Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County

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TABLE OF CONTENTS

TABLE OF CONTENTS iii
LIST OF TABLES i
LIST OF FIGURES ii
EXECUTIVE SUMMARY 3
Study Purpose and Objectives 4
Major Findings 5
  PCE Impacts to Groundwater Subbasins and Municipal Supply Wells 5
  Potential Impacts from Past Dry Cleaning Operations 6
  Magnitude of PCE Impacts to Groundwater from Past Dry Cleaner Operations 6
  Cost of Dry Cleaner Site Remediation 6
  Recommendations 7
  Origin and Funding for this Study 7
DISCLAIMER 8
INTRODUCTION 10
  Study Objectives 10
  Water Supply in Santa Clara County 10
  Groundwater Protection from Solvent Releases 11
  Dry Cleaner Operations and Impacts to Groundwater 13
  Dry Cleaner Study Background 15
  Purpose of Study 15
Groundwater Vulnerability from Dry Cleaner Operations 15
  Groundwater Vulnerability 15
  Solvent Usage in Dry Cleaning Operations – Types, Quantities and Trends 16
  Pathways for Perchloroethylene Impacts to Soil and Groundwater 17
  DNAPL Migration in the Subsurface 24
  Fate and Transport of PCE 27
  Summary of Groundwater Impacts from Dry Cleaning Operations 28
  PCE Impacts to Water Supply 29
Geography of Santa Clara County Dry Cleaning Operations 31
  Dry Cleaner Study Data Collection Methodology 31
  Drop-off vs. On-site Cleaning 31
  PCE Releases through Sanitary Sewers 31
Records Confirming On-site Cleaning 33
  Period of Record for Documentation Confirming On-Site Cleaning 33
  Evidence for Type of Solvent Used 33
  Determination of Continuous Dry Cleaning Operations at a Given Site 33
  Accuracy of Dry Cleaner Data Base and Mapped Locations 34
  Results of Dry Cleaner Data Compilation and Mapping 35
  Inferring PCE Quantities from Air District Records and DSTC Manifests 37
  Inferring PCE Usage from Period and Duration of Dry Cleaning Operations 38
  General Interpretation of Potential for Drinking Water Impacts from Dry Cleaners 39
Estimating the Potential for PCE Releases to Groundwater 41

The SiteRank Approach to Ranking Dry Cleaners for Threats to Groundwater Quality 41
Simplified SiteRank 44
Determination of Age-Duration as a Surrogate for Mass Released 44
DRASTIC Groundwater Vulnerability Ranking 48
Distance-Direction Ranking 48
Well Vulnerability 52
Overall Ranking Determination Using SSR 54
Sensitivity Analysis of Simplified SiteRank 56
Validating SSR Rankings 61
Summary of Simplified SiteRank Findings 62
Recommendations for Next Steps in Applying Simplified SiteRank 63
CONCLUSIONS **64**
Funding Recommendations 67
Further Study 67
References 68
***References for Main Text*: 68**
***References for Appendices:* 70**

APPENDICES 75
Appendix A: Chemical And Physical Properties Of Dry Cleaning Solvents 75
  Environmental Fate of PCE in Groundwater 86
  Toxicology of Perchloroethylene 86
Appendix B: The *SiteRank* Approach to Ranking Dry Cleaners for Threats to Groundwater Quality 89
Appendix C: Dry Cleaning Operations & Methods 96
  History of Dry Cleaning 96
  Development of Dry Cleaning Machines from 1930s to the Present 96
  Dry-Cleaning Solvent Usage Pattern in the United States from the 1920s to Present ... 100
  Description of the Dry-Cleaning Industry 103
  Dry Cleaning Process 106
  Other Chemicals Used in the Dry Cleaning Industry 110
  Chemicals Used In Solvent & Equipment Maintenance 114
Appendix D: Groundwater Impacts From Dry Cleaning Operations 115
  Overview 115
  Summary of Known Dry Cleaner Releases in Santa Clara County 115
  Magnitudes of PCE Impacts 118
  PCE Impacts to Water Supply 122
  Remediation of Dry Cleaner PCE Contamination 129
  Economics and Logistics of Dry Cleaner Site Assessment and Remediation 132
Appendix E: Regulations Governing Dry Cleaning Operations 140
  Air 140
  Drinking Water 141
  Wastewater 141
Appendix F: PCE Releases to the Environment 142
  Summary of Release Mechanisms 142
Appendix G: Pollution Prevention Strategies 149
Appendix I: Water Supply in Santa Clara County 155
  Overview 155
  Groundwater Basins 156
  Santa Clara Subbasin 156
  Coyote Subbasin 158
  Llagas Subbasin 158
  Groundwater Quality 158
  Water Supply from the Santa Clara Groundwater Basin 162
Appendix J: Groundwater Vulnerability 163
  Unconfined Aquifers 163
  Vertical Conduits 163
  Manmade Conduits 164
  Naturally Occurring Vertical Conduits 165
  Santa Clara Valley Water District's Well Search Program 165
Appendix K: The DRASTIC Spatial Index of Groundwater Sensitivity 166
Appendix L: Sewer Exfiltration 183
  L.1 City of Sunnyvale Sewer System 183

L.2 Implications of Influent Concentrations 186
L.3 General Review of Perchloroethylene and Sewer Lines 188
Appendix M : Preparers of Report 189
Appendix N : Dry Cleaner Ranking Maps by City 190

a. San Jose 191
b. Santa Clara 192
c. Sunnyvale 193
d. Mountain View 194
e. Palo Alto 195
f. Los Altos 196
g. Saratoga 197
h. Los Gatos 198
i. Cupertino 199
j. Campbell 200
k. Milpitas 201
l. Morgan Hill 202
m. Gilroy 203

LIST OF TABLES

Table 1 - Five Potential Mechanisms by which PCE in Sewer Lines Impacted Soil and Groundwater 21
Table 2: PCE Release Estimate for a Steady Drip 22
Table 3: PCE Release Estimate for Filter Cartridge Drainage 23
Table 4: Estimate of PCE Releases from Transfer and Storage 23
Table 5: Benchmark Fuel Leak Scenario - MtBE Release Estimate 24
Table 6: Regulatory Status of Dry Cleaner Cases in Santa Clara County (2002) 28
Table 7: Solvent Detections at Dry Cleaner Release Sites in Santa Clara County 29
Table 8: Past PCE Influent Concentrations at Santa Clara County Wastewater Treatment Plants 32
Table 9: Emissions Factors for Dry Cleaning Machines 37
Table 10: Total Dry Cleaner PCE Waste Generation by City 38
Table 11: Depth to Water Beneath Dry Cleaner Sites and Hydrogeologic Setting 40
Table 12: Historical Trends in Solvent Mileage by Machine Type 46
Table 13: Numeric Index of Solvent Mileage Rates for Rank Assignment to Cleaners Based on Years Operated 48
Table 14: Ranking for Cleaner Location Relative to Supply Well Location 51
Table 15: Well Construction Factors Used in Determining Well Vulnerability in SSR 54
Table 16: Numeric Values of SiteRank Output and Corresponding Map Symbols and Summary Ranks 55
Table 17: Sensitivity Analysis for 5 Cleaner - Well Pairs Selected Across Range of Overall Ranks 58
Table 18: SSR Ranks at Dry Cleaners Closest to Public Wells with PCE Detections Greater than 1 ppb 62
Table 19: Chemical Identity of Carbon Tetrachloride 75
Table 20: Physical and Chemical Properties of Carbon Tetrachloride 75
Table 21: Chemical Identity of Perchloroethylene 77
Table 22: Physical and Chemical Properties of Perchloroethylene 78
Table 23: Regulatory Limits and Water Quality Goals for Perchloroethylene 79
Table 24: Chemical Identity of 1,1,1-Trichloroethane 80
Table 25: Physical and Chemical Properties of 1,1,1-Trichloroethane 81
Table 26: Chemical Identity of Trichloroehylene 82
Table 27: Physical and Chemical Properties of Trichloroethylene 83
Table 28: Chemical Identity of Stoddard Solvent 84
Table 29: Physical and Chemical Properties of Stoddard Solvent 85
Table 30: Parameters Used for Pilot Site Rank Calculation 93
Table 31: PCE Mileage per 1000 kg of Clothing Cleaned 99
Table 32: 1991 Statewide Distribution of Machines & PCE Emissions by 102
Table 33: Types of Drycleaning Machines used in Santa Clara County 104
Table 34: Residual Amounts of PCE in Different Types of Fabric Immediately after Dry Cleaned 109
Table 35: Regulatory Status of Dry Cleaner Cases in Santa Clara County 116
Table 36: Chemical Use at Dry Cleaner Sites in Santa Clara County Based 116
Table 37: Summary of Solvent Detections at Dry Cleaner Release Sites in Santa Clara County 117
Table 38: Comparison of PCE Concentrations in Santa Clara County Sites and National Case Profiles 117
Table 39: Remedial Technologies Used at Dry Cleaner Release Sites in Santa Clara County 118
Table 40: PCE vs MtBE Maximum Concentrations in Plumes from Selected Studies 120
Table 41: Chemical Properties of MtBE and PCE 121
Table 42: PCE vs MtBE and Benzene Plume Length - Mace Study 121
Table 43: PCE vs MtBE Plume Length - Rong Study 122
Table 44: SCRD 2004 Survey - Soil Remediation 129
Table 45: SCRD 2004 Survey - Groundwater Remediation 130
Table 46: Investigation, Remedial Design and Installation, and Operating Costs 136
Table 47: Prohibited Equipment/Operation 140
Table 48: Acceptable Disposal Levels of Industrial Wastewater 141
Table 49: Five Potential Mechanisms for PCE Migration from Leaking Sewer Lines to Soil and Groundwater 142
Table 50: Dry-Cleaning Solvent Spills and Discharges at 334 Dry-Cleaning Facilities in the State of Florida 143
Table 51: Types of Equipment Failure 144
Table 52: Discharges due to Equipment and Machine Operation 144
Table 53: PCE Spilled during Equipment and Machine Maintenance 145
Table 54: Spillage of Solvent Contaminated Dry Cleaning Wast due to Poor Waste Management Practices 146
Table 55: Reported Spills of Solvent of 10 Gallons or More and their Source 147
Table 56: Ten Most Commonly Reported Sources of Solvent Discharges 148
Table 57: Pollution Prevention Techniques 149
Table 58: Detailed information for the Nine Plains Located in the Santa Clara Valley Groundwater Subbasin 157
Table 59: Santa Clara County Water Demand 162

LIST OF FIGURES

Figure 1 - Groundwater Subbasins in Santa Clara County _____11
Figure 2 - Solvent Plumes in Silicon Valley (northern Santa Clara County) _____13
Figure 3 - Solvent Cycle in Dry Cleaning Operations _____19
Figure 4 - Locations of Releases in 95 Dry Cleaner Cases Profiled on SCRD Website _____20
Figure 5 - Frequency of Identified Release Types _____20
Figure 6 - Reductive Dechlorination Pathway for Biotransformation of PCE _____27
Figure 7 - Summary of PCE Results from DHS Public Drinking Water Well Testing Program _____30
Figure 8 – Example Dry Cleaner Roof Vent Features from High Resolution Aerial Photos _____36
Figure 9 - Count of Dry Cleaners from Telephone Directories by Year, with Countywide Population _____36
Figure 10 - Dry Cleaner Operating Duration and Start Year _____39
Figure 11 - Depth to Water beneath Santa Clara County Dry Cleaner Sites, Grouped by Hydrogeologic Setting _____40
Figure 12 - Distances from Dry Cleaner Locations to Six Nearest Abandoned Wells _____41
Figure 13 - Locations of Current and Past Dry Cleaners in relation to Known Abandoned Wells 1946 - 2001 _____42
Figure 14 - Apparent Solvent Mileage for Santa Clara County Dry Cleaners Derived from Air Permit Data _____45
Figure 15 - Dry Cleaner Age-Duration Sub-Ranking as a Surrogate for Solvent Mileage _____47
Figure 16 - EPA Drastic Ratings for Santa Clara Groundwater Subbasin _____49
Figure 17 – Distances Between Dry Cleaners and Six Nearest Supply Wells _____50
Figure 18 - Generalized Shallow Groundwater Flow Directions Derived from Fuel Leak Investigations _____52
Figure 19 - Geometric Relationship of Well Vulnerability Factors for SSR _____53
Figure 20 - Ranked Dry Cleaners– Downtown San Jose Area _____55
Figure 21 - Ranked Dry Cleaners in the Santa Clara Groundwater Subbasin _____56
Figure 22 –Directional Difference vs. Distance: Distance-Direction Sub-Ranks _____57
Figure 23 – Configuration of Wells and Dry Cleaners for SiteRank Pilot Calculations _____92
Figure 24 - Lithologic Variability Among 7 Closely Spaced Wells in Wellfield for SiteRank Pilot Calculation _____94
Figure 25 - PCE Concentration Distribution in Sites Profiled by SCRD _____119
Figure 26 - PCE Plume Lengths at Sites in SCRD Survey _____119
Figure 27 - SCRD Site Profile Data - Peak PCE Concentrations in Soil vs. Groundwater _____120
Figure 28 - Frequency of PCE Detection in Santa Clara County Drinking Water Supply Wells - 1984 – 2001 _____123
Figure 29 - Prevalence of Soil and Groundwater Remediation Technologies among Sites Profiled by SCRD. _____130
Figure 30 - Prevalence of Remedial Technology Combinations among Sites Profiled by SCRD _____131
Figure 31 - Cost to Complete Site Assessment, SCRD 2002 _____132
Figure 32 - Range of Completed Site Assessment Costs, SCRD 2002 _____134
Figure 33 - Detailed Range of Completed Site Assessment Costs in SCRD Site Profiles _____134
Figure 34 - Range of Completed Remediation Costs, SCRD Site Profiles _____135
Figure 35 - Comparison of Assessment Costs between Sites with and without Water Supply Well Impacts (Number of Cases vs. Cost in Dollars) _____137
Figure 36 and Figure 37 – Cost for Site Assessment vs. Plume Length and PCE Concentration _____137
Figure 38 and Figure 39 - Remediation Costs vs. Plume Length and Maximum PCE Concentrations _____138
Figure 40 and Figure 41 – Annual Remediation Operating Costs vs. Plume Lengths and Maximum PCE Concentrations _____138
Figure 42 (top) and Figure 43 (bottom) - Comparison of Assessment and Remediation Costs by State _____139
Figure 44 - DHS Compliance Monitoring and SWRCB GAMA Study Data for Perchloroethylene, North Santa Clara County _____160
Figure 45 - DHS Compliance Monitoring and SWRCB GAMA Study Data for Perchloroethylene, South Santa Clara County _____161

EXECUTIVE SUMMARY

The threat of groundwater contamination posed by dry cleaning operations is primarily a legacy issue. Dry cleaners today have greatly improved usage and handling of solvents. Perchloroethylene (PCE) remains the most prevalent solvent used for dry cleaning. Dry cleaning machinery has evolved substantially and is designed to be leak-proof, air-tight, and to minimize waste generation. Dry cleaning facilities are subject to multiple permits, and are regularly inspected. A few dry cleaners have switched to “environmentally safe” solvents in their operations. Failures and operator error can nonetheless occur, representing a minor continuing threat to groundwater. The greater threat to groundwater quality is from past dry cleaning operations from as long as 50 years ago, a threat which remains significant today.

In past decades, the volume of solvent to dry clean clothes was as much as five to ten times greater than present usage. Past solvent handling and disposal practices generated significant PCE releases to soil and groundwater, and equipment and machinery were prone to leaks. In earlier decades, solvent waste disposal practices at dry cleaning operations were not regulated, and once regulations were adopted, it took some time to implement local enforcement programs. Dry cleaning equipment plumbed to drain solvent-laden wastewater directly to sewers and septic tanks created significant soil and groundwater contamination problems. Similarly, the past practice of dumping solvent waste in landfills or directly to the ground continues to threaten groundwater quality today. A related consequence of soil and shallow groundwater contamination from past dry cleaning operations is the potential risk of intrusion of PCE vapors into occupied homes and businesses overlying former dry cleaner release sites.

PCE is a health concern because it is classified as a probable human carcinogen by the International Agency for Research on Cancer. PCE is regulated in drinking water by the California Department of Health Services[1] and US EPA with a Maximum Contaminant Level (MCL) of 5 micrograms per liter (parts per billion). The California Department of Health Services (DHS) adopted the MCL in 1989. In 2001, the California Office of Environmental Health Hazard Assessment revised the Public Health Goal (PHG) for PCE in drinking water to 0.06 micrograms per liter (parts per billion, or, 60 parts per trillion) (OEHHA, 2001). The Public Health Goal is based solely on scientific and public health considerations without regard to economic considerations, and is not a regulatory standard. There has been no announcement whether the new, lower PHG will trigger a reevaluation of the MCL. Currently, public water systems serving more than 10,000 connections must report Public Health Goal exceedances to their governing bodies and the public with a Public Health Goal Report, as required by the Calderon-Sher Act of 1997 (SB 1307).

Epidemiological studies provide evidence that PCE may promote formation of carcinogenic tumors in the esophagus and lymphatic system. Available data are quite limited in terms of the ability to quantify cancer risks associated with oral exposure to PCE, since the majority of the human data concern occupational exposure by the inhalation route. Most of the evidence for human carcinogenicity is based on inhalation exposures in the dry-cleaning industry (OEHHA,

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[1] In 2007, this agency’s name changed to California Department of Public Health.

2001). Inhalation exposure to a much lesser degree may also occur where PCE in soil and groundwater migrates in vapor form into occupied homes and businesses.

This study catalogued the locations and years of operations for current and former dry cleaning operations in Santa Clara County. Past dry cleaner operational practices, solvent usage, groundwater subbasin vulnerability, and municipal supply well vulnerability are explored to develop a system to rank the relative risk of groundwater contamination from dry cleaner solvent releases. The systematic ranking of the threat posed by dry cleaners provides a means of prioritizing dry cleaning sites for further investigation. The ranking system will be useful to regulatory agencies for determining which cases warrant more aggressive investigation and remediation.

Study Purpose and Objectives

The overall purpose of this study is to rank current and historical dry cleaner sites according to their potential to impact groundwater quality in general, and municipal and private supply wells in particular. Additional study objectives include obtaining a detailed, quantitative understanding of the temporal and geographic distribution of dry cleaner operations in a major urban/suburban region (all of Santa Clara County). Secondary objectives include obtaining an improved understanding of how dry cleaning chemicals were released to soil and groundwater during past dry cleaning operations. Further, trends in dry cleaner site investigation and remediation are reviewed, with the goal of developing recommendations for regulatory oversight of dry cleaner sites by the Regional Water Quality Control Board, the California Department of Toxic Substances Control, and County of Santa Clara Department of Environmental Health.

The primary study objectives were completed through data collection, literature research, database and geographic information system (GIS) development, spatial analysis, and site threat ranking algorithm development and implementation. Telephone and business directories were reviewed to compile records for locations of past and current dry cleaning facilities. The completed dry cleaner inventory shows that dry cleaning businesses operated at an estimated 1,250 unique locations throughout Santa Clara County between 1946 and 2001. The research methods used were not able to reliably distinguish between facilities that operated dry cleaning equipment and those that only served as drop-off locations and did not operate equipment. By indirect lines of evidence, dry cleaning plants using PCE or other dry cleaning solvents operated at about sixty percent of these locations for at least one year.[2] There have therefore been approximately 750 unique locations where dry cleaning machinery was operated in Santa Clara County.

To determine solvent usage for current and recent dry cleaning operations, staff reviewed Bay Area Air Quality Management District (BAAQMD) permit files, Department of Toxic Substances Control (DTSC) hazardous waste manifest records, Publicly Owned Treatment Works (POTW) industrial pretreatment records, Fire Department Hazardous Materials Management Plan (HMMP) records and Business License Records. 224 operating facilities were identified as operating active dry cleaning plants in 2001. The locations of identified current and

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[2] Of 370 cleaners within Santa Clara County listed in the yellow pages in 1998, 224 were recorded in the Bay Area Air Quality Management District's 1998 annual report on emissions.

past dry cleaners were integrated into the District's Geographic Information System (GIS) to facilitate spatial analysis and site threat ranking. Historic and current trends in solvent usage were estimated using wastewater treatment plant influent concentration data, air quality studies, and review of air pollution control and dry cleaning industry literature.

Secondary objectives were met by reviewing the literature on historic dry cleaning operational practices, contaminant release scenarios, PCE impacts to water supply, fate and transport of PCE, investigation and cleanup approaches, and dry cleaning site regulatory programs.

Major Findings

PCE Impacts to Groundwater Subbasins and Municipal Supply Wells

A review of PCE impacts to groundwater indicates that even deep drinking water wells in Santa Clara County are *potentially* vulnerable to historic releases of PCE from dry cleaners; however, *actual incidence of PCE detections in drinking water wells is very low*. Only 3.3 % of all public water supply wells tested (17 out of 520) between 1986 and 2003 had detections of PCE at any level, and only 2 wells have had detections above the 5 ppb Maximum Contaminant Level at any time since 1986. Some wells contaminated by PCE have been shut down at considerable cost to the water system owners. The cause of PCE contamination in the 17 wells with PCE detections is not known; however, in two-thirds of these 17 wells, dry cleaners are located nearby. Because this study did not survey past locations of other PCE using businesses such as brake shops, printing shops, electronics, metal degreasing, etc., it is not possible to attribute the PCE detections in these 17 wells to past dry cleaning operations.

Major users of PCE in Santa Clara County include electronics manufacturing, printing shops, and auto repair facilities, in addition to dry cleaners. The effort to compile all current and past locations of facilities using PCE is too large to incorporate into this study; therefore, this study focused only on dry cleaners.

Groundwater vulnerability is highest where hydrogeologic features allow shallow contamination to migrate to deeper aquifers, such as high permeability unconfined aquifers and man-made or natural vertical conduits. Vulnerability of individual municipal supply wells to surficial contamination varies with well construction features such as well seal depth, depth to first perforated interval, well age, and other well bore flow. Vertical groundwater gradient also affects supply well susceptibility to contamination. Where groundwater is moving downward, there is an increased potential for contamination, whereas upward vertical groundwater gradients prevent downward migration of dissolved contaminants. Because PCE is 1.6 times heavier than water, large quantities of waste PCE released all at once will sink through water and migrate downward through sands and gravels until impeded by fine grained lenses of clay and silt. Density driven downward migration of dense non-aqueous phase liquids like PCE could persist even in the presence of a small upward vertical gradient. PCE releases from dry cleaners can occur in both the dissolved phase in water trap wastewater, and in pure phase, as a dense non-aqueous phase liquid (DNAPL)

Potential Impacts from Past Dry Cleaning Operations

A review of historic and current dry cleaning operations and solvent usage indicates that the potential for historic releases is significant. By some estimates, 75% of dry cleaner facilities operated in USA in past decades have caused environmental contamination. Currently permitted operations do not present a significant source of ongoing contamination, due to regulation and inspection, improved equipment, and improved operating practices. Currently permitted facilities may be sources of groundwater contamination where hazardous waste laws are violated. Hazardous waste violations involving dry cleaning facilities in Santa Clara County are relatively rare, but nevertheless do occur. In 2004, a Los Gatos dry cleaning operator's illegal disposal of PCE waste into a floor drain resulted in fines and jail time (SJ Mercury News, 2004). A review of dry cleaning release case profiles from sites surveyed nationwide indicates that 38% to 46% of sites have presumptive evidence of the presence of DNAPLs in the subsurface. The presence of PCE in the subsurface in DNAPL form comprises a long-term threat to groundwater quality because residual DNAPL is resistant to biodegradation and can continue to dissolve under natural conditions for decades.

