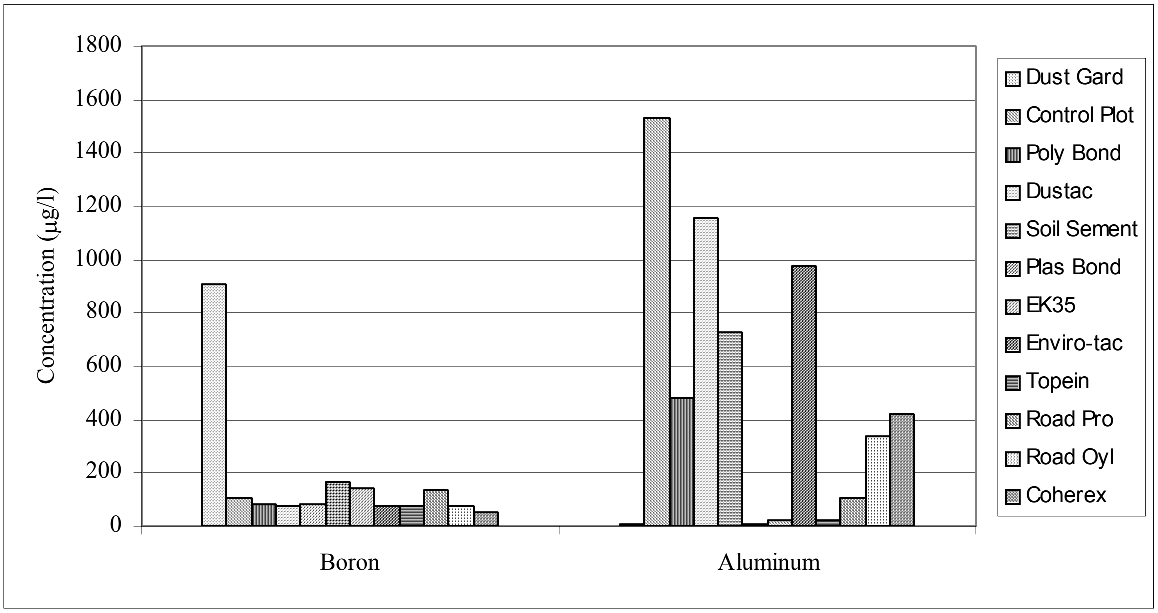


Figure 5-31: Boron and aluminum concentrations detected in the soil extract samples.

Only small amounts of chromium were found in the soil extract (Figure 5-32). Plots treated with Plas-Bond, Enviro-tac, and Road Oyl showed chromium concentrations slightly higher than the control (0.43 µg/L). Lead concentrations in the soil extracts were about two times greater than that of the control (0.37 µg/L) for plots treated with Road Pro and Enviro-tac (Figure 5-32).

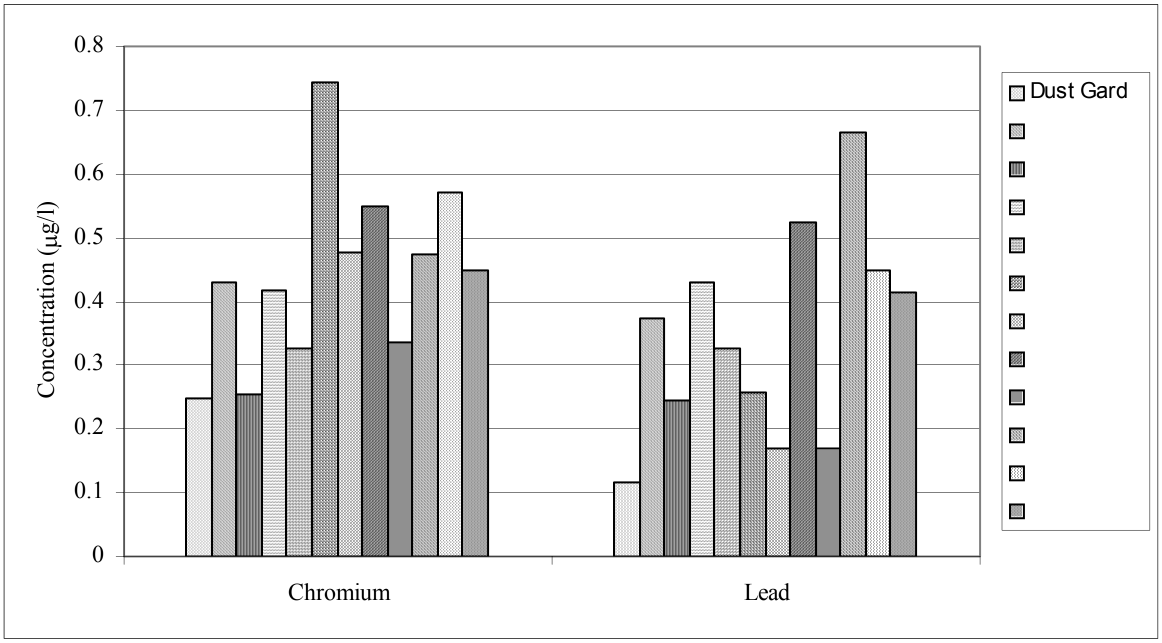


Figure 5-32: Chromium and lead concentrations detected in the soil extract.

The level of arsenic in the soil extracts (Figure 5-33) was highest in the control plot (3.18 µg/L). The same was observed for the runoff analysis. Selenium concentrations in the soil extracts were 2-3 times of that of the control (0.04 µg/L) only for the plots treated with Dust Gard and Topein (Figure 5-33). The local Las Vegas soils are known to contain selenium and arsenic and these results reflect this fact.

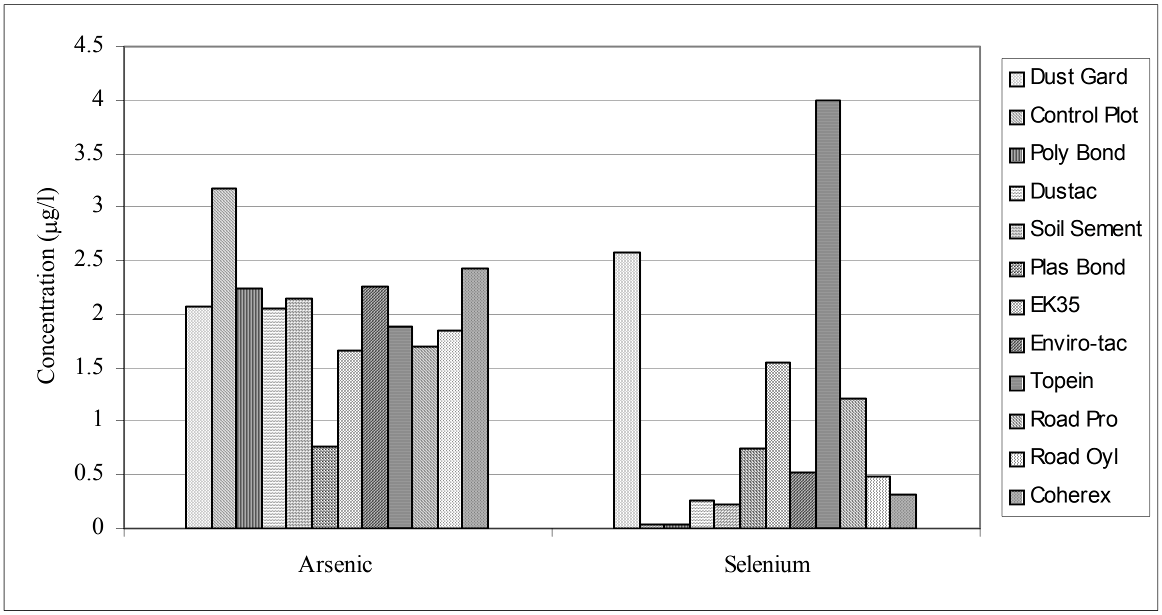


Figure 5-33: Arsenic and selenium concentrations detected in the soil extract.

Only the plots treated with EK-35, Enviro-tac, and Topein presented barium concentrations (Figure 5-34) almost twice of the control plot (88.75 µg/L). Iron concentrations (Figure 5-34) in the majority of the soil extracts were lower than the control (400 µg/L). The same was observed in the runoff analysis and may indicate that iron's mobility is hindered by suppressants application.

Mercury concentrations 2-3 times greater than the control were detected in the soil extracts from the plots to which Enviro-tac, EK-35, and Soil Sement were applied (Figure 5-35). In the case of Soil Sement higher mercury concentrations were also found in the runoff samples.

A summary of the results of the soil extract analyses is presented in Section 7.

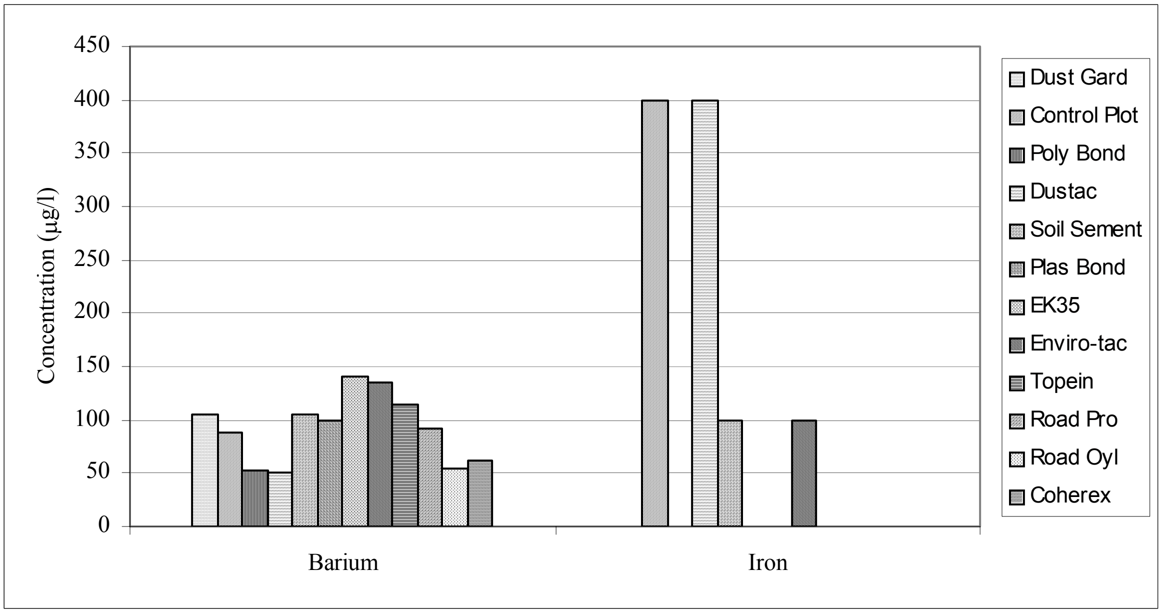


Figure 5-34: Barium and iron concentrations detected in the soil extract.

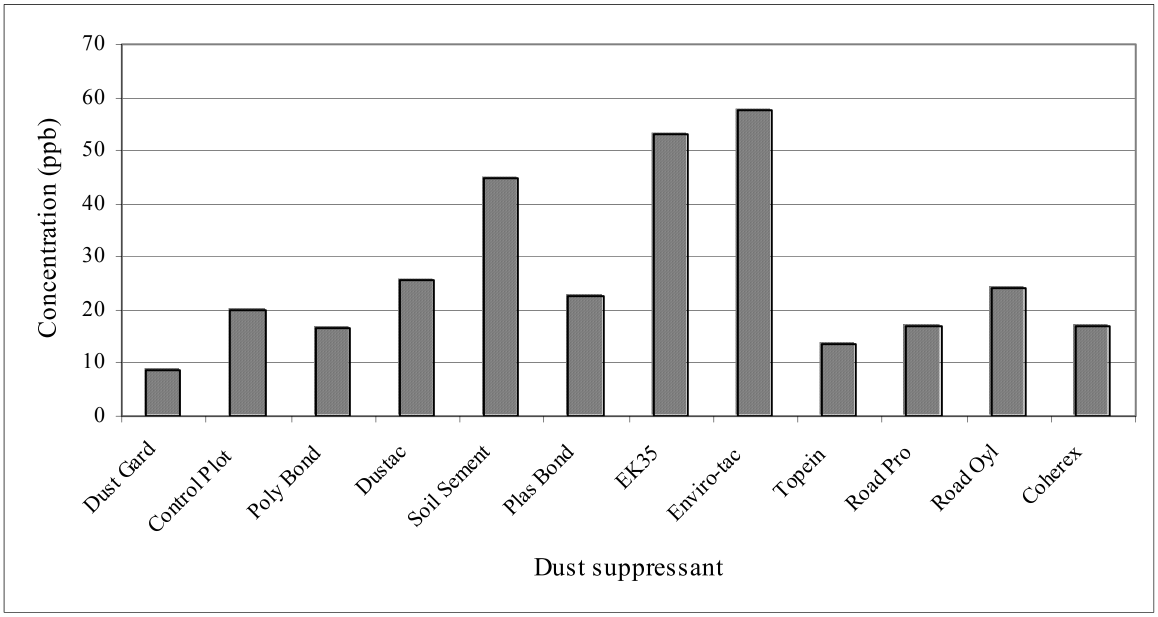


Figure 5-35: Mercury concentrations detected in the soil extract.

SECTION 6: POTENTIAL IMPACTS FOR THE LAS VEGAS VALLEY

In this section the results from Sections 4 and 5 are used to illustrate the potential impacts that the use of dust suppressants may have on the Las Vegas Valley watershed nonpoint source runoff. The results presented in Section 5 indicate that the application of dust suppressants may reduce the concentration of suspended solids, but in most cases, the levels of other harmful chemicals and metals will increase. In this section, the results obtained in Section 5 were used to determine the increase/decrease in the load of a contaminant due to the application of dust suppressants. The loads obtained from the test plot were extrapolated to areas of the Las Vegas Valley that could potentially be treated with dust suppressants (i.e., disturbed lands).

6.1. PROCEDURES

Las Vegas Valley is presently among the fastest growing cities in the United States. This rapid growth results in large desert areas being disturbed for construction of new developments. Since most of the construction is on vacant lands, the percent area of disturbed vacant lands is increasing. According to James (2000), there was approximately 600 km^2 (151,189 acres) of vacant land in the Las Vegas Valley in the year 2000. Of this 600 km^2, approximately 10-20% of the vacant lands are disturbed. Thus, the worst case scenario presented in this section is that approximately 120 km^2 (20% of 600 km^2) of disturbed land exists in the Las Vegas Valley and could potentially be treated with dust suppressants.

As mentioned in the previous sections, the application of dust suppressants impacts the hydrologic characteristics of the surface as well as the runoff quality. These effects are mainly due to the dust suppressants creating a different soil surface where they are applied as well as their inherent chemical composition. The impacts due to their application may be broadly classified into two: a) the quantity of runoff is either increased or decreased; b) the concentration of various elements in the runoff is either increased or decreased.

To properly assess the impacts, it is necessary to calculate the load from a surface. The load extrapolated for a disturbed area for a particular storm event is calculated using:

$$L = D \times A \times R \times C \times 10$$

L = load (kg) for a rainfall event
D = depth of rainfall event (cm)
A = area of the land for which the load is being estimated (km^2)
R = runoff coefficient of the land under consideration, for the rainfall event for which the depth is being used
C = concentration of the element under consideration (mg/l)

The change in load (ΔL) due to the application of a dust suppressant for a particular area can be calculated using:

$$\Delta L = L_i - L_c$$

L_i = load from the area treated with dust suppressant *i*.
L_c = load from the area due to natural soils (control)

Four different scenarios were evaluated for estimating the change in loads due to dust suppressant application. The different scenarios are:

- 100% of the disturbed land treated with dust suppressant
- 75% of the disturbed land treated with dust suppressant
- 50% of the disturbed land treated with dust suppressant
- 25% of the disturbed land treated with dust suppressant

6.2. ASSUMPTIONS

The analysis presented in this section is based on the following assumptions:

- There are approximately 120 km^2 of disturbed vacant land in the Las Vegas Valley.
- The dilution rates for the dust suppressants when applied in the Las Vegas Valley are the same as that used in the study.
- The concentration of the parameters measured in the initial runoff represents the concentrations for all of the runoff volume.
- The loads are for a single rainfall event having an intensity of 23 mm/hr that occurs uniformly over the disturbed vacant land areas.
- The concentration of contaminants in the runoff from the areas treated with dust suppressants is the same as the concentrations of the contaminants from the test plots in this study.
- The runoff coefficients from the areas treated with dust suppressants is the same as the runoff coefficients from the tests plots in this study.
- Only one type of dust suppressant is used on the disturbed vacant lands for each scenario.
- There is no dilution or change in concentration of the runoff due to fate and transport in the downstream conveyance channels.
- The dust suppressant is applied once for a land surface and the calculations do not reflect any long term accumulation on the surface due to reapplication.

6.3. RESULTS

Six parameters were evaluated for the change in loads due to dust suppressant application (runoff volume, nitrate, phosphate, sulfate, TSS, and chloride). A similar rainfall event used in the field experiments (23 mm/hr or 0.89 in/hr) was used to estimate the load due to a single rainfall event. Figure 6-1 through Figure 6-3 present the change in load due to the application of dust suppressant for the six parameters under the four different scenarios.

Phosphate and TSS loads are reduced for many dust suppressants. The only dust suppressant that caused an increase in phosphate loading was Soil Sement. Nitrate loads were increased due to the application of Dustac, Soil Sement, EK35, Enviro-tac, Topein, and Roadpro. Chloride loads are increased for the all of the dust suppressants. Sulfate loads remained the same for 7 of the 11 dust suppressants and increased for EK35, Road Pro, Road Oyl, and Coherex. Lastly, there is increased volume of runoff for all the dust suppressants except Poly-Bond and Dust Gard. It is noteworthy that in some cases, the load was decreased even though the concentration of the chemical coming out of the dust suppressant plot was higher than the control plot. This is due to the dust suppressant plot having a lower runoff coefficient which would create less runoff volume.

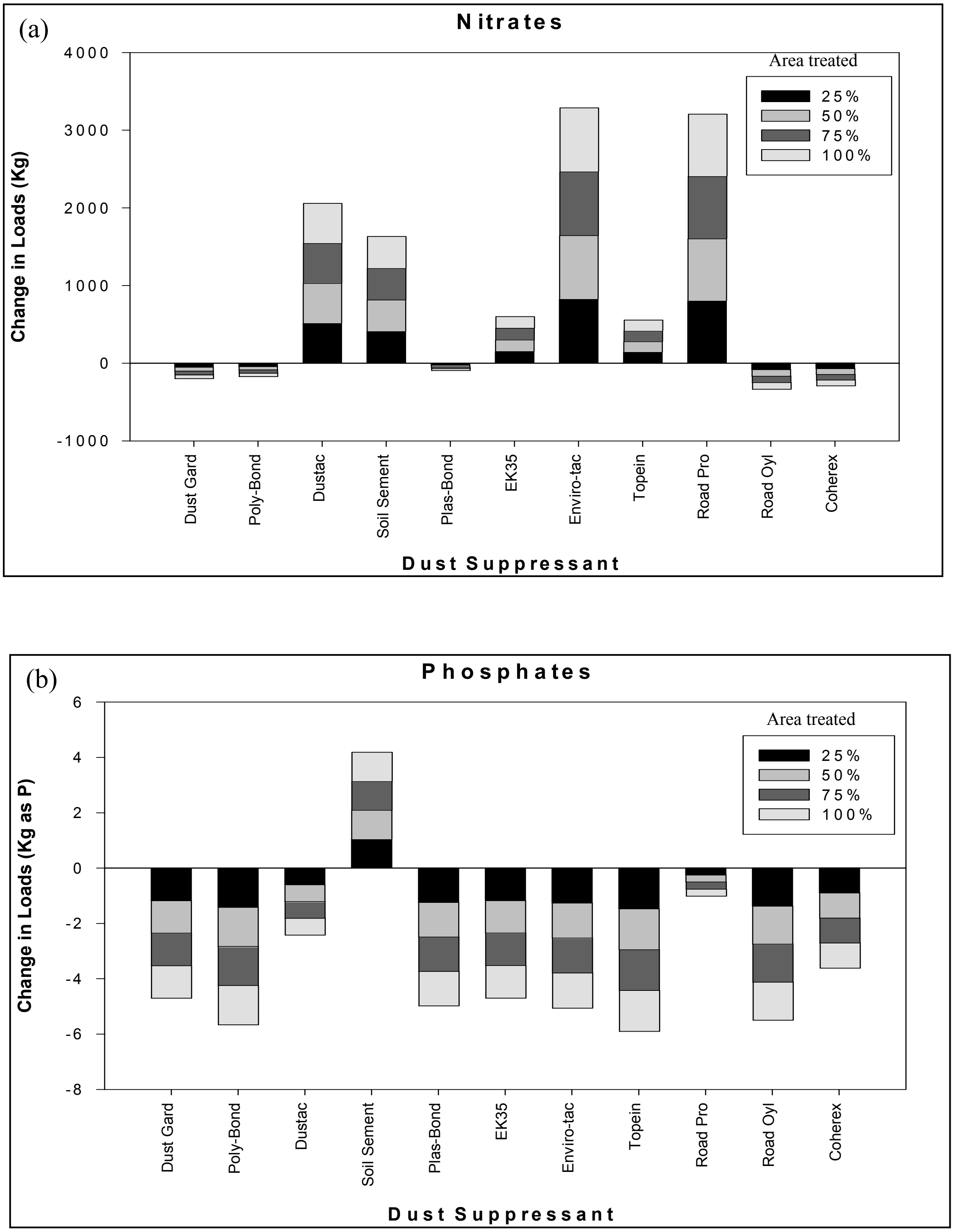
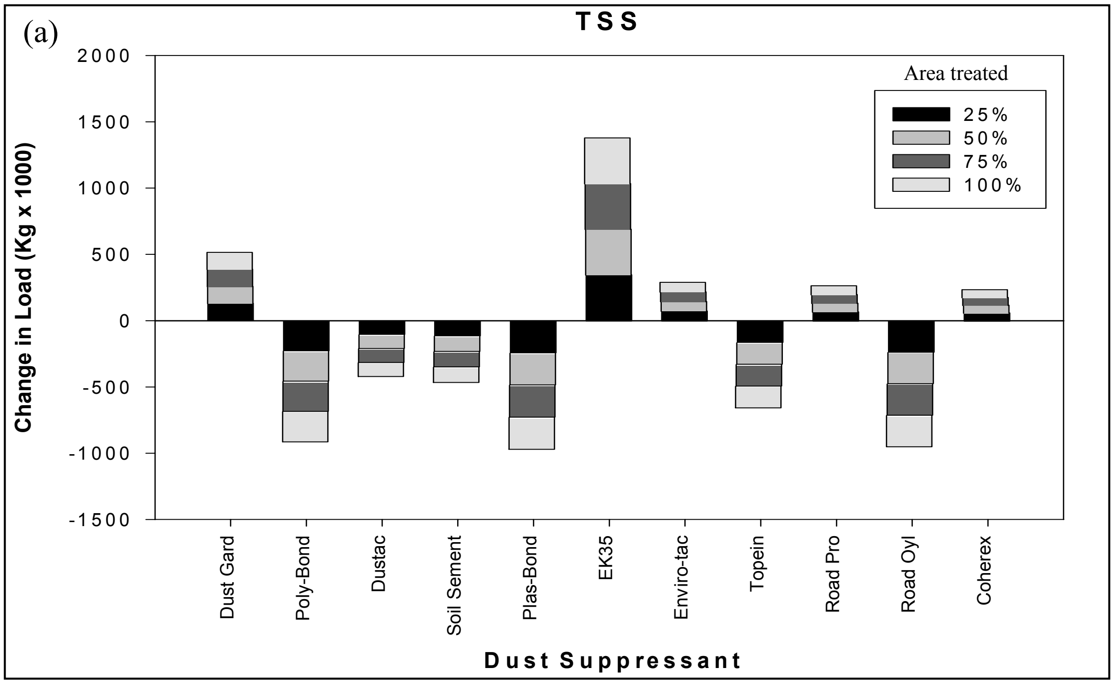


Figure 6-1: Change in (a) nitrate loads and (b) phosphate loads. The different shadings represent the change in loads due to the application of dust suppressants on 25%, 50%, 75%, or 100% of disturbed vacant lands.



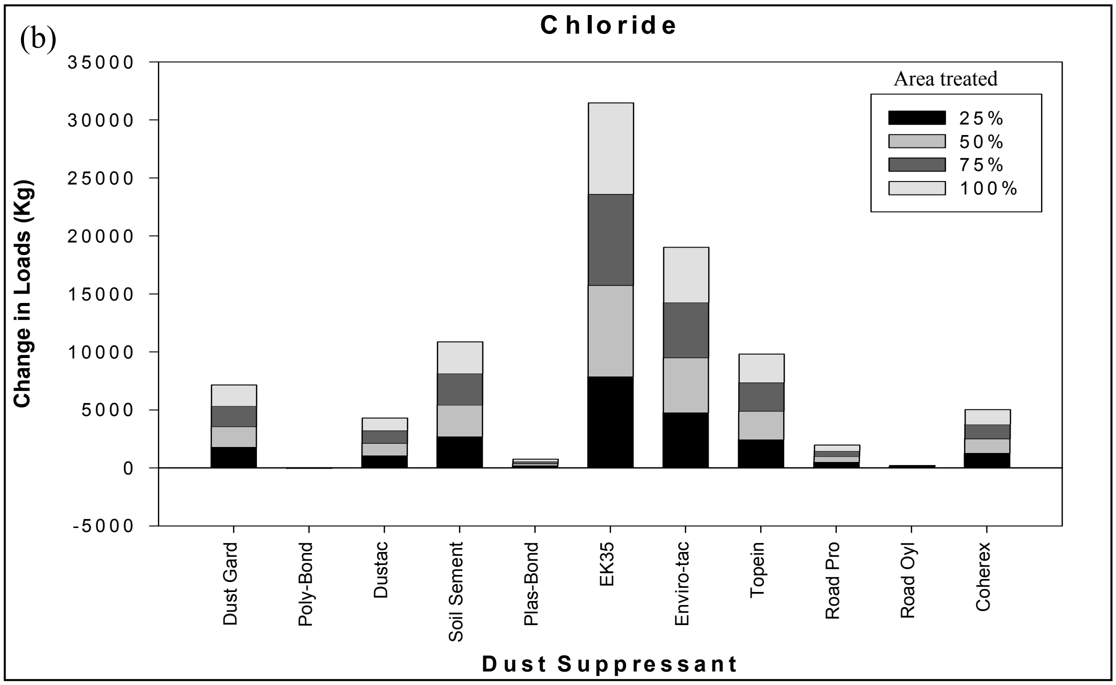


Figure 6-2: Change in (a) TSS and (b) chloride loads. The different shadings represent the change in loads due to the application of dust suppressants on 25%, 50%, 75%, or 100% of disturbed vacant lands.

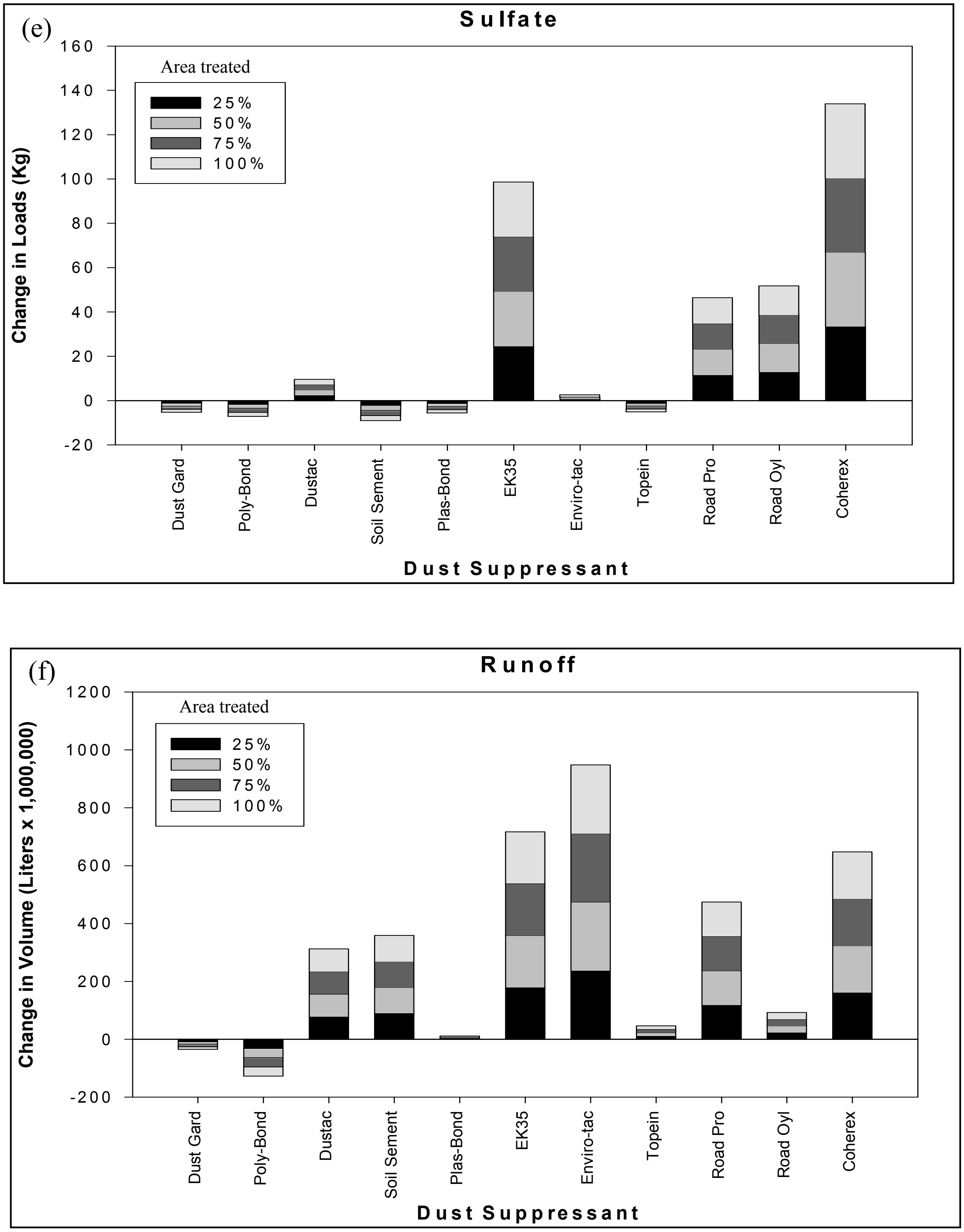


Figure 6-3: Change in (a) sulfate loads and (b) runoff volume. The different shadings represent the change in loads due to the application of dust suppressants on 25%, 50%, 75%, or 100% of disturbed vacant lands.

SECTION 7: CONCLUSIONS

The study presented here provides information for making a preliminary assessment of the water quality impacts from the application of dust suppressants to disturbed lands. In general, all dust suppressants investigated contributed constituents to the runoff quality to some degree. The majority of the dust suppressants evaluated resulted in higher runoff coefficients which translates to higher runoff volumes that may impact stormwater management facilities. Table 7-1 and Table 7-2 summarize the impacts for each product and following is a summary of the findings for the major categories of dust suppressants.

7.1. PETROLEUM-BASED

The runoff from the petroleum-based dust suppressant (Coherex) presents the highest number of parameters with concentrations above that of the control plot. The other petroleum-based dust suppressant (Road Pro) also presents a high number of parameters with concentrations greater than the control. Although both dust suppressants are petroleum-based, some differences are observed in the runoff water quality; while very high concentrations of sulfate and ammonia are observed in the runoff from the Coherex plot, only small concentrations of these components were observed in the runoff from the Road Pro plot. The runoff from the petroleum-based products also contained the greatest number of metals with concentrations above that of control. Compared to the other dust suppressants, petroleum-based products generated runoff with the highest concentrations of contaminants above those of the control plot. Application of these suppressants is likely to contribute metals, volatile and semi-volatile compounds, sulfate, ammonia, nitrate, sulfide, coliform bacteria, hardness, TDS, and sulfide to runoff waters.

The soil extracts from the plots treated with these suppressants showed high nitrate, ammonia, organic content, metals, and TDS concentrations. Similar to what was observed in the runoff, the soil extracts of petroleum-based products have the largest number of contaminants with concentrations above that of the control. A comparison of the runoff and soil extracts results show a significant difference between Coherex and Road Pro. The number of contaminants with concentrations above the control plot was higher in the runoff of Coherex while the concentrations in the soil extract were higher for Road Pro. This implies that Coherex washed out more easily from the soil than Road Pro.

The application of both petroleum-based dust suppressants created runoff volumes that were at least 200% higher than the control plot. The timing of the initial runoff from the plots treated with dust suppressants was approximately 30 minutes earlier than the control plot. Both of these conclusions have implications for the impacts to downstream stormwater conveyance facilities.

7.2. ACRYLIC POLYMERS

A large number of parameters with concentrations greater than those of the control plot were also found for all acrylic-polymers. The iso-alkane (EK-35) and the acrylic polymer (Enviro-Tac) showed higher concentrations of contaminants than Poly-bond and Soil Sement. The runoff of the plot treated with EK-35 also contained a higher number of metal contaminants than the other acrylic polymers. Soil Sement is the acrylic polymer with the least number of contaminants, but lead and selenium were detected in the runoff of the plots treated with this dust suppressant. Acrylic polymers are likely to contribute volatile and semi-volatile organic compounds, organic carbon, TDS, alkalinity, hardness sulfate, metals, and nitrate to the runoff. Application of EK-35 resulted in a two unit reduction in pH.