Magnitude of PCE Impacts to Groundwater from Past Dry Cleaner Operations

PCE released from past dry cleaning operations has a significant *potential* to impair groundwater, as determined from evaluation of PCE release sites from across the country. The general potential for groundwater degradation from PCE has not manifested as large-scale impacts to public water supply wells in Santa Clara County. PCE plumes emanating from dry cleaner release sites can potentially extend more than a mile, and can be significantly longer than plumes of methyl *tert* butyl ether (M*t*BE), the fuel oxygenate commonly added to gasoline. PCE release case studies from across the nation are profiled on the State Coalition for Remediation of Dry Cleaners (SCRD) website. A few summary statistics are helpful for appreciating the threat posed by PCE releases from past dry cleaner sites:

- 55% of cases profiled report maximum PCE concentrations in groundwater $10,000 ppb
- The maximum concentration among national case profiles was 8,700,000 ppb, and the average of maximum detections was 162,000 ppb.
- The maximum PCE plume length among national case profiles was 14,200 feet, while the average plume length was 1,270 feet.
- PCE plume lengths are generally an order of magnitude longer than reported in plume length studies of M*t*BE.

The potential threat to groundwater from PCE impacts appears by these measures to be greater than impacts from M*t*BE. The low Public Health Goal of 0.06 ppb for PCE results in a greater likelihood of a dry cleaner facility impacting a municipal and domestic water supply.

Cost of Dry Cleaner Site Remediation

The costs to investigate and remediate dry cleaner releases in the United States are enormous. A review of SCRD profile sites indicates costs of contaminant assessment up to a million dollars for one site and cleanup costs at another have exceeded seven million dollars. More than a million dollars has been spent on an ongoing dry cleaner remediation project at a site in Los Gatos. As discussed in Appendix E, the national median cost to investigate and remediate a dry cleaner release site is $300,000 where a water supply well has been impacted, and $226,000 where wells have not been impacted.

Thirteen states[3] have developed dry cleaner programs that educate facility operators on best management practices, provide technical assistance with investigation and cleanup of releases, and provide a funding or reimbursement program to assist dry cleaners in investigation and cleanup. Some of these programs are highly effective. The State of California does not yet have a dry cleaner cleanup fund available to address orphan dry cleaner release sites.

Recommendations

The recommendations section at the end of this report suggests refinements to improve the ranking algorithm used for prioritization of dry cleaner release sites. These suggestions include:

1. add a capture zone evaluation function for supply wells
2. use more accurate data for groundwater flow directions
3. address seasonal fluctuations in groundwater flow directions
4. incorporate more detailed geologic data into the algorithm
5. refining mass-release estimates
6. validate well vulnerability estimates
7. account for seasonal variability in pump discharge
8. conduct further validation work on the algorithm.

Origin and Funding for this Study

This study was originated by the San Francisco Bay Regional Water Quality Control Board's *Groundwater Committee*, comprised of Regional Board staff from the Toxics Division, and staff from San Mateo County Environmental Health, Alameda County Water District, and the Santa Clara Valley Water District (District). The Groundwater Committee produced a report entitled *South Bay Groundwater Protection Evaluation Report* (SFBRWQCB, 2003), which found that the combination of past dry cleaner operations and leaking sewer lines may pose a significant threat to groundwater quality. The District conducted the present study using a grant from the State Water Resources Control Board's Cleanup and Abatement Account Fund, which is administered by the Division of Clean Water Programs. The San Francisco Bay Regional Water Quality Control Board sponsored the District's grant application, and invited the District to conduct the Study.

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[3] States with mandated programs and funding for drycleaner site remediation: Alabama, Connecticut, Florida, Illinois, Kansas, Minnesota, Missouri, North Carolina, Oregon, South Carolina, Tennessee, Texas, and Wisconsin .

DISCLAIMER

All of the information presented in this document is for the purpose of evaluating the potential threat to groundwater quality posed by historic dry cleaning operations. Data presented in map and tabular form is not intended to be a reliable record of past dry cleaning activity. Sites listed in tables and maps may have been drop-off locations, without dry cleaning plant operations. Records may be incomplete and errors may be present. Available records may have been overlooked. Due to street renumbering, street name changes, parcel divisions, and redevelopment, mapped locations may be erroneous. For these and many other reasons, *data from this report should not be used to make a final determination of whether a given property is potentially contaminated, whether dry cleaners operated at a particular location, or that a particular property did not have a dry cleaning operation on it. Copies of telephone directories used to compile the data in this report are on available at the Santa Clara Valley Water District upon advance request. Interpretations regarding whether a facility operated at a given location, whether the potential for a release is high or low, and whether a release poses a risk to a water supply well are matters of professional judgment best left to experienced regulatory officials and environmental consultants. The authors recommend independent verification of the information presented in this study for any decisions related to health risk, real estate transactions, or groundwater protection.*

Limitations in the scope of a study and/or lack of information (information gaps) can be a source of uncertainty associated with any scientific investigation. Limitations of this study are related to information gaps in the availability of:

- Addresses**:** Street names have changed, streets have been renumbered, parcels have been subdivided or redeveloped, and freeway construction and other land use changes have substantially impeded ability to fully trace some listed dry cleaning operations.
- Air permits: The Bay Area Air Quality Management District (BAAQMD) started their air emissions permitting program in 1972. Prior to 1972, it was not always possible to determine if the dry cleaner listed in the telephone directories were on-site cleaning facilities or drop-off facilities. Air District files are maintained for staff use and may not be ideally suited to the purposes pursued in this study;
- Historical Maps: Errors and omissions
- Telephone directories:
  - There were several years in which telephone directories and/or California Polk Directory were not available (i.e., they were missing from libraries).
  - Some of the dry cleaners did not have advertisements, thus, it was not apparent if they were on-site cleaners or merely drop-off facilities.
- Mass released: an empirical relationship was developed to rank potential mass released using an age-duration surrogate. This portion of the analysis has high uncertainty.

It is the authors’ view that these limitations and data gaps do not severely compromise the conclusions. However, uncertainty must be taken into account when considering the strength of the conclusions and recommendations. Some of the recommendations presented address the limitations described above.

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INTRODUCTION

Study Objectives

This study seeks to evaluate the potential for past dry cleaner operations in Santa Clara County to cause groundwater contamination by perchloroethylene, the most commonly used dry cleaning solvent. A method for ranking past dry cleaners for their potential to contaminate groundwater is applied and adapted to available data to assist with prioritizing which of the many past dry cleaner operations warrant further investigation. This report includes extensive supporting information as Appendices on the modes of PCE release from dry cleaners, the nature and history of dry cleaning operations, the characteristics of dry cleaning solvents, analysis of groundwater vulnerability in Santa Clara County, and a comparison of national profiles of PCE releases, costs of investigation, and costs of remediation. The focus of this effort is to further protect the groundwater subbasins in Santa Clara County, where groundwater comprises nearly half of the water supply for more than 1.7 million people.

Water Supply in Santa Clara County

Water supply in Santa Clara County is managed by the Santa Clara Valley Water District (District), which is responsible for water supply, flood protection and watershed management throughout the county's 1,300 square miles. The District manages the the groundwater subbasins and provides wholesale water supply to the county's 15 cities, 1.7 million residents and more than 200,000 commuters. The District's responsibilities include providing a reliable supply of high quality water, and to manage flood and storm waters along the county's 700 miles of creeks and rivers in an environmentally sensitive manner. The District operates and maintains a County-wide water conservation and distribution system to convey raw water for groundwater recharge and treated water for wholesale to private and public retailers.

The District supplies high-quality water to 13 private and public water retailers, which in turn distribute it to their customers. By recharging the groundwater subbasins, the District ensures that adequate groundwater is available for water retailers and private well owners. Nearly half of the District's water supply comes from local sources, such as groundwater, and more than half is imported.

There are three interconnected groundwater subbasins within the county. The Santa Clara Subbasin in the northern part of the County extends from Coyote Narrows at Metcalf Road to the County's northern boundaries. The Coyote Subbasin extends from Metcalf Road south to Cochrane Road, where it joins the Llagas Subbasin at a groundwater divide. The Llagas Subbasin extends from Cochrane Road, near Morgan Hill, south to the County's southern boundary at the Pajaro River (SCVWD, 2001). A map of the groundwater subbasins is provided in Figure 1.

In 2004, the groundwater subbasins supplied 159,000 acre-feet of the total water use of 381,000 acre-feet (SCVWD, 2004). The remainder of the total water use was supplied from treated surface water and recycled water.

Groundwater is critical to the water supply needs of Santa Clara County. Increased demands and the possibility of reduced imported water in the future make effective and efficient management of the groundwater subbasins essential. The goal of the District's groundwater management program is to ensure that all groundwater resources are sustained and protected for current and future beneficial uses (SCVWD, 2001).

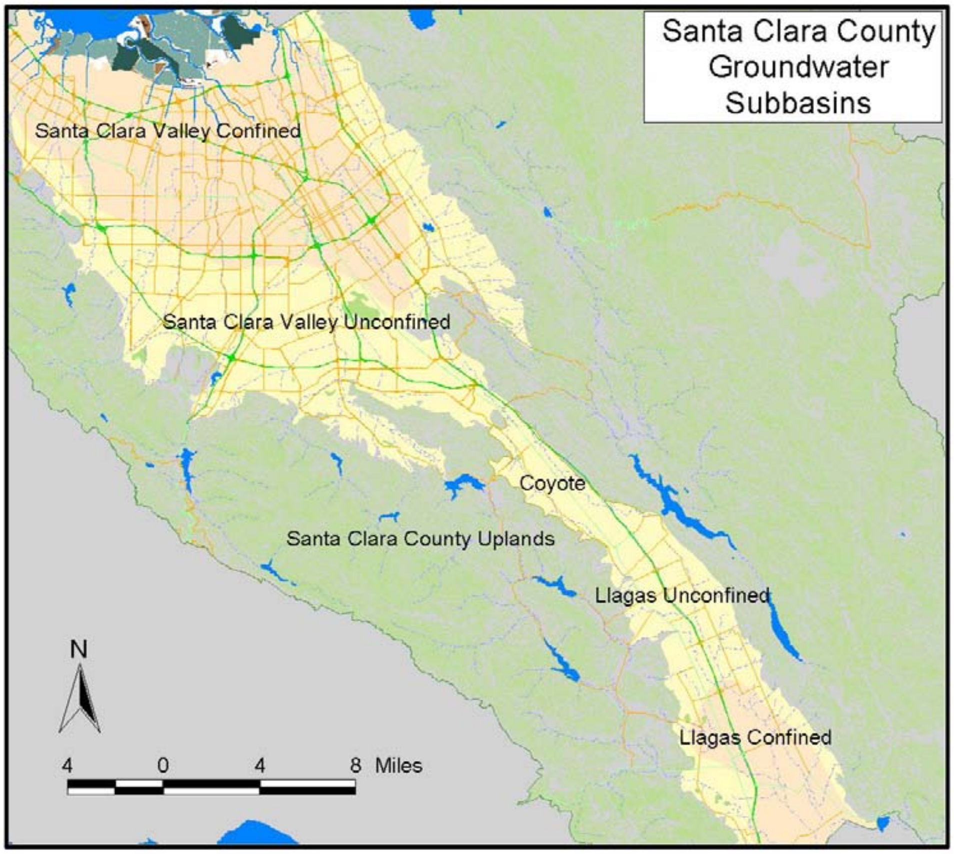

Figure 1 - Groundwater Subbasins in Santa Clara County

Groundwater Protection from Solvent Releases

There has been a very high incidence of groundwater contamination in northern Santa Clara County, also known as Silicon Valley. The dense concentration of electronics manufacturing activity in Silicon Valley has resulted in a large number of chlorinated solvent releases. The manufacture of semiconductors, printed circuit boards, and other electronics, used large quantities of chlorinated solvents for vapor degreasing and other cleaning applications.

Underground storage of chlorinated solvents, coupled with spills, leaks, improper handling and disposal, and other problems has resulted in a large number of chlorinated solvent release sites in Santa Clara County. On a county-wide basis, Santa Clara County has had the largest number of Superfund sites in the nation. Figure 2 presents a map showing extent of solvent releases to groundwater in Silicon Valley.

The contamination seen in Figure 2 looks severe, but it is primarily confined to the uppermost groundwater aquifers, and in most instances has not penetrated to lower aquifers from which drinking water is obtained. A review of public water supply well water quality testing for chlorinated solvents shows that only a small number of wells have had detections of any chlorinated solvents above laboratory reporting limits. The majority of those wells that have had chlorinated solvent detections have not exceeded their respective Maximum Contaminant Levels or other applicable regulatory standards.

The reasons for the seemingly paradoxical occurrence of widespread groundwater contamination from electronics manufacturing and other historical uses of chlorinated solvents, and the relative absence of impacts to public water supply wells, may include:

- The majority of major solvent release sites occur above the confined zone. Confining clay layers may inhibit the downward migration of contaminants. Groundwater under pressure in a confined zone tends to move upward, which may also limit downward migration of contaminants.

- Typical municipal well construction includes multiple zones of well casing perforations (well screens), whose lengths and deep locations tend to dilute surficial contamination entering the uppermost well screen with clean groundwater from lower aquifers.

It appears that the fortuitous juxtaposition of the geology of the Santa Clara Subbasin and geography of Silicon Valley’s electronics manufacturing industry has prevented severe impacts to Santa Clara County’s groundwater supply. Extensive testing of drinking water supplied by water supply wells has shown that Santa Clara County’s groundwater is remarkably clean. Some of the more problematic occurrences of groundwater contamination have occurred where electronics manufacturing facilities were sited within the forebay region of the Santa Clara Subbasin. For example, the former Fairchild Camera and Instrument Company and IBM’s former San Jose facility were both located in the forebay region, where groundwater is not protected by laterally extensive confining layers. Public water supply wells were impacted in both of these solvent release sites.

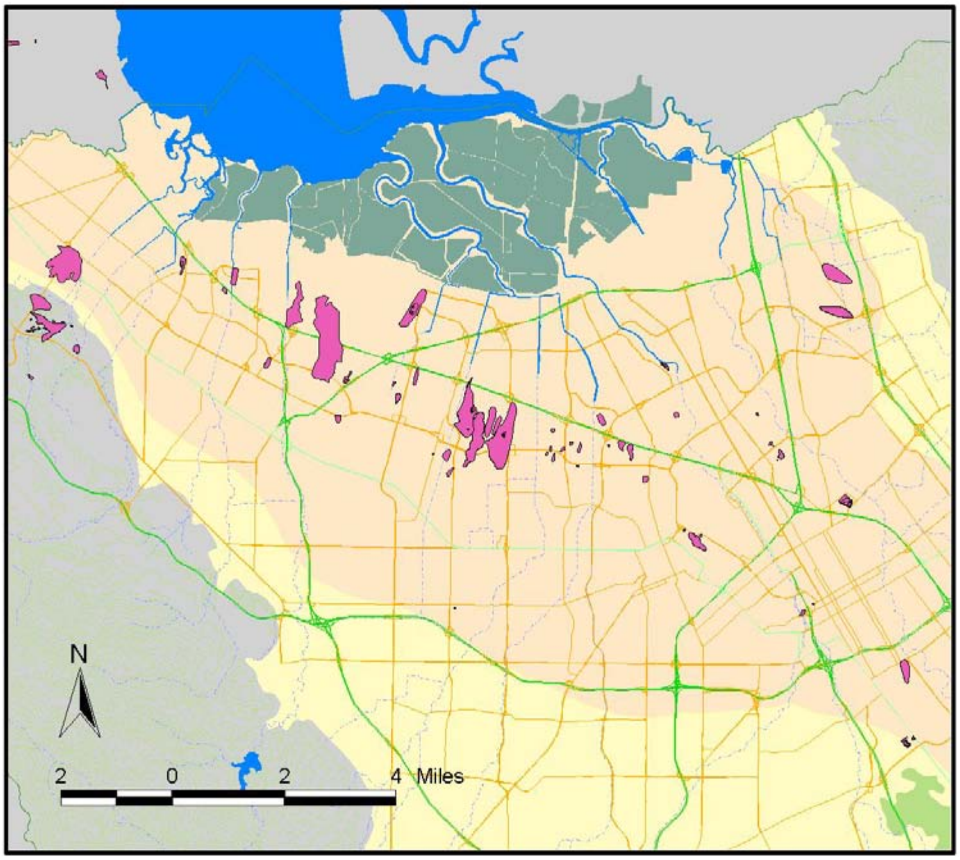

Figure 2 - Solvent Plumes in Silicon Valley (northern Santa Clara County)

While the majority of the electronics manufacturing facilities have been located in the north county along the rail line and the 101 freeway corridor, the geographic distribution of dry cleaners has followed a different pattern. Dry cleaners tend to be located in the shopping districts of residential neighborhoods, many of which are located at the base of the foothills along the edges of the Santa Clara Subbasin in the forebay region, overlying aquifers that are more susceptible to groundwater contamination. A large number of dry cleaners also operated in and near downtown San Jose, overlying the confined zone, where drinking water aquifers are relatively isolated from surficial contamination by thick and laterally extensive aquitards.

Dry cleaners used a surprisingly large volume of solvents during the 1950s, 1960s and 1970s, and may present a groundwater threat of similar magnitude to some electronics manufacturing industries. It is therefore important to obtain a detailed appreciation for the number of unique dry cleaner operation "footprints" in the county, and to develop tools to prioritize their investigation.

Dry Cleaner Operations and Impacts to Groundwater

There are approximately 36,000 active dry cleaning facilities in the United States, including commercial, industrial, and coin-operated facilities (USEPA, 1998). Most of these facilities are associated with soil and groundwater contaminated by dry cleaning solvents, as indicated by a recent survey of state dry cleaner programs by the State Coalition for Remediation of

Drycleaners (SCRD). The survey estimates that 75% of these facilities have caused soil and groundwater contamination (Schmidt, R., et al, 2001). In addition to the active dry cleaning facilities, there are an unknown number of former dry cleaning sites that also likely to have contaminated soil and groundwater. These contaminated sites are most often due to releases of PCE from historic dry cleaning operations (permitted or non-regulated discharges). Historically permitted or non-regulated PCE releases at dry cleaner facilities are numerous and well documented. These release scenarios include unintentional spilling, equipment leakage, transfer releases, storage problems, and discharges to ground and sewer lines.

Dry cleaner releases have impacted drinking water supplies throughout the country. In California, PCE from a variety of sources including dry cleaners has impacted nearly 900 wells out of 16,000 tested. In Santa Clara County, 17 of 520 municipal and small water system wells tested have had detections of PCE during the 18 year period from 1984 through 2002. These numbers do not take into account the numerous actual and potential impacts to non-regulated wells, such as domestic wells. These figures also do not account for PCE impacts below reporting thresholds that may be higher than the Public Health Goal for PCE. The drinking water maximum contaminant level of PCE is 5 µg/L (micrograms per liter, or, parts per billion – ppb).

The State of California Public Health Goal (PHG) is 0.06 µg/L (0.1% of the MCL or MCL is set at more than 80 times the PHG). It is also expected that many contaminated dry cleaner facilities and their related groundwater plumes would exceed the most stringent Environmental Screening Level (ESL) for PCE of 130 µg/L in groundwater for risk to indoor air. Volatilization from PCE plumes to indoor air in overlying occupied buildings can present a risk to human health.

Concentrations of PCE in groundwater at many past dry cleaner facilities are often well above advisory action levels for protection of public health. While this alone does not mean that that these facilities will be involved in an impact to a potential receptor (e.g. a drinking water well), it is significant. A review of dry cleaner cases profiled on the SCRD website reveals that the maximum PCE concentration in groundwater exceeded the Maximum Contaminant Lever (MCL) of 5 µg/L at all 95 profiled sites, and that 67% of the 95 profiled sites exceeded 1000 µg/L (Schmidt, R., et al, 2004).

Between 38% and 46% of sites in the SCRD survey appear to have DNAPL present in the subsurface, based on presumptive evidence of DNAPL presence. The SCRD dry cleaner case profiles revealed that the minimum site investigation cost was $2,000 and the maximum was reported at $1,000,000. A similar analysis of remediation installation and design costs was conducted from the 95 SCRD profile sites. The minimum remediation design and installation cost was $18,000 and the maximum was reported at $7,037,000.

Dry cleaning businesses are often operated as small family-owned businesses. Costs for investigation and cleanup of dry cleaner releases can be significantly more than business owners can absorb. In thirteen states, a state-operated dry cleaner fund is operated remediate dry cleaner release sites, particularly where no owner or insurance policy can be located to finance remediation. California has not established a dry cleaner fund.

Dry Cleaner Study Background

The San Francisco Bay Regional Water Quality Control Board's Groundwater Committee, which includes staff from the Regional Board, Alameda County Water District, Santa Clara Valley Water District, and San Mateo County Environmental Health Services Division, completed a report titled "Comprehensive Groundwater Protection Evaluation for South San Francisco Bay Basins," in May 2003. The report identified dry cleaning operations as a significant threat to groundwater quality. The recommendations related to dry cleaners were:

- A comprehensive inventory of historical and current dry cleaner facilities should be developed.
- Historical and current dry cleaner facilities should be prioritized with respect to groundwater threats for further evaluation/investigation.
- The S.F. Regional Board should work with cities, counties, Certified Unified Program Agencies, and the Bay Area Air Quality Management District to develop a pilot project in a specific city or other area for identifying and prioritizing dry cleaner facilities based on threats to groundwater quality.
- California should join EPA's State Coalition for Remediation of Dry cleaners and develop a statewide dry cleaner monitoring and remediation program.

Based on the Regional Board Groundwater Committee's recommendations in the draft report prepared in 2001, the Regional Board invited the Santa Clara Valley Water District to submit a proposal for funding to conduct a detailed analysis of past and current dry cleaner operations in Santa Clara County. The Regional Board prepared Resolution 118 support the District's study proposal and requested funding in the form of a $70,600 grant from the State Water Pollution Cleanup and Abatement Account for fund the study. The Santa Clara Valley Water District contributed additional funding to finalize the study. RWQCB Resolution 118 is presented as Appendix A.

Purpose of Study

The overall purpose of this study was to conduct a detailed analysis of historic and current dry cleaner operations, identify historical locations of dry cleaners in Santa Clara County and prioritize current and historical dry cleaner sites for their potential to impact groundwater quality. Additional study objectives were to gain a detailed, quantitative understanding of the temporal and geographic distribution of dry cleaner operations in a major urban/suburban region (all of Santa Clara County), recommend a strategy for prioritizing investigation of releases and corrective action, and develop conclusions and recommendations for regulatory oversight of dry cleaner sites.

Groundwater Vulnerability from Dry Cleaner Operations

Groundwater Vulnerability

In the unconfined forebay region, accidental hazardous materials spills can leach directly into groundwater. Stratification of alluvial sediments in the forebay is usually weak and permeability is relatively high. Contaminants originating in the forebay region can potentially migrate laterally toward the basin interior into both the confined lower aquifer zone. Vertical conduits such as abandoned irrigation wells can transport contaminants from shallow groundwater to deeper municipal drinking-water supply aquifers. On a site-specific or individual contamination case basis, the presence or absence of vertical conduits is unknown and must be established by investigation. The topic of vertical conduits was addressed in much more detail in the Groundwater Committee's May 2003 report, "Comprehensive Groundwater Protection Evaluation for South San Francisco Bay Basins." Groundwater protection strategies must account for all potential pathways that pollutants can follow from sources to municipal or private water supply wells. There are many manmade vertical conduits in the South Bay that may act as portals for contaminant migration into municipal water supplies (California Regional Water Quality Control Board, 2001).

Solvent Usage in Dry Cleaning Operations – Types, Quantities and Trends

Solvent selection for textile dry cleaning has undergone a progression from various hydrocarbon solvents to a range of chlorinated solvents, to carbon dioxide, based on factors ranging from quality of cleaning process, economics, worker health and safety, air quality regulations, and technology evolution. The key solvents used in significant quantities are briefly described here; additional information on dry cleaning chemicals, solvent properties, and solvent toxicity is provided in Appendices B and C.

Stoddard Solvent

In the early 1920s, the development of Stoddard solvent was heralded as a major research breakthrough in the dry cleaning industry. In 1928, Stoddard solvent was adopted by dry-cleaners in the United States. Until 1962, Stoddard solvent usage exceeded chlorinated solvents; it is less commonly used today, but some dry-cleaners still use it to clean drapes, suedes and leathers.

140° F Solvent

140° Solvent was also introduced in the late 1920s (it was named after its flashpoint of 140° F). 140 ° Solvent was safer than Stoddard solvent because of the higher flashpoint. It was permitted to be used in some places where Stoddard was prohibited.

Carbon Tetrachloride

Carbon Tetrachloride (CCl_4) was the first chlorinated solvent to be produced in the United States; large scale production started in the early 1900s. In 1914, U.S. production of CCl_4 was 10 million pounds, used mostly for dry cleaning and fire extinguishers. By the late 1940s, PCE largely replaced CCl_4 as a dry-cleaning solvent (the ratio of PCE:CCl_4 was 3:1). In 1962, estimated use of CCl_4 in the dry-cleaning industry decreased to 2 - 3 million pounds nationally, a small fraction of total annual dry cleaning solvent usage. By the 1970s, the usage of CCl_4 as a dry cleaning solvent was negligible. CCl_4 is no longer used in the dry cleaning industry because it does not perform as well as PCE, and more importantly, because it is considerably more toxic than PCE.

Trichloroethylene

Trichloroethylene (TCE) was first used as a dry-cleaning solvent in the 1930s in the United States. TCE use as a dry cleaning solvent declined rapidly in the 1940s when it was found to attack newly favored cellulose acetate dyes. TCE is no longer used in the dry cleaning industry.

Perchloroethylene

Perchloroethylene (PCE) was introduced to the US dry cleaning industry in the late 1930s to early 1940s. PCE became the solvent of choice for most small dry-cleaners. Large industrial dry-cleaners mostly used petroleum based cleaners (e.g., Stoddard solvent). As of 1952, the dry-cleaning industry used 80% of the PCE produced. Over the following decades, PCE usage by the dry-cleaning industry decreased; from 1972 to 1975, the usage of PCE decreased from 75% to 63%. By 1990, only 50% of the PCE manufactured was used by the dry-cleaning industry. In the United States today, 85 to 90% of dry-cleaners use PCE. Review of BAAQMD records shows that 87% of Santa Clara County dry cleaners used PCE in 2001.

Stabilizers and Additives Used in Dry Cleaning Operations

Chlorinated solvents are inherently unstable; they are prone to react with acids, alkali metals, water, oxygen, and ultraviolet light. Solvent stabilizers are a class of compounds added to chlorinated solvents to inhibit these reactions by removing acids, reacting with metal salts, or protecting from ultraviolet light. PCE does not require a metal inhibitor, but may require acid acceptors for degreasing applications. In the presence of light and air, PCE slowly auto-oxidizes to trichloroacetyl chloride. Stabilizers, such as amines or phenols, inhibit the decomposition process to extend solvent life and protect equipment and materials. Cyclohexene oxide and butoxymethyloxirane are also listed as inhibitors in PCE (Joshi et al, 1989). Compared to other chlorinated ethanes and ethenes, PCE is relatively stable, and generally requires only small amounts of stabilizers (Mohr, T.K., 2001).

Stabilizers and additives to PCE may assist the site investigator with forensic analysis to identify PCE sources and potentially link the contamination to dry cleaning operations as a source, or distinguish a given occurrence of PCE as originating from an electronics or auto maintenance facility instead.

Pathways for Perchloroethylene Impacts to Soil and Groundwater

A “pathway” for PCE to impact soil or groundwater is the path a chemical will take from its point of use or storage to soil and to groundwater. The paths by which PCE impacts soil and groundwater depend on source characteristics and subsurface properties. Source characteristics define the mode of PCE release to the subsurface. Source characteristics include the release location and the potential mass released. Some releases will result in PCE leaked or spilled as pure product, dissolved in waste water, or released as a vapor. Subsurface characteristics determine the path of PCE from the release point to groundwater. Soil grain size, soil organic content, pore size, geochemical environment, microbial activity, and heterogeneities control the migration of PCE, as do larger subsurface features such as confining aquitard layers.

Source Characteristics

Detailed source investigation focus upon the nature and location of PCE releases, and are therefore critical to successful investigation and ultimately remediation. Source identification allows investigations to focus upon the points of release and resulting migration pathway. Source characteristics may be difficult to determine for historic dry cleaner releases, because it may not be possible to reconstruct machine locations, floor drain locations, and other features helpful for identifying release points. Interviews of past operators are helpful for understanding potential release mechanisms and better understanding source characteristics.

Release Types

A recent study by the Florida Department of Environmental Protection and Florida State University provides a comprehensive review of release mechanisms based on a survey of 334 dry cleaners. This detailed review provides an excellent resource for identifying potential release mechanisms and sources (Florida DEP, 2002). A summary of this study is presented in Appendix G of this report. Release mechanisms can be summarized as:

- Solvent Storage and Transfer
- Equipment Operation and Maintenance
- Equipment Failure
- Other Spills, and
- Discharges to Leaking Sewer Lines.

The Florida study showed that more PCE mass is released as a result of solvent transfer, storage and operations than due to sewer line discharges. Other studies consider sewer line discharges to be the main discharge point for PCE (Cohen W.L., Izzo V.J., 1992). The soil beneath the floor slab in the vicinity of the dry cleaning machines and distillation units was identified as the area within dry cleaning operations most frequently contaminated PCE. Contamination was also frequently detected near the service door where solvent deliveries were received; in areas where solvents and spent cartridge filters were stored; and in areas where solvent contaminated wastes were discharged (i.e. sewer connections and leaking lines) (Florida DEP, 2002).

General familiarity with the dry cleaner solvent use cycle during dry cleaner operation is helpful for planning investigations to determine locations of release. Figure 3 below presents a diagram of solvent use in typical dry cleaner operations (University of Tennessee, 1997).

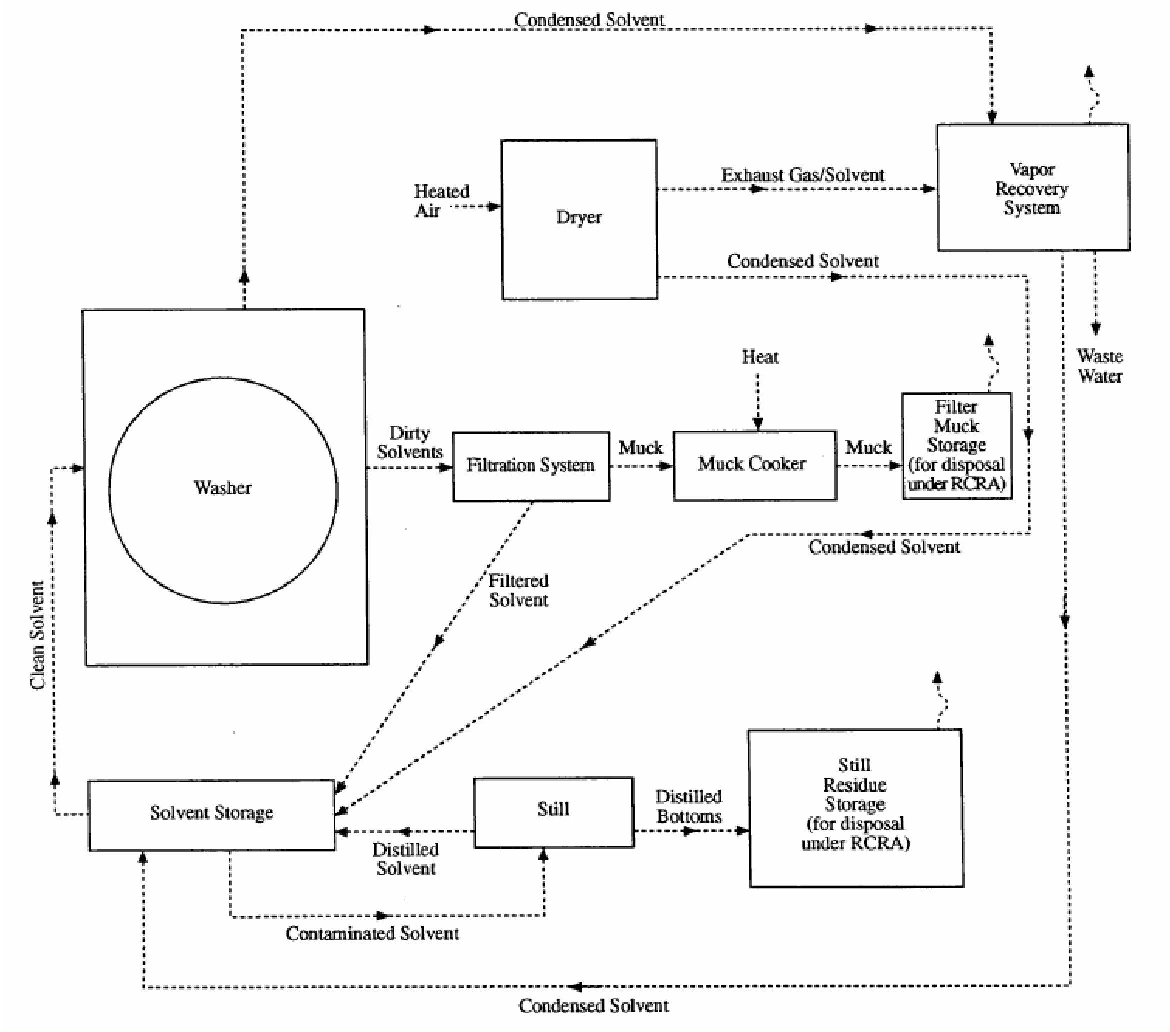

Figure 3 - Solvent Cycle in Dry Cleaning Operations

The SCRD survey of 95 dry cleaner case profiles corroborates the Florida study's conclusions regarding the locations of releases within the dry cleaning operation, as shown in Figure 4.

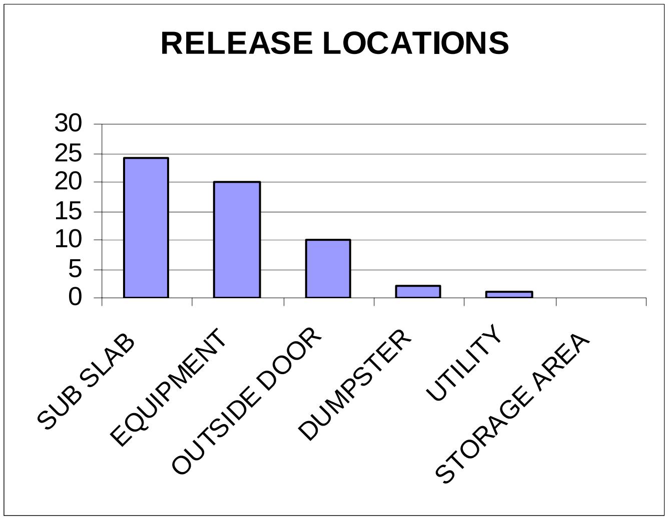

Figure 4 - Locations of Releases in 95 Dry Cleaner Cases Profiled on SCRD Website

The SCRD case profile review also looked at release mechanisms. 40 of the 95 sites included data on release mechanisms. Among the 40 case studies with information on mode of release, as depicted in Figure 5, tanks are the second most frequent release types noted, following releases to sewer lines. The number of release mechanisms associated with equipment failures and operation is apparently underestimated in the SCRD case profiles, which provide less detailed information on release mechanisms than the Florida study. In Figure 4 above, the large number of sub-slab and under-equipment source locations is most likely associated with releases from equipment failures.

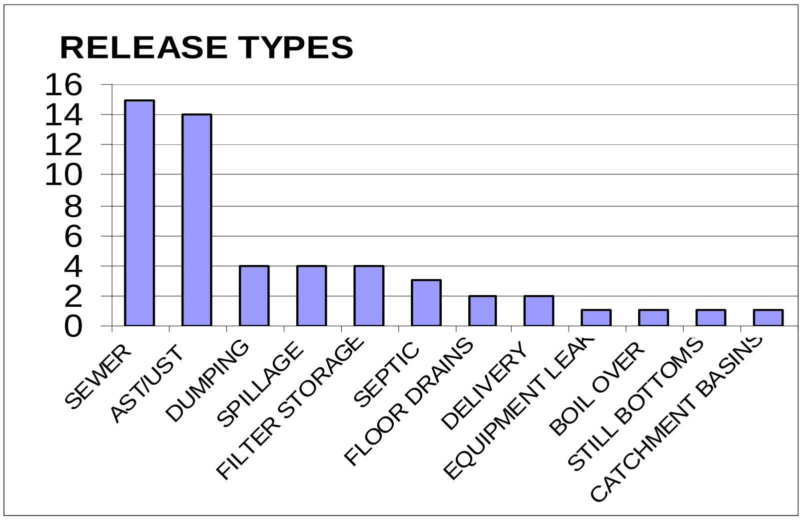

Figure 5 - Frequency of Identified Release Types

A 1992 study by California's Central Valley Regional Water Quality Control Board profiled five potential mechanisms by which PCE migrated out of sewer lines into surrounding and underlying soil and groundwater. The first four methods were caused by PCE contaminated liquids and sludges settling in low spots in the sewer lines. The five potential mechanisms are summarized in Table 1 below:

Table 1 - Five Potential Mechanisms by which PCE in Sewer Lines Impacted Soil and Groundwater

Mechanism/Pathway	Detailed Explanation
1. Through breaks or cracks in the sewer pipes.	As pure product or dissolved phase
2. Through pipe joints and other connections.	As pure product or dissolved phase
3. By leaching in liquid form directly through sewer lines into the vadose zone, because:	a. Sewer pipes aren't impermeable to water or PCE; b. Dense liquids settle in low spots in the sewer pipe, causing an increase in hydraulic head which provides a larger driving force to move PCE downward through the pipe; c. PCE's viscosity is less than water, so PCE will flow through a pipe wall more easily than water.
4. By saturating the bottom of the sewer piper with high concentration of PCE-containing liquids, PCE will volatilize from the outer edge of the pipe into the soils:	a. PCE will turn into a vapor at the liquid-soil air interface at the outer edge of the pipe. Because PCE's vapor density is almost 6 times greater than air, the PCE vapor will sink and migrate downwards to the groundwater.
5. By penetrating the sewer pipe as a vapor:	a. Concentration of PCE vapor in the pipe usually is greater than in surrounding soils which causes a diffusion through the sewer pipe to the less concentrated area; b. Gas can penetrate the pipe due to pressure; and/or c. Vapor pressure increase to above atmosphere which causes a pressure gradient that forces PCE gas through the pipe into the vadose zone. Once outside the pipe, the PCE gas tends to sink downwards towards the water table, where it may dissolve into groundwater.

Release Location

Release location is an important factor in a PCE pathway. Releases above slab versus releases above unpaved surfaces versus release below ground may have different characteristics. Releases above slab will volatize more readily than subsurface releases. Releases to bare ground will leach through soil more readily than above slab releases. PCE releases from sewer lines may migrate to groundwater more readily due to leaching from the leaking line and vapors sinking to and dissolving into the water table. Releases associated with discharge from waste water separators to sewer lines is a prime example of differences in migration pathways and source potential. Separator water may be saturated with PCE or even contain non-aqueous phase product, but it is diluted in the sewer line from combining water sources. Sewer line leaks may occur at some distance from the dry cleaning operation, whereas operational or transfer releases occur at point sources at the facility and will generally be pure product. These differences will affect the fate and transport and migration potential of a release.

Release Mass

Different release mechanisms can result in different masses released. The Florida Study compiled a list of release mechanisms with associated spill volumes. For instance, a delivery truck spill may be 10 gallons, filter gasket failure 150 gallons, and an above ground tank coupling failure 275 gallons. Even “de minimis daily losses” (small ongoing releases) such as a minor solvent leak, dripping at the rate of one drop per second will result in one gallon of solvent being discharged during an eight hour (working) day (EPA, 1994). Solvent drips can result in significant volumes lost over time (six working days per week at 52 weeks a year = 312 gallons/year).

Based on reported spill quantities for different releases, estimates can be made for the potential quantity of PCE that could be released over a set period of time. Tables 2, 3, 4, present different release scenarios with potential release quantities as identified in the Florida study.

Table 4 presents benchmark comparison of estimated M*t*BE mass released in a fuel leak scenario. Fuel leaks have been studied much more intensively than dry cleaning release mechanisms, and therefore provide a useful comparator for the Florida study’s estimates. Counterintuitively, the M*t*BE release scenario using a leak rate below the standard leak detection threshold results in a leak rate of similar magnitude to the three PCE release scenarios evaluated. One might have expected a significantly larger M*t*BE release quantity due to the substantially larger throughput quantities of gasoline at a typical gas station (up to 1000’s of gallons per day), compared with the relatively small quantity of PCE typically used at a dry cleaning facility. This comparison does not address large releases from fuel USTs, such as structural failure.

Table 2: PCE Release Estimate for a Steady Drip

A solvent leak dripping at a rate of one drop/second results in one gallon of solvent discharged during an 8 hour work day	
pce drip mass release estimate	
leak rate	
1gpd	
leak duration	
312d*10 years	6d/wk
Estimated undetected leak rate over 10 years	
3650	gallons
Ave PCE by volume 10 years	
100%	
Estimated undetected leak rate of PCE over 10 yrs	
3650	**gallons**

Table 3: PCE Release Estimate for Filter Cartridge Drainage

Filter Change (can contain up to 1 gallon of PCE). Must be drained at least 24 hours. If not, PCE will be spilled when the un-drained spent cartridge filters are removed from the filter cartridge. In the past, un-drained spent filter cartridges were collected and stored outside the dry cleaner's service door. PCE drained directly to the ground or the pavement.	
pce filter mass release estimate	
leak rate	
1gpd	
leak duration	
312d*10 years (closed one day a week)	
Estimated undetected leak rate over 10 years	
3120	gallons
Ave PCE by volume 10 years	
50%	
Estimated undetected leak rate of PCE over 10 yrs	
1560	**gallons**

Table 4: Estimate of PCE Releases from Transfer and Storage

pce storage/transfer mass release estimate	
leak rate	
45 gpd (based on the geomean of 5 different release scenarios)	
leak duration	
2d*10 years (based two occurrences/yr)	
Estimated undetected leak rate over 10 years	
900	gallons
Ave PCE by volume 10 years	
75 -100% (based on distallation source and product source)	
Estimated undetected leak rate of PCE over 10 yrs	
675	**gallons**
900	**gallons**

Table 5: Benchmark Fuel Leak Scenario - M*t*BE Release Estimate

Maximum leak detection of recent UST equipment 1990-2000, estimate of undetected releases	
mtbe mass release estimate	
Undetected leak rate (based on leak detection equipment capabilities)	
0.2 gph	
Leak Duration	
24hrs*365days*10yrs	
Estimated undetected leak rate over 10 years	
17520	gallons
Ave MtBE by volume 1990-2000	
8%	
Estimated undetected leak rate of MtBE over 10 yrs	
1402	**gallons**

Repeated releases at the same location can also increase DNAPL penetration in the vadose zone. Releases of a few gallons (tens of liters) can penetrate a vadose zone tens of feet thick and impact groundwater. Larger volumes would be able to penetrate thicker vadose zones (Feenstra et al, 1996). Leaks occurring outside facilities in storage areas without double containment, on bare ground, or in areas otherwise unattended, the magnitude of the release would be greater than leaks occurring in attended areas within the shop above concrete slabs.

DNAPL Migration in the Subsurface

Contaminant transport is controlled primarily by characteristics of the subsurface environment and the chemical characteristics of the contaminant. Most dry cleaners released PCE, so the chemical characteristics of the contaminant will not vary much from site to site. Contaminant composition may vary depending on the type of cleaning and associated solvent formulations used, as well as the type of waste removed from clothing or textiles. For example, dry cleaning at an industrial uniform cleaning shop may produce a mixture of waste solvent and engine oil and grease from mechanic's overalls or cooking grease from chef's aprons. Addition of detergents to remove water soluble wastes from clothing may act as a surfactant and increase the solubility of PCE in groundwater.

In most Santa Clara County settings, PCE must first migrate through the unsaturated zone before reaching groundwater. PCE is often released from dry cleaners as DNAPL, but in some cases (distillation water, leaking sewers) the PCE may be in dissolved form or in vapor phase. Physical, chemical and biological features of the vadose zone will influence the fate and transport of PCE. Flow dynamics are controlled by geologic heterogeneities at scales from individual soil particles and pore spaces to larger geologic features (i.e. faults, aquitards, etc).

The degree to which DNAPL migrates through the subsurface depends on the balance among driving forces, for example gravity exceeding the restricting force of capillary pressure. A study contrasting two release scenarios illustrates how the driving forces may control migration of DNAPL into soil. Two releases were simulated, one an instantaneous release over 1.1 ft^2 and the other a drip release over 0.16 in^2. The gravity forces of ponding in the instantaneous release simulation caused greater lateral migration than the drip release by overcoming soil capillary forces and driving the PCE into shallow sand laminations (Cohen, R.M., and Mercer, J.W., 1993).

Hydrodynamic forces can also control or restrict movement, but are generally not as significant as gravity and capillary pressure.

DNAPL migration to groundwater can also be controlled by the size of the release and thickness of the vadose zone. As DNAPL moves through the vadose zone, it becomes trapped in the porous media due to the effects of interfacial tension and capillary pressure. If the release volume is small, the vadose zone thick, or a competent stratigraphic barrier is of sufficient size, the residual DNAPL becomes exhausted and is confined to the vadose zone (Cohen, R.M., and Mercer, J.W., 1993). Volatilization can also play a role in confining DNAPL to the vadose zone. In a thick vadose zone with a high vapor pressure, volatilization may deplete the DNAPL before reaching groundwater. Exhausted residual DNAPL can still present a threat to groundwater quality. Rainfall or other recharge can dissolve residual DNAPL, causing groundwater contamination. Volatilization can also cause groundwater contamination as dense vapors sink through the porous media and come into contact with underlying groundwater.

In the case of vapor phase solvent movement, groundwater contamination can occur in directions opposite groundwater flow directions, and will typically reside in the upper portion of the aquifer (Cohen, R.M., and Mercer, J.W., 1993). Sites where PCE is found in greater concentrations at the upper portion of the saturated zone may have residual exhausted DNAPL in the vadose zone, or may otherwise be dominated by vapor transport. Where larger volumes of DNAPL migrate through groundwater, DNAPL impacts generally result in greater concentrations with depth.

Given sufficient driving forces, DNAPL will move through the saturated zone by the path of least resistance until stopped at a geological impediment such as low permeability soils (stratigraphic barriers). Where such barriers are encountered, DNAPL will pool at the bottom of the water table. Even small differences in hydraulic conductivity can inhibit vertical migration. The vertical migration of DNAPL is controlled more by gravity and stratigraphy than groundwater flow because it is denser than water, and less viscous than water.