The soil extract from the plots treated with these dust suppressants showed similar trends to those found for the runoff. The extracts from the EK-35 and Enviro-tac plots had higher concentrations of metals, alkalinity, organic content, and nitrate. Poly-bond and Soil Sement had smaller number of contaminants with high concentrations, as compared to Enviro-tac and EK-35.

The hydrologic impacts from plots treated with acrylic polymers were mixed. The runoff volume was increased for 3 of the 4 products and the maximum increase in runoff was 431% higher than the control plot. These dust suppressants created a surface with a runoff coefficient similar to that of a residential development (e.g., runoff coefficient of 0.40-0.50). All acrylic polymers had an earlier time to initial runoff (10 to 30 minutes earlier).

7.3. LIGNINSULFONATE

The ligninsulfonate dust suppressants (Dustac and Topein) also present a high number of components with concentrations above those of the control, but the concentrations of most contaminants found are smaller than those present in the petroleum-based and some of the acrylic products. The runoff water quality for both is very similar, except that volatile and semi-volatile compounds were observed in Topein, but not in Dustac. A moderate number of metals were also found in the runoff of both suppressants. Use of these suppressants can potentially increase organic content, TDS, sulfate, nitrate, metals, and chloride to runoff waters.

The soil extract from Topein shows a large number of contaminants at high concentrations. The quality of the extract is comparable to those found for petroleum-based and tall oil products. While the runoff from both Dustac and Topein presented similar quality, the quality of the soil extract for Topein is worst. It appears that the contaminants from Dustac are more easily leached out than those of Topein.

Plots treated with ligninsulfonate increased the runoff coefficient by 21 to 142%, and had a time to initial runoff 5 to 25 minutes earlier than the control plot runoff. These hydrologic impacts are small compared to petroleum-based and acrylic polymer dust suppressants.

7.4. ORGANIC NONPETROLEUM-BASED (TALL OIL)

The organic nonpetroleum-based product (Road Oyl) had a moderate number of parameters with concentrations above that of the control plot. A high number of metals were detected in the runoff treated with this product. Application of tall oil is likely to contribute to volatile organic compounds, organic carbon, TDS, hardness, sulfide, ammonia, and metals.

Contrary to the findings for the runoff, the soil extract of Road Oyl contains the highest number of contaminants with concentration above that of the control. The quality of the soil extract of this plot is comparable to those to which petroleum-based products where applied. Thus, the contaminants from Road Oyl adsorb to the soil and are not easily leached by rainfall.

The hydrologic impacts from plots treated with Road Oyl was a slight increase in runoff (42%) and an earlier time to initial runoff (15 minutes earlier). The hydrologic impacts from this product are relatively small compared to petroleum-based and acrylic polymers.

7.5. FIBER MULCH

The runoff from the plot treated with the fiber mulch (Plas-bond) presented a small number of components above that of the control. The major contributions of this suppressant to runoff are hardness, sulfate, organic carbon, TDS, and metals.

Interestingly, the number of contaminants with concentrations higher than the control, was very high for the soil extract of Plas-bond. Specifically, there were a high number of metals with high concentrations in the Plas-bond extract. These results imply that most contaminants present in Plas-bond are not easily leached out with rainfall, but they remain in the soil.

The application of fiber mulch to the plots had a large impact on the hydrologic characteristics of the soil surface. All of the rainfall in the first hour of the simulation was absorbed by the paper fiber in the product. Surfaces that are treated with fiber mulch will receive lower runoff volume during the initial part of the storm; however, runoff rates will increase (still below the control plot) as the product becomes saturated.

7.6. MAGNESIUM CHLORIDE

The magnesium chloride (Dust Gard) contributes the smallest number of contaminants to the runoff. It also contains less metals, but the boron concentration in this suppressant was especially high. The major contributions to runoff from the application of this suppressant are ions that will result in increased salinity and conductivity.

The soil extract from the magnesium chloride plot showed a relatively low number of contaminants at concentrations greater than the control. It showed the same high concentrations of boron and chloride found in the runoff analyses.

The plot treated with magnesium chloride had a reduced runoff coefficient (i.e., less runoff volume) and the time to runoff initiation was increased. The hydrologic impacts from surfaces treated with magnesium chloride will not adversely change the downstream flow in a watershed.

7.7. FINAL OBSERVATIONS

The water quality impacts of treating large areas with dust suppressants and the downstream loading was illustrated for the Las Vegas Valley for phosphate, TSS, chloride, nitrate, sulfate, and runoff volume. Noteworthy observations are that chloride concentrations increased for all of the dust suppressants, and phosphate and TSS loads were reduced for the majority of the dust suppressants. The extrapolation of the concentrations from the experimental plots to a large area implies many assumptions, but provides an integration of the results in Section 5 (concentration of contaminants) with the results of Section 6 (change in runoff volume).

Although several compounds that effect water quality have been detected in the runoff of the plots to which dust suppressants were applied, this information alone should not be used to evaluate the impacts of dust suppressants to water quality. This information should be combined with dust suppressant “effectiveness”, frequency of application, and proximity to water bodies to make a thorough evaluation of the impacts. A dust suppressant that generates acceptable water quality in the runoff, but has to be reapplied frequently, could generate the same pollutant loading as a dust suppressant that is less frequently applied, but generates a runoff of worst quality.

Table 7-1: Summary of the contaminants present in the runoff as compared to the control plot. A "+" indicates concentrations greater than the control plot. A "++" indicates the highest concentrations found. A "-" refers to concentrations less than the control.

Compound	Dust Gard MG	Control	Poly Bond AP	Dustac LIG	Soil Sement AP	Plas Bond FM	EK-35 SI	Envirotac AP	Topein LIG	Road Pro PB	Road Oyl ON	Coherex PB
Nitrate	-	1.60	-	++	+	-	-	+	+	++	-	-
Phosphate	-	90.02	-	-	-	-	-	-	-	-	-	-
Alkalinity	-	42.00	+	+	-	-	+	++	-	+	+	+
Hardness	+	40.00	+	+	+	++	+	+	+	+	+	+
Cyanide	-	0.00	+	+	++	-	++	+	+	-	-	+
Ammonia	-	0.75	-	-	-	-	-	-	-	-	++	++
Sulfate	+	9.00	+	+	+	+	+	+	-	-	-	++
Sulfide	-	0.04	-	-	-	-	++	-	-	+	++	++
TDS	-	272.50	-	+	-	++	+	+	+	+	+	+
TSS	++	5757.50	-	-	-	-	-	-	-	-	-	-
Salinity	+	0.09	+	+	+	++	+	+	+	+	-	+
Conductivity	+	156.35	+	+	+	++	+	+	+	+	-	+
TOC	+	4.48	+	+	+	+	++	+	+	+	+	++
COD	-	7.50	-	+	-	-	+	++	+	+	+	+
BOD	-	0.00	+	-	+	+	++	+	+	+	+	++
Chloride	++	3.74	+	+	+	+	+	+	++	+	-	+
Turbidity	+	8100.00	-	-	-	-	-	-	-	-	-	-
Coliform	-	556.00	-	-	-	-	-	-	-	-	-	++
Volatile Org.	-	13.90	+	-	-	-	++	++	+	+	+	+
Non-Volatile	-	ND	++	-	-	-	+	++	+	-	-	+
Boron	++	89.184	-	-	-	-	+	-	-	+	-	-
Aluminum	-	577.698	-	-	-	-	-	-	-	-	++	+
Chromium	-	1.067	-	++	-	-	+	-	-	+	-	+
Manganese	-	13.219	-	+	-	+	+	+	-	+	+	++
Nickel	-	0.469	-	+	+	+	+	-	+	+	+	++
Copper	-	2.156	+	+	+	+	+	+	+	+	+	++
Zinc	-	4.381	+	+	+	+	+	-	-	-	++	++
Arsenic	-	2.067	-	-	-	-	-	-	-	-	-	-
Selenium	+	0.125	+	+	+	+	+	+	+	+	+	++
Silver	+	0.011	+	++	+	-	+	-	+	+	+	+
Cadmium	-	0.034	-	-	-	-	-	+	-	+	++	+
Barium	+	20.249	+	+	+	+	+	+	+	+	+	++
Thallium	++	0.106	+	-	+	+	-	+	+	0	-	++
Lead	+	1.086	-	+	++	-	-	-	+	-	+	+
Iron	-	0.400	-	-	-	-	-	-	-	-	++	++
Mercury	-	23.000	-	-	+	-	-	-	0		++	-
Count	14		17	20	18	15	23	20	19	21	21	29

MG: Magnesium Chloride	AP: Acrylic Polymer	SI: Synthetic Iso-alkane	ON: Organic nonpetroleum
LIG: Lignonsulfonate	FM: Fiber Mulch	PB: Petroleum-based	

Table 7-2: Summary of the contaminants present in the soil extract as compared to the control plot. A "+" indicates concentrations greater than the control plot. A "++" indicates the highest concentrations found. A "-" refers to concentrations less than the control.

Compound	**Dust Gard MG**	**Control**	**Poly Bond AP**	**Dustac LIG**	**Soil Sement AP**	**Plas Bond FM**	**EK-35 SI**	**Envirotac AP**	**Topein LIG**	**Road Pro PB**	**Road Oyl ON**	**Coherex PB**
Nitrate	-	0.75	+	-	+	+	++	-	++	++	+	+
Phosphate	-	82.86	-	-	-	-	-	-	-	-	-	-
Alkalinity	+	44.00	-	-	-	-	++	++	-	+	-	-
Hardness	+	40.00	+	+	-	++	+	+	+	+	+	+
Cyanide	-	0.00	-	+	++	-	+	-	-	-	++	-
Ammonia	-	0.26	-	-	-	-	-	-	-	-	+	++
Sulfate	+	16.50	+	-	-	++	-	-	+	-	-	+
Sulfide	-	0.04	-	-	-	-	-	++	-	-	-	-
TDS	+	117.50	+	+	+	++	+	+	+	+	+	+
Salinity	+	0.10	-	-	-	++	+	-	+	+	-	-
Conductivit	+	110.50	+	-	-	++	+	-	+	+	+	+
TOC	+	8.37	+	+	+	+	++	-	+	+	++	+
COD	-	18.70	+	+	-	+	++	++	+	+	+	+
Chloride	++	2.41	+	-	+	+	+	+	+	+	+	+
pH	-	9.28	-	-	-	-	-	-	-	-	-	-
Boron	++	106.894	-	-	-	+	+	-	-	+	-	-
Aluminum	-	1533.112	-	-	-	-	-	-	-	-	-	-
Chromium	-	0.430	-	-	-	++	+	+	-	+	+	+
Manganese	-	13.088	-	+	-	++	-	+	+	-	-	-
Nickel	+	0.532	+	+	+	++	+	+	+	+	+	+
Copper	-	4.577	-	++	+	-	-	+	+	+	+	-
Zinc	-	7.799	-	+	-	+	++	+	+	+	+	+
Arsenic	-	3.181	-	-	-	-	-	-	-	-	-	-
Selenium	+	0.037	-	+	+	+	+	+	++	+	+	+
Silver	-	0.029	-	-	-	-	-	-	-	++	+	-
Cadmium	-	0.013	-	+	-	-	-	++	+	-	++	-
Barium	+	88.753	-	-	+	+	++	++	+	+	-	-
Thallium	+	0.000	+	-	+	+	+	+	+	+	+	+
Lead	-	0.375	-	+	-	-	-	+	-	++	+	++
Iron	-	0.400	-	-	-	-	-	-	-	-	-	-
Mercury	-	20.000	-	+	++	+	++	++	-	-	+	-
Count	13		10	13	11	18	18	17	17	19	19	15

MG: Magnesium Chloride	AP: Acrylic Polymer	SI: Synthetic Iso-alkane	ON: Organic nonpetroleum
LIG: Lignonsulfonate	FM: Fiber Mulch	PB: Petroleum-based	

SECTION 8: REFERENCES

Clark County Regional Flood Control District (CCRFCD), 1999. *Hydrologic Criteria and Drainage Design Manual*.

Fetter, C.W., 1994. *Applied Hydrogeology*. Macmillan College Publishing Company.

Hanes, R.E., Zelanzny, L.W., and Blaser, R.E., 1970. *Effects of Deicing Salts on Water Quality and Biota.* National Cooperative Highway Research Program, Report Nº91.

Hanes, R.E., Zelanzny, L.W., Verghese, K.G., Bosshart, R.P., Carson, E.W.Jr., Wolf, D.D., 1976. *Effects of Deicing Salts on Plant Biota and Soil.* National Cooperative Highway Research Program, Report Nº170.

Mays, Larry W., 2001. *Water Resources Engineering*, John Wiley & Sons, Inc.

McCuen, R. E., 1998. *Hydrologic Analysis and Design*, Prentice-Hall, Inc.

James, D., Pulgarin, J., Gingras, T., Edwards, S., Venglass, G., Becker, J., Licon, A., Swallow, C., Gambatese, J., Luke, B., 1999. *Field Testing of Dust Suppressants Using a Portable Wind Tunnel*. Final Report for Clark County Health District.

James, D., 2001. *Valley-wide Vacant Lands Inventory and PM-10 Emission Factor Estimates*. Final Report for Clark County Health District.

National Deposition Atmospheric Program. <http://nadp.sws.uiuc.edu/nadpdata/siteinfo.asp?id=NV00&net=NTN>

APHA, 1995. *Standard Methods for the Examination of Water and Wastewater*, 19th edition, American Public Health Association, Washington, D.C.

United States Department of Agriculture, 1985, *Soil Conservation Service*. Soil survey of Las Vegas Valley Area, Nevada.

USEPA, 2002. *Air Trends 1995 Summary*- http://www.epa.gov/oar/aqtrnd95/pm10.html

United States Environmental Protection Agency – Office of Pesticides Programs – <http://www.epa.gov/oppfead1/international/piclist.htm>

Zoldoske, David F., Solomon Kenneth H., 1998, *Coefficient of Uniformity - What it tells us*, Center for Irrigation Technology, Irrigation notes, California State University, Fresno, California.

APPENDIX A: LITERATURE REVIEW

Appendix A - Literature Review
Dust Suppression and its Environmental Impacts

1.0 INTRODUCTION

In recent years, studies on fugitive dust control have significantly increased in the United States because of greater emphasis on attainment of National Ambient Air Quality Standards. The Clean Air Act regulates the amount of PM-10 (particulate matter less than 10 μm in diameter) in the air. The United States Environmental Protection Agency (USEPA) has established a health-based national air quality standard for PM-10 with an annual average of 50 $\mu g/m^3$ and a maximum daily concentration of 150 $\mu g/m^3$ (USEPA, 2002).

Airborne dust can come from several sources. Cowherd *et al.* (1989) divide the main sources into two categories: process sources (industrial operations that modify the chemical or physical characteristics of feed materials) and open dust sources (solid particles generated by wind or machinery acting on exposed materials). Open land and unpaved roads are two major open dust sources. Fugitive dust can be released into the air when wind blows over disturbed and undisturbed land. Breakage of the natural soil crust by agriculture, construction, and mining activities loosens soil particles on the surface making it easier for the wind to pick them up. Dust particles are composed mainly of silicon, aluminum, and iron oxides (Gillies *et al.*, 1999). Fugitive dust may be harmful to humans if silica or asbestos is present in significant amounts (Singer *et al.*, 1982). Concerns for human health exposure include effects on the respiratory system, damage to lung tissue, premature death, and cancer.

The release of particulate matter from industrial sources can often be prevented at the source. Releases from land-based, or non-point sources, are more difficult to control. One technique used to control the release of fugitive dust is the application of dust suppressants to the soil surface to stabilize disturbed lands and unpaved roads.

Dust suppressants are commercially available stabilizers that abate dust by changing the physical properties of the soil surface. State and federal agencies, mining companies, communities, and construction firms use suppressants to abate fugitive dust, reduce erosion and maintenance costs, and to meet the PM-10 regulations set by the USEPA. Materials used as dust suppressants include water, salts, asphalt emulsion, vegetable oils, molasses, synthetic polymers, mulches, and lignin products. These materials are generally effective in minimizing dust; however, little is known about the effects of those products on the environment and human health (Hanes *et al.*, 1970, Hanes *et al.*, 1976). Impacts will depend upon their composition, application rates, and interactions with other environmental components. Potential environmental impacts include: surface and groundwater quality deterioration; soil contamination; toxicity to soil and water biota; toxicity to humans during and after application; unintentional air pollution; accumulation in soils; changes in hydrologic characteristics of the soils; and impacts on native flora and fauna populations.

Regulations to control and permit the application of dust suppressants to disturbed land and unpaved roads have not been established in the United States to date by the USEPA. There is concern that the solution to the PM-10 problem, dust suppression, may in the future become an environmental issue itself. Examples of environmental solutions that became environmental liabilities include the addition of MTBE to replace lead in gasoline and the spraying of dioxin-containing used oil to control dust in Times Beach, Missouri. To assure that the chosen technologies to control fugitive dust do not become a future liability, it is important to develop policies and guidelines to control the application of dust suppressants. This literature review summarizes the current status of the use of dust suppressants with respect to existing regulations, types of materials used, application rates, effectiveness, environmental impacts, and costs. The objective of this review is to provide the panelists with some background information on suppressants to aid the panel discussion.

1.1 Dust Suppressant Evaluation Programs

Recently, there has been progress towards evaluating dust suppressant technology and their potential environmental impacts. In the U.S., the USEPA in collaboration with the American Society of Civil Engineers has helped to develop a private certification program for dust suppressants (ETV/USEPA, 2001). Another certification program exists at the state level, in California (Cal/EPA, 2001). The state of Nevada has recently issued interim guidelines for the application of dust suppressants to disturbed lands (NDEP, 2001). Pennsylvania regulates dust suppressants and other materials used in road construction through a pollution prevention grant program, the Dirt and Gravel Roads Maintenance (DGRM) program (DGRMP, 2000). The state of Michigan requires a permit from the Department of Environmental Quality for the application of oil field brines used to control dust and stabilize soils (MDEQ, 2000).

1.1.1 Environmental Technology Verification Program – US EPA

An Environmental Technology Verification (ETV) program for dust suppressants was developed by the Air Pollution Control Technology (APCT) Verification Center (APCTVC), the Environmental Technology Evaluation Center (EvTEC), and the Highway Innovative Technology Evaluation Center (HITEC). The APCTVC is one of the U. S. Environmental Protection Agency's Environmental Technology Verification (ETV) Programs. EPA's verification partner in the APCTVC is the Research Triangle Institute (RTI), a nonprofit research organization. EvTEC and HITEC are two Innovation Centers within the Civil Engineering Research Foundation (CERF), the research and technology transfer arm of the American Society of Civil Engineers (ASCE). The verification protocol was developed with the input of an expert panel containing representatives from federal, state, and local environmental agencies, the private sector, and academia. CERF held their first technical panel meeting on dust suppressants in June 1999 and RTI held their first meeting in November 2000. The main objective of the verification is to provide independent, objective field and laboratory tests of a suppressant's performance and baseline environmental impacts (ETV/USEPA, 2001). For the evaluation process, manufacturers/vendors submit applications to ETV describing their technology or product, its function, available tests or performance data, and the objectives desired from the evaluation (ETV/USEPA, 2001). ETV convenes a panel to evaluate the application. The manufacturer/vendor also participates in the panel as a liaison member to provide information about the product being evaluated by the panel. The panel, with the assistance of the manufacturer/vendor, identifies performance and environmental issues that have to be addressed to gain acceptance of the technology users. The panel then advises ETV on the development and execution of the evaluation plan to provide data that will address the panel's concern. After the issues have been addressed, ETV issues an evaluation report and summary verification statement that describes the results of the tests to help users make informed purchases.

1.1.2 California Technology Certification Program

The California Department of Environmental Protection (Cal/EPA) Certification Program (CalCert) is managed through a certification board. The certification board draws expertise from the Air Resources Board, the State Water Resources Control Board, the Department of Toxic Substances Control's Hazardous Waste Technology Program, and the Office of Environmental Health Hazardous Assessment. The Office of Environmental Technology coordinates certification activities. Cal/EPA has recently issued an evaluation report for the dust suppressant PennzSuppress® D from the Pennzoil-Quaker State Company (Cal/EPA, 2001). The evaluation report reveals that the suppressant is able to reduce 85% of PM-10 emissions. Concentration of metals, volatile and non-volatile organic compounds, as well as the toxicity effects of PennzSupress® D to several freshwater species were found to be within the acceptability criteria of the regulatory agencies.

1.1.3 Environmental Technology Verification Program - Canada

Environment Canada, through a partnership with the private sector, has developed the Environmental Technology Verification (ETV) program. This program is similar to its counterpart in the U.S., except that it issues a license to the manufacturer/vendor. Environmental technology vendors apply to the program for verification of the claims. If the claims are verified successfully, ETV issues three documents: a verification certificate, a technology fact sheet, and a final verification report, much like the California certification program. In 1999, Soil Sement® was licensed by the Canadian ETV program as a dust suppressant (Environmental Canada). The product achieved 95% PM-10 suppressant efficiency, that is, it reduced dust in the air by 95% for three months after application and 80% after 11 months. Acute toxicity tests with Soil Sement® yield LC_{50} for rainbow trout (96-h) and *Daphina magna* (48-h) of at least 7,000 ppm and 21,000 ppm, respectively.

1.1.4 Nevada Guidelines

In Southern Nevada, a dust palliative working group composed of air and water quality professionals from state and local agencies, including the Southern Nevada Water Authority, Clark County Health District, Clark County Comprehensive Planning, Clark County Regional Flood Control District, City of Las Vegas, UNLV Department of Civil and Environmental Engineering, and the Nevada Department of Environmental Protection (NDEP) was formed to draft the Interim Guidelines on Dust Palliatives Use in Clark County, Nevada (NDEP, 2001). The working group was formed at the request of Commissioner Erin Kenny and in response to direction from the Nevada Legislature to provide recommendations regarding the use of dust suppressants in the Las Vegas Valley. The working group met several times and identified a number of existing state regulations and codes that could be applicable to the use of dust palliatives and the protection of human health and the environment. However, because the environmental impacts of the various dust suppressant products have not been fully evaluated, the working group decided, and NDEP concurred, that it would not be prudent to recommend or deny the use of such products based solely on the aforementioned regulations. Thus, in addition to state regulations, some incorporated recommendations are based on information currently available in the scientific literature. The main objective of the guidelines is to outline practices and procedures that should be followed to ensure compliance with the new Clark County Air Quality regulations (effective January 1, 2001) in a manner that minimizes adverse environmental impacts. The guidelines aim at facilitating the implementation of air quality fugitive dust controls in a manner that prevents human exposure to harmful constituents and protects soil and water resources while achieving air quality objectives. The guidelines are intended to serve as interim recommendations until permanent and enforceable regulations can be developed based on more complete scientific data. It is envisioned that the permanent regulations will be more comprehensive in scope. The guidelines state that the application of dust palliatives may be subject to sample collection and testing for compliance with applicable regulations of the Nevada Administrative Code and the Nevada Revised Statutes. Sample collection may be conducted by the Nevada Division of Environmental Protection. Basis for the Interim Guideline include existing Nevada regulations concerning contamination of soils, contamination of groundwater, contamination of surface waters, hazardous waste disposal, and used and mixed oils.

The guidelines state that suppressants containing banned pesticides, restricted pesticides, dioxin, PCBs, and asbestos should never be applied. The guidelines further restrict: (a) the use of organic petroleum products, deliquescent/hygroscopic salts, and lignin-based palliatives within twenty (20) yards of open bodies of water, including lakes, streams, canals, natural wastes and flood control channels, and drinking water well-heads. This buffer zone is intended to prevent leachate from these palliatives from reaching an open body of water or a ground water aquifer; (b) the use of surfactants containing phosphates is highly discouraged because of adverse impacts on water quality. Surfactants by themselves are not allowed for use as a dust palliative because they do not form a durable soil surface. Non-phosphate surfactants may be combined with dust palliatives to assist penetration of dust palliatives into hydrophobic soils; (c) any person who applies any pesticide material with a dust palliative is required to hold a valid pesticide applicators license issued by the State of Nevada; (d) fiber mulch products should not be used as a dust palliative in traffic areas. These products do not hold up well for traffic use; (e) use of deliquescent/hygroscopic salts should be limited to magnesium chloride and only used for short-term (less than one year) stabilization of unpaved roads. Treated unpaved roads must be periodically maintained with additional applications of water and magnesium chloride as needed to maintain effectiveness. Magnesium chloride is not effective, even with product reapplication, for periods of more than one year. Magnesium chloride should not be used on trafficked areas within twenty (20) yards of an open body of water, a drinking water well-head, natural or artificial drainage channel, or other surface water feature; (f) organic petroleum products, including modified and unmodified asphalt emulsions, should not be used on non-traffic areas; (g) use of deliquescent/hygroscopic salts is highly discouraged for non-traffic stabilization. These salts require frequent re-watering to be effective in the Las Vegas Valley; (h) lignin-based palliatives are not recommended for non-traffic stabilization.

Surface binding action of lignin-based palliatives may be reduced or completely destroyed when heavy rains occur.

The guidelines also suggest the types of suppressants to be applied to specific areas as well as dilution and application rates. Several local agencies, the Southern Nevada Water Authority, Clark County Health District, Clark County Comprehensive Planning, Clark County Regional Flood Control District, and the City of Las Vegas, are currently funding a study in the Department of Civil and Environmental Engineering of the University of Nevada Las Vegas to evaluate the potential impacts of dust suppressants on the quality of runoff from disturbed lands. Final report of this research project is due to local agencies on June 30, 2002.

1.1.5 Dirt and Gravel Roads Maintenance program - Pennsylvania

The application of dust suppressants in Pennsylvania is regulated under the Dust and Gravel Roads Maintenance program. Pennsylvania's State Conservation Commission Dirt & Gravel Roads Pollution Prevention Program is a grant program. It is an innovative effort to educate the public about pollution problems from roads and fund "environmentally sound" maintenance of unpaved roadways that have been identified as sources of dust and sediment pollution. Signed into law in April 1997 as Section 9106 of the PA Vehicle Code. The program created a dedicated, non-lapsing fund - $4 million per year – to provide money to local communities for education and local road maintenance by way of streamlined appropriations to local conservation districts for use by local road maintenance entities under the environmental guidance of a local Quality Assurance Boards (QABs). Section 91060(f)(7) of the Vehicle code requires Quality Assurance Boards to adopt standards that prohibit the use of environmentally harmful materials and practices in dirt and gravel road maintenance. The objectives of the Pennsylvania protocol are: (1) To prohibit the use of environmentally harmful materials or practices on Dirt and Gravel Roads Maintenance Program projects; (2) To recommend procedures that will satisfy the program's non-pollution requirement with a minimum of paperwork; (3) To provide Conservation Districts with a statewide information exchange system which will allow them to establish eligibility of local products; (4) To employ a product clearance system and notify conservation districts of products determined to be eligible for statewide use.

The Interim program's requirements for compliance with the non-pollution criteria are currently in the draft form. In general, the guidelines call for compliance with all existing laws and conditions via a purchase contracting process, rather than a regulatory process. Vendors would comply voluntarily as part of their sales agreement. It is anticipated that such an approach would minimize challenges in court by product manufacturers.

The program places the responsibility of proving that a product meets Pennsylvania's existing laws on the manufacturer. It is expected that the adoption of such practice will minimize paperwork because it will be done once for each covered product. Participants may purchase products, listed as eligible and be reimbursed provided they have an active liability contract with the manufacturer and the conservation districts establishes that the product is approved. The program will be applied statewide to insure that individual QAB's will not be sued for refusal to buy certain products.

It is the responsibility of the vendor, as a condition of sale, to prove that the commercial product does not degrade the environment or create hazards in accordance with the standards of the DGRP program. The vendor has to have an EPA-Certified laboratory test the product according to the specified test procedures. Laboratory personnel complete the tests, certify the results, and report the eligibility of the product for program funding in writing. The State Conservation Commission (SCC) will review the submission to confirm the certificate as authentic. The manufacturer must also (a) certify that the product submitted for testing is representative of the product as marked; (b) provide a copy of the certificate of eligibility to the conservation district; (c) provide the participant with a signed copy of a liability contract assuming all liability for supply, transport, application and curing of the product. The product must also comply with Pennsylvania's environmental laws on waste discharge, water quality, toxic substances, air quality hazardous and cut back asphalts. The guidelines divide the products used in dirt and gravel roads into solids (e.g. stone, geotextile, salts as crystals) and aqueous (e.g. brines, emulsions). Aqueous products must undergo the following required tests: a 7-day rainbow trout survival and growth test, and a 7-day cladoceran (*Ceriodaphinia dubia*) survival and reproduction test. Each product tested must report the NOEC, LOEC, LC_{50} and CHV values for the survival and growth of rainbow trout and one for the survival and reproduction of cladocerans. A MSDS sheet for each product should accompany the application. In addition, the materials have to undergo bulk and leach analysis. Bulk analysis should follow methods established in EPA SW-846 and leach analysis should be performed according to EPA Method 1312. Components analyzed in these tests include: pH, major, minor, and trace components, radionuclides, moisture content, loss of ignition (LOI) at 1000°C, metals, cyanide, volatile, and non-volatile organic compounds. The laboratory has to report each constituent that exceeds the trigger levels (50% of SPLP limits, as set forth in current PA DEP Mining Regulations Module 25). If any trigger level (s) is exceeded, a second sample of the material should be tested.

1.1.6 Application of Oil Field Brine Regulations - Michigan

The state of Michigan has established regulations to control the application of Oil Field Brines. These brines are produced at oil and gas well facilities and are used for dust control and soil stabilization. The Michigan Department of Environmental Quality, through regulation R324.705 (3), requires a permit for the application of brines for ice and dust control and soil stabilization. Pursuant to this general permit, applicants of brine may begin as soon as the conditions of the general permit have been met. Failure to comply with the terms and provisions of the permit may result in civil and/or criminal penalties. The requirements for oil field application as dust suppressant and road stabilizers in Michigan include:

1. No application can occur until a certificate of authorization of coverage on a form approved by the Department is issued.
2. Only brine that meets the requirements of R 324.705 (3) of Part 615, as amended, may be used for ice and dust control and soil stabilization on land, such as roads, parking lots and other land.
3. To prevent other contaminants from becoming part of the brine discharge, brine shall be applied with vehicular equipment dedicated to this use or hauling fresh water.

4. Brine shall be applied for dust control and soil stabilization in accordance with the following criteria: (a) brine may be applied to the surface of roads, parking lots, and other land up to four applications each year south of the southern county lines of Madison, Lake, Osceola, Clare, Cladwin, and Arenac Counties. Counties north of this line may apply only three times per year; (b) brine may be applied to the surface of roads being used as a detour and on other areas during construction as necessary to control dust up to six applications each year; (c) brine must be applied to roads and parking areas with equipment described by the term "spreader bar". This device shall be constructed to deliver a uniform application of brine over a width of at least eight feet; (d) brine may be applied at a maximum rate of 1,500 gallons per lane mile of road or 1,250 gallons per acre of land, provided runoff does not occur; (e) Brine shall be applied in a manner to prevent runoff.
5. Brine shall be applied for ice control in accordance with the following criteria: (a) brine shall be applied only on paved roads or paved parking lots; (b) brine shall be applied at a maximum rate of 500 gallons per lane mile of road or 400 gallons per acre of land; (c) brine must be applied only when the air temperature is above 20°F, unless used for pre-wetting solid salt; (d) brine must be applied with equipment designed to direct the discharge to the center of the pavement or high sides of curves.
6. Brine application measurement methods must be used to ensure that the brine application rates are within the general permit.
7. Brine shall not be applied at a location determined to be a site of environmental contamination for chlorides.
8. Records shall be kept of the use of brine and should contain driver's name, location, loading date, source of brine, date of brine application, and gallons applied. Records should be kept by the applicant for a period of three calendar years after application and should be available for inspection by the Department or a peace officer.

2.0 DUST SUPPRESSANT TYPES AND THEIR EFFECTIVENESS

The products most frequently used to control fugitive dust are listed in Table 1. In 1991, 75-80% of all dust suppressants used were chlorides and salt brine products, 5-10% were ligninsulfonates, and 10-15% were petroleum-based products (Travnik, 1991). There are many studies on the effectiveness of dust suppressants; However, there is little information on the potential environmental impacts of these compounds.

Table 1 – Most commonly used dust suppressants (modified from Bolander, 1999a).