Detection of DNAPL in the subsurface can be very difficult. DNAPL eludes detection when it migrates along narrow pathways thin sand lenses and fractures, in directions independent of groundwater flow controlled by stratigraphic heterogeneities, and when it pools at low spots above low permeability soils. Unlike a widely distributed contaminant, a sample must intercept the exact location where DNAPL has collected in order to detect it. The somewhat random nature of DNAPL movement may preclude precision sampling to delineate DNAPL occurrence in the subsurface.

Low-permeability soils sloping in directions opposite the prevailing groundwater flow direction may cause solvent to migrate in directions different than groundwater flow direction. DNAPL will flow with the slope of the underlying low permeable unit, which may be opposite the direction of groundwater flow. Predicting or detecting DNAPL movement is particularly difficult at sites with heterogeneous interbedded and discontinuous stratigraphies (US EPA, 2004). In one study simulating PCE released to a stratified sandy aquifer underlain by a clay layer, DNAPL pooled atop low permeability horizons, with the greatest amount of DNAPL pooling on the clay aquitard. Between the layers, residual saturations were lower and more variable (Kueper et al, 1993). In sedimentary environments with discontinuous stratigraphic barriers, DNAPL moves along a barrier until a higher permeability unit is encountered. Then DNAPL migrates vertically until another stratigraphic barrier is encountered. This ‘stairstepping' effect can move DNAPL significant distances from the source, possibly in directions opposite to groundwater flow.

Where underlying low permeability material undulates or forms bowl shapes (stratigraphic traps), DNAPL will pool. Multiple stratigraphic traps can make detection of DNAPL particularly difficult. Given sufficient DNAPL accumulation, DNAPL can overflow stratigraphic traps and spread across the low permeability unit along its slope (Cohen, R.M., and Mercer, J.W., 1993). If enough DNAPL pools in a trap, penetration of the underlying stratigraphic barrier can occur. Denser DNAPLs have better potential to penetrate underlying geologic barriers. Thick pools of DNAPL are relatively rare; even thin DNAPL pools have sufficient capillary pressure to penetrate geologic barriers (McWhorter, D., 1996). Consequently, many low permeability units will not present sufficient barriers to vertical DNAPL migration.

Given sufficient vertical pressure, DNAPL can migrate through fractures, root holes or other vertical conduits such as abandoned wells. For a non-constant release, DNAPL migration will be eventually be exhausted by residual saturation, stratigraphic traps, and capillary pressures. Residual DNAPL, either in the vadose or saturation zone, will act as a long-term source of dissolved groundwater contamination. Dissolving residual DNAPL under natural conditions can take hundreds of years (Cohen, R.M., and Mercer, J.W., 1993; Pankow, J., et al, 1996). Groundwater contamination by DNAPLs is a legacy issue that will continue to threaten groundwater resources well into the future if not identified and remediated. It is therefore very important to review the potential for groundwater contamination at all locations where dry cleaner machinery was operated and where PCE is likely to have been released to the subsurface.

The first and most critical step in investigation of contamination associated with dry cleaner operations is to identify potential release scenarios and locations of sources. For many dry cleaner investigation sites, the release mechanism will not be known and may have occurred over long periods of time. However, the studies summarized above show how releases can occur.

Investigations should focus on those release scenarios identified as most common:

- Equipment releases
- Solvent Transfer
- Contact Water Discharge to Sewers and Septic Systems
- Storage (includes tanks)
- Filter Disposal
- Other Dumping and Spilling

Investigations should also focus on the most common source areas:

- Sub Slab, particularly under existing or former dry cleaner equipment
- Outside the Delivery Doors
- Storage Areas
- Dumpsters
- Sewer and Septic Lines

Dry Cleaning operations and equipment have evolved over the last 100 years. The number of different release scenarios is significant to understanding the vulnerability of underlying aquifers. Site investigations may not reveal all historic release types and locations; however, appropriate investigations should be able to identify most of the significant sources and their locations.

Fate and Transport of PCE

The environmental behavior of PCE in groundwater is governed by source characteristics (quantity and pattern of releases) and hydrogeologic characteristics and processes such as advection, dispersion, sorption, chemical transformation, and biotransformation. When PCE is spilled, it can migrate into the vadose zone and underlying aquifers where it forms highly concentrated and complex "source zones" that are extremely difficult to clean up. Larger quantities of DNAPL in the source zone will continue to add to the dissolved solvent plume for a long time.

DNAPL will pool, finger, and form ganglia (discrete blobs of solvent) as DNAPL penetrates and moves through the saturated zone, creating a very complex three-dimensional distribution of solvent in the source zone. These zones can be very difficult to locate and characterize. Groundwater flow through and around DNAPL pools and ganglia can be significantly slowed increasing the persistence of DNAPL and making them extremely difficult to remediate. Dissolved PCE plumes originate from the saturated source zones, and from infiltration of water through PCE trapped in the vadose zone. Advection causes dissolved PCE to move with groundwater flow. Density driven movement is not a significant migration factor for dissolved PCE.

In groundwater, PCE can undergo chemical and biological transformation to other organic compounds. PCE can be transformed microbiologically or abiotically. Anaerobic conditions, which favor reductive transformations, are more prevalent in low-permeability zones and in the source areas of contaminated sites. PCE can undergo reductive dechlorination catalyzed by anaerobic bacteria. Reductive dechlorination occurs as a sequence of reactions as shown in Figure 6 below:

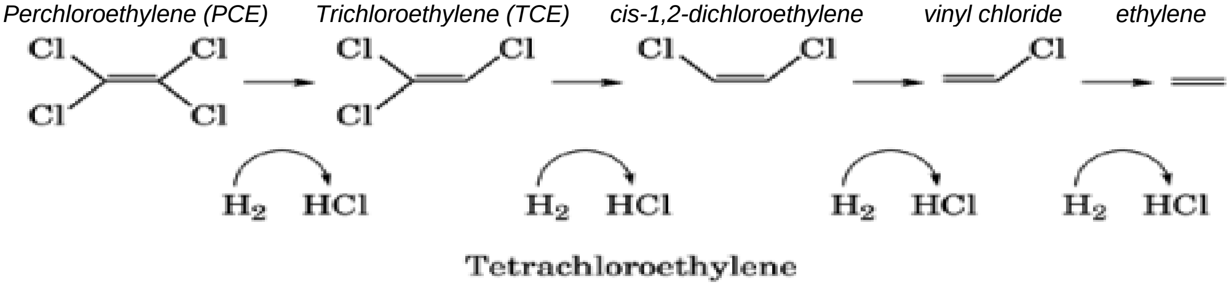

Figure 6 - Reductive Dechlorination Pathway for Biotransformation of PCE

In microbially-mediated reductive dechlorination, chloride atoms in the PCE molecule are replaced with hydrogen atoms. Replacement of one chloride transforms PCE to TCE. Replacement of a second chloride transforms TCE to cis-1,2-dichloroethylene (cis-12DCE), then cis-DCE is transformed to vinyl chloride, and finally vinyl chloride is converted to the harmless substances ethylene and chloride. However, anaerobic degradation rarely proceeds to completion in groundwater, leading to accumulation of vinyl chloride, a potent human carcinogen. In aerobic groundwater environments, i.e. where dissolved oxygen is present at levels greater than 2 mg/L, PCE is not subject to reductive dechlorination, and is therefore relatively persistent. Aerobic groundwater conditions are prevalent in much of Santa Clara County’s groundwater. At older dry cleaner releases sites, PCE degradation reaction products will be found if degradation is occurring in groundwater. Testing for degradation products and groundwater geochemistry can provide useful information on the fate of PCE and possible methods to enhance natural biodegradation.

Summary of Groundwater Impacts from Dry Cleaning Operations

This Section summarizes the nature of impacts from dry cleaning operations on groundwater, including a review of known impacts in Santa Clara County; a more detailed discussion of this topic is provided as Appendix E. The potential for past dry cleaning operations to contaminate soil and groundwater with PCE is well-established. For example, a 2001 study showed that 75% of dry cleaner release sites surveyed in several state dry cleaner programs had evidence of releases that caused soil and groundwater contamination (Schmidt, et al, 2001). The severity and magnitude of releases vary, and the potential for contaminating supply wells depends on proximity to wells, geologic and groundwater conditions, vertical conduits, well construction, and duration of dry cleaner operations. A 1992 well investigation program conducted by the Central Valley Regional Water Quality Control Board identified 21 PCE impacted drinking water wells in Central Valley towns, and found that dry cleaners were the likely source of PCE for 20 of those wells (Izzo, V.J., 1992).

Table 6 summarizes the regulatory status of dry cleaner release sites in Santa Clara County. Of the 38 dry cleaner release sites listed by the Regional Water Quality Control Board in Santa Clara County in 2002, 7 sites (19 percent) are in the ‘release confirmation’ or ‘remedial investigation’ phase and 2 sites (5 percent) are under active remediation. Five sites (13 percent) are considered inactive; 33 sites (87 percent) are either actively pursuing investigation and/or remediation, or have been closed.

Table 6: Regulatory Status of Dry Cleaner Cases in Santa Clara County (2002)

Site Status	Number of Sites	Sites (%)
Inactive	5	13%
Release Confirmation - Preliminary Investigation	4	11%
Remedial Investigation/ Remedial Action Plan	3	8%
Active Remediation	2	5%
Verification Monitoring	2	5%
Closed	13	34%
Active - Unknown Status	8	21%
No Action	1	3%
Total	38	100%

Table 7 presents a summary of soil and groundwater sampling results at 26 dry cleaner sites in Santa Clara County.

Table 7: Solvent Detections at Dry Cleaner Release Sites in Santa Clara County

	Soil (ppm)		**Groundwater (*ppb*)**	
	PCE	**Stoddard Solvent**	**PCE**	**Stoddard Solvent**
Number of Results	7	2	14	3
Maximum Concentration	250	39,000	24,000	5,500,000
Mean	41	-	6,293	-
Median	41	19,501	1,100	14,000

As demonstrated in Appendix E, the potential threat to groundwater resources from PCE releases appears greater than the threat posed by M*t*BE releases from leaking underground fuel tanks at gas stations.

PCE Impacts to Water Supply

Water retailers in California are required by the California Department of Health Services (DHS) to regularly test water quality to ensure that all water served to the public meets health-based standards. The regulatory compliance level for PCE in drinking water, i.e., the Maximum Contaminant Level, is 5 ppb. Santa Clara County groundwater pumped for drinking water supply has been tested for PCE since the 1970s or earlier. Data was obtained from DHS in electronic format from 1982 through the 2002. During that time period, 4.5% of the 5,440 analyses conducted on samples from public supply wells indicated PCE presence. Most of these detections resulted from repeat analyses in impacted wells, and many were at 1 ppb or less with a laboratory reporting limit of 0.5 ppb. Counting only detections greater than 1 ppb, the frequency of detection becomes 1.8%. The total number of wells in Santa Clara County with PCE detections listed in the DHS Database in the past 22 years is 17 wells out of 469 tested, or 3.6 %. The total number of wells with at least two PCE detections above 1 ppb is 8, or 1.7 %. In 2003, only 2 wells had detections, with the maximum PCE detection at 2.8 ppb. The maximum detected PCE concentration in any drinking water well was 10 ppb in 1992, representing the only MCL exceedance in the period of record. Figure 7, below, summarizes PCE results from the DHS program for public water supply well testing.

In 2002, the State Water Resources Control Board's Groundwater Ambient Monitoring and Assessment program (GAMA) was conducted in Santa Clara County to test water supply wells for Volatile Organic Compounds (VOCs) using ultra-low level laboratory reporting limits. At ultra-low concentrations, presence of VOCs was used to constrain groundwater residence time. Concentrations at ultra-low levels do not constitute a health threat, as they are generally well below applicable regulatory standards.

The GAMA program performed analysis for PCE at ultra-low levels in 166 wells. PCE was detected in 10 wells above the reporting limit, which ranged from 5 to 40 parts per trillion (ppt). Detected concentrations ranged from 5 to 59 part per trillion. The Public Health Goal is 60 parts per trillion, while the regulatory standard, the Maximum Contaminant Level (MCL), is 5,000 parts per trillion (5 parts per billion, ppb). DHS data from 2002 showed only 2 wells with PCE detections, ranging from 690 ppt to 2,200 ppt (0.69 ppb to 2.2 ppb). Figure 7 displays the frequency of PCE detections in water supply wells from the DHS database. About 95% of tests (5,194 analyses) were non-detect. The common reporting limits for PCE in routine municipal well sample analyses are 0.5 and 0.1 ppb, both of which are greater than the Public Health Goal

Appendix E presents information on site assessment, the prevalance of various remedial strategies employed at dry cleaner release sites, and the costs associated with various approaches for remediating soil and groundwater impacted by dry cleaner release sites

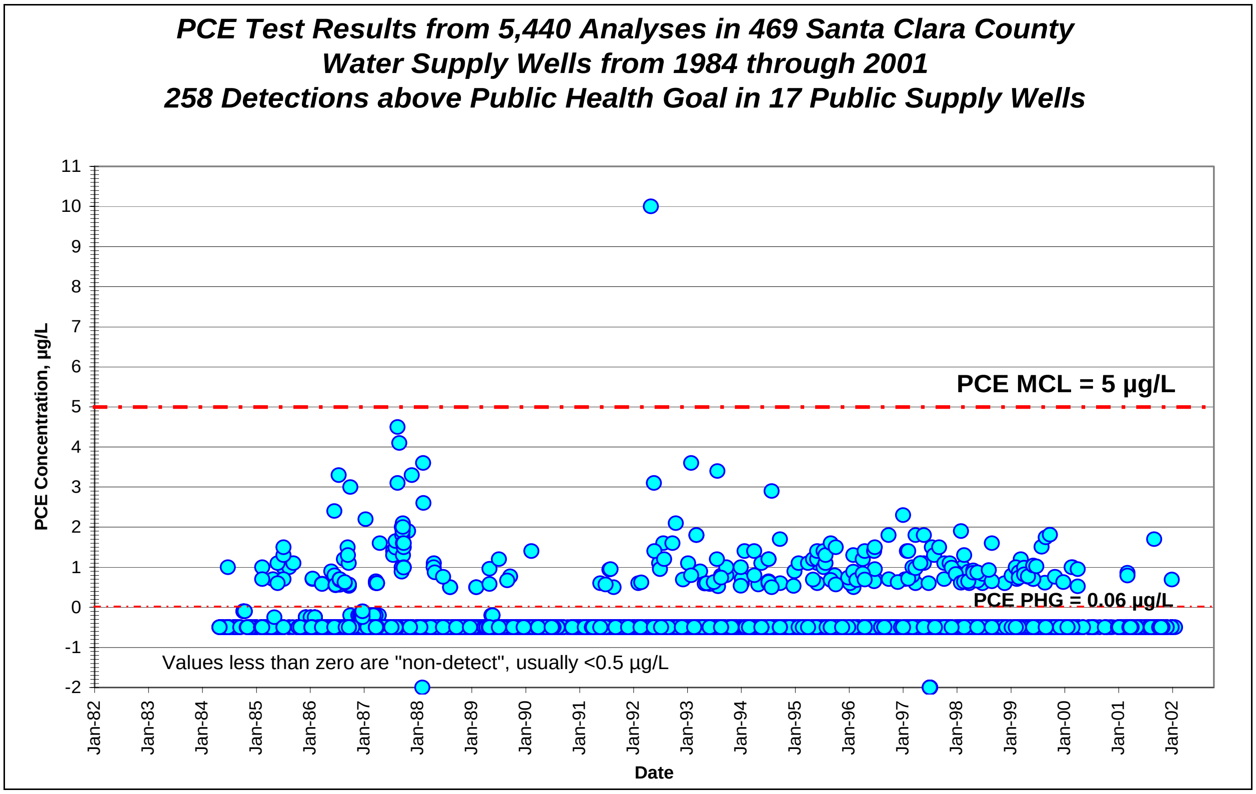

Figure 7 - Summary of PCE Results from DHS Public Drinking Water Well Testing Program

Geography of Santa Clara County Dry Cleaning Operations

Dry Cleaner Study Data Collection Methodology

Dry cleaner locations were determined by collecting records reflecting the physical address of a current or past dry cleaning business. These records include telephone directory listings, business directory listings, Sanborn fire insurance maps, and shopping mall directories. Other data sources reviewed but not used include business licenses and chamber of commerce listings. Records were recorded from telephone and business directories for every year for which the directories were available. The date range of the records obtained is from 1946 to 2001.

The primary source of directories was the San Jose Martin Luther King Library; however, directories were also reviewed at libraries in Santa Clara, Sunnyvale, Palo Alto, Morgan Hill, and Gilroy. None of the libraries visited had complete, continuous collections of either telephone or business directories. The incomplete records used as the basis for this study prevent a concise and exhaustive analysis of all cleaners. Accordingly, data presented in this study should by no means be considered complete; some cleaners may not have been included in the database due to omissions, missing records, data entry error, or other causes.

Drop-off vs. On-site Cleaning

Some dry cleaning businesses operated drop-off storefronts at which no cleaning plant was operated. Customer cleaning articles are received at drop-off storefronts and transported to a central cleaning plant. Telephone directory listings include advertisements and line entry listings that may reveal whether a given dry cleaning business operated a plant on site. Business names or advertising claims for ‘one-hour’ or ‘same-day’ service can identify those cleaners operating plants on site. A dry cleaning business listing in a telephone or business directory does not by itself establish that perchloroethylene was used at a particular business. Other lines of evidence, such as permits from the Bay Area Air Quality Management District (BAAQMD), document whether PCE or another dry cleaning solvent was used at a given business. The current ratio of storefronts to on-site cleaning plants, determined by comparing telephone directory listings to BAAQMD permit records, is 60 %. This percentage can be used to make general assumptions about the approximate number of cleaning plants operating in the groundwater subbasins in past decades, prior to dry cleaner permitting by BAAQMD. The percentage of storefronts to cleaning plants cannot, however, help confirm PCE use at specific business.

PCE Releases through Sanitary Sewers

Prior to the adoption of cradle-to-grave regulation of hazardous wastes in the mid-1980s, it was permissible and common for dry cleaning plants to discharge condensate wastewater laden with up to 150 ppm PCE to sanitary sewers. PCE exfiltration from sewer lines connected to dry cleaners in the 1980s and earlier was a primary route of subsurface contamination from dry cleaners (see Figure 5). A survey of past influent concentrations of PCE and other VOCs was conducted for the Regional Board’s Groundwater Committee report, “A Comprehensive Groundwater Protection Evaluation for South San Francisco Bay Basins” (RWQCB, 2002). Data obtained for that survey, presented as Appendix M of this report, revealed that a substantial mass of PCE was routinely discharged to sanitary sewers, even after commencement of industrial pretreatment inspections. For this study, additional POTW influent data were collected for the

City of Gilroy, where PCE has been consistently detected in water supply wells at levels below the Maximum Contaminant Level. Table 8 summarizes selected maximum PCE concentrations in POTW influent over the last 20 years.

Table 8: Past PCE Influent Concentrations at Santa Clara County Wastewater Treatment Plants

Past PCE Influent Concentrations at Santa Clara County Wastewater Treatment Plants				
	Treatment Plant	**PCE Influent Concentration, parts per billion (µg/L)**	**Dry Season Flow, million gallons per day (MGD)**	***Maximum* pounds PCE discharged per year**
2000	San Jose-Santa Clara	15.5	135 MGD	6,374
1998	San Jose-Santa Clara	5.7	135 MGD	2,344
1998	Sunnyvale	6	17.4 MGD	317
1997	Gilroy	3.7	5.9 MGD	66
1992	Gilroy	3.7	5 MGD	41
1991	Gilroy	2.7	5 MGD	23
1986	Sunnyvale	40	11 MGD	1,350
1986	Gilroy	1.5	4.4 MGD	19
1985	Gilroy	9	4.4 MGD	121

***Assumptions and notes**: This table lists selected* detections *from quarterly monitoring; these facilities also have many years with no PCE detection in their influent. Data were not sought from all facilities for each year. Concentrations are assumed to be for dry season flows; storm season flow does not increase mass discharged and can be ignored; mass of solvents arriving at POTW in vapor form or adsorbed to solids is not accounted for; dry season daily flows are estimated. The* estimated *pounds PCE per year assumes that PCE is present at the measured concentration throughout the year. In reality, concentrations are likely to vary from non-detect to a range of detected values; <u>this approach is likely to overestimate the mass of PCE moving through a sewer network</u>. All of the measured concentrations are within wastewater treatment plant permit conditions, which usually allow for 1 ppm volatile organic compounds; no violations for solvent discharges from these treatment plants were issued. PCE measured in wastewater plant influent may have multiple sources; in addition to dry cleaners, numerous other industries may have discharged PCE to the sewer.*

Where sewer lines reside above the water table, exfiltration of PCE as vapors, dissolved phase, and DNAPL, may impact underlying groundwater. Where sewer lines reside below the water table year-round or seasonally, infiltration of surrounding groundwater can be expected, greatly reducing the potential impact of PCE transit through sewer lines. In some locations where sewer lines are below the water table, sewer lines may act as a sink for local plumes of PCE and other chlorinated solvents.

The threshold of effort required to factor sewer line submergence into analysis of dry cleaner impacts to groundwater prevented completion of a more rigorous and quantitative analysis of the role of sewer lines in facilitating PCE transport and distribution in the subsurface environment in Santa Clara County. This report reviews this issue in qualitative terms, drawing inference from past POTW data and literature citations.

Records Confirming On-site Cleaning

Records documenting on-site PCE use at Santa Clara County dry cleaning facilities are available for the past decade. These records include the hazardous waste manifest records obtained from the Department of Toxic Substances Control, records maintained by local industrial pretreatment permitting programs operated by sanitary districts and city wastewater treatment plants, and building permits for ventilation equipment at dry cleaning plants. Fire department and County Environmental Health Department records may include hazardous materials management plans (HMMPs), which document PCE use at dry cleaning businesses. Delivery records from PCE suppliers may exist but were not obtained for this study

Period of Record for Documentation Confirming On-Site Cleaning

The period of available records that reliably document PCE use varies by record type. DTSC hazardous waste manifests have been recorded in paper form since the mid-1980s, but are available in electronic form for only the past six years. Industrial pretreatment permits are available from the mid-1980s. Discharging dry cleaning condensate wastewater to the sewer was prohibited in Santa Clara County jurisdictions beginning in 1986 at the earliest, and 1991 at the latest. Many programs continued to issue ‘zero-discharge’ permits, which required cleaners to obtain a permit and annually testify that wastewater from dry cleaning operations is not being discharged to the sewer. Industrial pretreatment programs continue to inspect dry cleaners. Some dry cleaning plants have on-site industrial wastewater pretreatment equipment to remove PCE to less than 1 ppm prior to discharge to the sewer. BAAQMD permit records begin in the late 1970s at the earliest. HMMPs can generally be found from the early 1990s forward.

Evidence for Type of Solvent Used

Where documentation indicates that dry cleaning plants were operated, available information regarding the type of solvent used is reliable for at most two decades. This study did not produce documentation from which it can be reliably established that a particular cleaner operating in the 1970s or 1960s used PCE or another solvent. Because PCE was the dominant dry cleaning solvent during the 1970s and 1960s, the assumption is made that these dry cleaners used PCE. BAAQMD records specifically list which type of solvent was used and the total permitted annual emissions. DTSC hazardous waste manifests also distinguish PCE from hydrocarbons. HMMPs also list the type of material used. Early records from Sanborn Fire Maps listed dry cleaning plants and storage tanks because flammable hydrocarbon cleaning agents were commonly used. Currently, about 88% of operating dry cleaning plants in Santa Clara County use PCE and 11% use hydrocarbon cleaning agents. As of 2002, one cleaner was using Green Earth, a decamethylcylcopentasiloxane solvent, while two used Rynex, a dipropylene glycol tertiary-butyl ether solvent. Appendix B discusses these alternative cleaning solvents.