Suppressant Type	*Products*
Water	Fresh and seawater
Salts and brines	Calcium chloride, and magnesium chloride
Petroleum-based organics	Asphalt emulsion, cutback solvents, dust oils, modified asphalt emulsions
Non-petroleum based organics	Vegetable oil, molasses, animal fats, ligninsulfonate, and tall oil emulsions
Synthetic polymers	Polyvinyl acetate, vinyl acrylic
Electrochemical products	Enzymes, ionic products (e.g. ammonium chloride), sulfonated oils
Clay additives	Bentonite, montmorillonite
Mulch and fiber mixtures	Paper mulch with gypsum binder, wood fiber mulch mixed with brome seed

2.1 Water

Surface watering is an immediate, inexpensive short-term solution to control dust (Gebhart *et al.*, 1999). Water suppresses dust by agglomerating surface particles. However, the effectiveness depends upon temperature and humidity. Water can be effective for a period as short as half an hour and as long as twelve hours (Foley *et al.*, 1996, Schwendeman, 1981). Several light applications of water to control dust are more effective than a single heavy application. Heavy watering may penetrate to the subgrade, turn the dust into mud, and potentially result in road failure (Langdon and Williamson, 1983). Thompson (1990) found water was 85% effective in controlling dust in coal mines. Water effectiveness in controlling dust in roads and dirty beds has been estimated to be 40% (Travnik, 1991, Foley *et al.*, 1996). Water has little residual effect. Once applied it evaporates quickly, especially in hot, dry climates (Kestener, 1989a). Cowherd *et al.* (1989) reports that dust suppression efficiency decays from 100% to 0% in a very short time. Seawater is more effective than fresh water as a suppressant owing to the presence of salts. However, water quality is an important consideration when water is being used as a dust suppressant. Systems that use water with high concentration of suspended solids require higher maintenance than those that use clean water. The water used for dust control should have a pH between 6 and 8, and hardness should not exceed 120 ppm as calcium carbonate. Water containing algae and microscopic plants should also be avoided unless it is treated for those organisms (Thompson, 1990).

2.2 Salts and Brines

The most widely used compounds in this category of suppressants are magnesium chloride ($MgCl_2$), and calcium chloride ($CaCl_2$) (Addo and Sanders, 1995). Salts suppress dust by attracting moisture from the air, which keeps the surface humid (Foley *et al.*, 1996). Magnesium chloride and calcium chloride have both hygroscopic and deliquescent properties. Salts are deliquescent when they can absorb moisture from the air and become liquid. This occurs because the vapor pressure of the salts is lower than that of water at the same temperature and pressure. Salts are hygroscopic when they can absorb moisture and retain it by resisting evaporation (Addo and Sanders, 1995). Sodium chloride is not a very useful suppressant in arid regions because it only absorbs water when the humidity exceeds 75%.

Calcium chloride is a by-product of the ammonia-soda (Solvay) process and a joint product from natural salt brines. It is commercially available as pellets at 94-97% purity, flakes at 77–80% purity, and a clear odorless, colorless liquid at 35–38% solids. All forms of calcium chloride are soluble in water and alcohol, and the water solutions are neutral or slightly alkaline. The ability of calcium chloride to absorb water from the air is a function of the relative humidity and ambient temperature. Calcium chloride is more effective in places that have high humidity and low temperatures (Foley *et al.*, 1996). Bolander (1999a) reports that calcium chloride at a temperature of 25°C, for example, starts to absorb water at 29% relative humidity, and at 38°C it starts to absorb water at 20% relative humidity.

Magnesium chloride is created either from seawater evaporation or from industrial by-products prepared from magnesium ammonium chloride hexahydrate in the presence of HCl. It is commercially available as an odorless, colorless liquid. It promotes binding of smaller particles by absorbing moisture from the air (Satterfield and Ono, 1996). It is a more effective salt than calcium chloride because it increases the surface tension and has a harder surface when it is dry (Foley *et al.*, 1996). It has a low freezing point (-34°C) and serves as a de-icing agent. Magnesium chloride needs a minimum of 32 % humidity to absorb water from the air independent of the temperature. It remains more hygroscopic at higher temperature than calcium chloride and is therefore more suitable to dry climates (Langdon and Williamson, 1983). Table 2 summarizes the effectiveness of several salts in minimizing fugitive dust. Compared to water, salts are more effective in controlling dust if sufficient moisture is available. The effectiveness of salts to control dust significantly decreases with time. The dust abatement properties of magnesium chloride have been found to last about 12 weeks (Monlux, 1993). Another problem with salts is that they migrate readily in the environment. DeCastro *et al.* (1996) modeled the movement of road stabilization additives of road surface to determine how long the additives remained effective. They found that calcium and magnesium chlorides are easily carried from the soil.

Table 2 – Effectiveness of salts as dust suppressants.

Suppressant Type	***Effectiveness***	***Reference***
Calcium chloride	Compared to control, retained 55% of the aggregates.	Sanders and Addo, 1993
Magnesium chloride	Compared to control, retained 77% of the aggregates.	Sanders and Addo, 1993
Magnesium chloride sprayed during street sweeping	26% $MgCl_2$ solution reduced dust from 0.05 lb/yd^2 (sprayed with water) to 0.004 lb/yd^2. 60% $MgCl_2$ solution reduced dust from 0.024 lb/yd^2 (sprayed with water) to 0.01 lb/yd^2.	Satterfield and Ono, 1996
Calcium chloride, magnesium chloride, and ligninsulfonate	Application to unpaved roads resulted in reduction of fugitive dust by 50-70% and increased aggregate retention by 42-61%. Under low relative humidity and high temperatures ligninsulfonate was more effective in controlling dust than chloride salts.	Sanders *et al.*, 1997
Petro-tac, Coherex, Soil-Sement Generic Petroleum Resin, and Calcium chloride	Immediately after application, these suppressants are 95% effective in controlling dust particles < 15, 10, and 2.5 μm. Over a 30-day period, effectiveness decreased in some cases as much as 50% and in others as little as 10%.	Muleski and Cowherd, 1987

2.3 Organic Non-Petroleum Products

Organic non-petroleum products include ligninsulfonate, tall (pine) oil, vegetable derivatives, and molasses.

Ligninsulfonate

Ligninsulfonate is derived from the sulfite pulping process in the paper industry where wood is processed using sulfuric acid to break down the wood fiber. Lignin is a complex amorphous aromatic polymer that acts as a binder for the cellulose fibers in wood. It represents 17-33% dry weight of the wood and is resistant to hydrolysis (Kirk *et al.*, 1980). In the wood pulping process, the wood fiber is the valuable product and the pulp liquor, which contains lignin, is wasted. This waste liquor is processed further and neutralized prior to being used as a dust palliative. The available concentrate is usually a mixture of 50% solids to 50% water (Langdon and Williamson, 1983). Ligninsulfonates are light tan to dark brown powder with no pronounced odor. They are also known as Spent Sulfite Liquor (SSL) and are non-hygroscopic products, stable in dry form, relatively stable in aqueous solution, and practically insoluble in all organic solvents. They decompose in temperatures above 200°C (Lewis, 1993). Ligninsulfonates act as a weak cement by binding the soil particles together. They penetrate well into the soil and can be rebladed when wet.

Ligninsulfonates remains effective during long dry periods with low humidity. They also tend to remain plastic, allowing reshaping and traffic compaction when applied to soils with high amounts of clay. The effectiveness of ligninsulfonates may be reduced or completely destroyed in the presence of heavy rain because of the solubility of these products in water (Bolander, 1999a).

Tall (pine) Oil Products

Tall oil is a by-product of the wood pulp industry recovered from pine wood in the sulfate Kraft paper process. It contains rosin, oleic and linoleic acids. Tall oil is used in flotation agents, greases, paint alkyd resins, linoleum, soaps, fungicides, asphalt emulsions, rubber formulations, cutting oils, and sulfonated oils (Merck Index, 1989). Tall oil promotes adherence between soil particles, however, its surface binding actions can be limited or destroyed if this product is exposed to long–term rainfall. Increasing the residual content of tall oil was found to promote an increase in the tensile strength and resistance to periodic wetting or wet freeze of these products (Bolander, 1999a).

Vegetable Oil Derivatives

Vegetable oils are extracts from the seeds, fruit, or nuts of plants and are generally a mixture of glycerides (Lewis, 1993). Some examples of vegetable oils are canola oil, soybean oil, cottonseed oil, and linseed oil. Vegetable oils abate dust by promoting agglomeration of the surface particles.

Molasses

Molasses is the thick liquid left after sucrose has been removed from the mother liquor in sugar manufacturing. It contains approximately 20% sucrose, 20% reducing sugar, 10% ash, 20% organic nonsugar, and 20 % water (Lewis, 1993). This type of dust suppressant provides temporary binding to the surface particles (Bolander, 1999a). Additional applications are necessary during the year, mainly after heavy rains, because molasses will dissolve in water (Addo and Sanders, 1995). Table 3 lists major studies performed on the effectiveness of non-petroleum based products and polymers to abate dust.

2.4 Synthetic Polymer Products

The adhesive property of synthetic polymers promotes the binding of soil particles. In the laboratory, Bolander (1999b) investigated the effect of adding synthetic polymers to dense-graded aggregate. The results show that polymers increased the tensile strength of clays on typical roads and trails up to ten times. Synthetic polymer emulsions did not change the compacted dry density. The tests showed that synthetic polymers applied in wet climates would tend to break down if exposed to moisture or freezing for an increased time.

Table 3 – Effectiveness of non-petroleum based and polymer products as dust suppressants.

Suppressant Type	*Effectiveness*	*Reference*
Sprinkling of 40 ml/m^2/day of canola oil on swine barns	Reduction of dust concentration from 3.8 mg/m^3 to 0.6 mg/m^3 (84% reduction).	Senthilselvan *et al.*, 1997
Lignin used on unpaved roads	Compared to the untreated section, 63% more aggregates were retained.	Sanders and Addo, 1993
Lignsulfonate used to control dust fungi and endotoxins in livestock housing facilities	Mass of dust, fungi, and endotoxins were reduced 6, 4, and 3 fold respectively, when lignosulfonate solutions (27-39%) were applied.	Breum *et al.*, 1999
Synthetic polymer and tall oil	Increased tensile strength of soil. Strength dependent upon curing time.	Bolander, 1999b
Polymer emulsion (PE)	Initial = 94% After 3 months = 96% After 11 months = 38%	Gilles *et al.*, 1997
Polymer Emulsion (PEP)	Initial = 99% After 3 months = 72% After 11 months = 49%	Gilles *et al.*, 1997
Biocatalyst stabilizer (BS)	Initial = 33% - 5% After 11 months = 38%	Gilles *et al.*, 1997

2.5 Organic Petroleum Products

Organic petroleum-based materials consist of products derived from petroleum. These include used oils, solvents, cutback solvents, asphalt emulsions, dust oils, and tars. These products agglomerate fine particles, generally forming a coherent surface that holds the soil particles in place. Petroleum-based products are not water-soluble or prone to evaporation (Travnik, 1991). They generally resist being washed away, but oil is not held tightly by most soils and can be leached away by rain. Langdon and Williamson (1983) divided petroleum based products into different categories: cutbacks (e.g. DO-1, DO-2, DO-3, and DO-6KF), emulsions (e.g. DO-8, Coherex, and CSS-1), and others (e.g. DO-4, DO-6, DO-6P). Table 4 lists studies on the effectiveness of petroleum-based products.

Table 4 – Effectiveness of petroleum-based products as dust suppressants.

Suppressant Type	*Effectiveness*	*Reference*
Oiling (petroleum-based)	50 to 98%	Foley *et al.*, 1996
Water (0.44 gal/yd^2), petroleum resin (0.84 gal/yd^2), and emulsified asphalt (0.71 gal/yd^2).	Suppressants were capable of reducing particulate emissions more than 50% for at least a month. Reapplication of the suppressants was found to increase the lifetime for all suppressants. The lifetime of suppression tended to decrease with decreasing particle size.	Muleski *et al.*, 1983
Emulsion of hydrocarbon-based textile oil applied to bulk-stored wheat, corn, and soybeans	50% reduction (0.04%emulsion) 92% reduction.(0.07% emulsion) Similar results were found when mineral and rapeseed oils were applied.	Jayas *et al.*, 1992
Emulsified petroleum resin, petroleum residue,	In general, an increase in water content during suppressant application will improve the cohesive strength of the aggregates after drying.	Lane et al., 1983
Non-hazardous crude oil (NHCO)	Very effective in suppressing dust for a long period; after11 months= 92%effective	Gilles *et al.*, 1997

2.6 Electro-Chemical Products

These suppressants are usually derived from sulphonated petroleum and highly ionic products. This group of products includes sulphonated oils, enzymes, and ammonium chloride. The electro-chemical stabilizers work by expelling adsorbed water from the soil which decreases air voids and increases compaction (Foley *et al.*, 1996). A disadvantage of these products is the dependence upon the clay mineralogy and therefore they are only effective when specific minerals are present.

2.7 Clay additives

Clay additives are composed of silica oxide tetrahedra (SiO_4) and alumina hydroxide octahedra ($Al(OH)_6$) (Scholen, 1995). This type of dust suppressant agglomerates fine dust particles and increases the strength of the material under dry conditions.

Clay additives provide some tensile strength in warm dry climates, however, increasing the moisture contents promotes loss of their tensile strength (Bolander, 1999b).

2.8 Others

In addition to the categories listed in Table 1, several other suppressants and technologies have been used to abate dust. Foley *et al.* (1996) reported that dust emissions on unpaved roads could be reduced significantly even with small reductions in vehicle speed. Over 40% of the dust was reduced when vehicle speed was decreased from 47 to 31 miles per hour and over 50% was reduced by decreasing vehicle speed from 40 to19 miles per hour. Sealing or paving roads has been shown to reduce dust by

95-100%. Table 5 reports various treatments that have been successfully applied to unpaved roads to reduce dust.

Table 5 – Effectiveness of various treatments used to suppress dust.

Suppressant Type	*Effectiveness*	*Reference*
Sealing or bound paving	95-100%	Foley *et al.*, 1996
Chemical dust suppression	High initial efficiency, but it decays to zero after several months.	Cowherd *et al.*, 1989
Clay additive, chlorides, enzymes, and sulfonate	Increased tensile strength for moisture contents less than 5%.	Bolander, 1999b
Storage piles	95%	Thompson, 1990
Chemical dust suppression	40-98%	Foley *et al.*, 1996
Reduction of vehicle speed:		Foley *et al.*, 1996
from 47 mile/h to 31 mile/h	40-75%	
from 40 mile/h to 19 mile/h	50-85%	

3.0 APPLICATION RATES

3.1 Salts and Brines

Table 6 shows typical application rates for salts and brines used as dust suppressants. Typically, calcium chloride application rates are 1.0-2.0 lb/yd^2 (salt in the flake form) and 0.2-0.35 gal/yd^2 (for 35% solution of salt in water). Magnesium chloride application rates range from 0.3 to 0.5 gal/yd^2 (30% solution in water). Typical application frequency for salts is two times per season.

Table 6 – Application rates and frequencies for salts and brines dust suppressants.

Suppressant	***Application Rate***	***Application Frequency***	***Reference***
Calcium chloride flakes	1.5 lbs/yd^2	--------	Heffner, 1997
35% $CaCl_2$ in water solution	0.3 gal/yd^2	1-2 application/season	Hoover, 1981
Calcium chloride	0.5 gal/yd^2	--------	DeCastro *et al.*, 1996
Calcium chloride	Initial application: Flake: at 0.92-2.0 lb/yd^2 Liquid: 35-38% residual at 0.2-0.35 gal/yd^2 Follow-up: 1/2 to 1/3 of the initial dosage	1-2 applications/season	Bolander, 1999a
Calcium chloride	0.22-0.44 gal/yd^2 depending on traffic frequency.	1-2 applications/year	RTAC, 1987
Calcium chloride	Initial Application: Flake: 1.0–1.5 lb/yd^2 Pellet: 0.8–1.3 lb/yd^2 35% solution: 0.2–0.3 gal/yd^2 Follow-up:1/2 to 2/3 in initial dosage	2 applications/year	Sanders and Addo, 1995
Calcium chloride	Roads – 600 lb/lane-mile. Followed by subsequent applications after three to six weeks.	Heavy traffic roads: Three applications within 2 weeks	Singer *et al.*, 1982
Calcium or magnesium chloride	1.5 lb. Solids/yd. Blading, watering, scarifying, and compacting may be required.	Effective 1 year. Two applications/dry season	Schwendeman, 1981
Magnesium chloride (brine)	0.5 gal/yd^2	--------	Heffner, 1997
Magnesium chloride	0.5 gal/yd^2	--------	DeCastro *et al.*, 1996
Magnesium chloride	Initial application: undiluted–0.5 gal/yd^2 Follow-up: 1/2 of the initial dosage	1–2 treatments/season	Bolander, 1999a
Magnesium chloride	0.33–0.44 gal/yd^2 depending on traffic frequency	1-2 applications/year	RTAC, 1987
Magnesium chloride	Initial Application: 30% solution-0.5 gal/yd^2 Follow-up:1/2 initial dosage	2 applications/year	Sanders and Addo, 1995

3.2 Organic Non-Petroleum Products

Application rates and frequencies for organic non-petroleum products are shown in Table 7. Most of the organic non-petroleum products are applied two times per season and their application rates range from 0.2 to 1.0 gal/yd^2. However, tall oil's application rate is larger, 5.1 gal/yd^2 (50% concentrate diluted 1:4 with water).

Table 7 – Application rates and frequencies of organic non-petroleum dust suppressants.

Suppressant	*Application Rate*	*Application Frequency*	*Reference*
ESI-Duster	0.2 gal/yd^2	--------	Langdon and Williamson, 1983
Ligninsulfonate	1.5 gal/yd^2	1-2 applications/season	Hoover, 1981
Ligninsulfonate	0.5 gal/yd^2	--------	Bolander, 1999a
Organic non-petroleum (Lignin derivatives)	Typical application – 50% residual concentrate applied undiluted at 0.5 gal/yd^2 Powered form: 2.2 lb. To 222 gallons of water.	1-2 applications/season	Bolander, 1999a
Organic non-petroleum (Tall oil derivatives)	Typical application is 40-50% residual concentrate applied diluted 1:4 w/water at 5.1 gal/yd^2	1 every few years	Bolander, 1999a
Organic non-petroleum (Vegetable oils)	Typically 0.24-0.5 gal/yd^2	1 application/season	Bolander, 1999a
Ligninsulfonates	0.2-0.35 gal/yd^2 depending on traffic frequency	1-2 applications/year	RTAC, 1987
Ligninsulfonate	0.2 – 0.5 gal/yd^2	--------	Langdon and Williamson, 1983
Lignin derivatives	10 to 25% solution: 0.5–1.0 gal/yd^2 Powder: 1.0–2.0 lb/yd^2	1-2 applications/year	Sanders and Addo, 1995
Ligninsulfonate	2.5 lb. solids/yd. Road surface mixing, blading, watering, scarifying, and compacting are required.	Effective for about 10 months. Two applications per dry season	Schwendeman, 1981

3.3 Organic Petroleum Products

The application rates and frequency of organic petroleum products are depicted in Table 8. For surface treatments, rates between 0.2-1.5 gal/yd^2 are generally used. Organic petroleum products are typically applied 1-2 times per season.

Table 8 – Application rates and frequencies of organic petroleum-based dust suppressants.

Suppressant	*Application rate*	*Application Frequency*	*Reference*
Arcadias (DO-1, 2, 3), DO-4, DO-6PA, DO-8, CSS-1 (emulsion)	0.2 – 0.5 gal/yd^2	--------	Langdon and Williamson, 1983
Coherex	1-1.5 gal/yd^2	--------	Langdon and Williamson, 1983
Coherex	0.5-1.5 gal/yd^2	--------	Hoover, 1981
Oils	0.25 gal/yd^2	1 application/year	Hoover, 1981
CSS-1	A 9:1 water dilution of emulsion, sprayed at the rate of 0.1-0.15 gal/yd^2 and then bladed. After blading, a 3:1 water dilution of the emulsion should be applied at the same rate.	--------	Hoover, 1981
Organic Petroleum Products	Initial Application: 0.11-1.0 gal/yd^2 depending on road surface condition. Follow-up: Reduced application from the initial.	1–2 treatments/season	Bolander, 1999a
Organic Binders application rate	Liquid: 0.5 gal/yd^2 Dry powder: 1-2 lb/yd^2	--------	Hoover, 1981
Petroleum products	0.13-0.44 gal/yd^2 depending on traffic frequency.	1-2 applications/year	RTAC, 1987
Petroleum-based products	0.3 gal/yd. Road surface mixing. Blading, watering, and scarifying may be required.	Effective for 14 months. One application per dry season.	Schwendeman, 1981

3.4 Synthetic Polymer, Clay additives, and Others

Table 9 presents application rates used for synthetic polymers, clay additives, and other dust suppressants. Application rates for synthetic polymers vary significantly and are dependent upon the type of polymer used. However, polymers require a lower application frequency than that of petroleum-based, salts, and non-petroleum based products. Clay additives are applied at 1-3% by dry weight of the soil to which they are mixed. The suppressing effect of clays is long lasting and they are generally applied at extremely low frequencies (once every five years). Water application rate and frequency will depend mainly upon temperature and humidity. In general, water has to be applied frequently.

Table 9 – Application rates and frequencies of dust suppressants.

Suppressant	*Application Rate*	*Application Frequency*	*Reference*
Polybind Acrylic (co-polymer resin emulsion)	40 gal/acre of a 1:20 water dilution.	--------	Hoover, 1981
Synthetic polymer derivatives	Typical application: 40-50% residual concentrate applied diluted 1:9 w/water at a rate of 0.50 gal/yd^2.	Once every few years	Bolander, 1999a
Clay additives	Typical application rate is 1-3% by dry weight.	Once every 5 years	Bolander, 1999a
Water	0.5-4% water applied to conveyor belt systems.	As often as needed	Goldbeck, 1997
Bituminous and tars or resinous adhesives	0.1–1.0 gal/yd^2 depending on road surface condition and dilution.	1-2 applications/year	Sanders and Addo, 1995

4.0 ENVIRONMENTAL IMPACTS

4.1 Salts and Brines

The environmental impacts of salts and brines are summarized in Table 10. Disadvantages of calcium chloride include corrosion of vehicles and concrete and creation of a slippery surfaces when wet.

Calcium chloride is a highly soluble and it is capable of moving with water through soil as a leachate contaminating groundwater. Calcium chloride can also move as runoff and the dissociated calcium and chloride ions can drain into lakes, rivers, streams, and ponds. High concentrations of calcium chloride cause high soil salinity and may be toxic to plants. However, no conclusive studies have been performed to evaluate the effects of calcium chloride on plants. Salts concentrations greater than 400 ppm have been found to be toxic to trout. Concentrations greater than 1,830 mg/L killed Daphnia and crustaceans fish.

Table 10 – Environmental and human health impacts of salt and brine dust suppressants.

Suppressant	***Environmental and Human Health Impacts***	***References***
Saline water	--------	RTAC, 1987
Salts ($CaCl_2$, $NaCl_2$)	• Streams exhibited elevated chloride concentrations (about 31 times higher than upstream samples) at sampling stations located 50 and 100m downstream from the highway where salt was applied. Elevated chloride concentration continued after the end of winter salt application.	Demers and Sage, 1990
Salts ($CaCl_2$, $MgCl_2$)	• $CaCl_2$ and $MgCl_2$ are highly soluble and move through the soil w/water. Movement depends upon application rate and rainfall frequency. During wet periods, the salts move deeper into soils; during periods of evaporation they move toward the surface. Lateral movement of $CaCl_2$ and $MgCl_2$ occur, but at a smaller rate. • In areas of shallow groundwater (<25 ft) chloride could move through the soil and reach the groundwater.	Heffner, 1997
Salts ($CaCl_2$, $MgCl_2$, and NaCl)	• Affect plant growth by increasing osmotic pressure of the soil solution, altering plant's nutrition, and accumulating specific ions to toxic concentrations in plants. • 920 mg/L-Immobilized Daphnia • 1,830 mg/L-Killed Daphnia and other crustacean fish within 2 days. • $CaCl_2$ can affect water taste in concentrations ranging from 200-900 mg/L • NaCl can affect water taste in concentrations ranging from 150-350 mg/L	Sanders and Addo, 1993
Salts ($CaCl_2$, $MgCl_2$, and NaCl)	• $MgCl_2$ can irritate skin tissue with direct contact. • High salts concentrations can affect plant growth and increase the risk of vehicle corrosion. • Water quality: impacts generally negligible if proper buffer zone exists between treated area and water. • Fresh water aquatic impact: may develop at chloride concentrations as low as 400 ppm for trout and up to 10,000ppm for other fish species. • Plant: some species susceptible (pine, hemlock, poplar, ash, spruce, maple).	Foley *et al.*, 1996

Table 10 – Environmental and human health impacts of salt and brine dust suppressants (continued).

Suppressant	***Environmental and Human Health Impacts***	***References***
Chloride	• Pike, bass, and perch, experience harmful effects at chloride concentrations greater than 4, 000 ppm. Trout may begin to experience harmful effects at chloride concentrations exceeding 400 ppm. Chloride concentrations greater than 10, 000 ppm, for several days, negatively affect most fresh water aquatic organims.	Golden, 1991
Calcium Chloride	• Toxic to fruit trees • Washes away in heavy rain • Cause injury to skin and eyes with direct contact.	RTAC, 1987
Deicing Salts (NaCl, $CaCl_2$)	• Honey Locust deciduous tree, privet and honeysuckle deciduous shrubs, juniper evergreens, and Kentucky 31 tall fescue grass are resistant to quite heavy applications of deicing salts. Tulip poplar, green ash, rose, spirea, hemlock, and Kentucky bluegrass are less tolerance to salt. Deicing salts affect the physiology and growth of plants by changing soil solutions.	Hanes *et al.*, 1976, Hanes *et al.*, 1970
Chlorides and nitrates of various metals	• Toxicity threshold concentrations to fish and *Daphnia magna* vary with metal types, with sodium chloride being the least toxic (3,680 ppm) followed by calcium (920 ppm), magnesium (740 ppm), and potassium (432 ppm) chloride, the most toxic of the four salts. Gold fish (*Carassius auratus*) were not harmed by 5,000 ppm sodium chloride. In general, nitrates salts are more toxic than chloride salts. Crustaceans tolerate much less calcium chloride than fish do. Golden shiners (*Notemigonus crysoleucas*), a fish, were found to die at 5,000 ppm calcium chloride concentrations.	Anderson, 1984

4.2 Organic Non-Petroleum Products

The toxicity of ligninsulfonates to rainbow trout has been investigated. The 48-hour LC_{50} (concentration of ligninsulfonates which would be lethal to 50 percent of the tested population within 48 hours) value for ligninsulfonates was found to be 7,300 mg/L. A mortality of 50% was achieved for rainbow trout exposed to 2,500 mg/L ligninsulfonate for 275 hours. For concentrations equal to or higher than 2,500 mg/L rainbow trout showed loss of reaction to unexpected movements, rapid and irregular breathing, and finally loss of coordination before death. It has been found that calcium and sodium ligninsulfonate negatively affect the colon of guinea-pigs causing weight gain and producing ulceration in those animals. Reduced biological activity has been observed in water due to excessive discoloration caused by the introduction of ligninsulfonates. Ligninsulfonate compounds were reported not to prevent seed germination in the areas where it was applied. It has been suggested that ligninsulfonate is the most environmentally compatible dust suppressant (Schwendeman, 1981). Table 11 summarizes the environmental and human health impacts of non-petroleum based dust suppressants.

Table11 – Environmental and human health impacts of non-petroleum based dust suppressants.

Suppressant	***Environmental and Human Health Impacts***	***References***
Lignin	• Lignin discharged to a water body has a high coloring effect and introduces a large amount of organics. In an experiment performed over a period of 100 days less than 50% of the lignin present was oxidizable.	Raabe, 1968
Ligninsulfonate	• Increased biochemical oxygen demand and reduced light penetration in receiving waters because of the light yellow tint ligninsulfonate imparts to the water. • Excessive foaming and discoloration of receiving water bodies when ligninsulfonate is introduced. Fish have high tolerance for ligninsulfonate. • Ligninsulfonates have been shown to be toxic to rainbow trout. The LC_{50} at 48 hours was determined to be 7,500 ppm. Retarded effect on rainbow trout growth was observed at concentrations as low as 160 mg/L. • Biota living in lower portion of the water body is likely to be in greater risk because of increased oxygen demand.	Heffner, 1997
Ligninsulfonate	• Exposure of rainbow trout (salmo gairdneri) to sublethal concentrations of ligninsulfonate shows that at concentrations of 160 ppm and higher, the growth rates were lower. Higher ligninsulfonate concentrations had the most retarding effect on trout growth. No difference in quantitative and qualitative composition of the intestinal flora was observed in the groups that had different concentrations of ligninsulfonate. The activities of proteinases and nucleases were significantly impaired in fish exposed to concentrations of 1,280 ppm ligninsulfonate or higher, and those of amylases at concentrations of 320 ppm LS and higher.	Roald, 1977a
Ligninsulfonate	• The 48-hour LC_{50} found to be 7,300 ppm for rainbow trout. Exposure of rainbow trout to 2,500 ppm for 275 hours caused the death of 50% of the fish. Before dying these fish showed illness signs such as loss of reaction to sudden movements, fish swam close to the water surface, and rapid and irregular breathing. Fish lost coordination and kept lying on their sides for hours before dying..	Roald, 1977b

Table11 – Environmental and human health impacts of non-petroleum based dust suppressants (continued).

Suppressant	***Environmental and Human Health Impacts***	***References***
Ligninsulfonate	• Moderately toxic to rainbow trout • Slow biodegradation. It persists in the environment.	RTAC, 1987
Ligninsulfonate	• Receiving waters presented excessive foaming and discoloration, which is responsible for reducing the biological activity in the polluted water. • Does not prevent seed germination. • Contributes to long term oxygen demand.	Singer *et al.*, 1982
Ligninsulfonate	• Mass spill may de-oxygenate the water.	Foley *et al.*, 1996
Sodium Ligninsulfonate	• Four groups of guinea-pigs were given ligninsulfonate in concentrations varying from 10-40 g/L. In groups receiving ligninsulfonate the animals gained less weight than in the control group. Multiple focal ulcers were found mainly in the Caecum (large bowel). Ulceration incidence was found in two out of eight, two out of four, and four out of four animals that received 10 g/l, 20 g/l, and 40 g/l respectively.	Watt and Marcus, 1974
Sodium, calcium, and magnesium ligninsulfonate	• Guinea-pigs were fed with the same diet. During 8 weeks three groups of eight animals received 40 g/l of sodium, calcium and magnesium ligninsulfonate aqueous fluid, and one group received water without ligninsulfonate. Animals that took fluid containing magnesium ligninsulfonate showed less weight gain interference and no ulceration on the colon.	Watt and Marcus, 1976
Organic non-petroleum (lignin derivatives)	• High BOD that may be leached out and reach water bodies located close to the application area.	Bolander, 1999
Organic non-petroleum (Vegetable oils)	• Impacts on water quality, aquatic life, and plants are not well understood.	Bolander, 1999

4.3 Organic Petroleum Products

Organic petroleum based products are considered long lasting products for dust suppression. However, since some of them are oil waste, their environmental impacts may be high. Waste oil used as dust suppressant is typically associated with contaminants that are known to be either toxic or carcinogenic. The accidental introduction of a petroleum based dust suppressant (Coherex) into a stream in Southern Pennsylvania was found to affect fish and benthic macroinvertebrate communities and to kill an unknown number of fish. Organic petroleum-based products have also been found to be toxic to avian Mallard eggs. When the eggs were exposed to a concentration of 0.5 μL/egg of the product 60% mortality was observed by 18 days of development. Table 12 summarizes the environmental and human health impacts of organic petroleum-based dust suppressants.

Table 12 – Environmental and human health impacts of petroleum-based dust suppressants.

Suppressant	***Environmental and Human Health Impacts***	***References***
Petroleum products Used and waste oil	• The USEPA prohibits the use of waste or used oil or other materials which are contaminated or mixed with dioxins or any other hazardous waste as identified in the Hazardous Waste Amendments of 1984 (HSWA) for dust suppressants. Several studies in the mid 1980's showed that waste oils contained known toxic or carcinogenic compounds.	RTAC, 1987 Metzler, 1985 USEPA, 1984
Petroleum based binders	• One liter of hydrocarbon solution can contaminate 1,600 liters of groundwater. • Tars are carcinogenic. • Bunker oil contains toxic hydrocarbons. • Recycled oil waste carry environmental risk due to the presence of heavy metals and PCBs.	Foley *et al.*, 1996
RDCO (Clarifite;DO-4) Chevron oil product	• Exposure of avian Mallard eggs to DO-4 concentrations as little as 0.5 μL/egg resulted in a mortality of 60% of the embryos by 18 days of development. Egg exposure to mineral pigment, scouring, tannery, and methyl mercury chloride industrial effluents showed no toxicity to the same avian eggs.	Hoffman and Eastin, 1981
Coherex (petroleum resin)	• Coherex was spilled in and around a stream in Pennsylvania in 1987. The concentrations of the product were 2,320 mg/kg in day one, 3,550 mg/Kg in day 2, and 385 mg/Kg in day 59. A rainfall during days 3 and 10 flushed the stream and lowered the Coherex concentration causing damage to fish and microinvertebrate communities. 432 fish, 36 larval two-lined salamanders and 1 adult American toad were found dead and collected from day 0 to day 1. However, the stream reestablishment occurred 10 days after the spill due to similar unaffected upstream populations that repopulated the stream.	Ettinger, 1987
Organic petroleum products	• In general, these products are toxic. • Concerns with spills and leaching before the curing.	Foley *et al.*, 1996

4.4 Electro-Chemical Product

Electro-chemical products are thought to have minimum impact in the environment when used in their diluted form. However, it has been observed that vegetation could not be established in areas treated with sulfonated petroleum products (Foley *et al.*, 1996).