Determination of Continuous Dry Cleaning Operations at a Given Site

Dry cleaning businesses tend to change hands and move fairly often. Individual cleaning businesses, identified by unique names, have moved as many as four times in the span of 43 yrs. Continuous dry cleaner operations in a single location have been handled by as many as five different businesses, judging by name changes. Many cleaners, however, have operated at the same location under the same name for long periods of time, whether under single or multiple owners. Because the records from which the dry cleaner database was compiled are incomplete, data gaps prevent direct confirmation of continuous operations in most decades researched.

Assumptions were made where missing records resulted in data gaps of less than 3 years. Where dry cleaning businesses operating under the same name were found at the same location on either side of a record gap of 3 years or less, the assumption was made that the dry cleaner operated there continuously through the period of the record gap. Where a data gap greater than 3 years was accompanied by a change in business name, the assumption was made that one dry cleaning operation closed, and a subsequent dry cleaning operation commenced in the first year of record following the record gap.

Accuracy of Dry Cleaner Data Base and Mapped Locations

Multiple lines of evidence were pursued to identify locations of past dry cleaning operations. Nevertheless, the resulting record should not be viewed as a completely accurate or reliable list of where dry cleaners operated. The compiled database contains location errors, and, because telephone directories were the primary source of location data prior to the last decade, dry cleaning operations at locations where no on-site cleaning may have occurred are also listed. For this study, all listings were entered into the database, and all listed businesses were geo-coded[4] into the Geographic Information System (GIS). Therefore, at about 30 to 40 % of listed and mapped locations, dry cleaning equipment may not have actually been operated. Collection of specific evidence for on-site use of cleaning solvents involves a more substantial effort for each location and was not pursued for this study. For past dry cleaner operations that pre-date available records that maybe useful for establishing solvent usage, screening-level site investigation may be the most reliable option for determining whether solvents were used, and if so, which type.

Locational errors are inherent to most retrospective studies and mapping efforts that span several decades; however, geo-coding past dry cleaners and manual research of locations attained more than 90% successful address matching,. GIS software (ESRI ArcView 3.2 and ESRI ArcMap 8.2) was employed to match addresses obtained from telephone and business directories against available addresses in the current Barclays® assessors parcel and the TeleAtlas® streets databases for Santa Clara County. For about 8% of the dry cleaners entered into the database, computer generated address matches could not be completed. A number of factors contribute to the low match rate of telephone directory dry cleaning address against parcel and street data. Some listings are provided as street intersections. Others are listed by the name of the shopping center or strip mall in which they're located. Renamed streets confounded efforts to locate dry cleaners that operated in past decades. Renumbered streets and subdivided parcels were also problematic. Some listings did not include the City in which they're located, which in a few instances led to confusion because street number and street name were identical or very similar on streets that traverse several cities, but business names varied (e.g., El Camino Real). Some dry cleaners used different names at the same time for different services, e.g. leather or rugs vs. textiles. Other factors contributing to less reliable software-assisted or manual geo-coding include redevelopment efforts converting commercial retail to office, residential, or other uses. Land use information available from the Barclay's GIS parcel theme (electronic data mapping file) and the Association of Bay Area Governments was used to infer which parcels more likely held dry cleaners.

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[4] "geo-coding" is the semi-automated process by which addresses are matched with locations on maps using geographic information software (in this case, ESRI ArcView 3.2).

Research into parcel history at the County Assessors office was productive for resolving some locations. Another available method, not used for this study, is chain of title research by title insurance and realty companies. Postal route map books, if available and obtainable, could also help determine where a historical address was physically located. Following completion of a threshold of effort using the methods described above, a 'best-estimate' approach was adopted to assign locations for the remaining cleaner address listings. The final GIS theme of dry cleaners was checked against land use to confirm dry cleaning businesses were not assigned to parcels that have been continuously classified as residential land use.

In many instances, correctly matching a cleaner to a shopping center did not help to narrow down where within a large property the business was located. To resolve locations within strip malls, where sub-addresses such as "196-A So. Main Street" could not further specify the location without a site visit, high resolution digital aerial orthophotoquads in GIS were examined to identify roof fixtures associated with dry cleaning operations. Examples of roof fixtures that can reveal the location of a dry cleaner within a strip mall are shown in Figure 8.

Results of Dry Cleaner Data Compilation and Mapping

A total of approximately 1,250 dry cleaning businesses operated in Santa Clara County from 1946 through 2001. As of 2002, there were 379 BAAQMD-permitted dry cleaning plants (individual machines using solvents) operating at 224 unique locations in Santa Clara County. The trend in numbers of dry cleaners by year roughly reflects the increasing population trend in Santa Clara County. Counts of cleaners operating by year should be considered estimates based on available records; however the 2002 count based on BAAQMD permits is considered accurate. Figure 9 presents the numbers of listed dry cleaners by year, and the population trend. Significant shifts in the number of cleaners from one year to the next in Figure 9 reflect data availability, data collection and methodology issues, but most likely do not represent large changes in the number of operating cleaners from one year to the next.

PCE has been used for dry cleaning in the Santa Clara Valley groundwater subbasins for more than fifty years. Hazardous waste laws governing handling and disposal of PCE were adopted in the mid 1980s. Air pollution regulations required that dry cleaners operate under permit and control emissions beginning in the late 1970s. Therefore, the 1946 through 2001 period for this study includes at least three decades of unregulated use, handling, and disposal of PCE at dry cleaners and other facilities using solvents in Santa Clara County. The practice of discharging dry cleaning condensate wastewater to sewer lines was legally permissible and commonplace for at least forty years of the period during which dry cleaning with PCE was prevalent. Other unregulated practices, which were not illegal at the time but are viewed today as unwise, include disposal of PCE soaked filters in garbage dumpsters, dumping of waste PCE to storm drains, in dry wells, and on the ground, and bringing drummed wastes to unlined landfills and burn dumps. These practices, where employed, present a significant threat to groundwater, and may be the cause of substantial PCE contamination.

Figure 8 – Example Dry Cleaner Roof Vent Features from High Resolution Aerial Photos

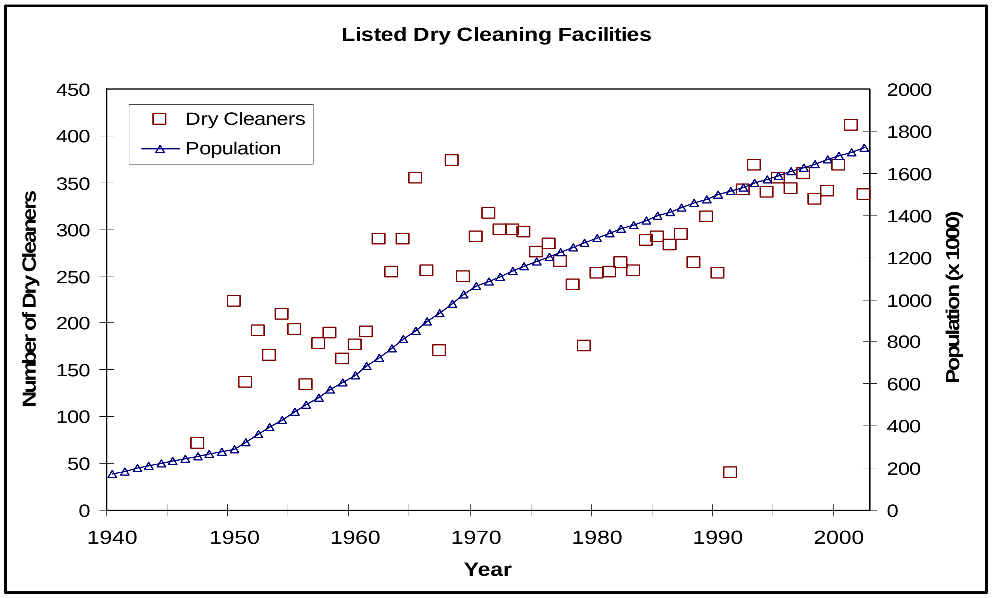

Figure 9 - Count of Dry Cleaners from Telephone Directories by Year, with Countywide Population

The evolution of better dry cleaning machinery has virtually eliminated PCE contamination from newer machinery. In older transfer machines, which required operators in past decades to carry clothing articles soaked with PCE from the cleaner to the dryer, successive dripping of pure PCE product onto concrete floors was often the cause of underlying soil and groundwater contamination. Cleaners active in the era during which transfer machines were prevalent, i.e. before 1968, were prone to releases from this practice.

Inferring PCE Quantities from Air District Records and DSTC Manifests

An indicator of the total volume of PCE used by dry cleaners is the total permitted PCE emissions obtained from BAAQMD's toxic air contaminants database. The BAAQMD reported in their 2000 annual report that the total permitted emissions of PCE by all industries in Santa Clara County was approximately 170,000 pounds (BAAQMD, 2000).

Table 9: Emissions Factors for Dry Cleaning Machines

(Pounds of PCE per 100 Pounds of Clothes)

Emissions Factors for Dry Cleaning Machines (Pounds of PCE per 100 Pounds of Clothes)			
		Machine Type	
Source	**Transfer**	**Dry-to-Dry (vented)**	**Dry-to-dry (non-vented)**
Machine Vent	4.0	3.1	0
Clothing Transfer	2.5	0	0
Equipment Leaks	2.5	2.5	2.5
Losses in Waste	3.2	3.2	3.2
Total	12.2	8.8	5.7

Source: Federal Register Volume 57 No 191, 10-1-92, and Center for Emission Control 09-92

Most cleaners emit far fewer pounds of PCE than their permits allow. However, PCE emissions made up a substantial percentage of all PCE used in past dry cleaning operations. In 1998, the total of all permitted PCE emissions in Santa Clara County was 202,537 pounds. The total permitted PCE emissions from dry cleaners in 1998 was 187,821 pounds, or 93% of all PCE emissions. Other sources of PCE emissions, in descending order, include municipal wastewater treatment plants, landfill gas emissions, metal fabrication, electronics, adhesive labels, printing, and groundwater remediation.

The hazardous waste manifest database obtained from DTSC for dry cleaning plants provide records of manifested hazardous waste collection from only a fraction of the dry cleaning plants operating in Santa Clara County during the period of the manifest database record[5]. Hazardous waste manifests are classified by the industries that generate the waste, according to their North American Industry Classification System codes (NAICS – formerly Standard Industrial Classification (SIC) codes). The DTSC manifest database prepared for this study queried Santa Clara County manifest data for NAICS number 81232 (SIC number 7216). Wastes are further classified according to waste type as defined in the Resource Conservation and Recovery Act

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[5] The reasons for the absence of many dry cleaner listings in the DTSC database are unknown; this database may be incomplete or waste generation not listed in Table 10 may be due to dry cleaners not generated sufficient quantities of hazardous waste to require manifesting or database listing.

(RCRA). The RCRA code for spent halogenated solvents, including waste PCE, is F002, which was included in the query of the DTSC database. Other facilities use hydrocarbon cleaning agents, while some may be performing on-site solvent recycling or using mobile solvent recycling services. Table 10 presents quantities of PCE waste collected from dry cleaning plants in Santa Clara County, based on hazardous waste manifests.

Table 10: Total Dry Cleaner PCE Waste Generation by City

Total Dry Cleaner PCE Waste Generation by City, from DTSC Hazardous Waste Manifest Database, (Pounds PCE)

City	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**Total Pounds PCE, 1993 - 2002**	**Avg Pounds Waste per Year**
Campbell	0	0	0	0	0	2,235	1,770	1,575	1,695	315	7,590	759
Los Gatos	2,265	3,075	2,565	2,550	3,450	4,031	2,624	2,877	3,245	840	27,522	2,752
Milpitas	1,572	2,372	1,620	2,010	1,649	1,425	1,615	1,170	1,305	410	15,148	1,515
Morgan Hill	4,395	3,615	3,105	2,850	2,925	2,446	1,769	2,370	1,935	420	25,830	2,583
Mountain View	5,715	5,895	5,820	5,625	5,190	5,385	5,205	5,265	3,510	1,170	48,780	4,878
Palo Alto	1,950	2,730	975	2,280	6,495	3,630	3,690	2,730	1,530	285	26,295	2,630
San Jose	13,580	21,225	5,740	9,505	11,935	14,534	4,630	4,772	4,618	1,060	91,599	9,160
Santa Clara	3,885	3,285	3,810	2,235	2,055	1,977	720	768	197	55	18,987	1,899
Sunnyvale	2,355	0	0	0	27	22	148	592	1,449	683	5,276	528
Grand Total	35,717	42,197	23,635	27,055	33,726	35,685	22,172	22,119	19,484	5,238	**267,028**	26,703

Data not available for unincorporated areas or south county; zero values listed where database had no records.

Inferring PCE Usage from Period and Duration of Dry Cleaning Operations

Figure 10 presents a plot of starting year versus duration of continuous dry cleaning operations. Solvent mileage, i.e. the number of pounds of PCE used to clean 1,000 pounds of clothing, is much higher in current dry cleaning operations due to higher efficiency machines, vapor locks, better operator education and training, and improved inspection, regulation and enforcement by Air District, Hazardous Materials, and Industrial Pretreatment staff. For estimation purposes, it is assumed that older dry cleaners both used and released more solvent. Older cleaners were likely to have started operations using less efficient machinery, and operated prior to adoption and enforcement of emissions standards and hazardous waste laws. Volumes of PCE used at dry cleaners varied by the size of the operation. For example, industrial dry cleaning operations to clean uniforms used far greater quantities of PCE than smaller retail operations.

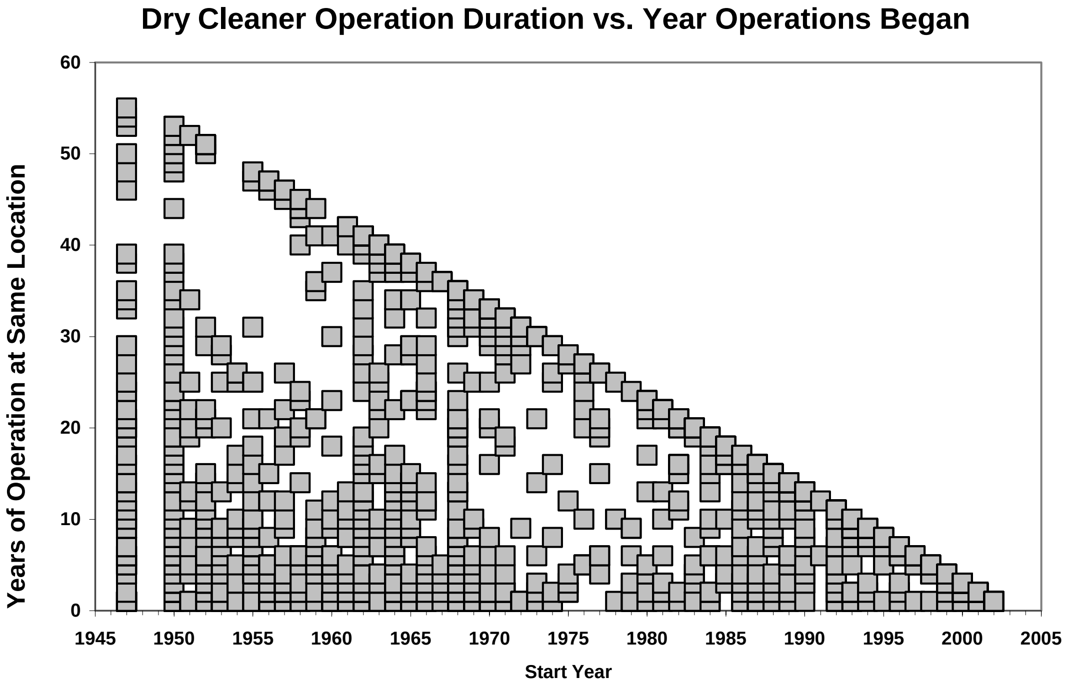

Figure 10 - Dry Cleaner Operating Duration and Start Year

General Interpretation of Potential for Drinking Water Impacts from Dry Cleaners

The degree to which current or past dry cleaning operations pose a threat to underlying groundwater and nearby public and private water supply wells is dependent upon several factors, including:

- the depth to the seasonal high water table,
- the distance from the cleaner to the nearest water supply well
- the distance from the cleaner to the nearest known abandoned well.

Figure 11 presents a graphical summary of the depth to water below current and past dry cleaning operations, grouped by hydrogeologic zone, i.e. forebay (recharge) zone, or confined zone. The same data are included in Table 11.

The majority of cleaners are located over shallow groundwater above the confined zone. Confining clays presumably offer protection to deeper underlying drinking water aquifers. More than 300 dry cleaners operated in the forebay, or recharge area, and more than 200 were located within 50 feet above the water table. In the transition zone, in which greater percentages of fine-grained aquifer materials result in less recharge, nearly 200 dry cleaners operated less than 30 feet above the water table, and more than 300 dry were located within 50 feet above the water table.

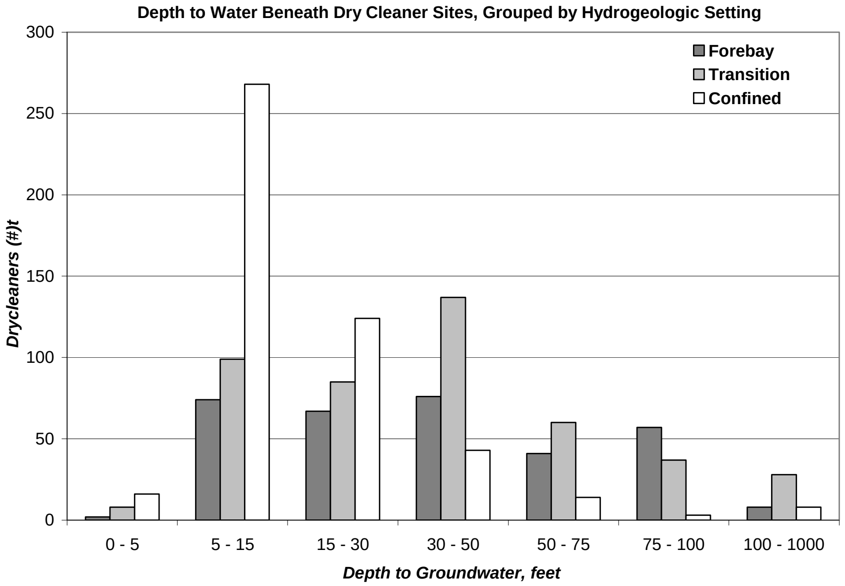

Figure 11 - Depth to Water beneath Santa Clara County Dry Cleaner Sites, Grouped by Hydrogeologic Setting

Table 11: Depth to Water Beneath Dry Cleaner Sites and Hydrogeologic Setting

Depth to Water Beneath Dry Cleaner Sites and Hydrogeologic Setting				
Depth to Water (feet)	**Forebay**	**Transition**	**Confined**	**Total**
0 - 5	2	8	16	26
5 - 15	74	99	268	441
15 - 30	67	85	124	276
30 - 50	76	132	43	251
50 - 75	41	60	14	115
75 - 100	57	37	3	97
100 – 1000	8	28	8	44
Total	325	449	476	1250

In the south county, groundwater vulnerability is highest, and depth to groundwater is fairly shallow. The Morgan Hill, Coyote Valley, and San Martin areas are more susceptible to contamination from dry cleaner releases than most other parts of the county. The south county communities obtain nearly all of their water supply from groundwater.

Abandoned wells may act as vertical conduits, conveying shallow groundwater contamination from dry cleaners to lower aquifers. Figures 12 and 13 present the proximity of past and current dry cleaners to known abandoned wells. Nearly 10% of cleaners are found within 250 feet of known abandoned wells; 30 dry cleaner locations are within 100 feet of known abandoned wells. Known locations of abandoned wells most likely represent only a small fraction of the total number of abandoned wells. Vertical conduits pose a significant threat to drinking water supply aquifers, particularly where they are co-located with dry cleaners and other users of chlorinated solvents. DNAPL can migrate rapidly through the gravel pack in the well annulus of abandoned or active irrigation, water supply, cathodic protection, domestic, and other wells.

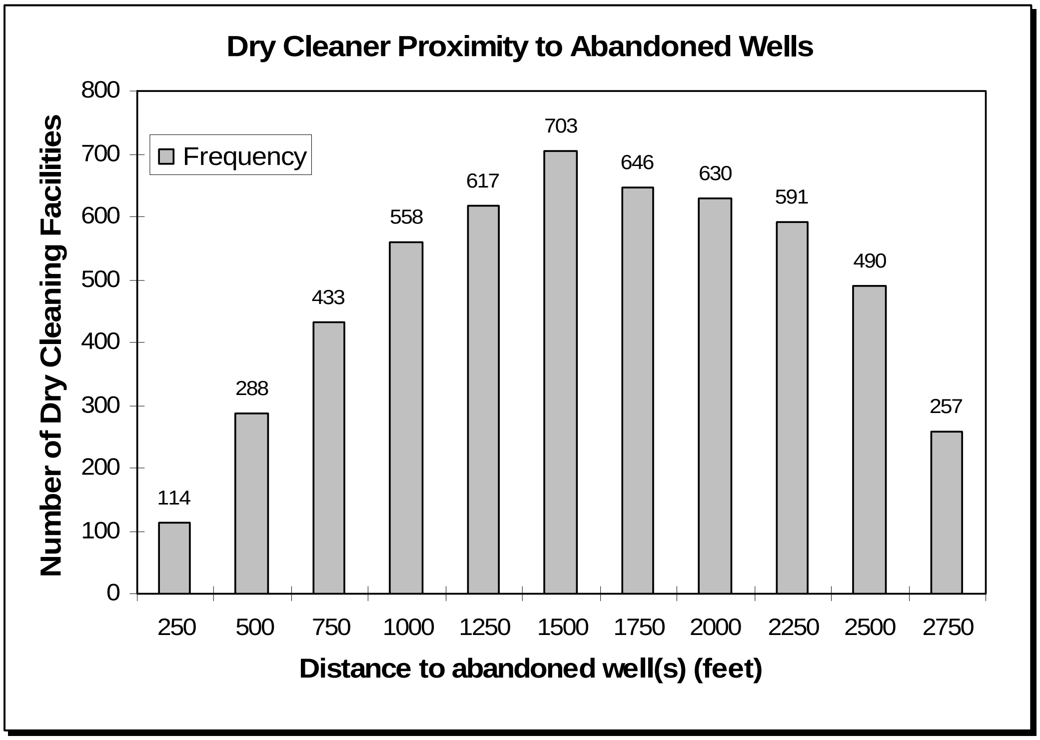

Figure 12 - Distances from Dry Cleaner Locations to Six Nearest Abandoned Wells

Estimating the Potential for PCE Releases to Groundwater

The SiteRank Approach to Ranking Dry Cleaners for Threats to Groundwater Quality

With more than a 1,000 unique locations of past and current dry cleaners, determining which sites present the greatest threat to groundwater resources becomes a difficult task. By treating all dry cleaners equally, time, effort, and funds may be over-allocated to low risk cases, while high risk cases may not receive sufficient attention. Therefore, a methodology is needed to determine which dry cleaners pose the greatest risk to protecting the beneficial uses of groundwater in Santa Clara County's groundwater subbasins. A method was developed using geographic information system software (GIS) that accounts for which generation dry cleaning equipment was likely in use based on when operations began, how long the dry cleaner operated, and the location of the dry cleaner relative to underlying groundwater vulnerability, groundwater flow direction, nearby supply wells, and nearby abandoned wells.

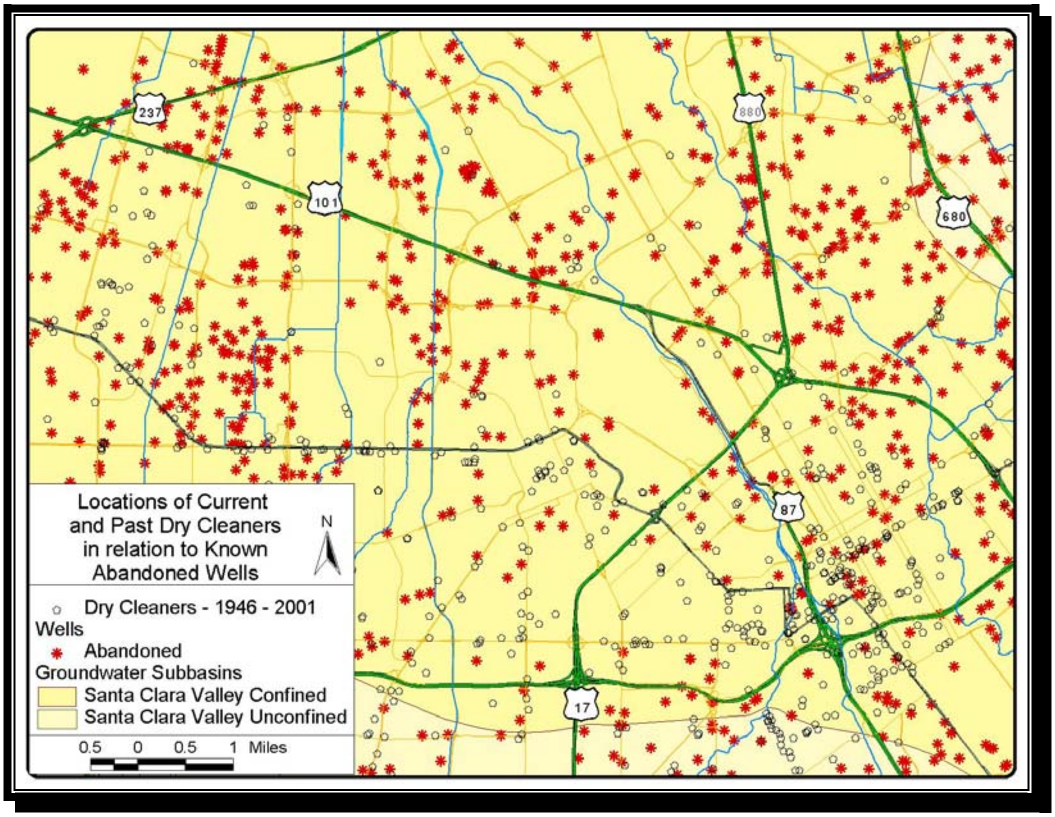

Figure 13 - Locations of Current and Past Dry Cleaners in relation to Known Abandoned Wells 1946 - 2001

Numerous previous methods have been developed to categorize and prioritize contamination sites for investigation, and to establish the degree to which cleanup must be performed. Approaches considered in prior efforts by the District to rank sites have included the following methods:

- fixed radius from a supply well,
- site location within the forebay or recharge zone,
- proximity to known abandoned wells,
- proximity to surface water,
- sensitivity of underlying groundwater as determined by applying EPA's *DRASTIC* methodology.

The District developed criteria for ranking Operating Gasoline Underground Storage Tank (UST) facilities with respect to M*t*BE threat to groundwater using a combination of these approaches. The criteria were developed using the District's highly developed GIS data and spatial querying. Gasoline UST facilities were considered to be high threat if they met the following criteria:

- Located within 2,000 feet of an active drinking water supply well
- Located within 500 feet from a known abandoned well
- Located within 500 feet of a creek
- Located anywhere within a recharge zone
- Located within an area determined to have high groundwater sensitivity using the DRASTIC scale (see Appendix L for an explanation of the DRASTIC scale).

An approach suitable for contrasting risks posed by sites with a wide range of chemicals of concern that accounts for aquifer conditions, source strength, well vulnerability and pumping, and contaminant fate and transport was found in *SiteRank*. The *SiteRank* algorithm was developed by Matthew C. Small for his Ph.D. research at the University of California at Berkeley, and is presented in his dissertation, "Managing the Risks of Exposure to Methyl Tertiary Butyl Ether (M*t*BE) Contamination in Ground Water at Leaking Underground Storage Tank (LUST) Sites" (Small, M. 2003). The *SiteRank* algorithm provides a simplified process-based, travel-time representation of contaminant fate and transport, combined with index-based scaling factors for chemical hazard and vertical migration. The *SiteRank* tool provides a dimensionally consistent screening tool that integrates both the relative strength of sources of contamination, and the vulnerability of water supply wells.

The input parameters for *SiteRank* include:

- Pumping Well Production: location, pumping rate, and days pumped per year
- Aquifer parameters: groundwater travel time from contaminant source to pumping well, and presence of intervening aquitards between source and well intake
- Source characteristics: location, estimated volume of release, and chemical(s) of concern
- Chemical properties: percent present in source (e.g. gasoline is 11% M*t*BE, dry cleaning solvent is 99% PCE), toxicity, retardation, solubility, half-life, and relative hazard

These parameters are converted to dimensionless factors, and then integrated into a ranking based on the sums of factors as follows:

$$\text{Rank} = \sum_{chemicals,k=1}^{n} \left(\frac{T_{i,j,k}\ V_{i,j}\ P_{j,k}\ S_k\ H_k\ U_i}{Z} \right), \text{ where}$$

- $T_{i,j,k}$ = Normalized inverse travel time for chemical k from source j to well i.
- $V_{i,j}$ = Volume of source j divided by capture zone volume for well i.
- $P_{j,k}$ = Percent of volume of chemical k in source j.
- S_k = Solubility factor for chemical k
- H_k = Hazard factor for chemical k.
- U_i = Usage factor for well i.
- $Z_{i,j}$ = relative vertical migration factor for source j with respect to well i.

Appendix C presents an example implementation of the SiteRank model, and includes a full explanation of each of the above terms and how they were assigned for Santa Clara County dry cleaner cases. While the District manages much of the data required to execute the SiteRank algorithm, the mechanics of implementing it on a basin-wide scale were considered too time-consuming to complete in a practical manner. Time consuming limitations included determining capture zones for production wells and estimating a vertical migration factor based on well logs. The District is in the process of creating a digitized database of lithology interpreted from well logs which could support automated determination of vertical migration factors at a future time. Improved groundwater modeling may also support automated delineation of capture zones for production wells. SiteRank was adapted with some simplifying assumptions as explained below to facilitate implementation within a spreadsheet model and GIS interface, and without running a groundwater flow model or querying the lithology database.

Simplified SiteRank

For this study, a simplified application of SiteRank was adopted to overcome data limitations and time and budget limitations. Simplified SiteRank (SSR) ranks dry cleaner-well pairs with respect to four categories of parameters, each of which is independently ranked before being combined for an overall ranking. The categories of parameters applied are:

- Source strength, as an indicator of relative mass released, represented by ranked Age-Duration;
- Groundwater Sensitivity, represented by DRASTIC rating as an indicator of soil type, depth to groundwater, slope, precipitation, recharge, and other factors (see Appendix L for a full description of DRASTIC);
- Location of dry cleaner with respect to nearest supply well(s) and groundwater flow direction, represented by a Distance-Direction factor as a surrogate for determination of capture zones and time of travel;
- Well Vulnerability, which lumps SiteRank's well usage factor and vertical migration factors, using well construction information from the District's partial database of well construction information.

These parameter categories, and the means by which they were populated with data or estimates and then ranked, are described further below. A Microsoft Excel spreadsheet was developed to assign quantitative rankings for each category.

Determination of Age-Duration as a Surrogate for Mass Released

The potential mass of PCE released from a given dry cleaner is related to the type of dry cleaning machinery used for a given operation, and the types of PCE handling practices that were the norm for the period in which the dry cleaner operated. Therefore, the year during which the dry cleaner began operations is deemed useful as an indicator of the potential mass released. In general, the earlier a dry cleaner began operations, the more likely it is that larger quantities of PCE were released to soil and groundwater through common PCE handling and disposal practices for that time period.

Solvent mileagehas improved substantially as a combination of regulation and improved engineering design for new dry cleaning equipment took effect. Different cleaners may have operated different generations of dry cleaning equipment during the same timeframe. Therefore, the decade or year in which a dry cleaner operated cannot be taken as a precise indicator for which type of machinery was used.

Transfer machines were effectively banned on October 1, 1998 in many California air basins by a prohibition on PCE emissions from clothing transfer between the washer and the dryer of the transfer machine system. 1998 can therefore be taken as a single point in time whereafter solvent mileage improved at most locations. Transfer machines were used exclusively until the 1960s; in 1995, 34% of dry cleaning machines in the United States were transfer machines. The trend toward improved machinery suggests a steady increase in solvent mileage. Table 12 lists machine types and year of introduction with solvent mileage rating.

The duration of operations is a second indicator of the potential mass released. Intuitively, the longer a cleaner operated, the greater the potential mass released. A dry cleaner that operated for ten years beginning in 1960, however, may have released a greater mass of PCE to soil and groundwater than a cleaner that operated for twenty years beginning in 1984, due to promulgation and enforcement of hazardous waste laws. The relationship of solvent used and released as a result of permissible and common practices of the period is most likely a step function, wherein a specific factor results in a decrease in either solvent used or solvent released. Factors leading to reduction in solvent usage or solvent releases include upgrades to new machinery, adoption and enforcement of restrictions on emissions and hazardous waste disposal. Other factors may have included change in ownership with a difference in solvent handling practices, as well as application of new on-site solvent recycling techniques to extend the life of the solvent. The dry cleaning industry literature focused heavily on advice to operators to assist them with maximizing solvent mileage; operators sought to eliminate solvent losses to improve profitability.

BAAQMD permit records began noting the type of dry cleaning machinery and solvent usage in 1983. A comparison of solvent mileage to year of permit issue is presented as Figure 14, which uses values for permitted solvent quantities for each cleaner and pounds clothes cleaned to calculate mileage. An expected upward trend in mileage (i.e., improved efficiency) is not reflected by Figure 14; possibly because date of permit issue may not be closely linked with which machine type is in use.

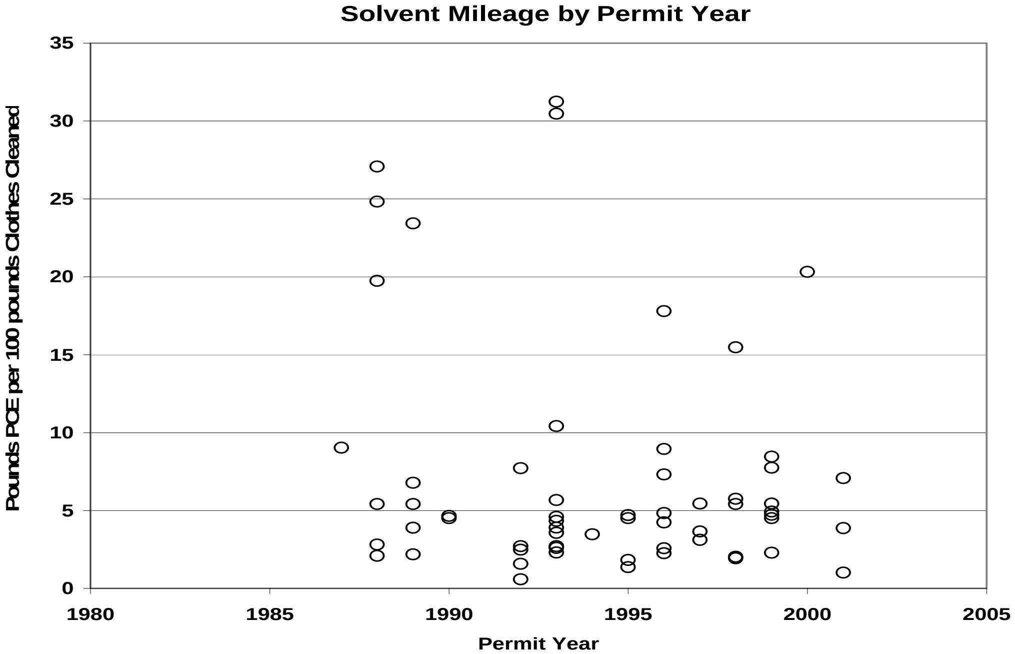

Figure 14 - Apparent Solvent Mileage for Santa Clara County Dry Cleaners Derived from Air Permit Data

Table 12: Historical Trends in Solvent Mileage by Machine Type

Machine Types	**Mileage** **(A)** pounds clothes cleaned per gallon PCE **(B)** pounds PCE per 1,000 pounds clothes cleaned			**Date Introduced**
Transfer	**(A)**	**(B)**	used exclusively until 1960s	1930
PCE-A1	85	**16.3**	1st Generation: Transfer machines	
PCE-A2	114	**12.2**	1st Generation: Transfer machines	
PCE-A3	128	**10.8**	1st Generation: Transfer machines	
Vented				late 1960s
PCE-B1	95	**14.6**	2nd Generation: Vented Dry-to Dry machines	
PCE-B1	95	**14.6**	2nd Generation: Vented Dry-to Dry machines	
PCE-B2	150	**9.24**	2nd Generation: Vented Dry-to Dry machines	
PCE-B3	176	**7.8**	2nd Generation: Vented Dry-to Dry machines	
Converted				late 1960s
PCE-C	254	**5.5**	3rd Generation: Closed-Loop (non-vented) Dry-to Dry machines	
Closed Loop				early 1990s
PCE-C	300	**4.62**	4th and 5th Generation: Closed-Loop (non-vented) Dry-to Dry machines (early 1990s (4th) & Late 1990's (5th) to present	

Solvent mileage is usually presented as number of pounds of PCE used to clean 1,000 pounds of clothing cleaned (B), but it is also cited as pounds clothes cleaned per gallon of PCE (A). 1 gallon of PCE is 13.6 pounds. Anecdotal information posted on the National Clothesline website state that machine efficiency has now improved to 700 pounds clothes cleaned per gallon, or, 2 pounds PCE per 100 pounds clothes cleaned - natclo.com, August '05.

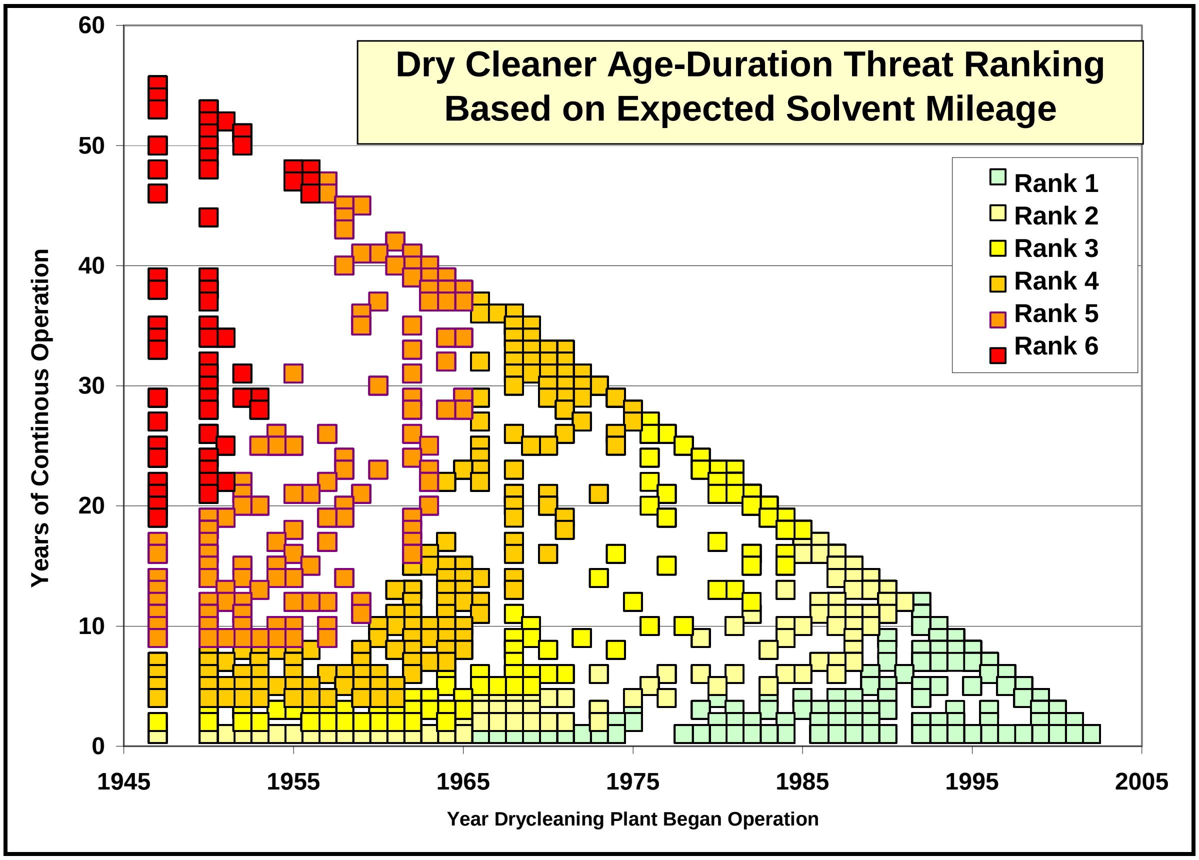

Figure 15 - Dry Cleaner Age-Duration Sub-Ranking as a Surrogate for Solvent Mileage

Figure 15 is in color; black and white printout will obscure distribution of relative sub-ranks

Because it is difficult to chart solvent usage patterns for each cleaner, an empirical relationship for Age-Duration was developed that allows relative ranking of a dry cleaner's potential to release PCE to soil and groundwater. The implicit assumption is that an older cleaner that operated for a longer period of time has higher potential to release PCE to soil and groundwater due to deminimis daily losses from drips, small spills, and routine practices such as draining filters. The empirical relationship, applied as a spreadsheet lookup table, provides a semi-continuous function of highest threat ranks given to dry cleaners whose operations began earliest and continued for the greatest number of years. Figure 15, above, presents the pattern of age-duration for dry cleaners compiled into the database for this study. Figure 15, above, displays the Age-Duration empirical function for ranking dry cleaners for the potential mass released.

The empirical function incorporates assumptions of solvent mileage for different generations of machines operating over different periods of time. The leakage factors are assumed constant for each generation of machine, and a potential leakage value is derived as the sum of the mileages over the lifetime of a dry cleaner operation. Table 13, below, list some of the assumptions used to develop the empirical ranking. While a leakage factor is applied here to develop ranks, the assumed percentages for leakage are not intended to be representative of actual releases, which may be more or less than the assumed values.

Table 13: Numeric Index of Solvent Mileage Rates for Rank Assignment to Cleaners Based on Years Operated

Date Range	Assumed Solvent Mileage *(gals PCE/1,000 lbs clothes cleaned)*	Date Range	Assumed Leakage
1946 - 1959	100	1947 – 1965	3 %
1960 – 1969	45	1965 – 1975	2 %
1970 – 1979	18	1976 – 1985	1 %
1980 – 2000	10	1986 – 1992	0.5 %
		1992 – 2000	0.1 %

The assumed solvent mileage and the assumed leakage factor were combined to produce a numeric index, from which ranks were assigned to cleaners based on the year operations started, and the number of years of continuous operation at the same location. The empirical Age-Duration function preserves the basic notion that older cleaners used more solvent and released a greater percentage of the solvent they use, and, that the cumulative impact of a cleaner operating at the same location for a long period of time has a greater potential to release more solvent.

Leakage rates are assumed to be higher in older cleaners because transfer machines were used in earlier decades. It was common practice to load wet clothing with residual PCE in hampers and roll or carry them to the spin dryer. Drips of PCE often permeated the floor slab in transfer machine operations. PCE handling practices such as draining filters outdoors, discarding PCE-laden mop water, discharging PCE-laden condensate water to septic tanks or the sanitary sewer were all commonplace and acceptable until regulatory oversight began in the mid-1980s. Therefore, it is appropriate to assign relative factors with higher values in earlier decades. This study does not confirm or document the assumed leakage rates used to apply ranks. The assumed values may be inherently incorrect; however, the relative ranking is valid. Solvent mileage assumptions are based on data collected from a variety of EPA studies and other literature sources. A summary of solvent mileage rates is shown in Table 13.

DRASTIC Groundwater Vulnerability Ranking

The DRASTIC groundwater vulnerability ranking for each dry cleaner location was obtained by a spatial query of the District's DRASTIC GIS shapefile. The highest rankings are assigned to locations within the subbasins where the combination of the factors that make up the DRASTIC index results in the rating of most vulnerable groundwater. Figure 16 presents a map displaying the DRASTIC rankings for different portions of the Santa Clara Subbasin. The inset in Figure 16 presents DRASTIC rankings in the Llagas and Coyote Subbasins.

Distance-Direction Ranking

Logistical and budgetary constraints prevented development of a capture zone or zone of contribution for each well. The District has developed a GIS tool for delineating the fixed-radius zone of contribution for a well based on pumping and prevailing groundwater flow direction, following the California Department of Health Services' *Drinking Water Source Assessment Program* protocol. The tool automatically generates the radius; however, the authors are not confident that this tool provides a reliable means for discounting potential impacts from dry cleaners.

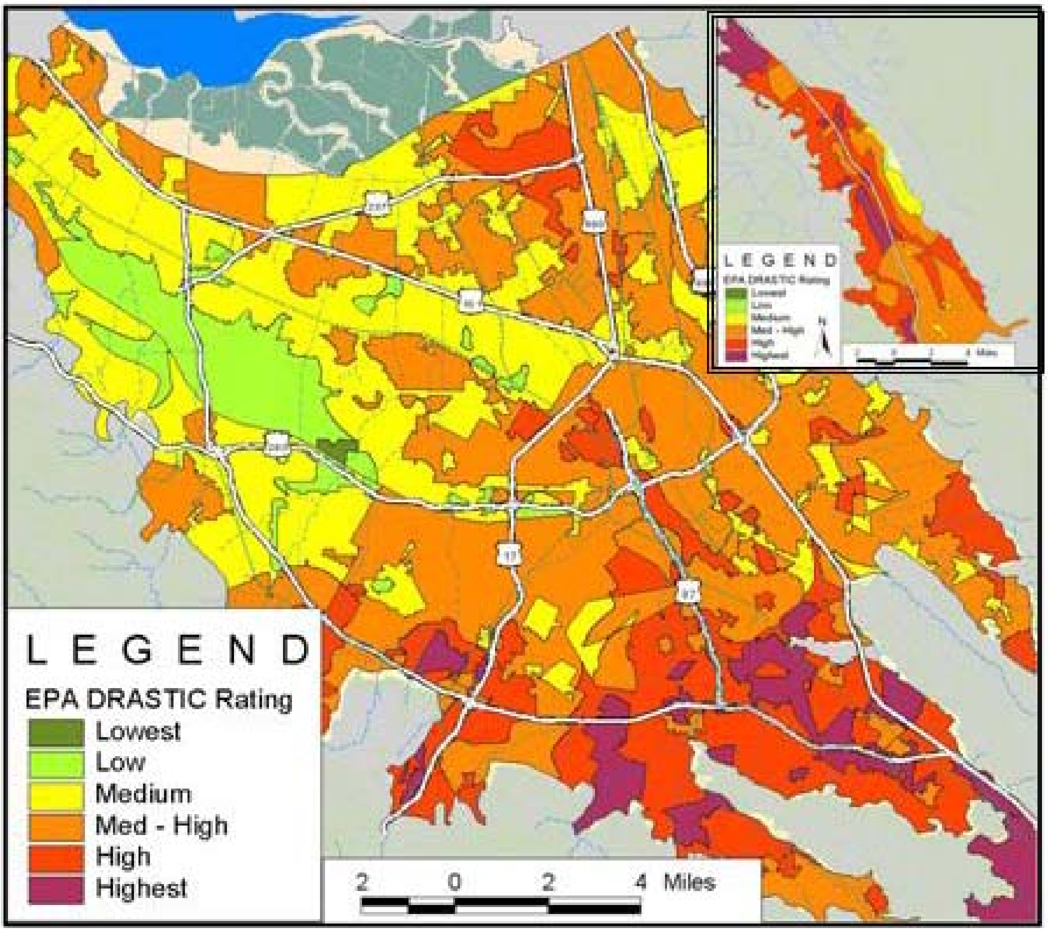

Figure 16 - EPA Drastic Ratings for Santa Clara Groundwater Subbasin

The fixed radius approach does not account for the three dimensional nature of capture zones, and more importantly, does not account for preferential pathways as might occur from natural features like buried and vertically accreted stream channel deposits. Other potential pathways of interest include utility trenches, and in particular, the conveyance of PCE waste some distance from the dry cleaner through sewer lines before a defect allows release of PCE into underlying groundwater.