5.0 COSTS

Reported costs for dust suppressants and dust suppressant application are shown in Table 13. It is difficult to compare application costs of dust suppressants because of the different materials and dilution ratios used. In general, bulk ligninsulfonate is about five times less expensive than Arcadias, Coherex, and CSS-1. The reported cost per acre for dust suppressant application reveals a wide range for different products used. In general, Chlortex (magnesium chloride) is the least expensive dust suppressant followed by ligninsulfonate, Pennzsuppress D (petroleum resin), and Plastex (paper mulch + gypsum binder).

Table13 – Reported dust suppressant costs.

Suppressants	***Bulk Product Cost***	***Reference***
Calcium Chloride	$114.00/ton-$273.00/ton $195 per dry ton	Langdon *et al.*, 1983 Hoover, 1981
Magnesium chloride	$67.00/ton-182 gal/ton	Langdon *et al.*, 1983
Ligninsulfonate	$40.00/ton	Langdon *et al.*, 1983
Arcadia DO-1	$210.00/ton	Langdon *et al.*, 1983
Arcadia DO-2	$210.00/ton	Langdon *et al.*, 1983
Arcadia DO-4	$175.00/ton	Langdon *et al.*, 1983
Arcadia DO-6KF	$215.00/ton	Langdon. *et al.*, 1983
Arcadia DO-6PA	$152.75/ton	Langdon *et al.*, 1983
Arcadia DO-8	$150.00/ton	Langdon *et al.*, 1983
Coherex (concentrate)	$285.60/ton	Langdon *et al.*, 1983
CSS-1	$150.00/ton	Langdon. *et al.*, 1983

Suppressants	***$ Cost / acre***	***Reference***
Chlorides	$283-$2,023/ acre	Foley *et al.*, 1996
Calcium chloride cost/mile at a 21-ft width and 2 lb/yd^2	£165	Hoover, 1981
Chlortex ($MgCl_2$)	$600/acre	James *et al.*, 1999
ESI-Duster	$9800 (bag of 50 lbs)	Langdon *et al.*, 1983
Dustac (Ligninsulfonate)	$750/acre	James *et al.*, 1999
Ligninsulfonate cost/mile length and 21-ft width	£350 ($800-$900)	Hoover, 1981
Organic Binders	$1011-$24282/acre	Foley *et al.*, 1996
Petroleum Binder	$2023-$5261/acre	Foley *et al.*, 1996
PennzsuppressD (petroleum resin)	$800/acre	James *et al.*, 1999
Surfactants	< $1619/acre	Foley *et al.*, 1996
Polymeric Binders	$6475/acre	Foley *et al.*, 1996
Polytex (acrylic polymer emulsion)	$700/acre	James *et al.*, 1999
Soil-Sement (acrylic polymer emulsion)	$1050/acre	James *et al.*, 1999
Plastex (paper mulch + gypsum binder)	$850/acre	James *et al.*, 1999
Hydroseed (wood fiber mulch + brome seed)	$1,200/acre	James *et al.*, 1999
Recycled Aggregate	$13,500/acre	James *et al.*, 1999
Ionic Stabilizers	$1,214-$4,047/acre	Foley *et al.*, 1996
Microbiological Binders	$3,642/acre	Foley *et al.*, 1996

6.0 REFERENCES

Addo, J. and Sanders, T., 1995. *Effectiveness and Environmental Impact of Road Dust Suppressants*, Mountain-Plains Consortium, Colorado State University, MPC Report No. 92-28A.

Anderson, B.G., 1984. *The Apparent Thresholds of Toxicity of Daphnia magna for Chlorides of Various Metals When Added to Lake Erie Water,* American Fisheries Society, Vol. 78, pp 96-113

Bolander, 1999a. *Dust Palliative Selection Application Guide,* United States Department of Agriculture.

Bolander, P., 1999b. *Laboratory Testing of Nontraditional Additives for Stabilization of Roads and Trail Surfaces,* Transportation Research Board, Proceedings from the Seventh International Conference on Low-Volume Roads, Transportation Research Record N° 1652, Volume 2, Washington, DC.

Breum, N.O., Nielsen, B.H., Lyngbye, M., 1999. *Dustiness of Chopped Straw as Affected by Ligninsulfonate as a Dust Suppressant,* Annals of Agriculture and Environmental Medicine: AAEM, Vol. 6, N°2, pp 133-140.

Cal/EPA, 2001. *Evaluation of the Pennzoil-Quaker State Company's PennzSuppress D Dust Suppressant,* California Environmental Protection Agency – Environmental Technology Certification Program, certificate N°.00-08-001.

Cowherd, C.Jr, Elmore, W.L., Durkee, K.R., 1989. *Potential Regulatory Approaches for the Control of Pm-10 Emissions From Urban Dust Sources*, Air and Waste Management Association Meeting. In: Proceedings of the 82nd Annual Meeting and Exhibition, from June 25-30, Vol. 3, Anaheim, California.

DeCastro, A., T.V. Edgar, D.H. Foster, and A.P. Boresi, 1996. *Physical and Chemical Stability of Admixtures in Unpaved Road Soils.* North Dakota State University, Bismarck, North Dakota.

Demers, C.L., Sage Jr., RW., 1990. *Effects of Road De-icing Salt on Chloride Levels in Four Adirondack Streams,* Water, Air, and Soil Pollution, Vol.49, pp 369-373.

DGRM - Dirt and Gravel Roads Maintenance Program, Pennsylvania, 2000. Center for Dirt and Gravel Road Studies, Penn State University.

Environmental Canada, http://www.etvcanada.com/English/e_home.htm, ETV Canada Inc.

Ettinger, W. S., 1987. *Impacts of a Chemical Dust Suppressant/ Soil Stabilizer on the Physical and Biological Characteristics of a Stream*, Journal of Soil and water

Conservation, Vol. 42, N° 2, pp 111-114.

ETV/USEPA, 2001. *Generic Verification Protocol for Dust Suppression and Soil Stabilization Products*, ETV Joint Verification Statement – The Environmental Technology Verification Program – Research Triangle Institute.

Foley, G., Cropley, S., and Giummara, G., 1996. *Road Dust Control Techniques – Evaluation of Chemical Dust Suppressant's Performance*, ARRB Transport Research Ltd., Special Report 54, Victoria, Australia.

Gebhart, D.L., Denight, M.L., Grau, R.H., 1999. *Dust Control Guidance and Technology Selection Key*. U.S. Army environmental Center – U.S. Army Corps of Engineering, AEC Report N° SFIM-AEC-EQ-CR-99002.

Gilles, J.A., Watson, J.G., Rogers, C.F., Chow, H.C., 1997. *PM10 Emissions and Dust Suppressants Efficiencies on an Unpaved Road, Merced County, CA*. In: Proceedings of the Air and Waste Management Association's 90th Annual Meeting and Exhibition, June 8-13, Toronto, Ontario, Canada.

Gillies, J. A., Watson, J. G., Rogers, C. F., DuBois, D., Chow, J. C., Langston, R., Sweet, J., 1999, *Long-term Efficiencies of Dust Suppressants to Reduce PM10 Emissions from Unpaved Roads*, Journal of the Air and Waste Management Association, Vol. 49.

Goldbeck, L.J., 1997. *Improving Plant Competitiveness Through Conveyor Dust Control Technologies*. In: Proceedings of the 59th Annual American Power Conference (Part 2), Volume 59-II, Chicago, Illinois, pp 600-605.

Golden, B.J., 1991. *Impact of Magnesium Chloride Dust Control Product on the Environment,* In: Proceedings of the Transportation Association of Canada Annual Conference, Volume 1, Winnipeg, Manitoba.

Hanes, R.E., Zelanzny, L.W., and Blaser, R.E., 1970. *Effects of Deicing Salts on Water Quality and Biota.* National Cooperative Highway Research Program, Report N°91.

Hanes, R.E., Zelanzny, L.W., Verghese, K.G., Bosshart, R.P., Carson, E.W.Jr., Wolf, D.D., 1976. *Effects of Deicing Salts on Plant Biota and Soil.* National Cooperative Highway Research Program, Report N°170.

Heffner, K., 1997, *Water Quality Effects of Three Dust-Abatement Compounds*, Washington Forest Service, United States Department of Agriculture.

Hoffman, D.J., Eastin, W.C., 1981. *Effects of Industrial Effluents, Heavy Metals, and*

Organic Solvents on Mallard Embryo Development, Toxicology Letters, Volume 9, N°1, pp 35-40.

Hoover, J.M., 1981. *Mission-Oriented Dust Control and Surface Improvement Processes for Unpaved Roads,* Final Report, Iowa Highway Research Board Project, H-194.

Interim Guidelines on Dust Palliative Use in Clark County, 2001. State of Nevada, Department of Conservation and Natural Resources – Division of Environmental Protection.

Jayas, D.S., White, N.D.G., Britton, M.G., 1992. *Effect of Oil Used for Dust Control on Engineering Properties of Stored Wheat,* American Society of Agricultural Engineers, Vol. 35, N°2, pp 659-664.

Kestner, M., 1989. *Using Dust Suppressants to Control dust Emissions – Part 1,* Powder and Bulk Engineering, Vol. 3, N°2.

Kimball, C.E., 1997. *Evaluating Groundwater Pollution Susceptibility of Dust Suppressants and Roadbed Stabilizers: Case Study of a Petroleum-based Product.* Transportation Research Record 1589, 64-49.

Kirk, T.K., Higuchi, T., Chang, H., 1980, *Lignin Biodegradation: Microbiology, Chemistry, and Potential Applications*, Volumes I and II, CRC Press, Inc., Boca Raton, Florida.

Kuula-Väisänen, P., Järvinen, H.L., Nieminen, P., 1995. *Calcium Chloride in Road Construction.* In: Sixth International Conference on Low-Volume Roads, Minneapolis, Minnesota, June 25-29, 1995, Conference Proceedings N°6, Vol. 2, PP 225-233 (Transportation Research Board: Washington, DC).

Lane, D.D., Baxter, T.E., Cuscino, T., and Cowherd, C.Jr., 2001. *Use of Laboratory Methods to Quantify Dust Suppressant Effectiveness,* Society of Mining Engineers of AIME, Vol. 274.

Langdon, B., Williamson, R.K., 1983. *Dust Abatement Material: Validation and Selection,* Transportation Research Record 898, pp 250-257.

Lewis, R.J., 1993, *Hawley's Condensed Chemical Dictionary,* Twelfth edition.

MDEQ Michigan Department of Environmental Quality, 2000. Waste Management Division. Groundwater Discharge General Permit – 221500-5.
www.deq.state.mi.us/documents/deq-wmd-gwp-Rule2215OilFieldBrine-1.pdf

Merck Index, 1989, *The Merck Index*, Eleventh Edition, Merck & Co., Inc., Rahway, New Jersey, USA.

Metzler, S. C., Jarvis, C., 1985. *Effects of Waste Oil Contamination*, Environmental Progress, Vol. 4, Issue1, pp 61-65.

Monlux, S., 1993. *Dust Abatement Product Comparison in the Northern Region*, Engineering Field Notes, USDA Forest Service, Vol. 25.

Muleski, G. E., Cowherd, C., 1987, *Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads*, Document Nº EPA-600/2-87-102, Air and Engineering Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Muleski, G.E., Cuscino, T.A. Jr, Cowherd, C.Jr., 1983. *Definition on the Long-term Control Efficiency of Chemical Dust Suppressants Applied to Unpaved Roads.* In: Proceedings of the Air pollution Association 76th APCA Annual Meeting, June 19-24, Atlanta, Georgia.

NDEP – Nevada Department of Environmental Protection, 2001. *Interim Guidelines on Dust Palliative Use in Clark County.* State of Nevada, Department of Conservation and Natural Resources – Division of Environmental Protection.

Raabe, E.W., 1968. *Biochemical Oxygen Demand and Degradation of Lignin in Natural Waters*, Journal Water Pollution Control Federation, Vol. 40, pp R145-R150.

Roald, S.O., 1977a. *Effects of Sublethal Concentrations of Lignosulfonates on Growth , Intestinal Flora and some Digestive Enzymes in Rainbow Trou*t, Aquaculture, Vol.12, pp 327-335.

Roald, S.O., 1977b. *Acute Toxicity of Ligninsulfonates on Rainbow Trout*, Bulletin of Environmental Contamination and Toxicology, Vol.17, Nº6, Springer-Verlag, New York Inc.

RTAC, Road and Transportation Association of Canada, 1987, *Guidelines for Cost Effective Use and Application of Dust Palliatives.*

Sanders, T.G., Addo, J.Q., Ariniello, A., and Heiden, W.F., 1997. *Relative Effectiveness of Road Dust Suppressants*, Journal of Transportation Engineering, Vol.123, Nº5.

Sanders, T.G., and J.Q. Addo, 1993. *Effectiveness and Environmental Impact of Road Dust Suppressants,* Mountain-Plains Consortium, North Dakota State University.

Satterfield, C.G., Ono, D., 1996, *Using Magnesium Chloride in Street Sweepers to*

Control PM-10 Emissions from Winter-Time Sanding of Roadways, Air and Waste Management Association, In: Proceedings of the 89th Annual Meeting and Exhibition, June 23-28, Nashville, Tennessee.

Scholen, D.E., 1995. *Stabilizer Mechanisms in Nonstandard Stabilizers*, In: Sixth International Conference on Low-Volume Roads, Minneapolis, Minnesota, June 25-29, Conference Proceedings N°6, Vol. 2, PP 252-260 (Transportation Research Board: Washington, DC)

Schwendeman, T.G., 1981. *Dust Palliative Evaluation – Part II.* USDA Forest Service, Gallatin National Forest

Senthilselvan, A., Zhang, Y., Dosman, J.A., Barber, E.M., 1997. *Positive Human Health Effects of Dust Suppressants with Canola Oil in Swine Barns,* American Journal of respiratory and Critical care Medicine, Vol. 156, pp 410-417.

Singer, R.D., Stevens, J.R., Gleason, J.R., Baker, D.A., Baker, T.M., and McEmber, A.V., 1982. *An Environmental Evaluation of Dust Suppressants: Calcium Chloride and Ligninsulfonate.* United States Department of Interior Bureau of Mines.

Thompson, G.L., 1990, *Dust Suppression Systems for Controlling Dust from Coal Handling Systems in Power Plants,* Fuel Strategies Coal Supply, Dust Control, and Byproducts Utilization, The 1990 International Joint Power Generation Conference Boston, Massachusetts, The American Society of Mechanical Engineers, Volume 8.

Travnik, W.A., 1991. *State of Art Dust Suppressants/Soil Stabilizers*, In: Proceedings of the 42nd Annual Road Builders' Clinic, March 5-7, Coeur D'Alene, Idaho, pp. 39-61

USEPA, 1984. *Hazardous and Solids waste amendments of 1984 (HSWA)*, Section 213 Amended Section 3004 of RCRA – Ban the use of hazardous waste and materials mixed with hazardous waste as dust suppressants.

USEPA, 2002. *Air Trends 1995 Summary-* http://www.epa.gov/oar/aqtrnd95/pm10.html

Watt, J. and Marcus, R., 1974. *Effect of Ligninsulfonate on the Colon of Guinea-pigs*, Proceedings of the Nutrition Society, Vol. 33, pp 65A-66A.

Watt, J. and Marcus, R., 1976. *Effect of Various Salts of ligninsulfonate on the colon of Guinea-pigs*, Proceedings of the Nutrition Society, Vol. 35, pp 76A.

APPENDIX B: WATER QUALITY STANDARDS

Table B.1 - Nevada Water Quality Criteria for Toxic Materials (NAC 445A.144)

Chemical	*Munic. or Dom. Supply (µg/l)*	*Aquatic life (µg/l)*	*Irrigation (µg/l)*	*Watering of Livestock (µg/l)*
Antimony	146	-	-	-
Arsenic	50	-	100	200
Arsenic (III)	-	-	-	-
1-Hour Aver.	-	342	-	-
96-Hour Aver.	-	180	-	-
Barium	2,000	-	-	-
Beryllium	0	-	100	-
Hardness <75 mg/l	-	-	-	-
Hardness >=75 mg/l	-	-	-	-
Boron	-	-	750	5,000
Cadmium	5	-	10	50
1-Hour Aver.	-	$0.85\ \exp\{1.128\ln(H)-3.828\}$	-	-
96-Hour Aver.	-	$0.85\ \exp\{0.7852\ln(H)-3.490\}$	-	-
Chromium (total)	100	-	100	1,000
Chromium (VI)	-	-	-	-
1-Hour Aver.	-	15	-	-
96-Hour Aver.	-	10	-	-
Chromium (III)	-	-	-	-
1-Hour Aver.	-	$0.85\ \exp\{0.8190\ln(H)+3.688\}$	-	-
96-Hour Aver.	-	$0.85\ \exp\{0.8190\ln(H)+1.561\}$	-	-
Copper	-	-	200	500
1-Hour Aver.	-	$0.85\ \exp\{0.9422\ln(H)-1.464\}$	-	-
96-Hour Aver.	-	$0.85\ \exp\{0.8545\ln(H)-1.465\}$	-	-
Cyanide	200	-	-	-
1-Hour Aver.	-	22	-	-
96-Hour Aver.	-	5.2	-	-
Fluoride	-	-	1,000	2,000
Iron	-	1,000	5,000	-
Lead	50	-	5,000	100
1-Hour Aver.	-	$0.50\ \exp\{1.273\ln(H)-1.460\}$	-	-
96-Hour Aver.	-	$0.25\ \exp\{1.273\ln(H)-4.705\}$	-	-

Table B.1 - Nevada Water Quality Criteria for Toxic Materials (NAC 445A.144) (Continued)

Chemical	*Munic. or Dom. Supply (μg/l)*	*Aquatic life(μg/l)*	*Irrigation(μg/l)*	*Watering of Livestock (μg/l)*
Manganese	-	-	200	-
Mercury	2	-	-	10
1-Hour Aver.	-	2	-	-
96-Hour Aver.	-	0.012	-	-
Molybdenum	-	19	-	-
Nickel	13.4	-	200	-
1-Hour Aver.	-	$0.85 \exp\{0.8460\ln(H)+3.3612\}$	-	-
96-Hour Aver.	-	$0.85 \exp\{0.8460\ln(H)+1.1645\}$	-	-
Selenium	50	-	20	50
1-Hour Aver.	-	20	-	-
96-Hour Aver.	-	5	-	-
Silver	-	$0.85 \exp\{1.72\ln(H)-6.52\}$	-	-
Sulfide				
undissociated hydrogen sulfide	-	2	-	-
Thallium	13	-	-	-
Zinc	-	-	2,000	25,000
1-Hour Aver.	-	$0.85 \exp\{0.8473\ln(H)+0.8604\}$	-	-
96-Hour Aver.	-	$0.85 \exp\{0.8473\ln(H)+0.7614\}$	-	-
Acrolein	320	-	-	-
Aldrin	0	3	-	-
Chlordane	0	2.4	-	-
24-Hour Aver.	-	0.0043	-	-
2,4-D	100	-	-	-
DDT & Metabolites	0	1.1	-	-
24-Hour Aver.	-	0.001	-	-
Demeton	-	0.1	-	-
Dieldrin	0	2.5	-	-
24-Hour Aver.	-	0.0019	-	-
Endosulfan	75	0.22	-	-
24-Hour Aver.	-	0.056	-	-

Table B.1 - Nevada Water Quality Criteria for Toxic Materials (NAC 445A.144) (Continued)

Chemical	*Munic. or Dom. Supply (μg/l)*	*Aquatic life (μg/l)*	*Irrigation (μg/l)*	*Watering of Livestock (μg/l)*
Endrin	0.2	0.18	-	-
24-Hour Aver.	-	0.0023	-	-
Guthion	-	0.01	-	-
Heptachlor	-	0.52	-	-
24-Hour Aver.	-	0.0038	-	-
Lindane	4	2	-	-
24-Hour Aver.	-	0.08	-	-
Malathion	-	0.1	-	-
Methoxychlor	100	0.03	-	-
Mirex	0	0.001	-	-
Parathion	-	-	-	-
1-Hour Aver.	-	0.065	-	-
96-Hour Aver.	-	0.013	-	-
Silvex (2,4,5-TP)	10	-	-	-
Toxaphene	5	-	-	-
1-Hour Aver.	-	0.73	-	-
96-Hour Aver.	-	0.0002	-	-
Benzene	5	-	-	-
Monochlorobenzene	488	-	-	-
m-dichlorobenzene	400	-	-	-
o-dichlorobenzene	400	-	-	-
p-dichlorobenzene	75	-	-	-
Ethylbenzene	1,400	-	-	-
Nitrobenzene	19,800	-	-	-
1,2-Dichloroethane	5	-	-	-
1,1,1-Trichloroethane (TCA)	200	-	-	-
Bis (2-chloroisopropyl) Ether	34.7	-	-	-
Chloroethylene (Vinyl Chloride)	2	-	-	-
1,1-Dichloroethylene	7	-	-	-
Trichloroethylene (TCE)	5	-	-	-
Hexachlorocyclopentadiene	206	-	-	-

Table B.1 - Nevada Water Quality Criteria for Toxic Materials (NAC 445A.144) (Continued)

Chemical	*Munic. or Dom. Supply (µg/l)*	*Aquatic life (µg/l)*	*Irrigation (µg/l)*	*Watering of Livestock (µg/l)*
2,4-Dichlorophenol	3,090	-	-	-
Isophorone	5,200	-	-	-
Trihalomethanes (total)	100	-	-	-
Tetrachloromethane(carbon tetrach.)	5	-	-	-
Phenol	3,500	-	-	-
Pentachlorophenol	1,010	-	-	-
1-Hour Aver.	-	exp{1.005ln(pH)-4.830}	-	-
96-Hour Aver.	-	exp{1.005ln(pH)-5.290}	-	-
Dinitrophenols	70	-	-	-
4,6-dinitro-2-methylphenol	13.4	-	-	-
Dibutyl Phthalate	34,000	-	-	-
Diethyl Phthalate	350,000	-	-	-
Dimethyl Phthalate	313,000	-	-	-
Di-2-ethylhexyl Phthalate	15,000	-	-	-
Polychlorinated Biphenyls (PCBs)	0	-	-	-
24-Hour Aver.	-	0.014	-	-
Fluoranthene (Polynuclear aromatic Hydocarbon)	42	-	-	-
Dichloropropenes	87	-	-	-
Toluene	14,300	-	-	-

Table B.2 - EPA National Recommended Water Quality Criteria for Priority Pollutants(EPA, 1999)

EPA Priority Pollutant	*Freshwater* CMC (μg/l)	CCC(μg/l)	*Saltwater* CMC(μg/l)	CCC(μg/l)	*Human Health for Consumption of:* Water+Org.(μg/l)	Organ. Only(μg/l)
Antimony	-	-	-	-	14	4,300
Arsenic	340	150	69	36	0.018	0.14
Beryllium	-	-	-	-	A,B	A
Cadmium	4.3	2.2	42	9.3	A,B	A
Chromium (VI)	16	11	1,100	50	A,B Total	A
Chromium (III)	570	74	-	-	A,B Total	A
Copper	13	9	4.8	3.1	1,300U	-
Cyanide	22	5.2	1	1	700	220,000
Lead	65	2.5	210	8.1	A	A
Mercury	1.4	0.77	1.8	0.94	0.05	0.051
Nickel	470	52	74	8.2	610	4,600
Selenium	0.18 - 1.78	5	290	71	170	11,000
Silver	3.4	-	1.9	-	-	-
Thallium	-	-	-	-	1.7	6.3
Zinc	120	120	90	81	9,100	69,000
Asbestos	-	-	-	-	7million fibers/l	-
2,3,7,8-TCDD Dioxin	-	-	-	-	1.30E-08	1.40E-08
Acrolein	-	-	-	-	320	780
Acrylonitrile	-	-	-	-	0.059	0.66
Benzene	-	-	-	-	1.2	71
Bromoform	-	-	-	-	4.3	360
Carbon Tetrachloride	-	-	-	-	0.25	4.4
Chlorobenzene	-	-	-	-	680	21,000
Chlorodibromomethane	-	-	-	-	0.41	34
Chloroethane	-	-	-	-	-	-

Table B.2 - EPA National Recommended Water Quality Criteria for Priority Pollutants(EPA, 1999) (Continued)

EPA	*Freshwater*		*Saltwater*		*Human Health for Consumption of:*	
Priority Pollutant	CMC (µg/l)	CCC(µg/l)	CMC(µg/l)	CCC(µg/l)	Water+Org.(µg/l)	Organ. Only(µg/l)
2-Chloroethylvinyl Ether	-	-	-	-	-	-
Chloroform	-	-	-	-	5.7	470
Dichlorobromomethane	-	-	-	-	0.56	46
1,1-Dichloroethane	-	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	0.38	99
1,1-Dichloroethylene	-	-	-	-	0.057	3.2
1,2-Dichloropropane	-	-	-	-	0.52	39
1,3-Dichloropropene	-	-	-	-	10	1,700
Ethylbenzene	-	-	-	-	3,100	29,000
Methyl Bromide	-	-	-	-	48	4,000
Methyl Chloride	-	-	-	-	A	A
Methylene Chloride	-	-	-	-	4.7	1,600
1,1,2,2-Tetrachloroethane	-	-	-	-	0.17	11
Tetrachloroethylene	-	-	-	-	0.8	8.85
Toluene	-	-	-	-	6,800	20,000
1,2-Trans-Dichloroethylene	-	-	-	-	700	140,000
1,1,1-Trichloroethane	-	-	-	-	A,B	A
1,1,2-Trichloroethane	-	-	-	-	0.6	42
Trichloroethylene (TCE)	-	-	-	-	2.7	81
Vinyl Chloride	-	-	-	-	2	525
2-Chlorophenol	-	-	-	-	120	400
2,4-Dichlorophenol	-	-	-	-	93	790
2,4-Dimethylphenol	-	-	-	-	540	2,300
2-Methyl-4,6-Dinitrophenol	-	-	-	-	13.4	765
2,4-Dinitrophenol	-	-	-	-	70	14,000
2-Nitrophenol	-	-	-	-	-	-

Table B.2 - EPA National Recommended Water Quality Criteria for Priority Pollutants(EPA, 1999) (Continued)

EPA	*Freshwater*		*Saltwater*		*Human Health for Consumption of:*	
Priority Pollutant	CMC (μg/l)	CCC(μg/l)	CMC(μg/l)	CCC(μg/l)	Water+Org.(μg/l)	Organ. Only(μg/l)
4-Nitrophenol	-	-	-	-	-	-
3-Methyl-4-Chlorophenol	-	-	-	-	>3,000	>3,000
Pentachlorophenol	19	15	13	7.9	0.28	8.2
Phenol	-	-	-	-	21,000	4,600,000
2,4,6-Trichlorophenol	-	-	-	-	2.1	6.5
Acenaphthene	-	-	-	-	1,200	2,700
Acenaphthylene	-	-	-	-	-	-
Anthracene	-	-	-	-	9,600	110,000
Benzidine	-	-	-	-	0.00012	0.00054
BenzoaAnthracene	-	-	-	-	0.0044	0.049
BenzoaPyrene	-	-	-	-	0.0044	0.049
BenzobFluoranthene	-	-	-	-	0.0044	0.049
BenzoghiPerylene	-	-	-	-	-	-
BenzokFluoranthene	-	-	-	-	0.0044	0.049
Bis2-ChloroethoxyMethane	-	-	-	-	-	-
Bis2-ChloroethylEther	-	-	-	-	0.031	1.4
Bis2-ChloroisopropylEther	-	-	-	-	1,400	170,000
Bis2-EthylhexylPhthalate	-	-	-	-	1.8	5.9
4-Bromophenyl Phenyl Ether	-	-	-	-	-	-
Butylbenzyl Phthalate	-	-	-	-	3,000	5,200
2-Chloronaphthalene	-	-	-	-	1,700	4,300
4-Chlorophenyl Phenyl Ether	-	-	-	-	-	-
Chrysene	-	-	-	-	0.0044	0.049
Dibenzoa,hAnthracene	-	-	-	-	0.0044	0.049
1,2-Dichlorobenzene	-	-	-	-	2,700	17,000
1,3-Dichlorobenzene	-	-	-	-	400	2,600

Table B.2 - EPA National Recommended Water Quality Criteria for Priority Pollutants(EPA, 1999) (Continued)

EPA	*Freshwater*		*Saltwater*		*Human Health for Consumption of:*	
Priority Pollutant	CMC (µg/l)	CCC(µg/l)	CMC(µg/l)	CCC(µg/l)	Water+Org.(µg/l)	Organ. Only(µg/l)
1,4-Dichlorobenzene	-	-	-	-	400	2,600
3,3'-Dichlorobenzidine	-	-	-	-	0.04	0.077
Diethyl Phthalate	-	-	-	-	23,000	120,000
Dimethyl Phthalate	-	-	-	-	313,000	2,900,000
Di-n-Butyl Phthalate	-	-	-	-	2,700	12,000
2,4-Dinitrotoluene	-	-	-	-	0.11	9.1
2,6-Dinitrotoluene	-	-	-	-	-	-
Di-n-Octyl Phthalate	-	-	-	-	-	-
1,2-Diphenylhydrazine	-	-	-	-	0.04	0.54
Fluoranthene	-	-	-	-	300	370
Fluorene	-	-	-	-	1,300	14,000
Hexachlorobenzene	-	-	-	-	0.00075	0.00077
Hexachlorobutadiene	-	-	-	-	0.44	50
Hexachlorocyclopentadiene	-	-	-	-	240	17,000
Hexachloroethane	-	-	-	-	1.9	8.9
Ideno1,2,3-cdPyrene	-	-	-	-	0.0044	0.049
Isophorone	-	-	-	-	36	2600
Naphthalene	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	17	1,900
N-Nitrosodimethylamine	-	-	-	-	0.00069	8.1
N-Nitrosodi-n-Propylamine	-	-	-	-	0.005	1.4
N-Nitrosodiphenylamine	-	-	-	-	5	16
Phenanthrene	-	-	-	-	-	-
Pyrene	-	-	-	-	960	11,000
1,2,4-Trichlorobenzene	-	-	-	-	260	940
Aldrin	3	-	1.3	-	0.00013	0.00014

Table B.2 - EPA National Recommended Water Quality Criteria for Priority Pollutants(EPA, 1999) (Continued)

EPA	*Freshwater*		*Saltwater*		*Human Health for Consumption of:*	
Priority Pollutant	CMC (µg/l)	CCC(µg/l)	CMC(µg/l)	CCC(µg/l)	Water+Org.(µg/l)	Organ. Only(µg/l)
alpha-BHC	-	-	-	-	0.0039	0.013
beta-BHC	-	-	-	-	0.014	0.046
gamma-BHC (Lindane)	0.95	-	0.16	-	0.019	0.063
delta-BHC	-		-	-	-	-
Chlordane	2.4	0.0043	0.09	0.004	0.0021	0.0022
4,4'-DDT	1.1	0.001	0.13	0.001	0.00059	0.00059
4,4'-DDE	-	-	-	-	0.00059	0.00059
4,4'-DDD	-	-	-	-	0.00083	0.00084
Dieldrin	0.24	0.056	0.71	0.0019	0.00014	0.00014
alpha-Endosulfan	0.22	0.056	0.034	0.0087	110	240
beta-Endosulfan	0.22	0.056	0.034	0.0087	110	240
Endosulfan Sulfate	-	-	-	-	110	240
Endrin	0.086	0.036	0.037	0.0023	0.76	0.81
Endrin Aldehyde	-	-	-	-	0.76	0.81
Heptachlor	0.52	0.0038	0.053	0.0036	0.00021	0.00021
Heptachlor Epoxide	0.52	0.0038	0.053	0.0036	0.0001	0.00011
Polychlorinated Biphenyls (PCBs)	-	0.014	-	0.03	0.00017	0.00017
Toxaphene	0.73	0.0002	0.21	0.0002	0.00073	0.00075

A - EPA has not calculated human health criterion for this contaminat. However, permit authorithies should address this contminat in NPDES permit actions using State's xisting narrative criteria for toxics.

B - A more stringent MCL has been issued by EPA. Refer to drinking water regulations (40 CFR 141) or Safe Drinking Water Hotline (1-800-426-4791) for values.