Intuitively, the further the distance between a cleaner and a well, the longer the travel time, and the greater the natural attenuation of the PCE released. If the well is located cross-gradient or upgradient of the dry cleaner, it is unlikely to be impacted by the dry cleaner unless horizontal conduits play a role in redistributing PCE contamination in unexpected directions. Figure 17 profiles the range of distances between past and current dry cleaners and the six nearest currently operating water supply wells, irrespective of groundwater flow directions or zones of contributions to supply wells. In Figure 17, distances are in feet and irrespective of flow direction. The total number of distances between dry cleaners and wells shown exceeds the number of past cleaners, 1250, because all pairings of dry cleaners to the six nearest wells are included in this summary.

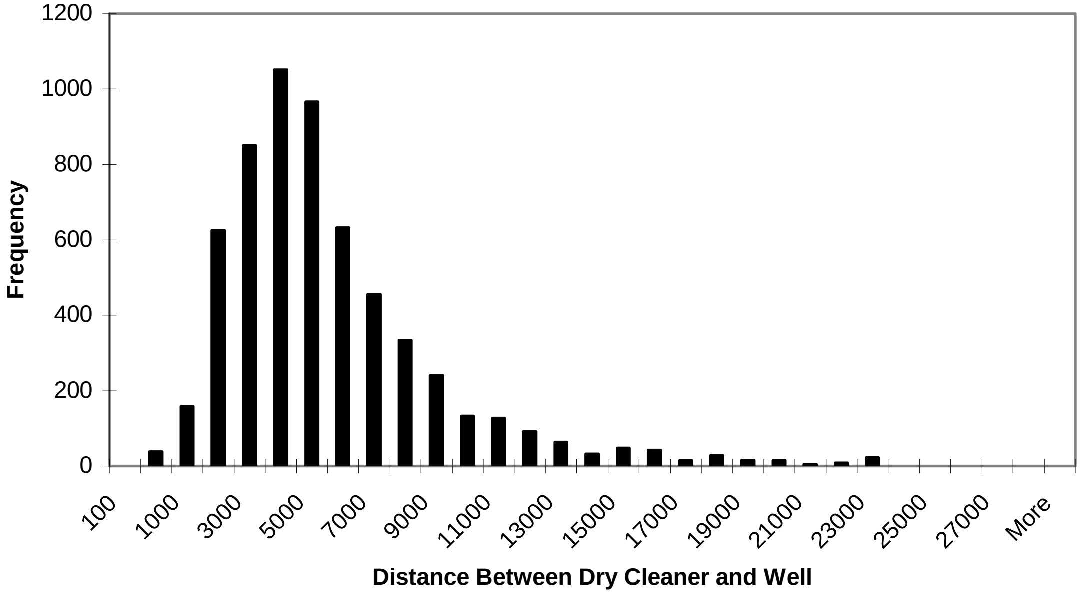

Figure 17 – Distances Between Dry Cleaners and Six Nearest Supply Wells

To account for the role of the radial distance from a pumping well to a source, the distances between dry cleaners and wells are weighted based on the logarithm of the inverse distance squared. The threat of a dry cleaner to a well decreases geometrically with increasing distance. A lookup table was used to gauge the compass degrees of separation between groundwater flow direction and the bearing from the dry cleaner to the well in a given pairing. The two weighted factors for distance and direction were then combined as a grouped ranking.

The Distance-Direction factor applies a higher rank to those dry cleaners located closest to wells in directions that are directly upgradient. Directional ranks are assigned to the differences of the bearings of lines from dry cleaners to the nearest six wells, and the prevailing shallow groundwater flow direction.

Prevailing groundwater flow direction was obtained by performing a spatial query of interpreted shallow groundwater flow directions derived from water level measurements at more than 2,000 fuel leak sites in Santa Clara County’s groundwater subbasins. These flow directions are generalized and unreliable, because seasonal shifts in groundwater flow direction may be substantial, and because reported flow directions from fuel leak sites may suffer from surveying errors, reporting errors, or other problems. The generalizations that produce the flow direction shapefile may also misrepresent known local variations in groundwater flow. A further limitation to using shallow groundwater flow direction information from fuel leak sites is that PCE released as DNAPL may migrate to lower aquifers whose flow directions may differ from shallow aquifer flow directions. Nevertheless, shallow groundwater flow directions are the dominant influence on solute transport from surficial sources, and the shallow aquifer is often has higher rates of groundwater flow than lower aquifers. The shallow groundwater flow direction shapefile was used as a convenient means of assigning a relative ranking. Figure 18 presents the generalized groundwater flow directions shapefile.

Lower rankings are applied to dry cleaners that are either furthest away from a well, or cross-gradient or downgradient of wells. All dry cleaners are assigned a positive value for the Distance-Direction ranking, because the determination of groundwater flow directions may be inaccurate. Horizontal conduits, such as sewer lines or utility trenches, may short-circuit the hydrologic isolation for a cleaner located outside the zone of contribution for a well.

In the original formulation of SiteRank, dry cleaners found to occur outside the capture zones of pumping wells were assigned a travel-time of zero, thereby removing them from the ranking analysis. In the application of SSR, all dry cleaners are given a ranking, permitting removal of a particular cleaner from a ranked list after closer inspection of the contributing factors. Table 14 lists ranks assigned for the directional difference between the bearing from a dry cleaner to a supply well and the assumed local groundwater flow direction interpreted from the groundwater flow direction shapefile. The distance between a cleaner and the nearest supply well was integrated into the distance-direction ranking by multiplying the rank in Table 14 by the log of the square of the inverse distance, thereby giving shorter distances the greatest weight.

Table 14: Ranking for Cleaner Location Relative to Supply Well Location and Assumed Groundwater Flow Direction

Degree Difference between Bearing from Cleaner to Well and Assumed Local Groundwater Flow Direction	Rank
< 18°	10
18° to < 36°	9
36° to < 54°	8
54° to < 72°	7
72° to < 90°	6
90° to < 108°	5
108° to <126°	4
126° to <144°	3
144° to <162°	2
162° to 180°	1

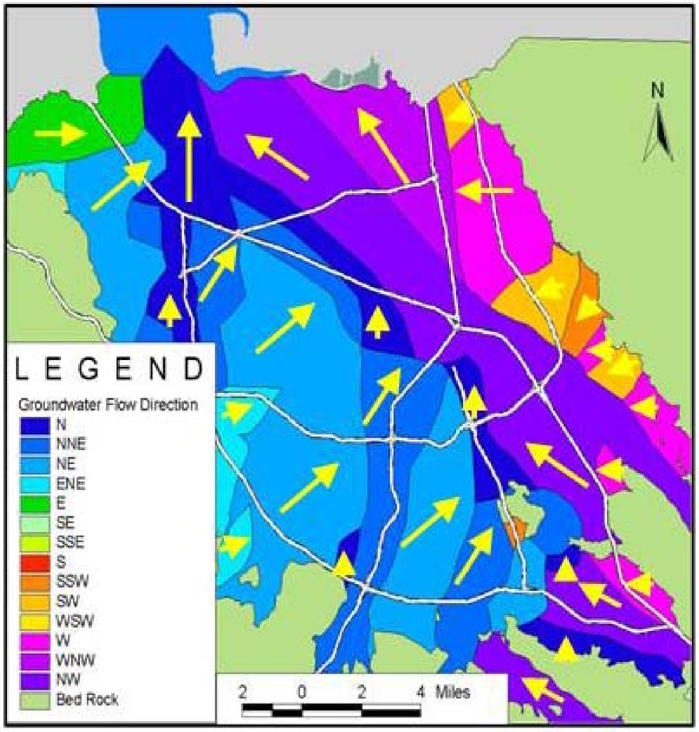

Figure 18 - Generalized Shallow Groundwater Flow Directions Derived from Fuel Leak Investigations

Well Vulnerability

The Well Vulnerability ratings applied for *SSR* are based upon the following features of well construction and operation:

- Depth of well seal (feet below ground surface)
- Depth to first perforated interval ((feet below ground surface)
- Length of gravel pack below seal and above first perforated interval (feet)
- Total annual pumping (gallons per year)
- Ratio of length of first perforated zone to total length of all perforated zones (ft/ft)

The Well Vulnerability ranking relates these factors as follows:

$$\text{Well Vulnerability} = \left(\frac{\frac{\text{seal depth}}{\text{gravel pack length}} \times \frac{\text{length of } 1^{\text{st}} \text{ perforated zone}}{\text{total length of all perforated zones}} \times \text{pumping rate [gal/yr]}}{\text{depth to } 1^{\text{st}} \text{ perforated zone}} \right)$$

The geometric relationship of these factors is shown in Figure 19, below:

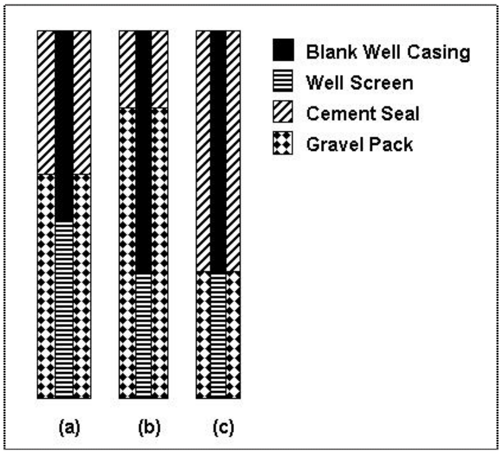

Figure 19 - Geometric Relationship of Well Vulnerability Factors for SSR

In Figure 19, the *Well Vulnerability* rating assigns the highest, or most vulnerable value to well (b), and least vulnerable to well (c), assuming all three wells have the same pumping rate, and lengths of both first and total perforated zones.

Groundwater is an important source of water supply throughout Santa Clara County; there are more than 6,000 registered water supply wells, including irrigation, industrial supply, domestic wells, small water system wells, and municipal wells. Because data for pumping and well construction is more available for the 460 active public water supply wells[6], this study focused primarily on active public supply wells and did not address potential impacts to domestic or other wells in Santa Clara County. The 460 public water supply wells include wells categorized as small water systems which pump substantially less than major municipal supply wells. The 460 wells also include standby wells and wells that are used infrequently. Some wells in this category are used primarily to irrigate public parks and golf courses, but are categorized as public wells because they also supply drinking faucets, restrooms, and club houses.

The information necessary to calculate well vulnerability was not available for all 460 public water supply wells used in the analysis. In order to include those wells for which some data were not available, averages for that factor were assigned to allow completion of the analysis. Where a higher ranking is assigned to a dry cleaner–well pair based on a well for which some data are not available, further investigation is needed to confirm that the basis for the high ranking truly reflects well integrity. Wells for which data are not available were tracked through the analysis, and are displayed in results maps using distinct icons to indicate where average values were assigned. Table 15, below, summarizes the available well construction data upon which the *SSR* Well Vulnerability ranking was performed.

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[6] Water well construction, geologic, and pumping data are not available to the public under California's Well Log Confidentiality Act; data were accessed by District staff to conduct this Water Board-initiated study.

Table 15: Well Construction Factors Used in Determining Well Vulnerability in SSR

Total Wells in *SSR* Analysis	460	
Total Wells with available seal depth data	222	Average Seal Depth = 45 feet
Total Wells with available depth to first perforated zone	330	Average depth to 1st Perforation = 186 ft
Total Wells with available total perforated length	330	Average total length of perforations = 152 ft
Total Wells with available pumping data	388	Average Pumping Rate =24 acre-feet per year

An acre-foot is the volume of water that covers one acre in water one foot deep, equal to 43,560 cubic feet, or 325,828 gallons.

The Well Vulnerability factor does not address vertical flow of water between perforated intervals within a well. Substantial vertical flows known as 'wellbore flow' are often observed in production wells when not pumping. Wellbore flow may further decrease the importance of aquitards in isolating deeper drinking water aquifers from shallow contamination occurring at dry cleaner release sites. Potentially as much as 20% of water supplied to deeper aquifers can be supplied by wellbore flow (Hansen, R., 2004). Field tests performed by the District using heat-pulse flow meters documented instantaneous downward flow in a well ¾ miles away from a pumped at 87 gallons per minute. Ignoring wellbore flow may underestimate the protective benefit of well seals and construction, aquitards, and upward hydraulic gradients; however, not accounting for wellbore flow may counterbalance any bias inherent to the method.

Consistent application of the Well Vulnerability factor provides a useful *relative* ranking. Well Vulnerability ratings in this study should not be interpreted in an absolute sense, i.e., a calculation that a given well has high integrity or low integrity does not necessarily translate to real-world well defects or vulnerability to contamination.

Overall Ranking Determination Using SSR

The four categories of parameters used for *Simplified SiteRank* are grouped and combined as an overall product. The distribution of the *Well Vulnerability* factor was found to be log-normally distributed due to the inclusion of the annual well discharge. Each category was checked for statistical distribution and transformed to a normal distribution if necessary. The overall ranking assigned to each dry cleaner–well pair was determined by multiplying the individual rankings for source strength, groundwater sensitivity, and well vulnerability as follows:

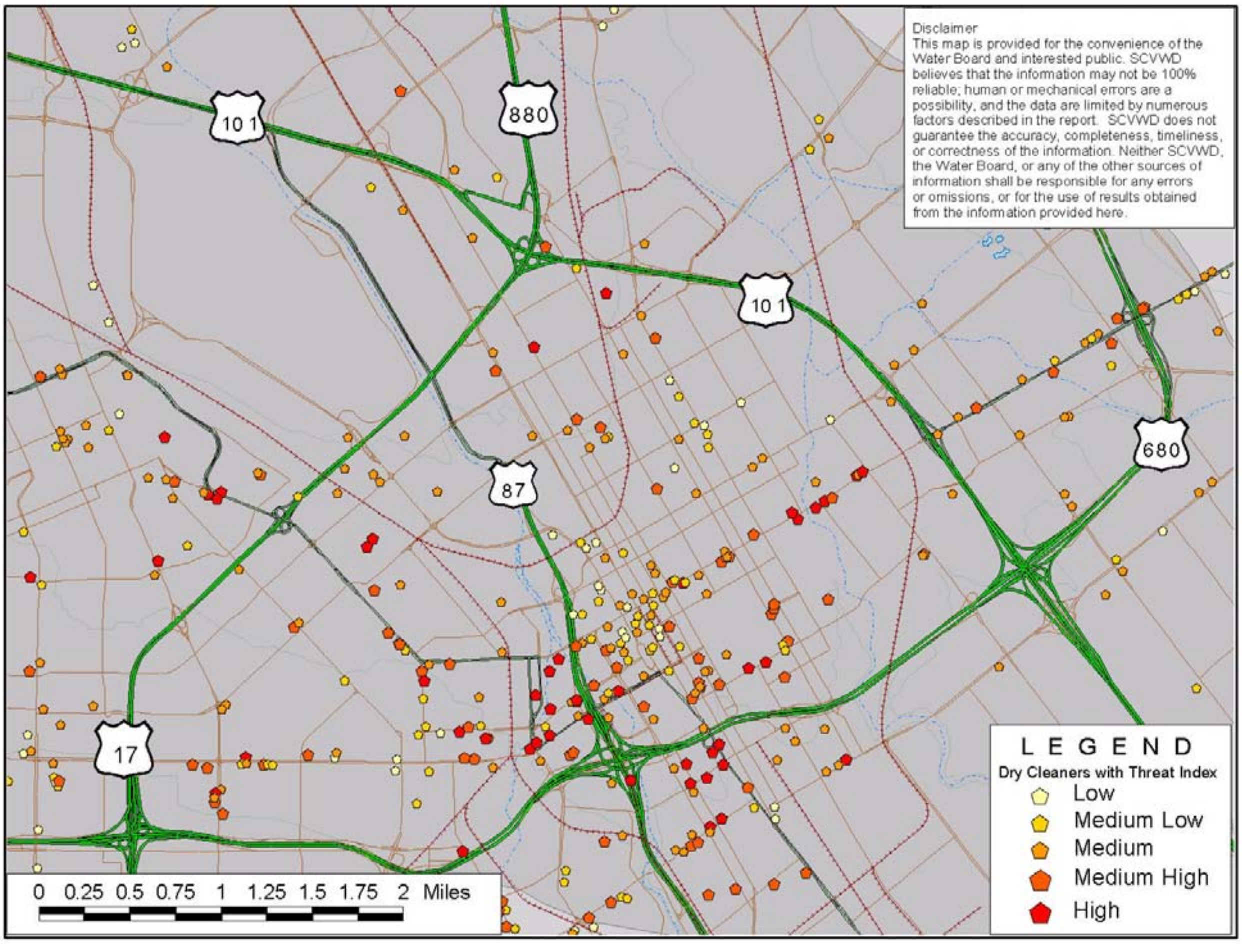
Overall Rank = (Age-Duration × DRASTIC Hazard Index × Distance-Direction × Well Vulnerability)

Table 16, below shows the breakdown of rankings used to map the results of *Simplified SiteRank* (SSR):

Table 16: Numeric Values of SiteRank Output and Corresponding Map Symbols and Summary Ranks

Map Symbol	Numeric Rank	Summary Rank
⬟	0 – 500	5
⬟	500 – 1,000	4
⬟	1,000 – 2,000	3
⬟	2,000 – 3,000	2
⬟	3,000 – 10,000	1

The 1,250 dry cleaners were paired with each of the nearest 6 water supply wells, regardless of whether the well is downgradient, cross-gradient, or upgradient of the well. The median distance from dry cleaner to well is 4,300 feet. A total of 6,002 dry cleaner–well pairs were analyzed using *SSR*. Figure 20 displays ranked past and current dry cleaners, together with nearby supply wells, in an the downtown San Jose area, overlying the confined water supply aquifer. Figure 21 provides a county-wide map of ranked dry cleaners and water supply wells. Maps of ranked dry cleaners for each city in Santa Clara County are provided in Appendix N.



Disclaimer
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Figure 20 - Ranked Dry Cleaners– Downtown San Jose Area

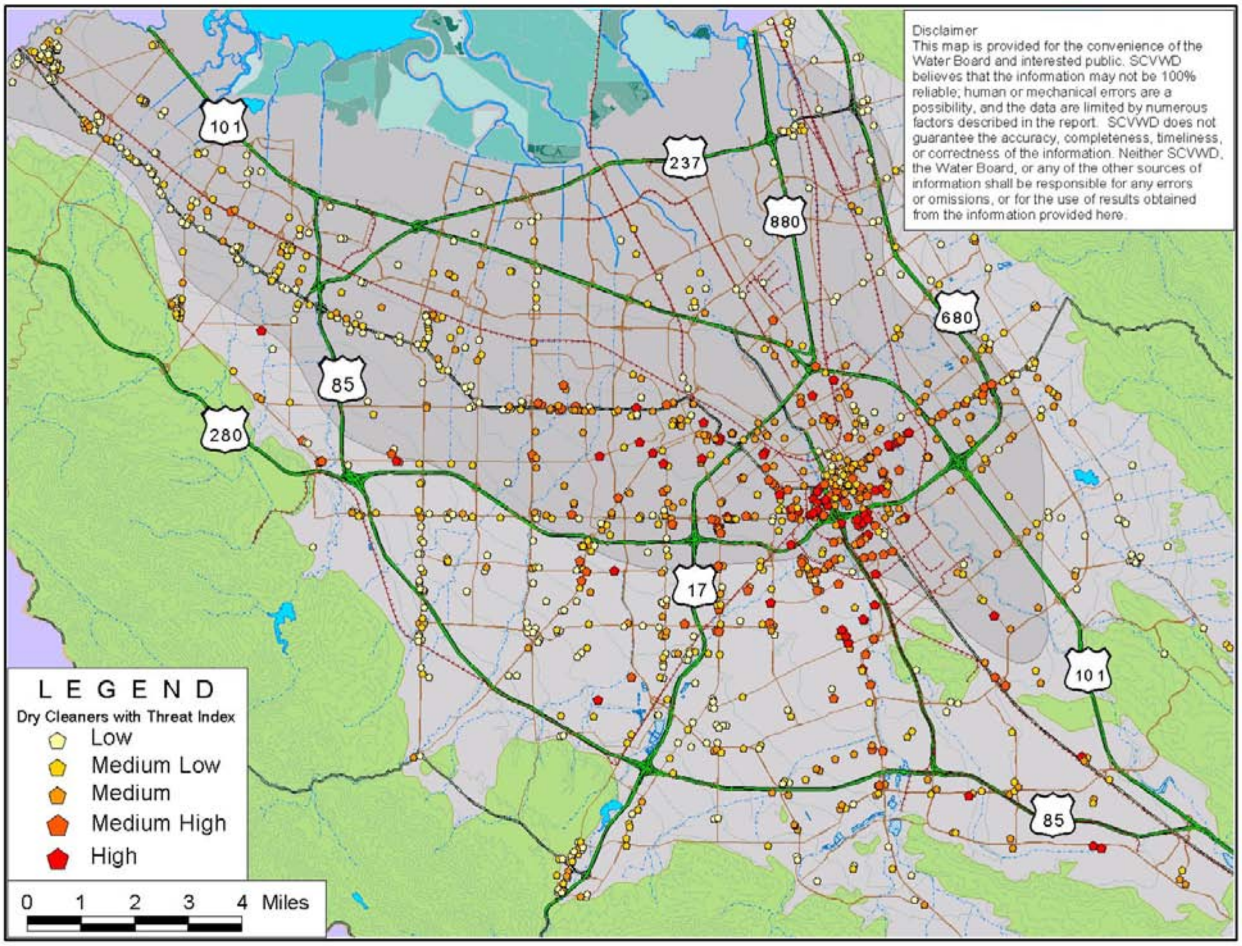

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Figure 21 - Ranked Dry Cleaners in the Santa Clara Groundwater Subbasin

Sensitivity Analysis of Simplified SiteRank

A sensitivity analysis was conducted to determine which factors most influence high or low rankings in *SSR*. For equations establishing linear relationships among factors, sensitivity analysis could be conducted by inspecting the equations used, because doubling a given factor would double the resulting rank. The final configuration of *SSR*, however, uses relationships that employ differences, ratios, lookup tables for empirical relationships and step functions, and log-transforms. Consequently, *SSR* does not lend itself to sensitivity analysis by inspection alone.