CMC - Criteria Maximum Concentration
CCC - Criteria Continuous Concentration

Table B.3 - EPA National Recommended Water Quality Criteria for Non Priority Pollutants(EPA, 1999)

EPA	*Freshwater*		*Saltwater*		*Human Health for Consumption of:*	
Non-Priority Pollutant	CMC (μg/l)	CCC(μg/l)	CMC(μg/l)	CCC(μg/l)	Water+Org.(μg/l)	Organ. Only(μg/l)
Alkalinity	-	20000	-	-	-	-
Aluminum pH 6.5 - 9.0	750	87	-	-	-	-
Ammonia	Freshwaster criteria are pH depent - Site dependent Saltwater Criteria are pH and Temperature dependent					
Aesthetic Qualities	Site Dependent					
Bacteria	Use dependent					
Barium	-	-	-	-	1,000	-
Boron	Site Dependent					
Chloride	860000	230000	-	-	-	-
Chlorine	19	11	13	7.5	c	-
Chlorophenoxy Herbicide/2,4,5-TP	-	-	-	-	10	-
Chlorophenoxy Herbicide/2,4-D					1000	
Chloropyrifos	0.083	0.041	0.011	0.0056	-	-
Color	Site Dependent					
Demeton	-	0.1	-	0.1	-	-
Ether, Bis Chloromethyl	-	-	-	-	0.00013	0.00078
Gases, Total Dissolved	Site Dependent					
Guthion	-	0.01	-	0.01	-	-
Hardness	Site Dependent					
Hexaxhlorocyclo-hexane-Technical	-	-	-	-	0.0123	0.0414
Iron	-	1000	-	-	300	-
Malathion	-	0.1	-	0.1	-	-
Manganese	-	-	-	-	50	100
Methoxychlor	-	0.03	-	0.03	100	-
Mirex	-	0.001	-	0.001	-	-
Nitrates	-	-	-	-	10000	-
Nitrosamines	-	-	-	-	0.0008	1.24
Dinitrophenols	-	-	-	-	70	14,000
Nitrosodibutylamine, N	-	-	-	-	0.0064	0.587
Nitrosodiethylamine, N	-	-	-	-	0.0008	1.24
Nitrosopyrrolidine, N	-	-	-	-	0.016	91.9
Oil and Grease	Site Dependent					

Table B.3 - EPA National Recommended Water Quality Criteria for Non Priority Pollutants(EPA, 1999) (Continued)

EPA	*Freshwater*		*Saltwater*		*Human Health for Consumption of:*	
Non-Priority Pollutant	CMC (μg/l)	CCC(μg/l)	CMC(μg/l)	CCC(μg/l)	Water+Org.(μg/l)	Organ. Only(μg/l)
Oxygen, Dissolved	Warmwater and coldwater matrix - see document o					
Parathion	0.065	0.013	-	-	-	-
Pentachlorobenzene	-	-	-	-	3.5	4.1
pH	-	6.5 - 9	-	6.5 - 8.5	5.0 - 9.0	-
Phosphorus Elemental	-	-	-	0.1	-	-
Phosphate Phosphorus	Site Dependent					
Solids Dissolved and Salinity	-	-	-	-	250,000	-
Solids Suspended and Turbidity	Site Dependent					
Sulfide-Hydrogen Sulfide	-	2	-	2	-	-
Tainting Substances	Site Dependent					
Temperature	Site Dependent					
Tetrachlorobenzene, 1,2,4,5	-	-	-	-	2.3	2.9
Tributyltin TBT	0.46	0.063	0.37	0.01	-	-
Trichlorophenol, 1,2,4,5	-	-	-	-	2600	9800

Table B.4 - Quality Criteria for Designated Beneficial Uses - NAC 445A.119

Beneficial Uses / *Parameter*		*Agricultural Use*		*Aquatic Life*								
				Cold Water		Warm Water						
		Irrigation	W. Livestock	Propagation	Put & Take	Propagation	Put & Take	Water Cont. Recreation	Water NonCont	Mun. Dom. Supply	Ind. Supply	Propagation Wildlife
Temperature °C		-	-	Site Dependent				15-34	-	-	-	-
pH units		4.5 - 9.0	5.0-9.0	6.5-9.0	6.5-9.0	6.5-9.0	6.5-9.0	6.5-8.3	-	5.0-9.0	3.0-11.7	7.0-9.2
Dissolved Oxygen - mg/l	>	-	Aerobic	5	5	5	5	Aerobic	Aerobic	Aerobic	-	Aerobic
Chlorides - mg/l	<	no value	1,500	-	-	-	-	-	-	250/400	-	1,500
Total Phosphates as P-mg/l		-	-	Site Dependent							-	-
Nitrates as N - mg/l	<	-	100	no value	-	90	90	-	-	10	-	100
Nitrites as N - mg/l	<	-	10	0.06	-	-	-	-	-	1	-	10
Total Nitrogen as N		-	-	Site Dependent							-	-
Un-ionized Ammonia as NH $_3$ - mg/l	<	-	-	0.02	Site Dependent			-	-	0.5 total NH3-N	-	-
TDS - mg/l	<	-	3,000	-	-	-	-	-	-	500/1000	-	-
Color (PT-CO)	<	-	-	-	-	-	-	-	-	75	-	-
Turbidity - NTU	<	-	-	10	10	50	50	-	-	no value	-	-
Fecal Coliform (MF/100ml)	<	1,000	1,000	-	-	-	-	200/400	1,000/2,000	2,000	-	1,000
Alkalinity as $CaCO_3$		-	-	Less than 25% change from natural conditions				-	-	-	-	30-130
Suspended Solids - mg/l	<	-	-	25-80	25-80	25-80	25-80	-	-	-	-	-
Sulfate - mg/l	<	-	-	-	-	-	-	-	-		-	-

Table B.5 - Action Levels for Soils Contaminants - NAC 445A - 2272

- If surface and ground water is the primary pathway of concern soil has to meet TCLP standards as per EPA Analytical Method 1311

- The concentration of petroleum substances should not exceed 100 mg/Kg as per EPA Analytical Method 8015

Table B.6 - Combined EPA Priority and Non-Priority Pollutant for Freshwater, Nevada's Beneficial Uses and Toxic Substances Regulations for Fresh Water and Soils (EPA, 1999 - NAC445A.119/144/2272)

Contaminant	*Nevada Regulation*	*EPA*	*Nevada Regulation*	*EPA*	*Nevada Regulation*
	NAC445A.2272	*Priority Pollutant*	*NAC445A.144*	*Non-Priority pollutants*	*NAC 445A.119*
	(TCLP Test) (mg/l)	Freshwater (μg/l)	Aquatic Life (μg/l)	Freshwater (μg/l)	Aquatic life
Acetone					
Aldrin	-	3	3		
Alkalinity	-	-	-	20,000	*
Aluminum	-	-	-	87-750	-
Arsenic	5	150 - 340	-	-	-
Bacteria (fecal coliform MF/100m)	-	-	-	Use dependent	-
Barium	100	-	-	-	-
Benzene	0.5	-	-	-	-
BOD					
Boron	-	-	-	Site dependent	-
Bromodichloromethane					
Cadmium	1	2.2 - 4.3	pH dependent	-	-
Carbon Tetrachloride	0.5	-	-	-	-
Chlordane	0.03	0.0043 - 2.4	0.0043-2.4	-	-
Chloride	-	-	-	230,000-860,000	-
Chlorobenzene	100	-	-	-	-
Chloroform	6	-	-	-	-
Chromium	5	11 - 570	pH dependent	-	-
COD					
Copper	-	9-13	pH dependent	-	-
Cyanide	-	5.2 - 22	5.2 - 22	-	-
2,4-D	10	-	-	-	-
4,4,4-DDD					
4,4-DDT	-	0.001-1.1	-	-	-
Demeton	-	-	0.1	-	-
Dibromochloromethane					
1,4-Dichlorobenzene	7.5	-	-	-	-
1,2-Dichloroethane	0.5	-	-	-	-
1,1-Dichloroethylene	0.7	-	-	-	-

Table B.6 - Combined EPA Priority and Non-Priority Pollutant for Freshwater, Nevada's Beneficial Uses and Toxic Substances Regulations for Fresh Water and Soils (EPA, 1999 - NAC445A.119/144/2272) (Continued)

Contaminant	*Nevada Regulation*	*EPA*	*Nevada Regulation*	*EPA*	*Nevada Regulation*
	NAC445A.2272	*Priority Pollutant*	*NAC445A.144*	*Non-Priority pollutants*	*NAC 445A.119*
	(TCLP Test) (mg/l)	Freshwater (μg/l)	Aquatic Life (μg/l)	Freshwater (μg/l)	Aquatic life
Dieldrin	-	0.056-0.24	0.0019-2.5	-	-
2,4-Dinitrotoluene	0.13	-	-	-	-
Dissolved Solids and salinity	-	-	-	-	-
alfa-Endosulfan	-	0.056-0.22	-	-	-
beta-Endosulfan	-	0.056-0.22	-	-	-
Endosulfan I					
Endrin	0.02	0.036-0.086	0.18	-	-
Guthion	-	-	0.01	-	-
Hardness	-	-	-	Site dependent	-
Heptachlor (and epoxide)	0.008	0.0038-0.52	0.0038 - 0.52	-	-
Hexachlorobenzene	0.13	-	-	-	-
Hexachlorobutadiene	0.5	-	-	-	-
Hexachloroethane	3	-	-	-	-
2-Hexanone					
Iron	-	-	1,000	-	-
Lead	5	2.5 - 65	pH dependent	-	-
Lindane	0.4	0.95	0.080-2.0	-	-
Malathion	-	-	0.1	-	-
Manganese	-	-	-	-	-
Mercury	0.2	0.77 - 1.4	0.012-2.0	-	-
Methoxychlor	10	-	0.03	-	-
Mirex	-	-	0.001	-	-
Nickel	-	52 - 470	pH dependent	-	-
Nitrates				-	90
Nitrobenzene	2	-	-	-	-
Oil and Grease				Site dependent	-
Parathion	-	-	0.013-0.065	-	-
Pentachlorophenol	100	15 - 15	pH dependent	-	-
pH				6.5 - 9	6.5 - 9
Phosphate phosphorus				Site dependent	-

Table B.6 - Combined EPA Priority and Non-Priority Pollutant for Freshwater, Nevada's Beneficial Uses and Toxic Substances Regulations for Fresh Water and Soils (EPA, 1999 - NAC445A.119/144/2272) (Continued)

Contaminant	*Nevada Regulation*	*EPA*	*Nevada Regulation*	*EPA*	*Nevada Regulation*
	NAC445A.2272	*Priority Pollutant*	*NAC445A.144*	*Non-Priority pollutants*	*NAC 445A.119*
	(TCLP Test) (mg/l)	Freshwater (µg/l)	Aquatic Life (µg/l)	Freshwater (µg/l)	Aquatic life
Polychlorinated biphenyls(PCB)	-	0.014	0.014	-	-
n-Propylbenzene					
Pyridine	5	-	-	-	-
Selenium	1	0.18 - 5	5.0-20.0	-	-
Silver	5	3.4	pH dependent	-	-
Thallium					
Toluene					
Toxaphene	0.5	0.0002 - 0.73	0.0002-0.73	-	-
Trichloroethylene	0.5	-	-	-	-
2,4,5- Trichlorophenol	400	-	-	-	-
2,4,6-Trichlorophenol	2	-	-	-	-
1,2,4-Trimethylbenzene					
1,3,5-Trimethylbenzene					
2,4,5-TP (Silvex)	1	-	-	-	-
Un-ionized Ammonia as NH3 (mg/l)	-	-	-	-	0.02
Vinyl chloride	0.2	-	-	-	-
o-Xylene					
m,p-Xylene					
Zinc	-	120	pH dependent	-	-

* - Less than 25% change from natural conditions

APPENDIX C: SYNTHETIC PRECIPITATION LEACHING PROCEDURE

METHOD 1312

SYNTHETIC PRECIPITATION LEACHING PROCEDURE

1.0 SCOPE AND APPLICATION

1.1 Method 1312 is designed to determine the mobility of both organic and inorganic analytes present in liquids, soils, and wastes.

2.0 SUMMARY OF METHOD

2.1 For liquid samples (i.e., those containing less than 0.5 % dry solid material), the sample, after filtration through a 0.6 to 0.8 µm glass fiber filter, is defined as the 1312 extract.

2.2 For samples containing greater than 0.5 % solids, the liquid phase, if any, is separated from the solid phase and stored for later analysis; the particle size of the solid phase is reduced, if necessary. The solid phase is extracted with an amount of extraction fluid equal to 20 times the weight of the solid phase. The extraction fluid employed is a function of the region of the country where the sample site is located if the sample is a soil. If the sample is a waste or wastewater, the extraction fluid employed is a pH 4.2 solution. A special extractor vessel is used when testing for volatile analytes (see Table 1 for a list of volatile compounds). Following extraction, the liquid extract is separated from the solid phase by filtration through a 0.6 to 0.8 µm glass fiber filter.

2.3 If compatible (i.e., multiple phases will not form on combination), the initial liquid phase of the waste is added to the liquid extract, and these are analyzed together. If incompatible, the liquids are analyzed separately and the results are mathematically combined to yield a volume-weighted average concentration.

3.0 INTERFERENCES

3.1 Potential interferences that may be encountered during analysis are discussed in the individual analytical methods.

4.0 APPARATUS AND MATERIALS

4.1 Agitation apparatus: The agitation apparatus must be capable of rotating the extraction vessel in an end-over-end fashion (see Figure 1) at 30 ± 2 rpm. Suitable devices known to EPA are identified in Table 2.

4.2 Extraction Vessels

4.2.1 Zero Headspace Extraction Vessel (ZHE). This device is for use only when the sample is being tested for the mobility of volatile analytes (i.e., those listed in Table 1). The ZHE (depicted in Figure 2) allows for liquid/solid separation within the device and effectively precludes headspace. This type of vessel allows for initial liquid/solid separation, extraction, and final extract filtration without opening the vessel (see Step 4.3.1). These vessels shall have an internal volume of 500-600 mL and be equipped to accommodate a 90-110 mm filter. The devices contain VITON®[1] O-rings which should be replaced frequently. Suitable ZHE devices known to EPA are identified in Table 3.

For the ZHE to be acceptable for use, the piston within the ZHE should be able to be moved with approximately 15 psig or less. If it takes more pressure to move the piston, the O-rings in the device should be replaced. If this does not solve the problem, the ZHE is unacceptable for 1312 analyses and the manufacturer should be contacted.

The ZHE should be checked for leaks after every extraction. If the device contains a built-in pressure gauge, pressurize the device to 50 psig, allow it to stand unattended for 1 hour, and recheck the pressure. If the device does not have a built-in pressure gauge, pressurize the device to 50 psig, submerge it in water, and check for the presence of air bubbles escaping from any of the fittings. If pressure is lost, check all fittings and inspect and replace O-rings, if necessary. Retest the device. If leakage problems cannot be solved, the manufacturer should be contacted.

Some ZHEs use gas pressure to actuate the ZHE piston, while others use mechanical pressure (see Table 3). Whereas the volatiles procedure (see Step 7.3) refers to pounds-per-square-inch (psig), for the mechanically actuated piston, the pressure applied is measured in torque-inch-pounds. Refer to the manufacturer's instructions as to the proper conversion.

4.2.2 Bottle Extraction Vessel. When the sample is being evaluated using the nonvolatile extraction, a jar with sufficient capacity to hold the sample and the extraction fluid is needed. Headspace is allowed in this vessel.

The extraction bottles may be constructed from various materials, depending on the analytes to be analyzed and the nature of the waste (see Step 4.3.3). It is recommended that borosilicate glass bottles be used instead of other types of glass, especially when inorganics are of concern. Plastic bottles, other than polytetrafluoroethylene, shall not be used if organics are to be investigated. Bottles are available from a number of laboratory suppliers. When this type of extraction vessel is used, the filtration device discussed in Step 4.3.2 is used for initial liquid/solid separation and final extract filtration.

4.3 Filtration Devices: It is recommended that all filtrations be performed in a hood.

4.3.1 Zero-Headspace Extraction Vessel (ZHE): When the sample is evaluated for volatiles, the zero-headspace extraction vessel described

---

[1] VITON® is a trademark of Du Pont.

in Step 4.2.1 is used for filtration. The device shall be capable of supporting and keeping in place the glass fiber filter and be able to withstand the pressure needed to accomplish separation (50 psig).

> NOTE: When it is suspected that the glass fiber filter has been ruptured, an in-line glass fiber filter may be used to filter the material within the ZHE.

4.3.2 Filter Holder: When the sample is evaluated for other than volatile analytes, a filter holder capable of supporting a glass fiber filter and able to withstand the pressure needed to accomplish separation may be used. Suitable filter holders range from simple vacuum units to relatively complex systems capable of exerting pressures of up to 50 psig or more. The type of filter holder used depends on the properties of the material to be filtered (see Step 4.3.3). These devices shall have a minimum internal volume of 300 mL and be equipped to accommodate a minimum filter size of 47 mm (filter holders having an internal capacity of 1.5 L or greater, and equipped to accommodate a 142 mm diameter filter, are recommended). Vacuum filtration can only be used for wastes with low solids content (<10 %) and for highly granular, liquid-containing wastes. All other types of wastes should be filtered using positive pressure filtration. Suitable filter holders known to EPA are listed in Table 4.

4.3.3 Materials of Construction: Extraction vessels and filtration devices shall be made of inert materials which will not leach or absorb sample components of interest. Glass, polytetrafluoroethylene (PTFE), or type 316 stainless steel equipment may be used when evaluating the mobility of both organic and inorganic components. Devices made of high-density polyethylene (HDPE), polypropylene (PP), or polyvinyl chloride (PVC) may be used only when evaluating the mobility of metals. Borosilicate glass bottles are recommended for use over other types of glass bottles, especially when inorganics are analytes of concern.

4.4 Filters: Filters shall be made of borosilicate glass fiber, shall contain no binder materials, and shall have an effective pore size of 0.6 to 0.8-μm . Filters known to EPA which meet these specifications are identified in Table 5. Pre-filters must not be used. When evaluating the mobility of metals, filters shall be acid-washed prior to use by rinsing with 1N nitric acid followed by three consecutive rinses with reagent water (a minimum of 1-L per rinse is recommended). Glass fiber filters are fragile and should be handled with care.

4.5 pH Meters: The meter should be accurate to ± 0.05 units at 25°C.

4.6 ZHE Extract Collection Devices: TEDLAR®[2] bags or glass, stainless steel or PTFE gas-tight syringes are used to collect the initial liquid phase and the final extract when using the ZHE device. These devices listed are recommended for use under the following conditions:

---

[2] TEDLAR® is a registered trademark of Du Pont.

4.6.1 If a waste contains an aqueous liquid phase or if a waste does not contain a significant amount of nonaqueous liquid (i.e., <1 % of total waste), the TEDLAR® bag or a 600 mL syringe should be used to collect and combine the initial liquid and solid extract.

4.6.2 If a waste contains a significant amount of nonaqueous liquid in the initial liquid phase (i.e., >1 % of total waste), the syringe or the TEDLAR® bag may be used for both the initial solid/liquid separation and the final extract filtration. However, analysts should use one or the other, not both.

4.6.3 If the waste contains no initial liquid phase (is 100 % solid) or has no significant solid phase (is <0.5% solid) , either the TEDLAR® bag or the syringe may be used. If the syringe is used, discard the first 5 mL of liquid expressed from the device. The remaining aliquots are used for analysis.

4.7 ZHE Extraction Fluid Transfer Devices: Any device capable of transferring the extraction fluid into the ZHE without changing the nature of the extraction fluid is acceptable (e.g., a positive displacement or peristaltic pump, a gas-tight syringe, pressure filtration unit (see Step 4.3.2), or other ZHE device).

4.8 Laboratory Balance: Any laboratory balance accurate to within ± 0.01 grams may be used (all weight measurements are to be within ± 0.1 grams).

4.9 Beaker or Erlenmeyer flask, glass, 500 mL.

4.10 Watchglass, appropriate diameter to cover beaker or Erlenmeyer flask.

4.11 Magnetic stirrer.

5.0 REAGENTS

5.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 Reagent Water. Reagent water is defined as water in which an interferant is not observed at or above the method's detection limit of the analyte(s) of interest. For nonvolatile extractions, ASTM Type II water or equivalent meets the definition of reagent water. For volatile extractions, it is recommended that reagent water be generated by any of the following methods. Reagent water should be monitored periodically for impurities.

5.2.1 Reagent water for volatile extractions may be generated by passing tap water through a carbon filter bed containing about 500 grams of activated carbon (Calgon Corp., Filtrasorb-300 or equivalent).

5.2.2 A water purification system (Millipore Super-Q or equivalent) may also be used to generate reagent water for volatile extractions.

5.2.3 Reagent water for volatile extractions may also be prepared by boiling water for 15 minutes. Subsequently, while maintaining the water temperature at 90 ± 5 degrees C, bubble a contaminant-free inert gas (e.g. nitrogen) through the water for 1 hour. While still hot, transfer the water to a narrow mouth screw-cap bottle under zero-headspace and seal with a Teflon-lined septum and cap.

5.3 Sulfuric acid/nitric acid (60/40 weight percent mixture) H_2SO_4/HNO_3. Cautiously mix 60 g of concentrated sulfuric acid with 40 g of concentrated nitric acid. If preferred, a more dilute H_2SO_4/HNO_3 acid mixture may be prepared and used in steps 5.4.1 and 5.4.2 making it easier to adjust the pH of the extraction fluids.

5.4 Extraction fluids.

5.4.1 Extraction fluid #1: This fluid is made by adding the 60/40 weight percent mixture of sulfuric and nitric acids (or a suitable dilution) to reagent water (Step 5.2) until the pH is 4.20 ± 0.05. The fluid is used to determine the leachability of soil from a site that is east of the Mississippi River, and the leachability of wastes and wastewaters.

NOTE: Solutions are unbuffered and exact pH may not be attained.

5.4.2 Extraction fluid #2: This fluid is made by adding the 60/40 weight percent mixture of sulfuric and nitric acids (or a suitable dilution) to reagent water (Step 5.2) until the pH is 5.00 ± 0.05. The fluid is used to determine the leachability of soil from a site that is west of the Mississippi River.

5.4.3 Extraction fluid #3: This fluid is reagent water (Step 5.2) and is used to determine cyanide and volatiles leachability.

NOTE: These extraction fluids should be monitored frequently for impurities. The pH should be checked prior to use to ensure that these fluids are made up accurately. If impurities are found or the pH is not within the above specifications, the fluid shall be discarded and fresh extraction fluid prepared.

5.5 Analytical standards shall be prepared according to the appropriate analytical method.

6.0 SAMPLE COLLECTION, PRESERVATION, AND HANDLING

6.1 All samples shall be collected using an appropriate sampling plan.

6.2 There may be requirements on the minimal size of the field sample depending upon the physical state or states of the waste and the analytes of concern. An aliquot is needed for the preliminary evaluations of the percent solids and the particle size. An aliquot may be needed to conduct the nonvolatile analyte extraction procedure. If volatile organics are of concern, another aliquot may be needed. Quality control measures may require additional aliquots. Further, it is always wise to collect more sample just in case something goes wrong with the initial attempt to conduct the test.

6.3 Preservatives shall not be added to samples before extraction.

6.4 Samples may be refrigerated unless refrigeration results in irreversible physical change to the waste. If precipitation occurs, the entire sample (including precipitate) should be extracted.

6.5 When the sample is to be evaluated for volatile analytes, care shall be taken to minimize the loss of volatiles. Samples shall be collected and stored in a manner intended to prevent the loss of volatile analytes (e.g., samples should be collected in Teflon-lined septum capped vials and stored at 4°C. Samples should be opened only immediately prior to extraction).

6.6 1312 extracts should be prepared for analysis and analyzed as soon as possible following extraction. Extracts or portions of extracts for metallic analyte determinations must be acidified with nitric acid to a pH < 2, unless precipitation occurs (see Step 7.2.14 if precipitation occurs). Extracts should be preserved for other analytes according to the guidance given in the individual analysis methods. Extracts or portions of extracts for organic analyte determinations shall not be allowed to come into contact with the atmosphere (i.e., no headspace) to prevent losses. See Step 8.0 (Quality Control) for acceptable sample and extract holding times.

7.0 PROCEDURE

7.1 Preliminary Evaluations

Perform preliminary 1312 evaluations on a minimum 100 gram aliquot of sample. This aliquot may not actually undergo 1312 extraction. These preliminary evaluations include: (1) determination of the percent solids (Step 7.1.1); (2) determination of whether the waste contains insignificant solids and is, therefore, its own extract after filtration (Step 7.1.2); and (3) determination of whether the solid portion of the waste requires particle size reduction (Step 7.1.3).

7.1.1 Preliminary determination of percent solids: Percent solids is defined as that fraction of a waste sample (as a percentage of the total sample) from which no liquid may be forced out by an applied pressure, as described below.

7.1.1.1 If the sample will obviously yield no free liquid when subjected to pressure filtration (i.e., is 100% solid), weigh out a representative subsample (100 g minimum) and proceed to Step 7.1.3.

7.1.1.2 If the sample is liquid or multiphasic, liquid/solid separation to make a preliminary determination of percent solids is required. This involves the filtration device discussed in Step 4.3.2, and is outlined in Steps 7.1.1.3 through 7.1.1.9.

7.1.1.3 Pre-weigh the filter and the container that will receive the filtrate.

7.1.1.4 Assemble filter holder and filter following the manufacturer's instructions. Place the filter on the support screen and secure.

7.1.1.5 Weigh out a subsample of the waste (100 gram minimum) and record the weight.

7.1.1.6 Allow slurries to stand to permit the solid phase to settle. Samples that settle slowly may be centrifuged prior to filtration. Centrifugation is to be used only as an aid to filtration. If used, the liquid should be decanted and filtered followed by filtration of the solid portion of the waste through the same filtration system.

7.1.1.7 Quantitatively transfer the sample to the filter holder (liquid and solid phases). Spread the sample evenly over the surface of the filter. If filtration of the waste at 4°C reduces the amount of expressed liquid over what would be expressed at room temperature, then allow the sample to warm up to room temperature in the device before filtering.

Gradually apply vacuum or gentle pressure of 1-10 psig, until air or pressurizing gas moves through the filter. If this point is not reached under 10 psig, and if no additional liquid has passed through the filter in any 2-minute interval, slowly increase the pressure in 10 psig increments to a maximum of 50 psig. After each incremental increase of 10 psig, if the pressurizing gas has not moved through the filter, and if no additional liquid has passed through the filter in any 2-minute interval, proceed to the next 10-psig increment. When the pressurizing gas begins to move through the filter, or when liquid flow has ceased at 50 psig (i.e., filtration does not result in any additional filtrate within any 2-minute period), stop the filtration.

NOTE: If sample material (>1 % of original sample weight) has obviously adhered to the container used to transfer the sample to the filtration apparatus, determine the weight of this residue and subtract it from the sample weight determined in Step 7.1.1.5 to determine the weight of the sample that will be filtered.

NOTE: Instantaneous application of high pressure can degrade the glass fiber filter and may cause premature plugging.

7.1.1.8 The material in the filter holder is defined as the solid phase of the sample, and the filtrate is defined as the liquid phase.

NOTE: Some samples, such as oily wastes and some paint wastes, will obviously contain some material that appears to be a liquid, but even after applying vacuum or pressure filtration, as outlined in Step 7.1.1.7, this material may not filter. If this is the case, the material within the filtration device is defined as a solid. Do not replace the original filter with a fresh filter under any circumstances. Use only one filter.

7.1.1.9 Determine the weight of the liquid phase by subtracting the weight of the filtrate container (see Step 7.1.1.3) from the total weight of the filtrate-filled container. Determine the weight of the solid phase of the sample by subtracting the weight of the liquid phase from the weight of the total sample, as determined in Step 7.1.1.5 or 7.1.1.7.

Record the weight of the liquid and solid phases. Calculate the percent solids as follows:

$$\text{Percent solids} = \frac{\text{Weight of solid (Step 7.1.1.9)}}{\text{Total weight of waste (Step 7.1.1.5 or 7.1.1.7)}} \times 100$$

7.1.2 If the percent solids determined in Step 7.1.1.9 is equal to or greater than 0.5%, then proceed either to Step 7.1.3 to determine whether the solid material requires particle size reduction or to Step 7.1.2.1 if it is noticed that a small amount of the filtrate is entrained in wetting of the filter. If the percent solids determined in Step 7.1.1.9 is less than 0.5%, then proceed to Step 7.2.9 if the nonvolatile 1312 analysis is to be performed, and to Step 7.3 with a fresh portion of the waste if the volatile 1312 analysis is to be performed.

7.1.2.1 Remove the solid phase and filter from the filtration apparatus.

7.1.2.2 Dry the filter and solid phase at 100 ± 20°C until two successive weighings yield the same value within ± 1 %. Record the final weight.

Caution: The drying oven should be vented to a hood or other appropriate device to eliminate the possibility of fumes from the sample escaping into the laboratory. Care should be taken to ensure that the sample will not flash or violently react upon heating.

7.1.2.3 Calculate the percent dry solids as follows:

$$\text{Percent dry solids} = \frac{\text{(Weight of dry sample + filter) - tared weight of filter}}{\text{Initial weight of sample (Step 7.1.1.5 or 7.1.1.7)}} \times 100$$

7.1.2.4 If the percent dry solids is less than 0.5%, then proceed to Step 7.2.9 if the nonvolatile 1312 analysis is to be performed, and to Step 7.3 if the volatile 1312 analysis is to be performed. If the percent dry solids is greater than or equal to 0.5%, and if the nonvolatile 1312 analysis is to be performed, return to the beginning of this Step (7.1) and, with a fresh portion of sample, determine whether particle size reduction is necessary (Step 7.1.3).

7.1.3 Determination of whether the sample requires particle-size reduction (particle-size is reduced during this step): Using the solid portion of the sample, evaluate the solid for particle size. Particle-size reduction is required, unless the solid has a surface area per gram of material equal to or greater than 3.1 cm^2, or is smaller than 1 cm in its narrowest dimension (i.e., is capable of passing through a 9.5 mm (0.375 inch) standard sieve). If the surface area is smaller or the particle size larger than described above, prepare the solid portion of the sample for extraction by crushing, cutting, or grinding the waste to a surface area or particle size as described above. If the solids are prepared for organic volatiles extraction, special precautions must be taken (see Step 7.3.6).

NOTE: Surface area criteria are meant for filamentous (e.g., paper, cloth, and similar) waste materials. Actual measurement of surface area is not required, nor is it recommended. For materials that do not obviously meet the criteria, sample-specific methods would need to be developed and employed to measure the surface area. Such methodology is currently not available.

7.1.4 Determination of appropriate extraction fluid:

7.1.4.1 For soils, if the sample is from a site that is east of the Mississippi River, extraction fluid #1 should be used. If the sample is from a site that is west of the Mississippi River, extraction fluid #2 should be used.

7.1.4.2 For wastes and wastewater, extraction fluid #1 should be used.

7.1.4.3 For cyanide-containing wastes and/or soils, extraction fluid #3 (reagent water) must be used because leaching of cyanide-containing samples under acidic conditions may result in the formation of hydrogen cyanide gas.

7.1.5 If the aliquot of the sample used for the preliminary evaluation (Steps 7.1.1 - 7.1.4) was determined to be 100% solid at Step 7.1.1.1, then it can be used for the Step 7.2 extraction (assuming at least 100 grams remain), and the Step 7.3 extraction (assuming at least 25 grams remain). If the aliquot was subjected to the procedure in Step 7.1.1.7, then another aliquot shall be used for the volatile extraction procedure in Step 7.3. The aliquot of the waste subjected to the procedure in Step 7.1.1.7 might be appropriate for use for the Step 7.2 extraction if an adequate amount of solid (as determined by Step 7.1.1.9) was obtained. The amount of solid necessary is dependent upon whether a sufficient amount of extract will be produced to support the analyses. If an adequate amount of solid remains, proceed to Step 7.2.10 of the nonvolatile 1312 extraction.

7.2 Procedure When Volatiles Are Not Involved

A minimum sample size of 100 grams (solid and liquid phases) is recommended. In some cases, a larger sample size may be appropriate, depending on the solids content of the waste sample (percent solids, See Step 7.1.1), whether the initial liquid phase of the waste will be miscible with the aqueous extract of the solid, and whether inorganics, semivolatile organics, pesticides, and herbicides are all analytes of concern. Enough solids should be generated for extraction such that the volume of 1312 extract will be sufficient to support all of the analyses required. If the amount of extract generated by a single 1312 extraction will not be sufficient to perform all of the analyses, more than one extraction may be performed and the extracts from each combined and aliquoted for analysis.

7.2.1 If the sample will obviously yield no liquid when subjected to pressure filtration (i.e., is 100 % solid, see Step 7.1.1), weigh out a subsample of the sample (100 gram minimum) and proceed to Step 7.2.9.

7.2.2 If the sample is liquid or multiphasic, liquid/solid separation is required. This involves the filtration device described in Step 4.3.2 and is outlined in Steps 7.2.3 to 7.2.8.

7.2.3 Pre-weigh the container that will receive the filtrate.

7.2.4 Assemble the filter holder and filter following the manufacturer's instructions. Place the filter on the support screen and secure. Acid wash the filter if evaluating the mobility of metals (see Step 4.4).

NOTE: Acid washed filters may be used for all nonvolatile extractions even when metals are not of concern.

7.2.5 Weigh out a subsample of the sample (100 gram minimum) and record the weight. If the waste contains <0.5 % dry solids (Step 7.1.2), the liquid portion of the waste, after filtration, is defined as the 1312 extract. Therefore, enough of the sample should be filtered so that the amount of filtered liquid will support all of the analyses required of the 1312 extract. For wastes containing >0.5 % dry solids (Steps 7.1.1 or 7.1.2), use the percent solids information obtained in Step 7.1.1 to determine the optimum sample size (100 gram minimum) for filtration. Enough solids should be generated by filtration to support the analyses to be performed on the 1312 extract.

7.2.6 Allow slurries to stand to permit the solid phase to settle. Samples that settle slowly may be centrifuged prior to filtration. Use centrifugation only as an aid to filtration. If the sample is centrifuged, the liquid should be decanted and filtered followed by filtration of the solid portion of the waste through the same filtration system.

7.2.7 Quantitatively transfer the sample (liquid and solid phases) to the filter holder (see Step 4.3.2). Spread the waste sample evenly over the surface of the filter. If filtration of the waste at 4°C reduces the amount of expressed liquid over what would be expressed at room temperature, then allow the sample to warm up to room temperature in the device before filtering.

Gradually apply vacuum or gentle pressure of 1-10 psig, until air or pressurizing gas moves through the filter. If this point if not reached under 10 psig, and if no additional liquid has passed through the filter in any 2-minute interval, slowly increase the pressure in 10-psig increments to maximum of 50 psig. After each incremental increase of 10 psig, if the pressurizing gas has not moved through the filter, and if no additional liquid has passed through the filter in any 2-minute interval, proceed to the next 10-psig increment. When the pressurizing gas begins to move through the filter, or when the liquid flow has ceased at 50 psig (i.e., filtration does not result in any additional filtrate within a 2-minute period), stop the filtration.

> NOTE: If waste material (>1 % of the original sample weight) has obviously adhered to the container used to transfer the sample to the filtration apparatus, determine the weight of this residue and subtract it from the sample weight determined in Step 7.2.5, to determine the weight of the waste sample that will be filtered.
>
> NOTE: Instantaneous application of high pressure can degrade the glass fiber filter and may cause premature plugging.

7.2.8 The material in the filter holder is defined as the solid phase of the sample, and the filtrate is defined as the liquid phase. Weigh the filtrate. The liquid phase may now be either analyzed (see Step 7.2.12) or stored at 4°C until time of analysis.

> NOTE: Some wastes, such as oily wastes and some paint wastes, will obviously contain some material which appears to be a liquid. Even after applying vacuum or pressure filtration, as outlined in Step 7.2.7, this material may not filter. If this is the case, the material within the filtration device is defined as a solid, and is carried through the extraction as a solid. Do not replace the original filter with a fresh filter under any circumstances. Use only one filter.

7.2.9 If the sample contains <0.5% dry solids (see Step 7.1.2), proceed to Step 7.2.13. If the sample contains >0.5 % dry solids (see Step 7.1.1 or 7.1.2), and if particle-size reduction of the solid was needed in Step 7.1.3, proceed to Step 7.2.10. If the sample as received passes a 9.5 mm sieve, quantitatively transfer the solid material into the extractor bottle along with the filter used to separate the initial liquid from the solid phase, and proceed to Step 7.2.11.

7.2.10 Prepare the solid portion of the sample for extraction by crushing, cutting, or grinding the waste to a surface area or particle-size as described in Step 7.1.3. When the surface area or particle-size has been appropriately altered, quantitatively transfer the solid material into an extractor bottle. Include the filter used to separate the initial liquid from the solid phase.

> NOTE: Sieving of the waste is not normally required. Surface area requirements are meant for filamentous (e.g., paper, cloth) and similar waste materials. Actual measurement of surface area is not recommended. If sieving is necessary, a Teflon-coated sieve should be used to avoid contamination of the sample.

7.2.11 Determine the amount of extraction fluid to add to the extractor vessel as follows:

$$\text{Weight of extraction fluid} = \frac{20 \times \%\ \text{solids (Step 7.1.1)} \times \text{weight of waste filtered (Step 7.2.5 or 7.2.7)}}{100}$$

Slowly add this amount of appropriate extraction fluid (see Step 7.1.4) to the extractor vessel. Close the extractor bottle tightly (it is recommended that Teflon tape be used to ensure a tight seal), secure in rotary extractor device, and rotate at 30 ± 2 rpm for 18 ± 2 hours. Ambient temperature (i.e., temperature of room in which extraction takes place) shall be maintained at 23 ± 2°C during the extraction period.

> NOTE: As agitation continues, pressure may build up within the extractor bottle for some types of sample (e.g., limed or calcium carbonate-containing sample may evolve gases such as carbon dioxide). To relieve excess pressure, the extractor bottle may be periodically opened (e.g., after 15 minutes, 30 minutes, and 1 hour) and vented into a hood.

7.2.12 Following the 18 ± 2 hour extraction, separate the material in the extractor vessel into its component liquid and solid phases by filtering through a new glass fiber filter, as outlined in Step 7.2.7. For final filtration of the 1312 extract, the glass fiber filter may be changed, if necessary, to facilitate filtration. Filter(s) shall be acid-washed (see Step 4.4) if evaluating the mobility of metals.

7.2.13 Prepare the 1312 extract as follows:

7.2.13.1 If the sample contained no initial liquid phase, the filtered liquid material obtained from Step 7.2.12 is defined as the 1312 extract. Proceed to Step 7.2.14.

7.2.13.2 If compatible (e.g., multiple phases will not result on combination), combine the filtered liquid resulting from Step 7.2.12 with the initial liquid phase of the sample obtained in Step 7.2.7. This combined liquid is defined as the 1312 extract. Proceed to Step 7.2.14.

7.2.13.3 If the initial liquid phase of the waste, as obtained from Step 7.2.7, is not or may not be compatible with the filtered liquid resulting from Step 7.2.12, do not combine these liquids. Analyze these liquids, collectively defined as the 1312 extract, and combine the results mathematically, as described in Step 7.2.14.

7.2.14 Following collection of the 1312 extract, the pH of the extract should be recorded. Immediately aliquot and preserve the extract for analysis. Metals aliquots must be acidified with nitric acid to pH < 2. If precipitation is observed upon addition of nitric acid to a small aliquot of the extract, then the remaining portion of the extract for metals analyses shall not be acidified and the extract shall be analyzed as soon as possible. All other aliquots must be stored under refrigeration (4C) until analyzed. The 1312 extract shall be prepared and analyzed according to appropriate analytical methods. 1312 extracts to be analyzed for metals shall be acid digested except in those instances where digestion causes loss of metallic analytes. If an analysis of the undigested extract shows that the concentration of any regulated metallic analyte exceeds the regulatory level, then the waste is hazardous and digestion of the extract is not necessary. However, data on undigested extracts alone cannot be used to demonstrate that the waste is not hazardous. If the individual phases are to be analyzed separately, determine the volume of the individual phases (to ± 0.5 %), conduct the appropriate analyses, and combine the results mathematically by using a simple volume-weighted average:

$$\text{Final Analyte Concentration} = \frac{(V_1)\ (C_1) + (V_2)\ (C_2)}{V_1 + V_2}$$

where:

V_1 = The volume of the first phase (L).
C_1 = The concentration of the analyte of concern in the first phase (mg/L).
V_2 = The volume of the second phase (L).
C_2 = The concentration of the analyte of concern in the second phase (mg/L).

7.2.15 Compare the analyte concentrations in the 1312 extract with the levels identified in the appropriate regulations. Refer to Section 8.0 for quality assurance requirements.

7.3 Procedure When Volatiles Are Involved

Use the ZHE device to obtain 1312 extract for analysis of volatile compounds only. Extract resulting from the use of the ZHE shall not be used to evaluate the mobility of non-volatile analytes (e.g., metals, pesticides, etc.).

The ZHE device has approximately a 500 mL internal capacity. The ZHE can thus accommodate a maximum of 25 grams of solid (defined as that fraction of a sample from which no additional liquid may be forced out by an applied pressure of 50 psig), due to the need to add an amount of extraction fluid equal to 20 times the weight of the solid phase.

Charge the ZHE with sample only once and do not open the device until the final extract (of the solid) has been collected. Repeated filling of the ZHE to obtain 25 grams of solid is not permitted.

Do not allow the sample, the initial liquid phase, or the extract to be exposed to the atmosphere for any more time than is absolutely necessary. Any manipulation of these materials should be done when cold (4°C) to minimize loss of volatiles.

7.3.1 Pre-weigh the (evacuated) filtrate collection container (see Step 4.6) and set aside. If using a TEDLAR® bag, express all liquid from the ZHE device into the bag, whether for the initial or final liquid/solid separation, and take an aliquot from the liquid in the bag for analysis. The containers listed in Step 4.6 are recommended for use under the conditions stated in Steps 4.6.1-4.6.3.

7.3.2 Place the ZHE piston within the body of the ZHE (it may be helpful first to moisten the piston O-rings slightly with extraction fluid). Adjust the piston within the ZHE body to a height that will minimize the distance the piston will have to move once the ZHE is charged with sample (based upon sample size requirements determined from Step 7.3, Step 7.1.1 and/or 7.1.2). Secure the gas inlet/outlet flange (bottom flange) onto the ZHE body in accordance with the manufacturer's instructions. Secure the glass fiber filter between the support screens and set aside. Set liquid inlet/outlet flange (top flange) aside.

7.3.3 If the sample is 100% solid (see Step 7.1.1), weigh out a subsample (25 gram maximum) of the waste, record weight, and proceed to Step 7.3.5.

7.3.4 If the sample contains <0.5% dry solids (Step 7.1.2), the liquid portion of waste, after filtration, is defined as the 1312 extract. Filter enough of the sample so that the amount of filtered liquid will support all of the volatile analyses required. For samples containing ≥0.5% dry solids (Steps 7.1.1 and/or 7.1.2), use the percent solids information obtained in Step 7.1.1 to determine the optimum sample size to charge into the ZHE. The recommended sample size is as follows:

7.3.4.1 For samples containing <5% solids (see Step 7.1.1), weigh out a 500 gram subsample of waste and record the weight.

7.3.4.2 For wastes containing >5% solids (see Step 7.1.1), determine the amount of waste to charge into the ZHE as follows:

$$\text{Weight of waste to charge ZHE} = \frac{25}{\text{percent solids (Step 7.1.1)}} \times 100$$

Weigh out a subsample of the waste of the appropriate size and record the weight.

7.3.5 If particle-size reduction of the solid portion of the sample was required in Step 7.1.3, proceed to Step 7.3.6. If particle-size reduction was not required in Step 7.1.3, proceed to Step 7.3.7.

7.3.6 Prepare the sample for extraction by crushing, cutting, or grinding the solid portion of the waste to a surface area or particle size as described in Step 7.1.3.1. Wastes and appropriate reduction equipment should be refrigerated, if possible, to 4°C prior to particle-size reduction. The means used to effect particle-size reduction must not generate heat in and of itself. If reduction of the solid phase of the waste is necessary, exposure of the waste to the atmosphere should be avoided to the extent possible.

> NOTE: Sieving of the waste is not recommended due to the possibility that volatiles may be lost. The use of an appropriately graduated ruler is recommended as an acceptable alternative. Surface area requirements are meant for filamentous (*e.g.*, paper, cloth) and similar waste materials. Actual measurement of surface area is not recommended.

When the surface area or particle-size has been appropriately altered, proceed to Step 7.3.7.

7.3.7 Waste slurries need not be allowed to stand to permit the solid phase to settle. Do not centrifuge samples prior to filtration.

7.3.8 Quantitatively transfer the entire sample (liquid and solid phases) quickly to the ZHE. Secure the filter and support screens into the top flange of the device and secure the top flange to the ZHE body in accordance with the manufacturer's instructions. Tighten all ZHE fittings and place the device in the vertical position (gas inlet/outlet flange on the bottom). Do not attach the extraction collection device to the top plate.

> Note: If sample material (>1% of original sample weight) has obviously adhered to the container used to transfer the sample to the ZHE, determine the weight of this residue and subtract it from the sample weight determined in Step 7.3.4 to determine the weight of the waste sample that will be filtered.

Attach a gas line to the gas inlet/outlet valve (bottom flange) and, with the liquid inlet/outlet valve (top flange) open, begin applying gentle pressure of 1-10 psig (or more if necessary) to force all headspace slowly out of the ZHE device into a hood. At the first appearance of liquid from the liquid inlet/outlet valve, quickly close the valve and discontinue pressure. If filtration of the waste at 4°C reduces the amount of expressed liquid over what would be expressed at room temperature, then allow the sample to warm up to room temperature in the device before filtering. If the waste is 100 % solid (see Step 7.1.1), slowly increase the pressure to a maximum of 50 psig to force most of the headspace out of the device and proceed to Step 7.3.12.

7.3.9 Attach the evacuated pre-weighed filtrate collection container to the liquid inlet/outlet valve and open the valve. Begin applying gentle pressure of 1-10 psig to force the liquid phase of the sample into the filtrate collection container. If no additional liquid has passed through the filter in any 2-minute interval, slowly increase the pressure in 10-psig increments to a maximum of 50 psig. After each incremental increase of 10 psig, if no additional liquid has passed through the filter in any 2-minute interval, proceed to the next 10-psig increment. When liquid flow has ceased such that continued pressure filtration at 50 psig does not result in any additional filtrate within a 2-minute period, stop the filtration. Close the liquid inlet/outlet valve, discontinue pressure to the piston, and disconnect and weigh the filtrate collection container.

> NOTE: Instantaneous application of high pressure can degrade the glass fiber filter and may cause premature plugging.

7.3.10 The material in the ZHE is defined as the solid phase of the sample and the filtrate is defined as the liquid phase.

> NOTE: Some samples, such as oily wastes and some paint wastes, will obviously contain some material which appears to be a liquid. Even after applying pressure filtration, this material will not filter. If this is the case, the material within the filtration device is defined as a solid, and is carried through the 1312 extraction as a solid.

If the original waste contained <0.5 % dry solids (see Step 7.1.2), this filtrate is defined as the 1312 extract and is analyzed directly. Proceed to Step 7.3.15.

7.3.11 The liquid phase may now be either analyzed immediately (see Steps 7.3.13 through 7.3.15) or stored at 4°C under minimal headspace conditions until time of analysis. Determine the weight of extraction fluid #3 to add to the ZHE as follows:

$$\text{Weight of extraction fluid} = \frac{\begin{array}{c}20 \times \%\ \text{solids (Step 7.1.1)} \times \text{weight}\\ \text{of waste filtered (Step 7.3.4 or 7.3.8)}\end{array}}{100}$$

7.3.12 The following steps detail how to add the appropriate amount of extraction fluid to the solid material within the ZHE and agitation of the ZHE vessel. Extraction fluid #3 is used in all cases (see Step 5.4.3).

7.3.12.1 With the ZHE in the vertical position, attach a line from the extraction fluid reservoir to the liquid inlet/outlet valve. The line used shall contain fresh extraction fluid and should be preflushed with fluid to eliminate any air pockets in the line. Release gas pressure on the ZHE piston (from the gas inlet/outlet valve), open the liquid inlet/outlet valve, and begin transferring extraction fluid (by pumping or similar means) into the ZHE. Continue pumping extraction fluid into the ZHE until the appropriate amount of fluid has been introduced into the device.

7.3.12.2 After the extraction fluid has been added, immediately close the liquid inlet/outlet valve and disconnect the extraction fluid line. Check the ZHE to ensure that all valves are in their closed positions. Manually rotate the device in an end-over-end fashion 2 or 3 times. Reposition the ZHE in the vertical position with the liquid inlet/outlet valve on top. Pressurize the ZHE to 5-10 psig (if necessary) and slowly open the liquid inlet/outlet valve to bleed out any headspace (into a hood) that may have been introduced due to the addition of extraction fluid. This bleeding shall be done quickly and shall be stopped at the first appearance of liquid from the valve. Re-pressurize the ZHE with 5-10 psig and check all ZHE fittings to ensure that they are closed.

7.3.12.3 Place the ZHE in the rotary extractor apparatus (if it is not already there) and rotate at 30 ± 2 rpm for 18 ± 2 hours. Ambient temperature (i.e., temperature of room in which extraction occurs) shall be maintained at 23 ± 2°C during agitation.

7.3.13 Following the 18 ± 2 hour agitation period, check the pressure behind the ZHE piston by quickly opening and closing the gas inlet/outlet valve and noting the escape of gas. If the pressure has not been maintained (i.e., no gas release observed), the ZHE is leaking. Check the ZHE for leaking as specified in Step 4.2.1, and perform the extraction again with a new sample of waste. If the pressure within the device has been maintained, the material in the extractor vessel is once again separated into its component liquid and solid phases. If the waste contained an initial liquid phase, the liquid may be filtered directly into the same filtrate collection container (i.e., TEDLAR® bag) holding the initial liquid phase of the waste. A separate filtrate collection container must be used if combining would create multiple phases, or there is not enough volume left within the filtrate collection container. Filter through the glass fiber filter, using the ZHE device as discussed in Step 7.3.9. All extracts shall be filtered and collected if the TEDLAR® bag is used, if the extract is multiphasic, or if the waste contained an initial liquid phase (see Steps 4.6 and 7.3.1).

NOTE: An in-line glass fiber filter may be used to filter the material within the ZHE if it is suspected that the glass fiber filter has been ruptured

7.3.14 If the original sample contained no initial liquid phase, the filtered liquid material obtained from Step 7.3.13 is defined as the 1312 extract. If the sample contained an initial liquid phase, the filtered liquid material obtained from Step 7.3.13 and the initial liquid phase (Step 7.3.9) are collectively defined as the 1312 extract.

7.3.15 Following collection of the 1312 extract, immediately prepare the extract for analysis and store with minimal headspace at 4°C until analyzed. Analyze the 1312 extract according to the appropriate analytical methods. If the individual phases are to be analyzed separately (<u>i.e.</u>, are not miscible), determine the volume of the individual phases (to 0.5%), conduct the appropriate analyses, and combine the results mathematically by using a simple volume- weighted average:

$$\text{Final Analyte Concentration} = \frac{(V_1)\ (C_1) + (V_2)\ (C_2)}{V_1 + V_2}$$

where:

V_1 = The volume of the first phases (L).
C_1 = The concentration of the analyte of concern in the first phase (mg/L).
V_2 = The volume of the second phase (L).
C_2 = The concentration of the analyte of concern in the second phase (mg/L).

7.3.16 Compare the analyte concentrations in the 1312 extract with the levels identified in the appropriate regulations. Refer to Step 8.0 for quality assurance requirements.

8.0 QUALITY CONTROL

8.1 A minimum of one blank (using the same extraction fluid as used for the samples) for every 20 extractions that have been conducted in an extraction vessel. Refer to Chapter One for additional quality control protocols.

8.2 A matrix spike shall be performed for each waste type (<u>e.g.</u>, wastewater treatment sludge, contaminated soil, etc.) unless the result exceeds the regulatory level and the data is being used solely to demonstrate that the waste property exceeds the regulatory level. A minimum of one matrix spike must be analyzed for each analytical batch. As a minimum, follow the matrix spike addition guidance provided in each analytical method.

8.2.1 Matrix spikes are to be added after filtration of the 1312 extract and before preservation. Matrix spikes should not be added prior to 1312 extraction of the sample.

8.2.2 In most cases, matrix spike levels should be added at a concentration equivalent to the corresponding regulatory level. If the analyte concentration is less than one half the regulatory level, the spike concentration may be as low as one half of the analyte concentration, but may not be less than five times the method detection limit. In order to avoid differences in matrix effects, the matrix spikes must be added to the same nominal volume of 1312 extract as that which was analyzed for the unspiked sample.

8.2.3 The purpose of the matrix spike is to monitor the performance of the analytical methods used, and to determine whether matrix interferences exist. Use of other internal calibration methods, modification of the analytical methods, or use of alternate analytical methods may be needed to accurately measure the analyte concentration in the 1312 extract when the recovery of the matrix spike is below the expected analytical method performance.

8.2.4 Matrix spike recoveries are calculated by the following formula:

$$\%R\ (\%\ \text{Recovery}) = 100\ (X_s - X_u)\ /\ K$$

where:

X_s = measured value for the spiked sample
X_u = measured value for the unspiked sample, and
K = known value of the spike in the sample.

8.3 All quality control measures described in the appropriate analytical methods shall be followed.

8.4 The use of internal calibration quantitation methods shall be employed for a metallic contaminant if: (1) Recovery of the contaminant from the 1312 extract is not at least 50% and the concentration does not exceed the appropriate regulatory level, and (2) The concentration of the contaminant measured in the extract is within 20% of the appropriate regulatory level.

8.4.1. The method of standard additions shall be employed as the internal calibration quantitation method for each metallic contaminant.

8.4.2 The method of standard additions requires preparing calibration standards in the sample matrix rather than reagent water or blank solution. It requires taking four identical aliquots of the solution and adding known amounts of standard to three of these aliquots. The forth aliquot is the unknown. Preferably, the first addition should be prepared so that the resulting concentration is approximately 50% of the expected concentration of the sample. The second and third additions should be prepared so that the concentrations are approximately 100% and 150% of the expected concentration of the sample. All four aliquots are maintained at the same final volume by adding reagent water or a blank solution, and may need dilution adjustment to maintain the signals in the linear range of the instrument technique. All four aliquots are analyzed.

8.4.3 Prepare a plot, or subject data to linear regression, of instrument signals or external-calibration-derived concentrations as the dependant variable (y-axis) versus concentrations of the additions of standards as the independent variable (x-axis). Solve for the intercept of the abscissa (the independent variable, x-axis) which is the concentration in the unknown.

8.4.4 Alternately, subtract the instrumental signal or external-calibration-derived concentration of the unknown (unspiked) sample from the instrumental signals or external-calibration-derived concentrations of the standard additions. Plot or subject to linear regression of the corrected instrument signals or external-calibration-derived concentrations as the dependant variable versus the independent variable. Derive concentrations for the unknowns using the internal calibration curve as if it were an external calibration curve.

8.5 Samples must undergo 1312 extraction within the following time periods:

SAMPLE MAXIMUM HOLDING TIMES (days)

	From: Field Collection To: 1312 extraction	From: 1312 extraction To: Preparative extraction	From: Preparative extraction To: Determinative analysis	Total Elapsed Time
Volatiles	14	NA	14	28
Semi-volatiles	14	7	40	61
Mercury	28	NA	28	56
Metals, except mercury	180	NA	180	360
NA = Not Applicable				

If sample holding times are exceeded, the values obtained will be considered minimal concentrations. Exceeding the holding time is not acceptable in establishing that a waste does not exceed the regulatory level. Exceeding the holding time will not invalidate characterization if the waste exceeds the regulatory level.

9.0 METHOD PERFORMANCE

9.1 Precision results for semi-volatiles and metals: An eastern soil with high organic content and a western soil with low organic content were used for the semi-volatile and metal leaching experiments. Both types of soil were analyzed prior to contaminant spiking. The results are shown in Table 6. The concentration of contaminants leached from the soils were reproducible, as shown by the moderate relative standard deviations (RSDs) of the recoveries (averaging 29% for the compounds and elements analyzed).

9.2 Precision results for volatiles: Four different soils were spiked and tested for the extraction of volatiles. Soils One and Two were from western and eastern Superfund sites. Soils Three and Four were mixtures of a western soil with low organic content and two different municipal sludges. The results are shown in Table 7. Extract concentrations of volatile organics from the eastern soil were lower than from the western soil. Replicate leachings of Soils Three and Four showed lower precision than the leachates from the Superfund soils.

10.0 REFERENCES

1. Environmental Monitoring Systems Laboratory, "Performance Testing of Method 1312: QA Support for RCRA Testing: Project Report". EPA/600/4-89/022. EPA Contract 68-03-3249 to Lockheed Engineering and Sciences Company, June 1989.

2. Research Triangle Institute, "Interlaboratory Comparison of Methods 1310, 1311, and 1312 for Lead in Soil". U.S. EPA Contract 68-01-7075, November 1988.

Table 1. Volatile Analytes[1]

Compound	CAS No.
Acetone	67-64-1
Benzene	71-43-2
n-Butyl alcohol	71-36-3
Carbon disulfide	75-15-0
Carbon tetrachloride	56-23-5
Chlorobenzene	108-90-7
Chloroform	67-66-3
1,2-Dichloroethane	107-06-2
1,1-Dichloroethylene	75-35-4
Ethyl acetate	141-78-6
Ethyl benzene	100-41-4
Ethyl ether	60-29-7
Isobutanol	78-83-1
Methanol	67-56-1
Methylene chloride	75-09-2
Methyl ethyl ketone	78-93-3
Methyl isobutyl ketone	108-10-1
Tetrachloroethylene	127-18-4
Toluene	108-88-3
1,1,1,-Trichloroethane	71-55-6
Trichloroethylene	79-01-6
Trichlorofluoromethane	75-69-4
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1
Vinyl chloride	75-01-4
Xylene	1330-20-7

---

[1] When testing for any or all of these analytes, the zero-headspace extractor vessel shall be used instead of the bottle extractor.

Table 2. Suitable Rotary Agitation Apparatus[1]

Company	Location	Model No.
Analytical Testing and Consulting Services, Inc.	Warrington, PA (215) 343-4490	4-vessel extractor (DC20S); 8-vessel extractor (DC20); 12-vessel extractor (DC20B)
Associated Design and Manufacturing Company	Alexandria, VA (703) 549-5999	2-vessel (3740-2); 4-vessel (3740-4); 6-vessel (3740-6); 8-vessel (3740-8); 12-vessel (3740-12); 24-vessel (3740-24)
Environmental Machine and Design, Inc.	Lynchburg, VA (804) 845-6424	8-vessel (08-00-00) 4-vessel (04-00-00)
IRA Machine Shop and Laboratory	Santurce, PR (809) 752-4004	8-vessel (011001)
Lars Lande Manufacturing	Whitmore Lake, MI (313) 449-4116	10-vessel (10VRE) 5-vessel (5VRE)
Millipore Corp.	Bedford, MA (800) 225-3384	4-ZHE or 4 1-liter bottle extractor (YT300RAHW)

---

[1] Any device that rotates the extraction vessel in an end-over-end fashion at 30 ±2 rpm is acceptable.

Table 3. Suitable Zero-Headspace Extractor Vessels[1]

Company	Location	Model No.
Analytical Testing & Consulting Services, Inc.	Warrington, PA (215) 343-4490	C102, Mechanical Pressure Device
Associated Design and Manufacturing Company	Alexandria, VA (703) 549-5999	3745-ZHE, Gas Pressure Device
Lars Lande Manufacturing[2]	Whitmore Lake, MI (313) 449-4116	ZHE-11, Gas Pressure Device
Millipore Corporation	Bedford, MA (800) 225-3384	YT30090HW, Gas Pressure Device
Environmental Machine and Design, Inc.	Lynchburg, VA (804) 845-6424	VOLA-TOX1, Gas Pressure Device

[1] Any device that meets the specifications listed in Step 4.2.1 of the method is suitable.

[2] This device uses a 110 mm filter.

Table 4. Suitable Filter Holders[1]

Company	Location	Model/ Catalogue #	Size
Nucleopore Corporation	Pleasanton, CA (800) 882-7711	425910 410400	142 mm 47 mm
Micro Filtration Systems	Dublin, CA (800) 334-7132 (415) 828-6010	302400 311400	142 mm 47 mm
Millipore Corporation	Bedford, MA (800) 225-3384	YT30142HW XX1004700	142 mm 47 mm

[1] Any device capable of separating the liquid from the solid phase of the waste is suitable, providing that it is chemically compatible with the waste and the constituents to be analyzed. Plastic devices (not listed above) may be used when only inorganic analytes are of concern. The 142 mm size filter holder is recommended.

Table 5. Suitable Filter Media[1]

Company	Location	Model	Pore Size (μm)
Millipore Corporation	Bedford, MA (800) 225-3384	AP40	0.7
Nucleopore Corporation	Pleasanton, CA (415) 463-2530	211625	0.7
Whatman Laboratory Products, Inc.	Clifton, NJ (201) 773-5800	GFF	0.7
Micro Filtration Systems	Dublin, CA (800) 334-7132 (415) 828-6010	GF75	0.7

[1] Any filter that meets the specifications in Step 4.4 of the Method is suitable.

TABLE 6 - METHOD 1312 PRECISION RESULTS FOR SEMI-VOLATILES AND METALS

		Eastern Soil (pH 4.2)		Western Soil (pH 5.0)	
	Amount Spiked (µg)	Amount Recovered* (µg)	% RSD	Amount Recovered* (µg)	% RSD
FORTIFIED ANALYTES					
bis(2-chloroethyl)-ether	1040	834	12.5	616	14.2
2-Chlorophenol	1620	1010	6.8	525	54.9
1,4-Dichlorobenzene	2000	344	12.3	272	34.6
1,2-Dichlorobenzene	8920	1010	8.0	1520	28.4
2-Methylphenol	3940	1860	7.7	1130	32.6
Nitrobenzene	1010	812	10.0	457	21.3
2,4-Dimethylphenol	1460	200	18.4	18	87.6
Hexachlorobutadiene	6300	95	12.9	280	22.8
Acenaphthene	3640	210	8.1	310**	7.7
2,4-Dinitrophenol	1300	896**	6.1	23**	15.7
2,4-Dinitrotoluene	1900	1150	5.4	585	54.4
Hexachlorobenzene	1840	3.7	12.0	10	173.2
gamma BHC (Lindane)	7440	230	16.3	1240	55.2
beta BHC	640	35	13.3	65.3	51.7
METALS					
Lead	5000	70	4.3	10	51.7
Cadmium	1000	387	2.3	91	71.3

* = Triplicate analyses.

** - Duplicate analyses; one value was rejected as an outlier at the 90% confidence level using the Dixon Q test.

TABLE 7 - METHOD 1312 PRECISION RESULTS FOR VOLATILES

	Soil No. 1 (Western)		Soil No. 2 (Eastern)		Soil No. 3 (Western and Sludge)		Soil No. 4 (Western and Sludge)	
Compound Name	Avg. %Rec.*	%RSD	Avg. %Rec.*	%RSD	Avg. %Rec.**	%RSD	Avg. %Rec.***	%RSD
Acetone	44.0	12.4	43.8	2.25	116.0	11.5	21.3	71.4
Acrylonitrile	52.5	68.4	50.5	70.0	49.3	44.9	51.8	4.6
Benzene	47.8	8.29	34.8	16.3	49.8	36.7	33.4	41.1
n-Butyl Alcohol (1-Butanol)	55.5	2.91	49.2	14.6	65.5	37.2	73.0	13.9
Carbon disulfide	21.4	16.4	12.9	49.5	36.5	51.5	21.3	31.5
Carbon tetrachloride	40.6	18.6	22.3	29.1	36.2	41.4	24.0	34.0
Chlorobenzene	64.4	6.76	41.5	13.1	44.2	32.0	33.0	24.9
Chloroform	61.3	8.04	54.8	16.4	61.8	29.1	45.8	38.6
1,2-Dichloroethane	73.4	4.59	68.7	11.3	58.3	33.3	41.2	37.8
1,1-Dichloroethane	31.4	14.5	22.9	39.3	32.0	54.4	16.8	26.4
Ethyl acetate	76.4	9.65	75.4	4.02	23.0	119.8	11.0	115.5
Ethylbenzene	56.2	9.22	23.2	11.5	37.5	36.1	27.2	28.6
Ethyl ether	48.0	16.4	55.1	9.72	37.3	31.2	42.0	17.6
Isobutanol (4-Methyl -1-propanol)	0.0	ND	0.0	ND	61.8	37.7	76.0	12.2
Methylene chloride	47.5	30.3	42.2	42.9	52.0	37.4	37.3	16.6
Methyl ethyl ketone (2-Butanone)	56.7	5.94	61.9	3.94	73.7	31.3	40.6	39.0
Methyl isobutyl ketone	81.1	10.3	88.9	2.99	58.3	32.6	39.8	40.3
1,1,1,2-Tetrachloroethane	69.0	6.73	41.1	11.3	50.8	31.5	36.8	23.8
1,1,2,2-Tetrachloroethane	85.3	7.04	58.9	4.15	64.0	25.7	53.6	15.8
Tetrachloroethene	45.1	12.7	15.2	17.4	26.2	44.0	18.6	24.2
Toluene	59.2	8.06	49.3	10.5	45.7	35.2	31.4	37.2
1,1,1-Trichloroethane	47.2	16.0	33.8	22.8	40.7	40.6	26.2	38.8
1,1,2-Trichloroethane	76.2	5.72	67.3	8.43	61.7	28.0	46.4	25.4
Trichloroethene	54.5	11.1	39.4	19.5	38.8	40.9	25.6	34.1
Trichlorofluoromethane	20.7	24.5	12.6	60.1	28.5	34.0	19.8	33.9
1,1,2-Trichlorotrifluoroethane	18.1	26.7	6.95	58.0	21.5	67.8	15.3	24.8
Vinyl chloride	10.2	20.3	7.17	72.8	25.0	61.0	11.8	25.4

* Triplicate analyses
** Six replicate analyses
*** Five replicate analyses

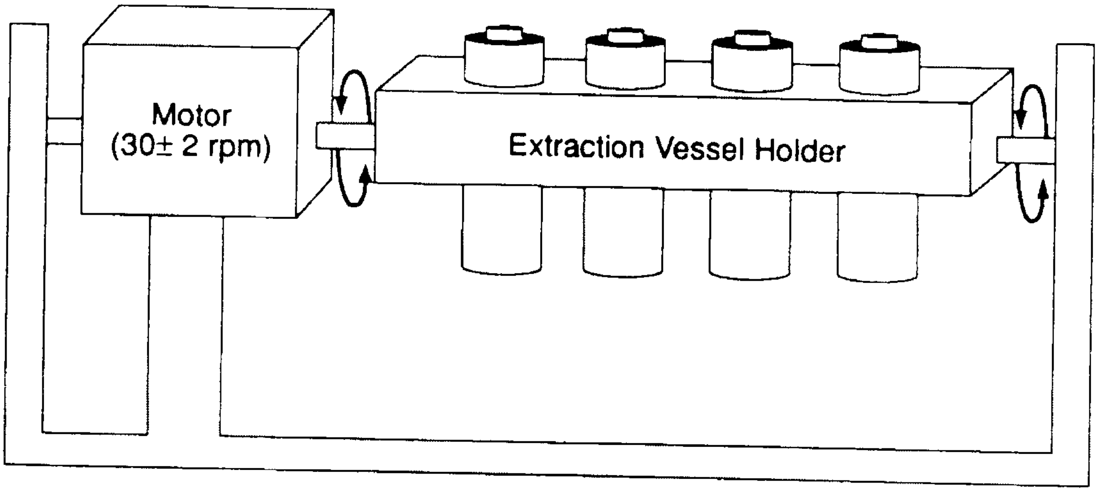


Figure 1. Rotary Agitation Apparatus

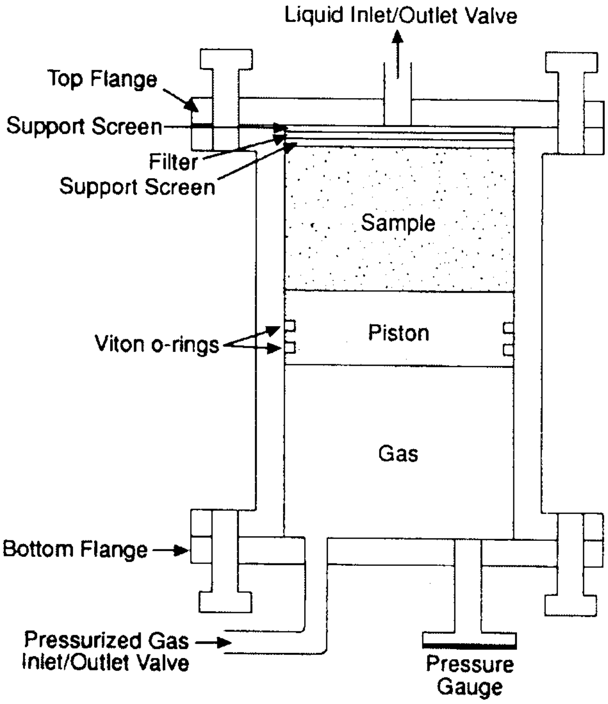
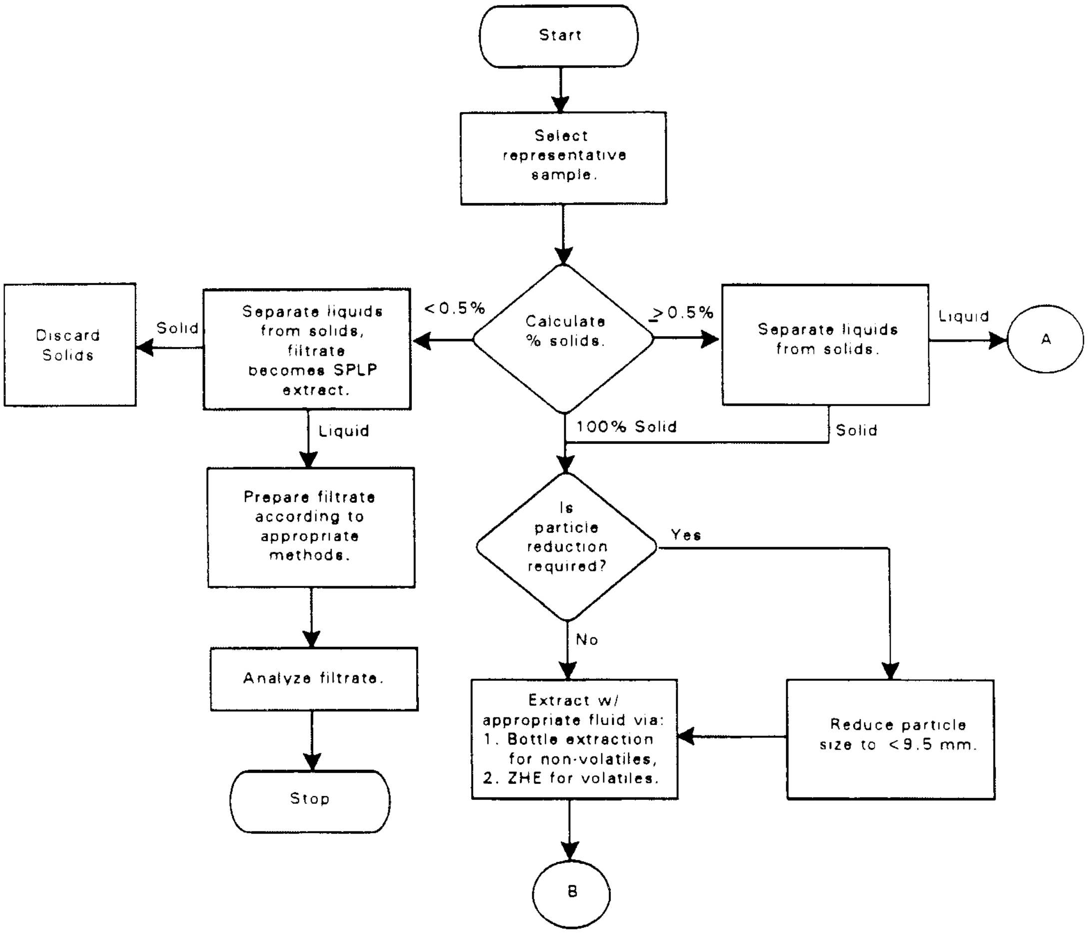
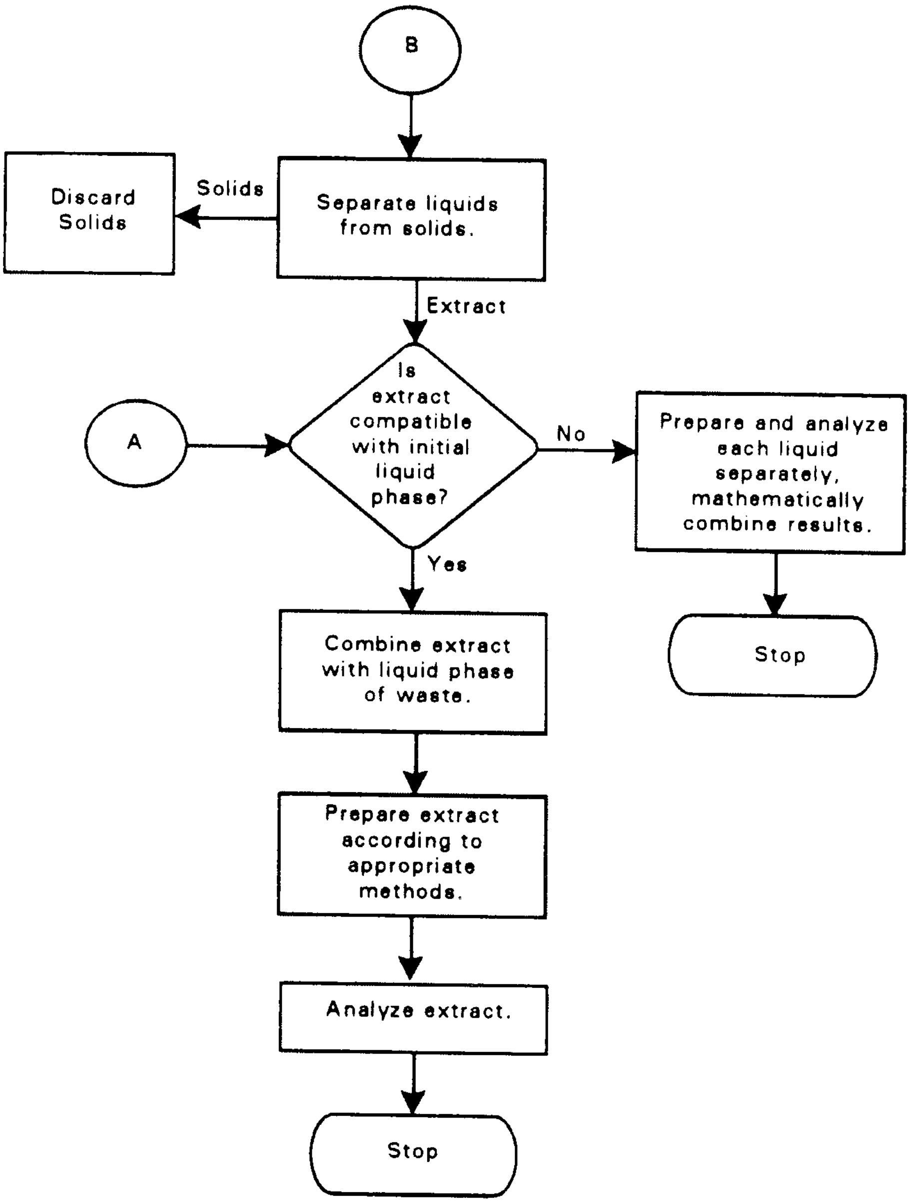


Figure 2. Zero-Headspace Extractor (ZHE)

METHOD 1312

SYNTHETIC PRECIPITATION LEACHING PROCEDURE




B
Discard Solids
Solids
Separate liquids from solids.
Extract
A
Is extract compatible with initial liquid phase?
No
Prepare and analyze each liquid separately, mathematically combine results.
Stop
Yes
Combine extract with liquid phase of waste.
Prepare extract according to appropriate methods.
Analyze extract.
Stop

APPENDIX D: SOIL CLASSIFICATIONS FOR TEST PLOTS

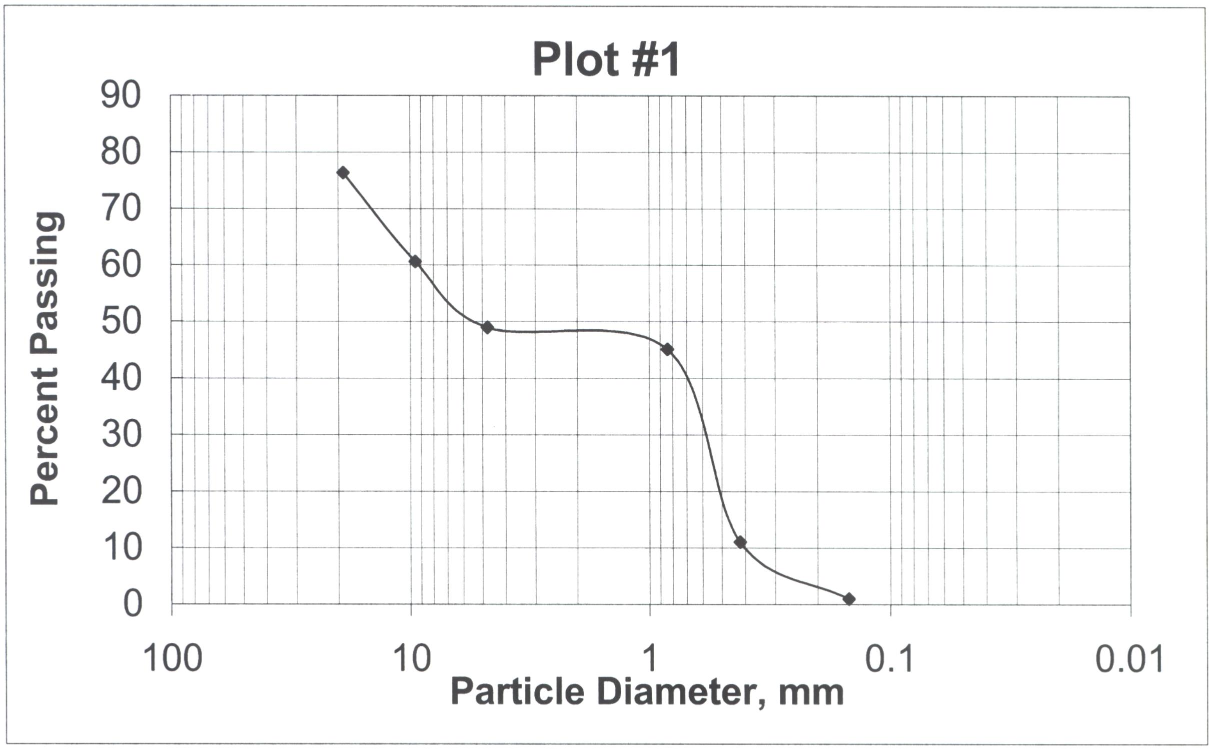
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Soil Properties	
K, Permeability (cm/s)	0.00016
e, Void Ratio	0.233
n, Porosity	0.189
ρ_d (kg/m^3)	1451.1
γ_d (kN/m^3)	14.24
ρ_{sat} (kg/m^3)	1789.5
γ_{sat} (kN/m^3)	17.55
ρ (kg/m^3)	1457.8
γ (kN/m^3)	14.30
w, Moisture content (%)	0.38
G_s, Specific Gravity	2.752

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	39.44
% Sands (retained on the No. 200 seive)	59.58
% Fines (passing through No. 200 seive)	0.89

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	9
D_{30}, particle diameter at 30% passing (mm)	0.58
D_{10}, particle diameter at 10% passing (mm)	0.4
C_c (Unconformity coefficient)	0.09
C_U (Gradation coeffeicient)	96.31



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #1 Sample Date: 5/16/01 Test Date: 6/27/01

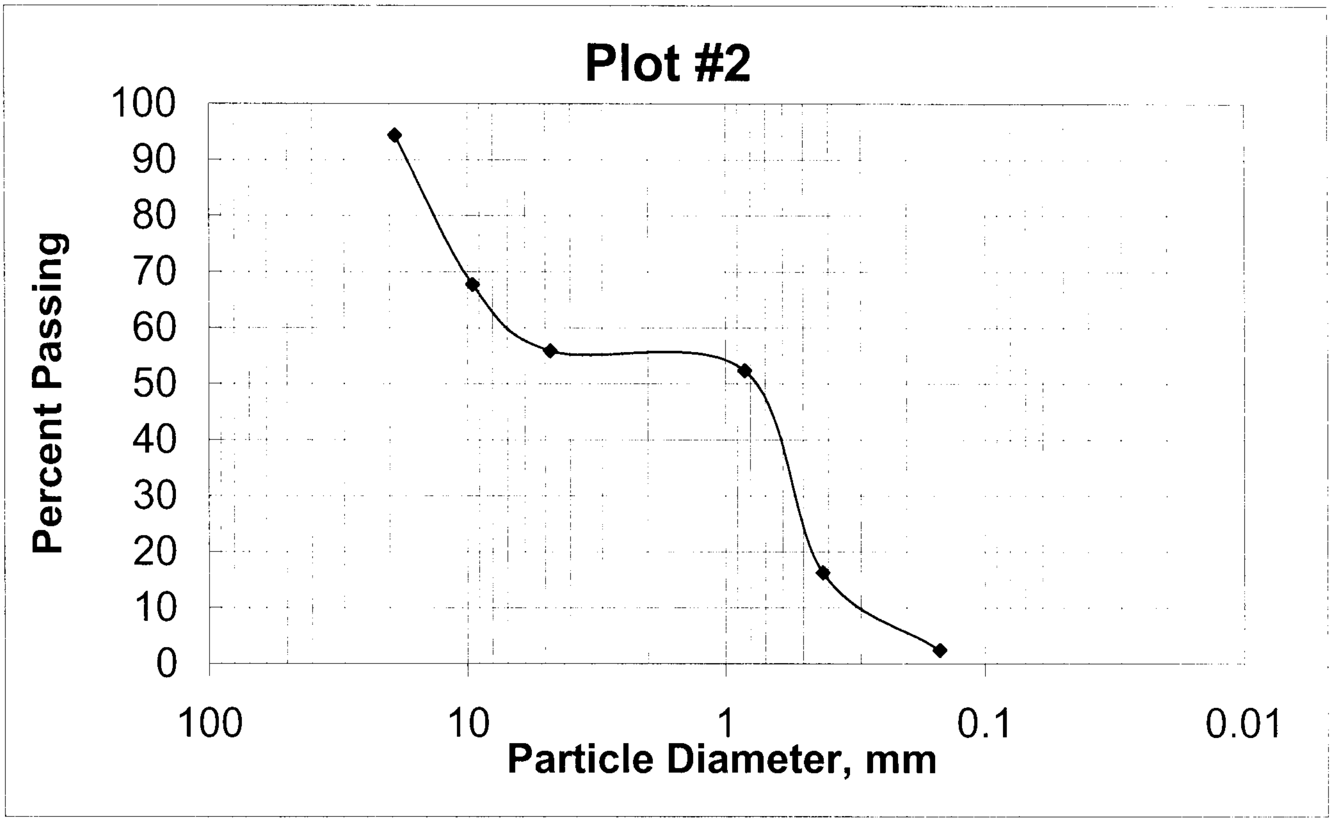
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Soil Properties	
K, Permeability (cm/s)	0.0003
e, Void Ratio	0.274
n, Porosity	0.215
ρ_d (kg/m^3)	1415.7
γ_d (kN/m^3)	13.89
ρ_{sat} (kg/m^3)	1803.3
γ_{sat} (kN/m^3)	17.69
ρ (kg/m^3)	1424.1
γ (kN/m^3)	13.97
w, Moisture content (%)	0.62
G_s, Specific Gravity	2.388

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	32.28
% Sands (retained on the No. 200 seive)	65.34
% Fines (passing through No. 200 seive)	2.30

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	7
D_{30}, particle diameter at 30% passing (mm)	0.55
D_{10}, particle diameter at 10% passing (mm)	0.2
C_c (Unconformity coefficient)	0.22
C_u (Gradation coeffeicient)	35.00



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #2 Sample Date: 5/16/01 Test Date: 6/27/01

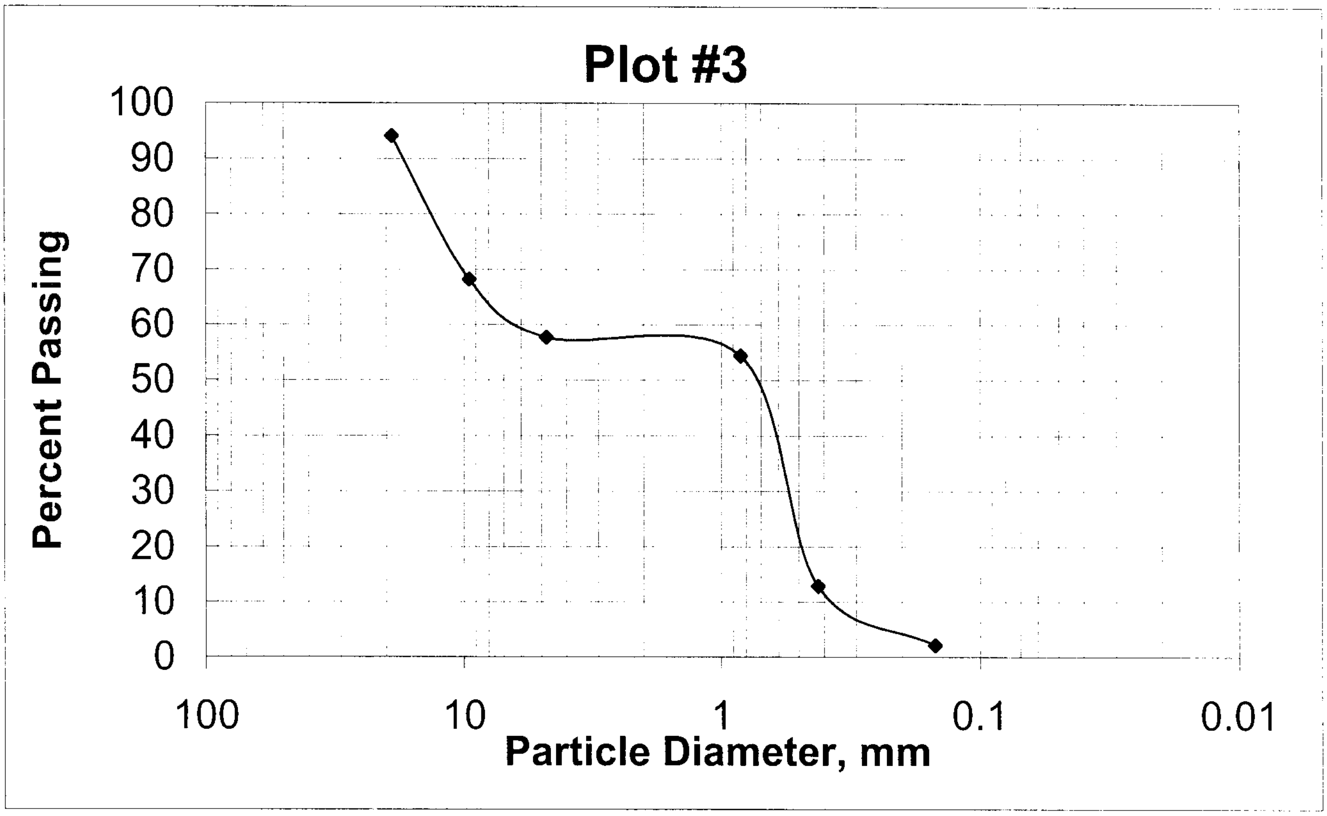
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Soil Properties	
K, Permeability (cm/s)	0.0004
e, Void Ratio	0.257
n, Porosity	0.204
ρ_d (kg/m^3)	1439.7
γ_d (kN/m^3)	14.12
ρ_{sat} (kg/m^3)	1809.3
γ_{sat} (kN/m^3)	17.75
ρ (kg/m^3)	1449.7
γ (kN/m^3)	14.22
w, Moisture content (%)	0.67
G_s, Specific Gravity	2.635

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	31.83
% Sands (retained on the No. 200 seive)	66.10
% Fines (passing through No. 200 seive)	2.01

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	6.5
D_{30}, particle diameter at 30% passing (mm)	0.55
D_{10}, particle diameter at 10% passing (mm)	0.39
C_c (Unconformity coefficient)	0.12
C_u (Gradation coeffeicient)	16.67



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #3 Sample Date: 5/16/01 Test Date: 6/27/01

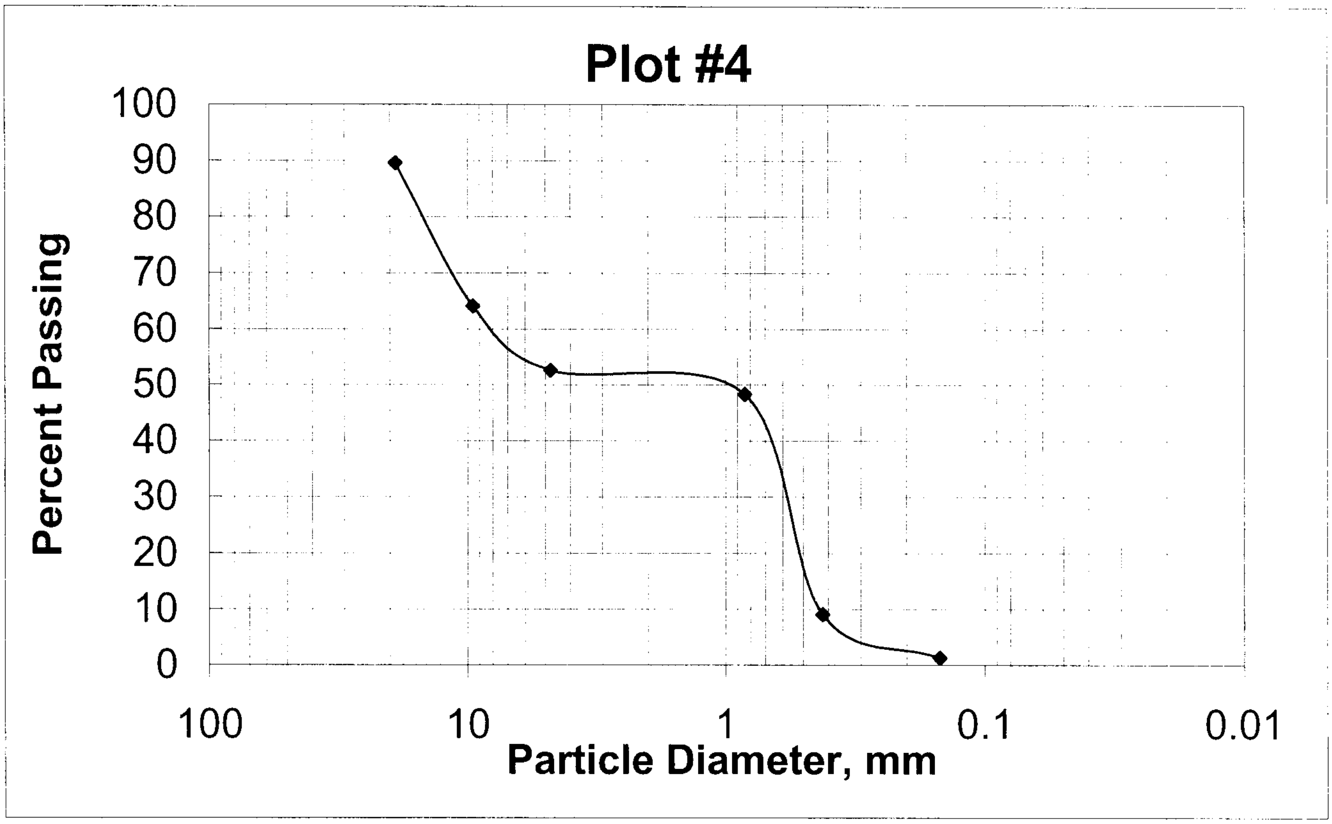
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	35.93
% Sands (retained on the No. 200 seive)	62.79
% Fines (passing through No. 200 seive)	0.60

Soil Properties	
K, Permeability (cm/s)	0.0003
e, Void Ratio	0.265
n, Porosity	0.209
ρ_d (kg/m^3)	1440.5
γ_d (kN/m^3)	14.13
ρ_{sat} (kg/m^3)	1821.5
γ_{sat} (kN/m^3)	17.87
ρ (kg/m^3)	1450.5
γ (kN/m^3)	14.23
w, Moisture content (%)	0.65
G_s, Specific Gravity	2.904

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	8
D_{30}, particle diameter at 30% passing (mm)	0.59
D_{10}, particle diameter at 10% passing (mm)	0.44
C_c (Unconformity coefficient)	0.10
C_u (Gradation coeffeicient)	18.18



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #4 Sample Date: 5/16/01 Test Date: 6/27/01

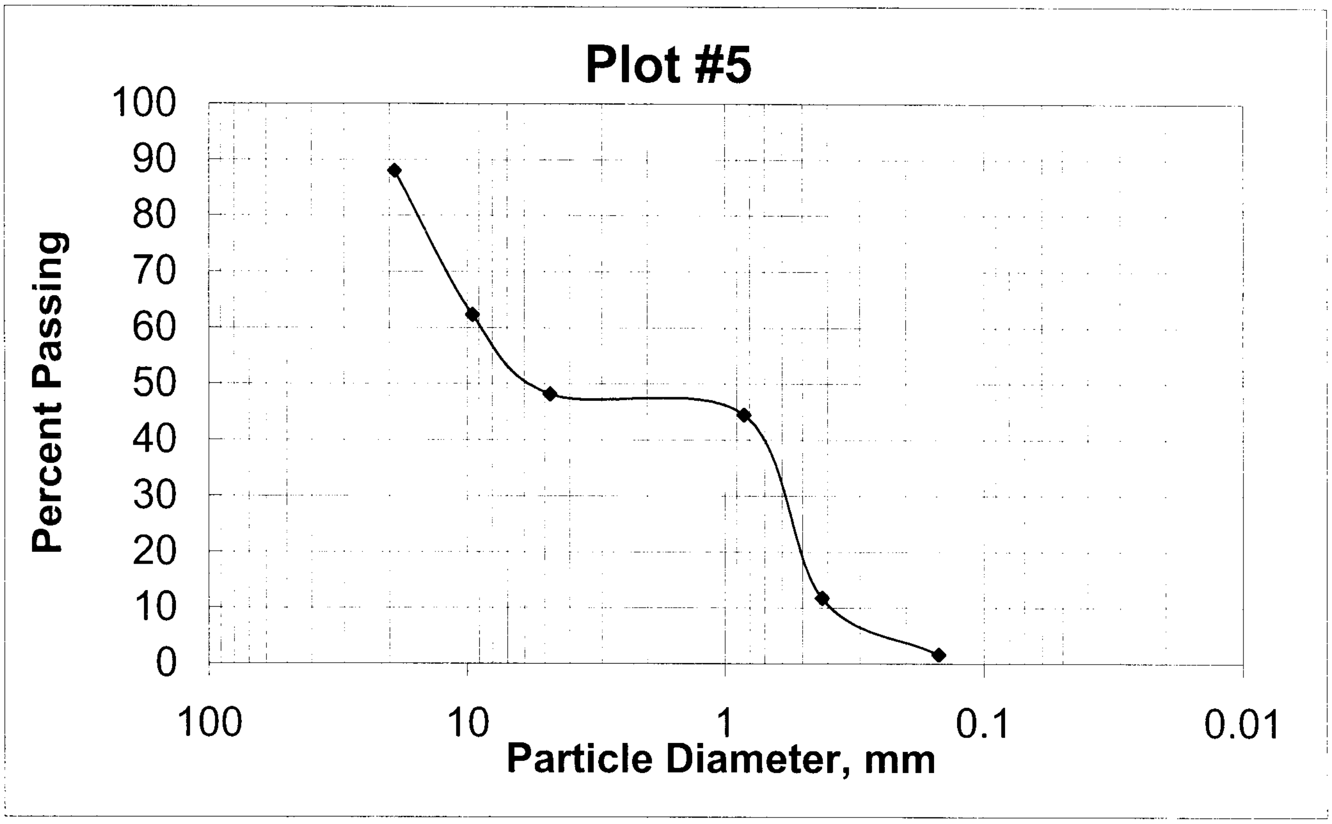
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Soil Properties	
K, Permeability (cm/s)	0.0005
e, Void Ratio	0.260
n, Porosity	0.206
ρ_d (kg/m^3)	1513.7
γ_d (kN/m^3)	14.85
ρ_{sat} (kg/m^3)	1907.0
γ_{sat} (kN/m^3)	17.87
ρ (kg/m^3)	1513.7
γ (kN/m^3)	14.93
w, Moisture content (%)	0.53
G_s, Specific Gravity	2.732

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	37.70
% Sands (retained on the No. 200 seive)	60.69
% Fines (passing through No. 200 seive)	1.56

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	9
D_{30}, particle diameter at 30% passing (mm)	0.6
D_{10}, particle diameter at 10% passing (mm)	0.4
C_c (Unconformity coefficient)	0.10
C_u (Gradation coeffeicient)	22.50



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #5 Sample Date: 5/16/01 Test Date: 6/27/01

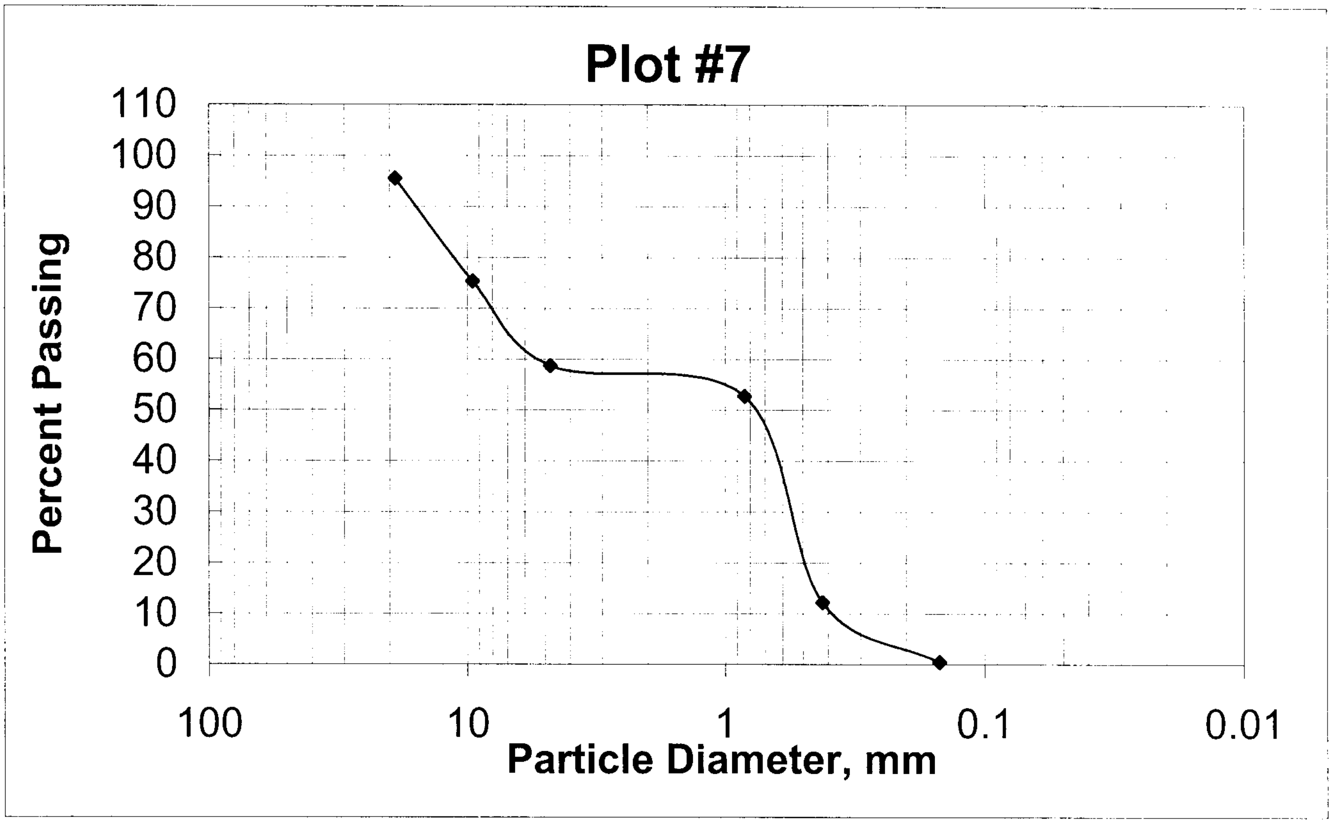
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Soil Properties	
K, Permeability (cm/s)	0.0001
e, Void Ratio	0.240
n, Porosity	0.193
ρ_d (kg/m^3)	881.32
γ_d (kN/m^3)	8.65
ρ_{sat} (kg/m^3)	1092.5
γ_{sat} (kN/m^3)	10.72
ρ (kg/m^3)	887.1
γ (kN/m^3)	8.70
w, Moisture content (%)	0.75
G_s, Specific Gravity	2.521

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	24.68
% Sands (retained on the No. 200 seive)	74.91
% Fines (passing through No. 200 seive)	0.42

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	5.5
D_{30}, particle diameter at 30% passing (mm)	0.55
D_{10}, particle diameter at 10% passing (mm)	0.4
C_c (Unconformity coefficient)	0.14
C_u (Gradation coeffeicient)	13.75



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #7 Sample Date: 5/16/01 Test Date: 6/27/01

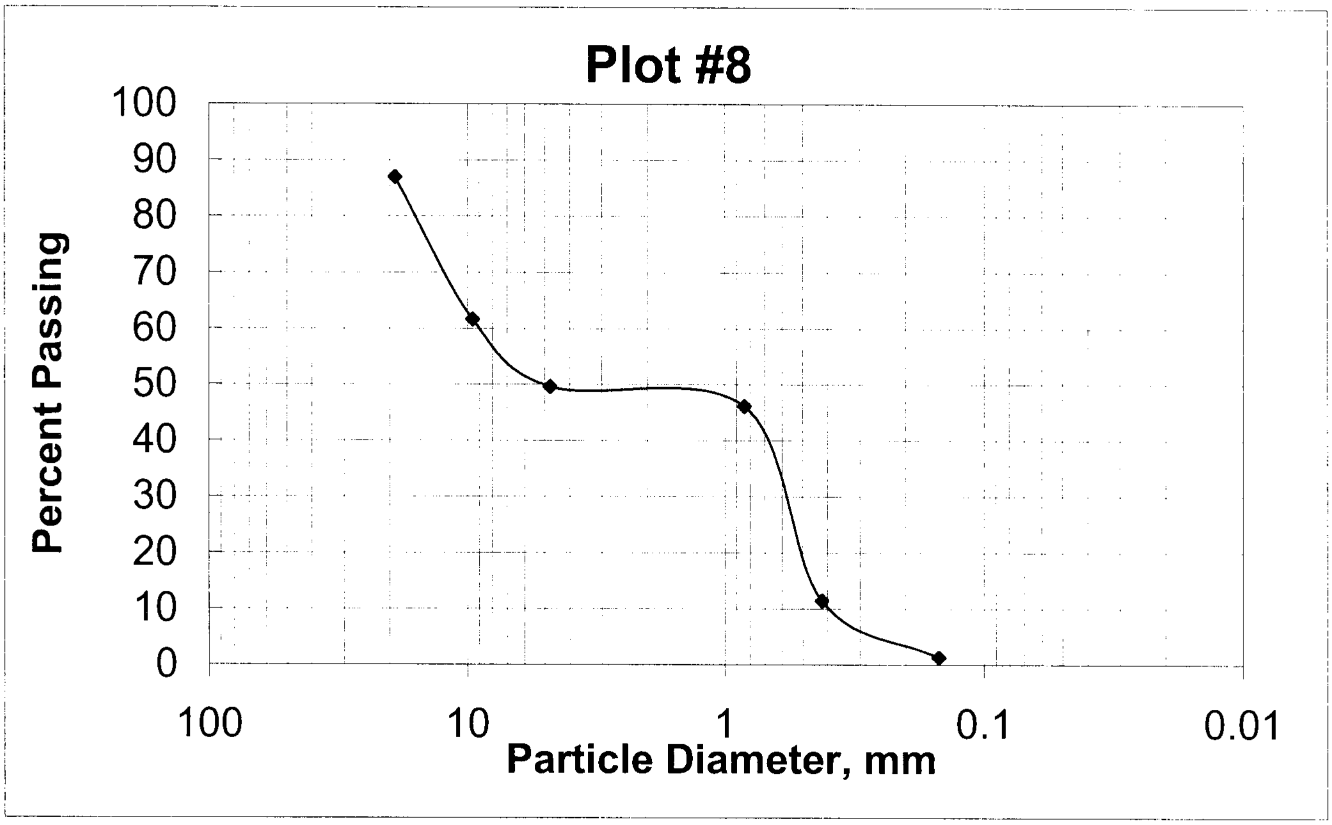
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Soil Properties	
K, Permeability (cm/s)	0.0003
e, Void Ratio	0.216
n, Porosity	0.178
ρ_d (kg/m^3)	1448.9
γ_d (kN/m^3)	14.21
ρ_{sat} (kg/m^3)	1762.3
γ_{sat} (kN/m^3)	17.29
ρ (kg/m^3)	1456.8
γ (kN/m^3)	14.29
w, Moisture content (%)	0.74
G_s, Specific Gravity	2.635

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	38.38
% Sands (retained on the No. 200 seive)	60.37
% Fines (passing through No. 200 seive)	1.10

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	9
D_{30}, particle diameter at 30% passing (mm)	0.58
D_{10}, particle diameter at 10% passing (mm)	0.3
C_c (Unconformity coefficient)	0.12
C_u (Gradation coeffeicient)	30.00



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #8 Sample Date: 5/16/01 Test Date: 6/27/01

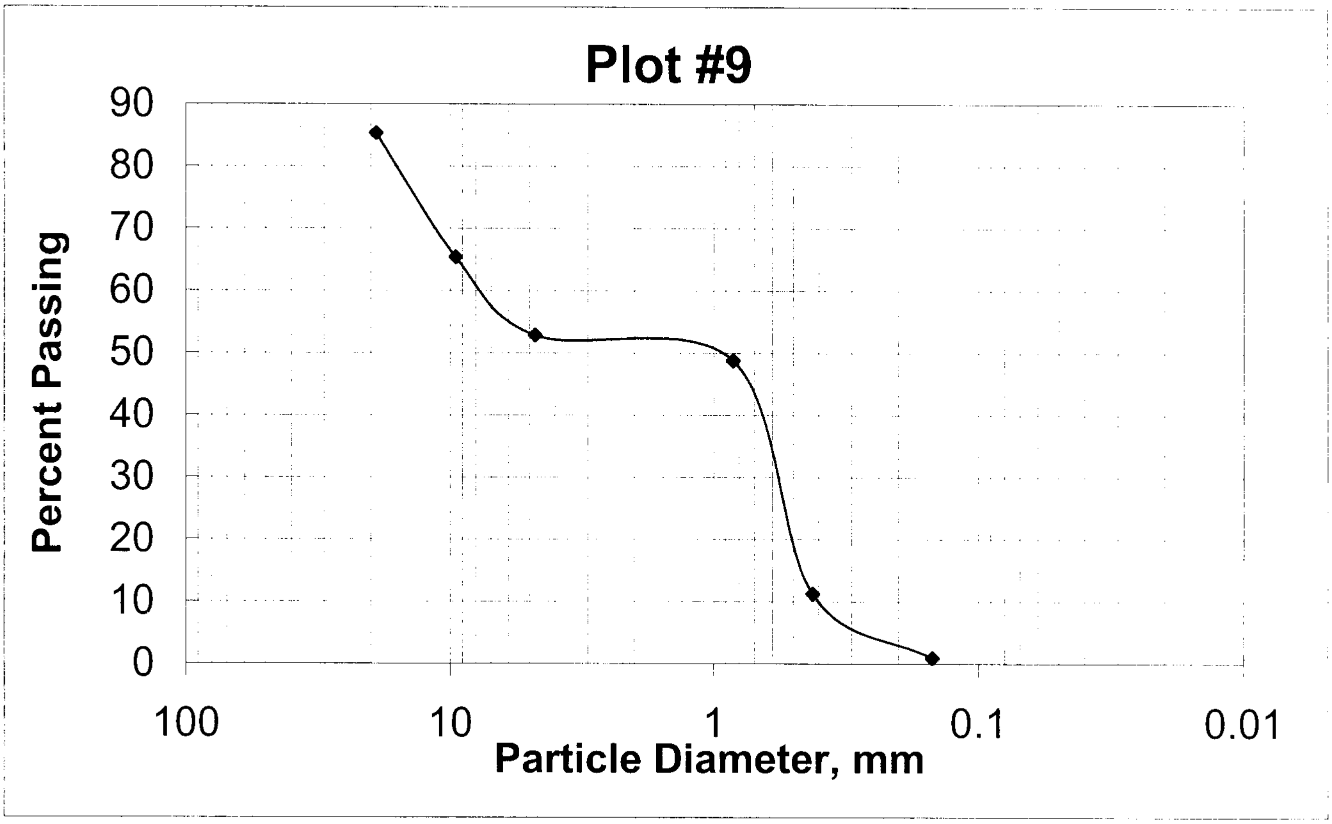
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	34.68
% Sands (retained on the No. 200 seive)	64.46
% Fines (passing through No. 200 seive)	0.87

Soil Properties	
K, Permeability (cm/s)	0.0003
e, Void Ratio	0.222
n, Porosity	0.182
ρ_d (kg/m^3)	1469.8
γ_d (kN/m^3)	14.42
ρ_{sat} (kg/m^3)	1796.5
γ_{sat} (kN/m^3)	17.62
ρ (kg/m^3)	1477.9
γ (kN/m^3)	14.50
w, Moisture content (%)	0.52
G_s, Specific Gravity	2.556

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	8
D_{30}, particle diameter at 30% passing (mm)	0.56
D_{10}, particle diameter at 10% passing (mm)	0.4
C_c (Unconformity coefficient)	0.10
C_u (Gradation coeffeicient)	20.00



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #9 Sample Date: 5/16/01 Test Date: 6/27/01

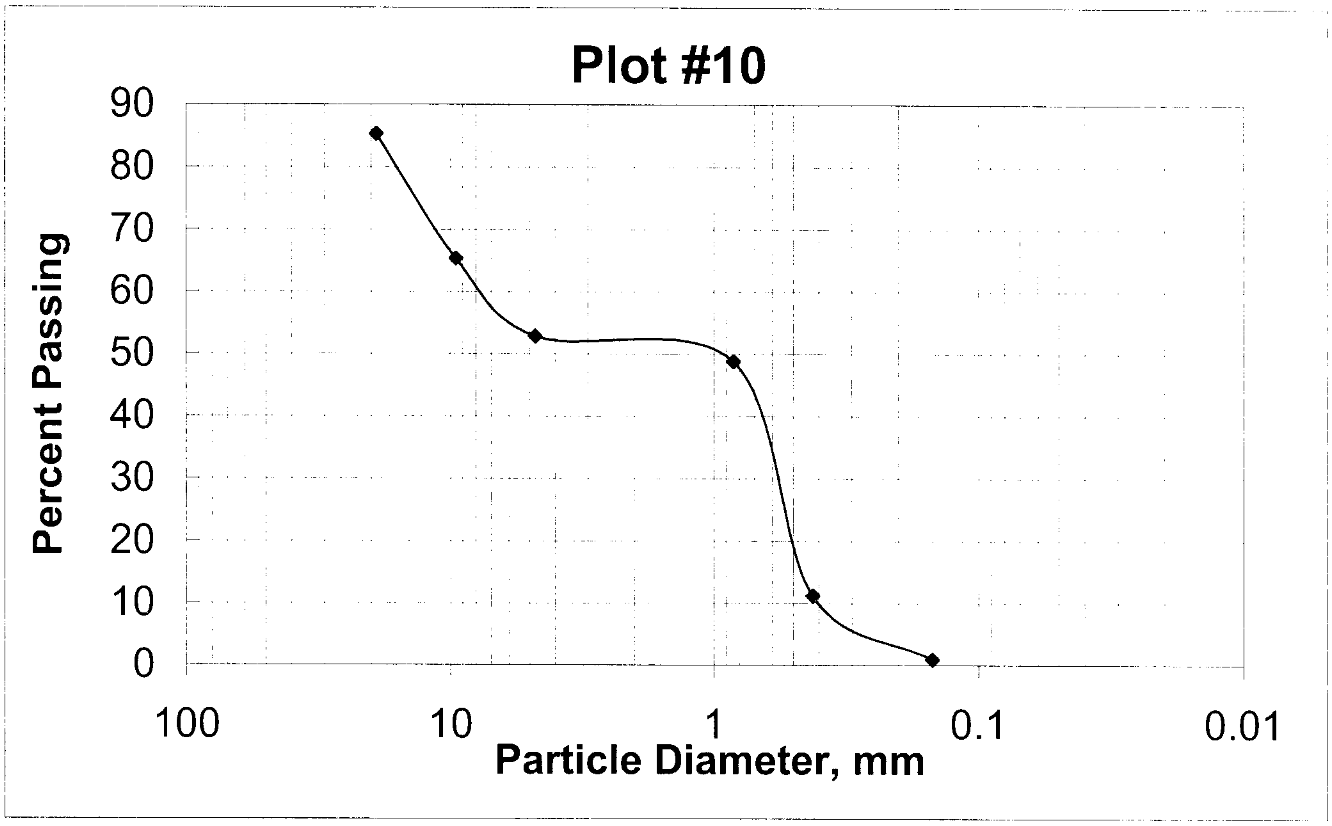
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Soil Properties	
K, Permeability (cm/s)	0.0002
e, Void Ratio	0.192
n, Porosity	0.161
ρ_d (kg/m^3)	1659.1
γ_d (kN/m^3)	16.28
ρ_{sat} (kg/m^3)	1977.7
γ_{sat} (kN/m^3)	19.40
ρ (kg/m^3)	1667.5
γ (kN/m^3)	16.36
w, Moisture content (%)	0.49
G_s, Specific Gravity	2.387

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	40.35
% Sands (retained on the No. 200 seive)	56.53
% Fines (passing through No. 200 seive)	3.11

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	8
D_{30}, particle diameter at 30% passing (mm)	0.57
D_{10}, particle diameter at 10% passing (mm)	0.3
C_c (Unconformity coefficient)	0.14
C_u (Gradation coeffeicient)	26.67



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #10 Sample Date: 5/16/01 Test Date: 6/27/01

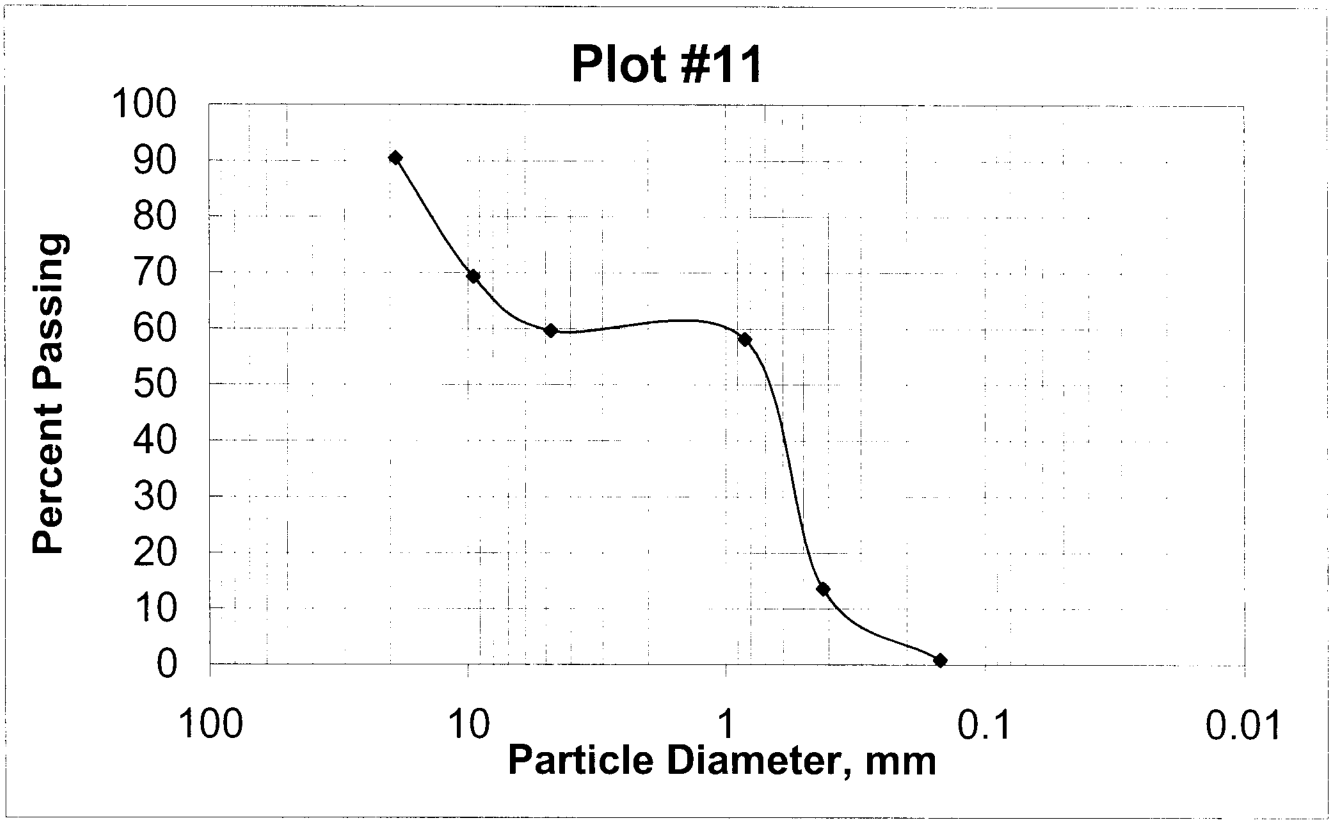
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	30.76
% Sands (retained on the No. 200 seive)	68.43
% Fines (passing through No. 200 seive)	0.80

Soil Properties	
K, Permeability (cm/s)	0.0003
e, Void Ratio	0.189
n, Porosity	0.159
ρ_d (kg/m^3)	1745.3
γ_d (kN/m^3)	17.12
ρ_{sat} (kg/m^3)	2074.3
γ_{sat} (kN/m^3)	20.35
ρ (kg/m^3)	1752.4
γ (kN/m^3)	17.19
w, Moisture content (%)	0.38
G_s, Specific Gravity	2.752

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	5
D_{30}, particle diameter at 30% passing (mm)	0.53
D_{10}, particle diameter at 10% passing (mm)	0.38
C_c (Unconformity coefficient)	0.15
C_u (Gradation coeffeicient)	13.16



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #11 Sample Date: 5/16/01 Test Date: 6/27/01

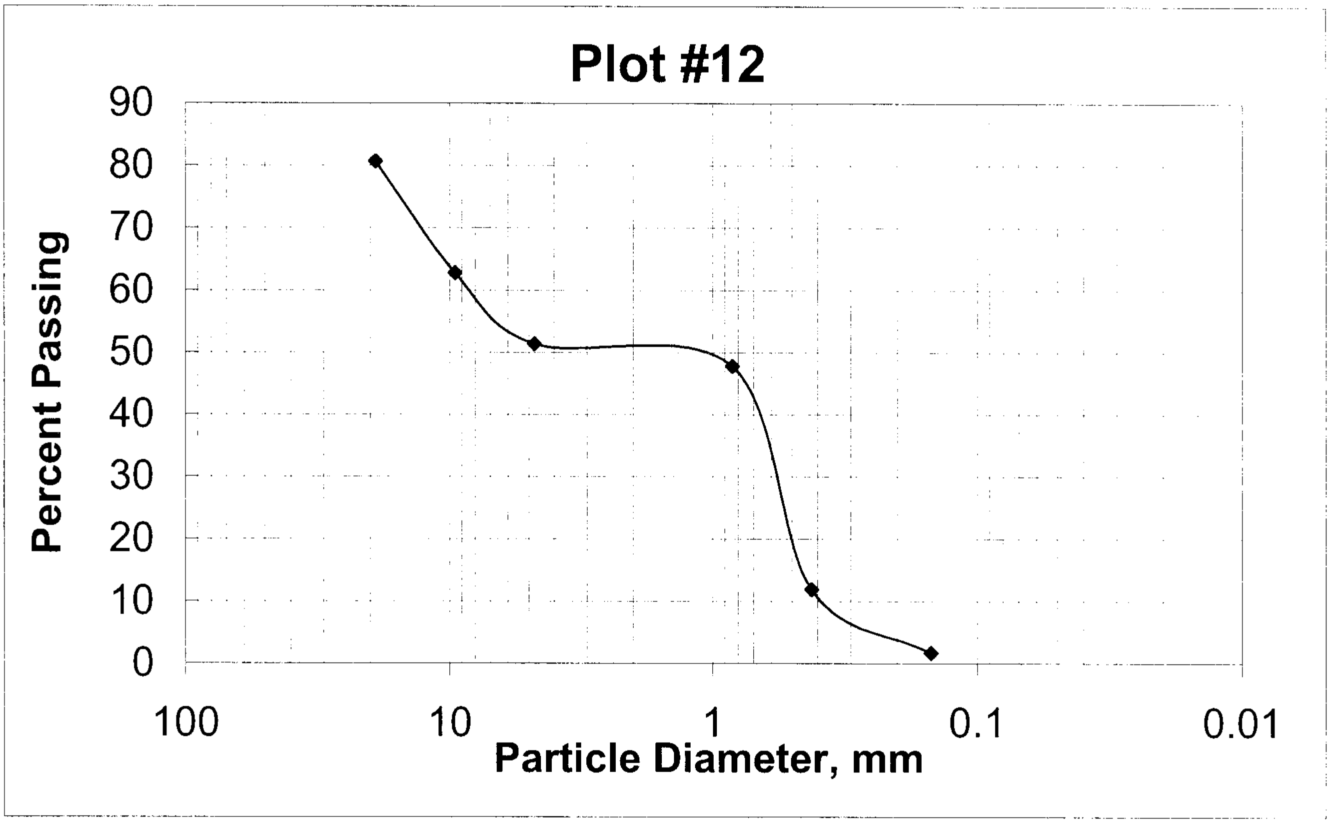
Soil Classification Summary

Soil classification	
USCS (Unified Soil Classification System)	SW w/ G
Well-Graded Sand with Gravel	

Partical Size Distribution	
% Gravel (retained on the No. 4 seive)	37.24
% Sands (retained on the No. 200 seive)	61.11
% Fines (passing through No. 200 seive)	1.55

Soil Properties	
K, Permeability (cm/s)	0.0002
e, Void Ratio	0.159
n, Porosity	0.137
ρ_d (kg/m^3)	1022.0
γ_d (kN/m^3)	10.03
ρ_{sat} (kg/m^3)	1184.2
γ_{sat} (kN/m^3)	11.62
ρ (kg/m^3)	1025.8
γ (kN/m^3)	10.06
w, Moisture content (%)	0.62
G_s, Specific Gravity	2.388

Distribution Curve	
D_{60}, particle diameter at 60% passing (mm)	8.6
D_{30}, particle diameter at 30% passing (mm)	0.57
D_{10}, particle diameter at 10% passing (mm)	0.5
C_c (Unconformity coefficient)	0.08
C_u (Gradation coeffeicient)	17.20



UNLV Department of Civil and Environmental Engineering	Dust Suppresant Project Charleston Resevoir Site Plot: #12 Sample Date: 5/16/01 Test Date: 6/27/01

APPENDIX E: AVERAGE COMPOSITION OF RAINFALL IN THE LAS VEGAS VALLEY

Appendix E - Average Composition of the Rainfall in the Las Vegas Valley

Site Name: Red Rock Canyon
Operating Agency: BLM
Program: National Atmospheric Deposition Program (NADP)

Latitude: 36:08:09 **Longitude: 115:25:32**
Elevation: 1137 m
Date range: 1995 to 2001

Site ID	Year	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	NH_4^+ (mg/l)	NO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{-2} (mg/l)	Date on	Date off
NV00	1995	0.31	0.043	0.016	0.075	0.200	1.150	0.100	0.590	01/03/95	01/09/96
NV00	1996	1.11	0.093	0.036	0.113	0.160	1.200	0.120	0.500	01/09/96	12/31/96
NV00	1997	0.62	0.049	0.027	0.071	0.290	1.270	0.120	0.740	12/31/96	12/30/97
NV00	1998	0.59	0.080	0.022	0.083	0.300	1.780	0.150	0.790	12/30/97	12/29/98
NV00	1999	0.44	0.052	0.008	0.052	0.330	1.410	0.110	0.630	12/29/98	12/28/99
NV00	2000	0.48	0.044	0.013	0.059	0.26	1.14	0.09	0.46	12/28/99	01/02/01
NV00	2001	0.66	0.068	0.042	0.113	0.69	2.15	0.16	1.01	01/02/01	01/01/02

Site ID	Year	Lab pH	Field pH	Lab Cond. (µS/cm)	Field Cond. (µS/cm)	Cation/ anion ratio	Sample vol. (ml)	Precip. (cm)	Days	Date on	Date off
NV00	1995	5.10	5.00	8.29	8.00	1.25	18612.9	28.34	371	01/03/95	01/09/96
NV00	1996	5.40	5.57	10.39	4.10	2.45	4356.8	13.09	357	01/09/96	12/31/96
NV00	1997	5.17	5.11	11.03	10.8	1.57	8475.0	14.21	364	12/31/96	12/30/97
NV00	1998	5.35	5.33	10.03	11.2	1.24	14425.8	24.77	364	12/30/97	12/29/98
NV00	1999	5.49	5.49	7.85	13.0	1.29	11693.3	16.92	364	12/29/98	12/28/99
NV00	2000	5.44	5.33	9.36	7.8	1.60	6774.6	15.71	371	12/28/99	01/02/01
NV00	2001	5.55	5.39	12.61	9.7	1.42	5874.5	20.21	364	01/02/01	01/01/02

<http://nadp.sws.uiuc.edu/nadpdata/siteinfo.asp?id=NV00&net=NTN>

APPENDIX F: SUMMARY OF LABORATORY METHODS, PRESERVATION, AND HOLDING TIMES

Appendix F

Summary of Laboratory Methods, Preservation, and Holding Times

PARAMETER	*CONTAINER* *	*PRESERVATION*	*MAXIMUM STORAGE RECOMMENDED/ REGULATORY♣*
pH	P, G	Analyze immediately	2h/stat
COD	P, G	Analyze as soon as possible, or add H_2SO_4 to pH<2; refrigerate	7 days / 28 days
Conductivity	P,G	Refrigerate	28 days / 28 days
TOC	G	Analyze immediately or refrigerate and add H_3PO_4 or H_2SO_4 to pH<2	7days / 28days
Ammonia Nitrogen	P, G	Analyze as soon as possible or add H_2SO_4 to pH<2, refrigerate	7days / 28days
BOD	P, G	Refrigerate	6 h/48 h
Cyanide	P, G	Add NaOH to pH>12,	24 h/14 d
Chloride	P, G	None required	28 days
Nitrate	P, G	Analyze as soon as possible or refrigerate	48 hours/48 hours (28 days for chlorinated samples)
Phosphate	G (A)	For dissolved phosphate filter immediately; refrigerate	48 hours / N.S.
Sulfate	P, G	Refrigerate	28 days / 28 days
Sulfide	P, G	Refrigerate; add 4 drops *2N* zinc acetate/100 ml; add NaOH to pH>9	28 days / 7 days
Metals	P (A)	For dissolved metals filter immediately, add HNO_3 to pH<2	6 months
Mercury	G	Bromine monochloride	28 days
TSS / TDS	P, G	Refrigerate	7 d / 2-7days
Alkalinity	P, G	Refrigerate	24h / 4 days
Salinity	G, wax seal	Analyze immediately or use wax seal	6 months
Hardness	P, G	Add HNO_3 to pH<2	6 months / 6 months
Turbidity	P, G	Analyze same day; store in dark up to 24 h, refrigerate	24 h / 48 h
Pesticides	G(S), TFE-lined cap	Refrigerate; add 1000mg ascorbic acid/L if residual chlorine present	7 days / 7 days until extraction
PCBs	G(S), TFE-lined cap	Refrigerate; add 1000mg ascorbic acid/L if residual chlorine present	7 d/7 d until extraction 40 d after extraction
Volatile Organics		Refrigerate	Analyze immediately
Microbial Count	Sterilized bottles	Add 9.0mL sample to test tube containing 1.0mL fixate	Refrigerate fixed samples at 4°C for 3 weekss

*P=plastic (polyethylene or equivalent); G=glass; G(A) or P(A)=rinsed with 1+1 HNO3♣ Refrigerate= storage at 4°C, in the dark. Stat = no storage allowed, analyze immediately (Standard Methods, 1995).

APPENDIX G: SALINITY CALCULATIONS

Appendix G - Salinity Calculation

Salinity was calculate using the following equations (Hill *et al.*, 1986):

$$S_{\mathrm{calc}} = S_{pss} - \frac{a_0}{1+1.5x+x^2} - \frac{b_0 f(t)}{1+y^{1/2}+y+y^{3/2}}$$

Where

S_{pss} is the value determined from the practical salinity scale 1978

$$S_{pss} = \sum_{i=0}^{5} \left(a_i + b_i f(t)\right) R_t^{i/2}$$

and:

$a_0 = 0.0080$ $b_0 = 0.0005$

$a_1 = -0.1692$ $b_1 = -0.0056$

$a_2 = 25.3851$ $b_2 = -0.0066$

$a_3 = 14.0941$ $b_3 = -0.0375$

$a_4 = -7.0261$ $b_4 = 0.0636$

$a_5 = 2.7081$ $b_5 = -0.0144$

$$f(t) = \frac{(t-15)}{1+0.0162(t-15)}$$

$x = 400\ R_t$ $y = 100\ R_t$

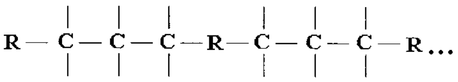
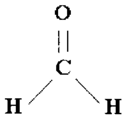
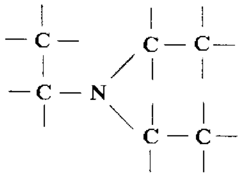
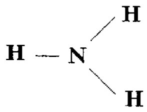
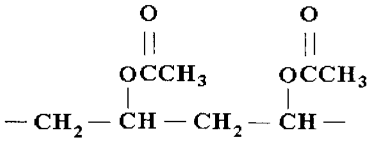
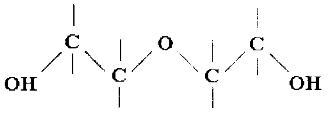
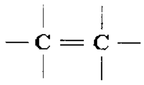
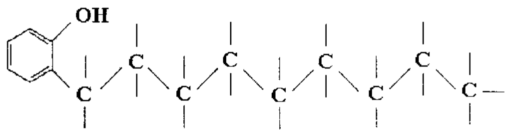
R_t is the ratio of conductivity of the water, at temperature t, to the conductivity of seawater of practical salinity, S = 35 (32.4356 g of KCl in a mass of 1 Kg of solution) at the same temperature, both at one standard atmosphere of pressure. The conductivity of standard seawater (S = 35) at 15°C is approximately 4.2914 S/m.

APPENDIX H: MAJOR COMPOSITION OF DUST SUPPRESSANT AS DESCRIBED IN MSDS

Appendix H - Major Composition of Dust Suppressant as described in the MSDS

Category	*Tested Suppressant*	*Composition*
Salt	Dust Gard	$MgCl_2$ (28-34%), SO_4 (1.5-3.5%), K (0.1-0.5%), Na (0.1-0.7%), Ca (<0.5%)
Organic Petroleum	Coherex	Heavy naphthenic distillate and/or heavy naphthenic extract
	Road Pro	Petroleum Asphalt (<70%) Water (>30%)
Synthetic iso-alkane	EK-35	Severely hydrotreated, high viscosity synthetic iso-alkane
Fiber Mulch	Plas-Bond	Water 500 lb gypsum 300 lb mulch 10-15 lb color
Acrylic Polymer	Poly-Bond	Acrylic polymer, individual residual monomers, formaldehyde, triethylamine, ammonia
	Soil Sement	Acrylic and polyvinyl acetate polymer, water
	Enviro-tac	Vinyl acetate, acrylic copolymer
Organic Non-petroleum	Road Oyl	Tall oil fractions (pitch%/rosin % 72/78), water, surfactants
Ligninsulfonate	Dustac	Lignosulfonic acid, calcium salt
	Topein	Sterol esters of C_{18} and C_{29} organic acids, nonylphenol, polyethylene, glycol ether, surfactant (mixture), hydrochloric acid, water

Chemical Formulation of Suppressant Compounds

Compounds	**Example Formulation**
Acrylic Polymer (Potential)	 $R-C-C-C-R-C-C-C-R\ldots$
Formaldehyde (HCHO)	
Triethylamine $(C_2H_5)_3N$	
Ammonia (NH_3)	
Polyvinyl Acetate Polymer $(C_4H_6O_2)$	 $-CH_2-\overset{\overset{\overset{O}{\Vert}}{OCCH_3}}{\overset{\vert}{CH}}-CH_2-\overset{\overset{\overset{O}{\Vert}}{OCCH_3}}{\overset{\vert}{CH}}-$
Glycol ether $(C_4H_{10}O_3)$	
Polyethylene (C_2H_4)	 $-C=C-$
Nonylphenol $(C_{15}H_{24}O)$	
Lignin