To perform sensitivity analysis on *SSR*, five ranked pairs were selected representing high, medium-high, medium, medium-low, and low rankings. Highest and lowest values were not used for sensitivity analysis because they may reflect outliers or errors. For each of these five pairs, all values were held constant, and the parameter of interest was first halved, and then doubled. The resulting change to the category ranking and the final ranking was recorded. This exercise was repeated for all parameters in the *Age-Duration*, *Distance-Direction*, and *Well Vulnerability* categories (*DRASTIC* is taken as a single ranking based on an earlier analysis).

Table 17 presents the results of the sensitivity analysis. The “direction” factor was found to have the greatest overall influence on the overall ranking. The direction factor is the difference between locally inferred groundwater flow direction and 'bearing', or compass direction from the dry cleaner to nearest well. This result is expected, because a dry cleaner located near a well but isolated by its location with respect to capture zones and flow paths is unlikely to cause contamination in the well. To test the sensitivity of the direction factor, the compass degree difference between bearing and groundwater flow direction was halved and doubled, which drastically alters the potential influence of the dry cleaner on possible well contamination. Prediction of flow directions and capture zones was limited by data availability issues. It is also a challenge to predict zones of contribution for deep wells, which may obtain their recharge from locations distant from the well head.

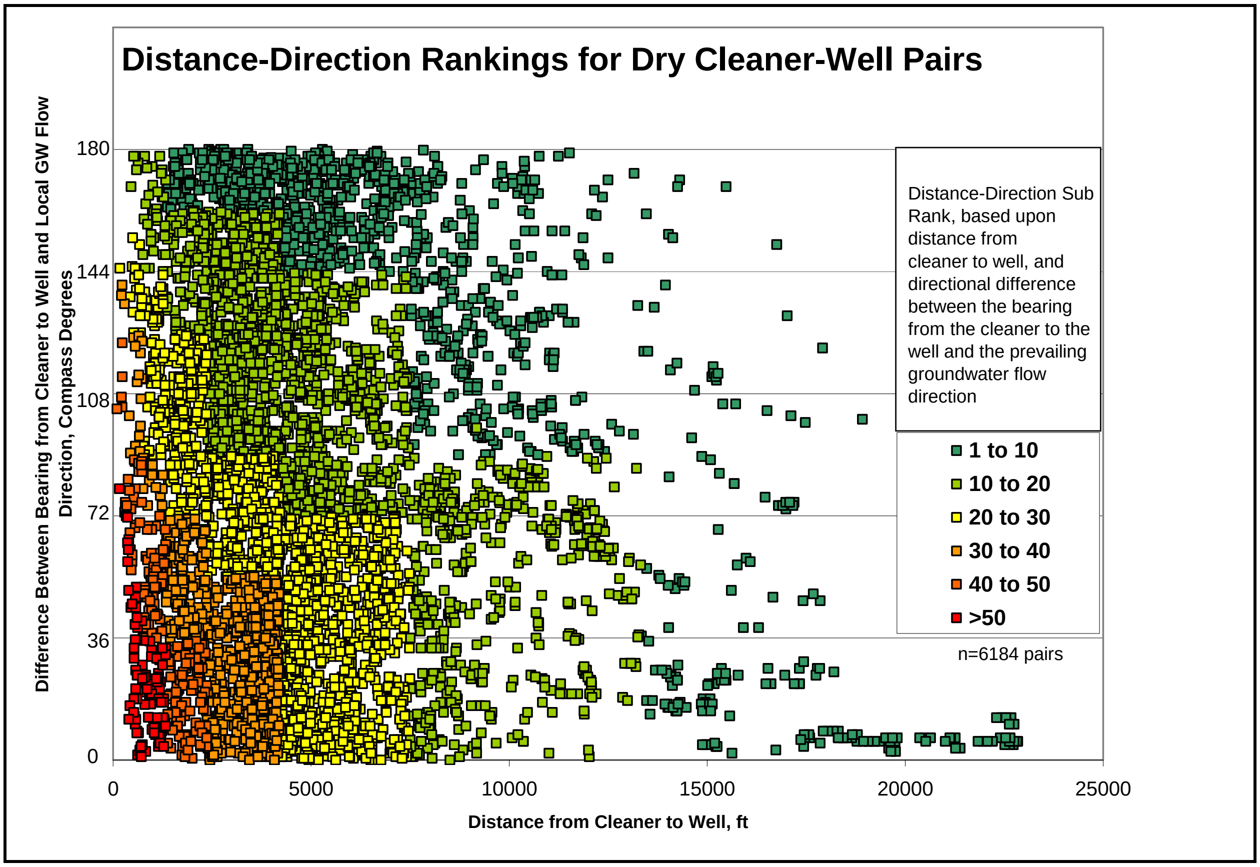

Figure 22 –Directional Difference vs. Distance: Distance-Direction Sub-Ranks

The sensitivity ranking showed that SSR is equally sensitive to several factors, including dry cleaner start year, duration of operations, as well as the well construction parameters seal depth, depth to first perforated interval, and total length of perforated intervals, and the DRASTIC groundwater sensitivity factor. Table 17 presents a series of charts profiling the results of sensitivity analysis.

Table 17: Sensitivity Analysis for 5 Cleaner - Well Pairs Selected Across Range of Overall Ranks

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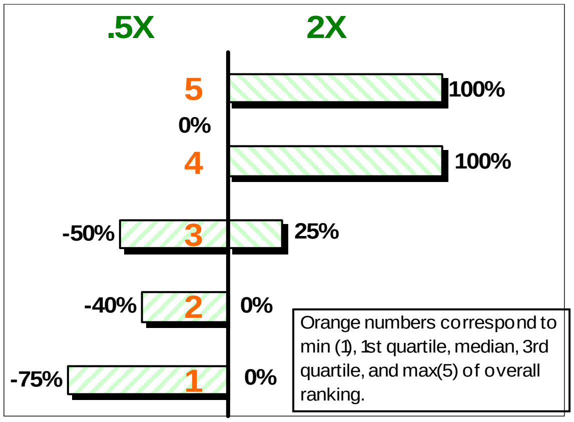

Orange numbers correspond to min (1), 1st quartile, median, 3rd quartile, and max(5) of overall ranking.
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<td>
Start Year: *Effect of halving and doubling the magnitude of mass released as a result of the year when the dry cleaner started operations. Start year was varied within the range of the study period, 1946 to 2002. If a cleaner's actual start year was 1970, testing the severity of doubling the effect of start year (2X) was done by changing the start year to half-way between 1946 and the actual year, i.e to 1958. Similarly, testing the relative severity of halving the effect of start year was done by changing start year to half-way between actual start year and end of study period, i.e., 1986.*
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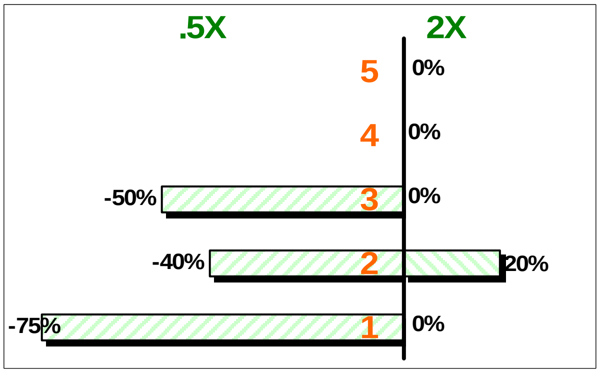

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<td>
Duration: *Effect of halving and doubling the duration of cleaner operations. Sensitivity of SSR was tested by doubling duration of operations, or substituting the maximum known duration of any cleaner when doubling duration put ending year into future, and by halving the duration of operations.*
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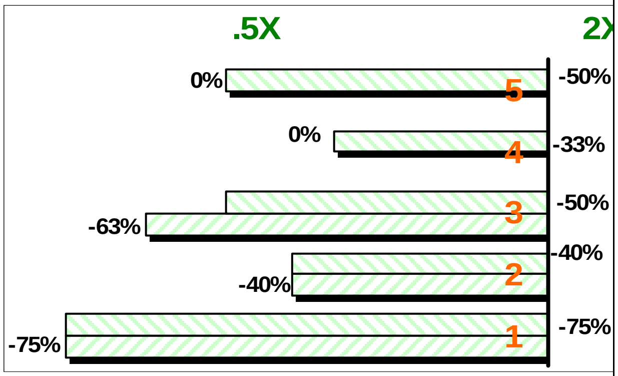

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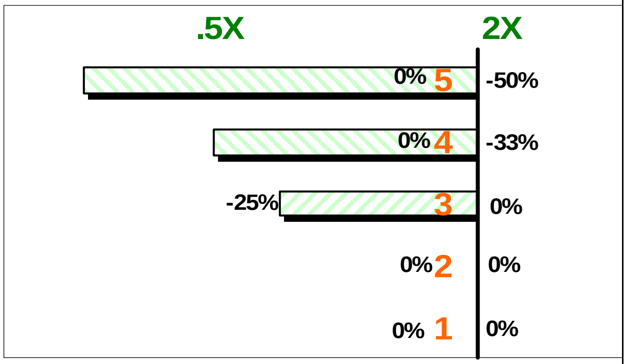

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<tr>
<td>Seal Depth: Effect of doubling or halving the depth of sanitary seal installed on the nearest water supply well on the Over-all SSR Rank. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves doubling the depth of the well seal. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves halving the depth of the well seal. Where well seal depth was not available, average seal depth for wells with seals was substituted.</td>
<td>Seal Depth: Effect of doubling or halving the depth of sanitary seal installed on the nearest water supply well on the Well Vulnerability Index. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves doubling the depth of the well seal. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves halving the depth of the well seal. Where well seal depth was not available, average seal depth for wells with seals was substituted.</td>
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<tr>
<td colspan="2">Cleaner-Well Pairs Tested represent minimum*, 1st quartile, median, 3rd quartile, and maximum* ranks.</td>
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Table 17 - Sensitivity Analysis - continued

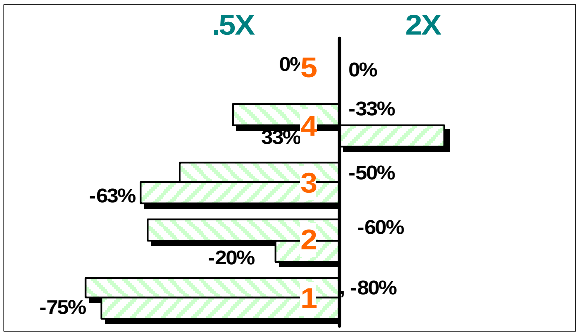
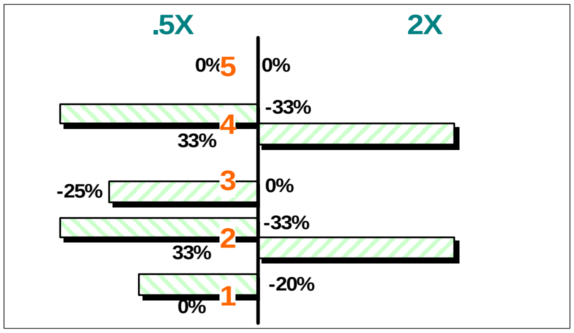
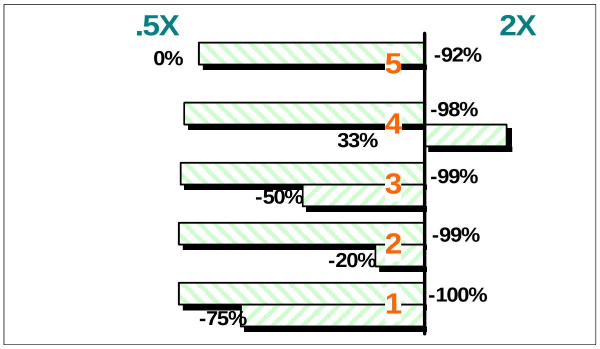
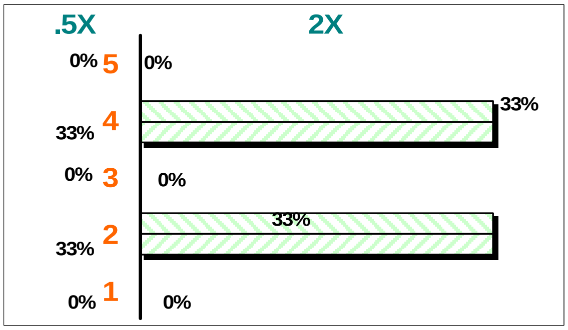
	
Depth to 1st Perforated Interval ("1st Perf"): Effect of doubling or halving the depth to the 1st Perf on the nearest water supply well on the Over-all SSR Rank. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves doubling the depth to the 1st Perf. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves halving the depth to the 1st Perf. Where depth to the 1st Perf was not available, average depth to 1st Perf for wells with seals was substituted.	Depth to 1st Perforated Interval ("1st Perf"): Effect of doubling or halving the depth to the 1st Perf on the nearest water supply well on the Well Vulnerability Index. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves doubling the depth to the 1st Perf. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves halving the depth to the 1st Perf. Where depth to the 1st Perf was not available, average depth to 1st Perf for wells with seals was substituted.
	
Length of Total Perforated Intervals ("Total Perfs"): Effect of doubling or halving the length of Total Perfs on the nearest water supply well on the Over-all SSR Rank. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves doubling the length of Total Perfs (i.e., increasing the effect of dilution on any PCE entering the well). The scenario for "doubling the severity of the threat" (2X) from the cleaner involves halving the Total Perfs, such that PCE entering the 1st perforated zone would be subject to less dilution . Where Total Perfs length was not available, average length of Total Perfs for wells with known perf lengths was substituted.	Length of Total Perforated Intervals ("Total Perfs"): Effect of doubling or halving the length of Total Perfs on the nearest water supply well on the Well Vulnerability Index. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves doubling the length of Total Perfs (i.e., increasing the effect of dilution on any PCE entering the well). The scenario for "doubling the severity of the threat" (2X) from the cleaner involves halving the Total Perfs, such that PCE entering the 1st perforated zone would be subject to less dilution . Where Total Perfs length was not available, average length of Total Perfs for wells with known perf lengths was substituted.

Table 17 – Sensitivity Analysis – continued

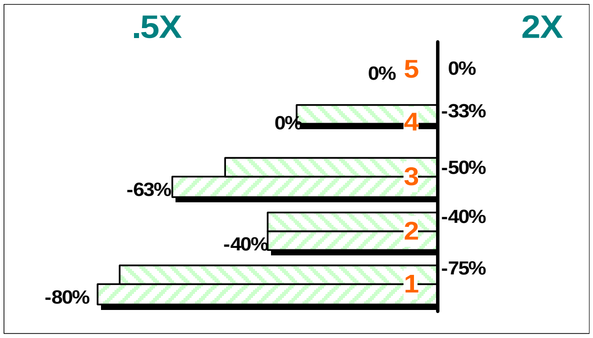
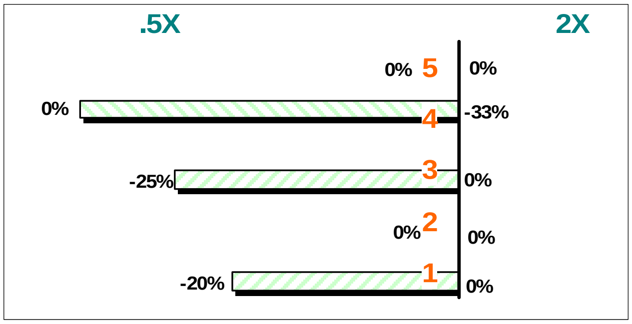
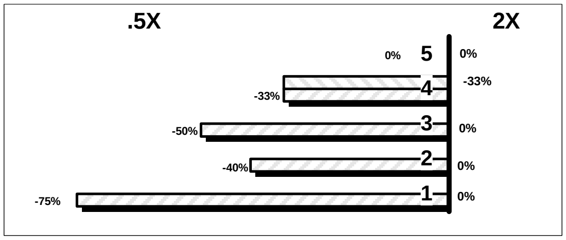
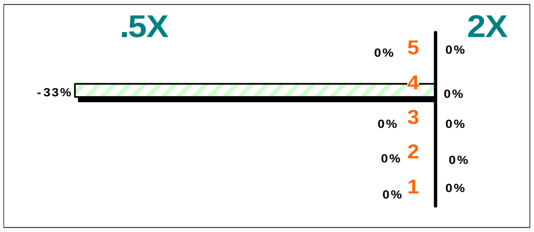
	
Length of Exposed Gravel Pack between Bottom of Seal and Top of 1st Perforated Interval ("GP Length"): Effect of doubling or halving the GP length on the nearest water supply well on the Over-all SSR Rank. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves halving the GP length. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves doubling the GP Length. Where GP length was not available, average GP length for wells with known GP lengths was substituted.	Length of Exposed Gravel Pack between Bottom of Seal and Top of 1st Perforated Interval ("GP Length"): Effect of doubling or halving the GP length on the nearest water supply well on the Well Vulnerability Index. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves halving the GP length. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves doubling the GP Length. Where GP length was not available, average GP length for wells with known GP lengths was substituted.
	
Pumping: Effect of doubling or halving the total pumping (gallons per year) of the nearest water supply well on the Over-all SSR Rank. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves halving the pumping. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves doubling the pumping. Where pumping data was not available, average annual pumping for wells with available pumping records was substituted.	Pumping: Effect of doubling or halving the total pumping (gallons per year) of the nearest water supply well on the Well Vulnerability Index. The scenario for "halving the severity of the threat" (0.5X) from the dry cleaner involves halving the pumping. The scenario for "doubling the severity of the threat" (2X) from the cleaner involves doubling the pumping. Where pumping data was not available, average annual pumping for wells with available pumping records was substituted.
	DRASTIC Groundwater Vulnerability Index ("DRASTIC Rank") Effect of decreasing or increasing the Drastic Index on the Overall SSR Rank. The scenario for "halving the severity of the threat" (0.5X) to groundwater from the dry cleaner involves lowering the DRASTIC Index by one. The scenario for "doubling the severity of the threat" (2X) to groundwater from the dry cleaner involves raising the DRASTIC Index by one. The DRASTIC Index ranges from 1 to 5. See Appendix E for details on DRASTIC, and for sensitivity analysis of DRASTIC rankings of groundwater vulnerability.

Table 17 – Sensitivity Analysis – continued

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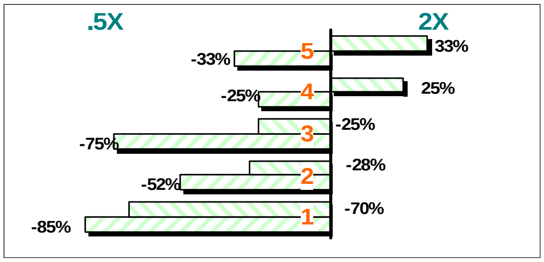

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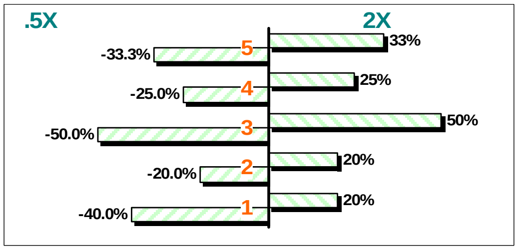

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<tr>
<td>Distance: Effect of varying distance between cleaner and nearest supply well on Overall SSR Rank. Algorithm uses the inverse distance squared as a surrogate for potential for PCE at a given dry cleaner location to flow into a nearby well. The scenario for "halving the severity of the threat" 0.5X involves doubling the distance; "doubling the severity" (2X) involves halving the distance.</td>
<td>Distance: Effect of varying distance between cleaner and nearest supply well on Distance-Direction Rank. Algorithm uses the inverse distance squared as a surrogate for potential for PCE at a given dry cleaner location to flow into a nearby well. The scenario for "halving the severity of the threat" 0.5X involves doubling the distance; "doubling the severity" (2X) involves halving the distance.</td>
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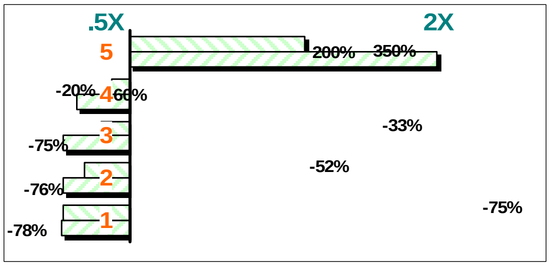

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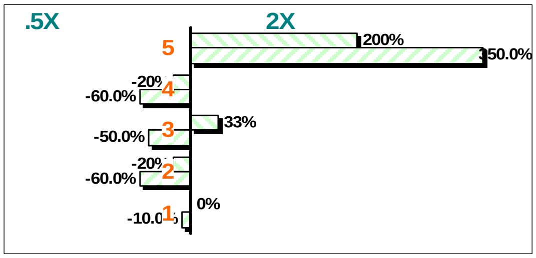

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<td>Difference Between Locally Inferred Groundwater Flow Direction and 'Bearing', or Direction from Dry Cleaner to nearest Well ("Direction"): Effect of varying the difference in position of dry cleaner and well with respect to groundwater flow direction on Overall SSR Rank. If cleaner is upgradient of well, it may pose a threat; if it is downgradient, it most likely will not. The scenario for "halving the severity" (0.5X) of the direction difference involves doubling the directional difference between bearing and groundwater flow (in compass degrees). This effectively moves the cleaner to a position that is more cross gradient or downgradient from the well in question. The scenario for "doubling the severity" (2X) of the direction difference involves halving the directional difference between bearing and groundwater flow in compass degrees, effectively moving the cleaner to a more upgradient position with respect to the well.</td>
<td>Difference Between Locally Inferred Groundwater Flow Direction and 'Bearing', or Direction from Dry Cleaner to nearest Well ("Direction"): Effect of varying the difference in position of dry cleaner and well with respect to groundwater flow direction on Distance-Direction Rank. If cleaner is upgradient of well, it may pose a threat; if it is downgradient, it most likely will not. The scenario for "halving the severity" (0.5X) of the direction difference involves doubling the directional difference between bearing and groundwater flow (in compass degrees). This effectively moves the cleaner to a position that is more cross gradient or downgradient from the well in question. The scenario for "doubling the severity" (2X) of the direction difference involves halving the directional difference between bearing and groundwater flow in compass degrees, effectively moving the cleaner to a more upgradient position with respect to the well.</td>
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Validating SSR Rankings

Five locations were selected where there are known impacts to drinking water supply wells. Ranks assigned to cleaners and wells were inspected to learn whether the current or past dry cleaners operated near impacted well received high ranks. The first validation test was applied in the same setting that *SiteRank* was tested. *SSR* did not assign high ranks to the dry cleaners nearest to the impacted well, and gave the highest threat index to the dry cleaner located furthest from the impacted well, based primarily on start year (1962) and duration of operations (6 years).

Simplified SiteRank does not predict whether a particular combination of dry cleaner and well will result in a well being impacted; instead, it ranks the relative degree of contamination threat posed by the combination of source strength (age-duration), position (distance-direction), groundwater vulnerability (DRASTIC rating), and well vulnerability. SSR should be applied only as a ranking tool to analyze the potential impacts from dry cleaners; it cannot predict actual impacts.

Three of the 50 highest ranked dry cleaners are located within a quarter mile of known PCE detections in public water supply wells; the majority of dry cleaners in the top 50 started operations in the 1940s, 1950s, and 1960s, or operated at the same location for up to 54 years.

Table 18: SSR Ranks at Dry Cleaners Closest to Public Wells with PCE Detections Greater than 1 ppb

SSR Ranks at Dry Cleaners Closest to Public Wells with PCE Detections Greater than 1 ppb						
PCE Concentration in Well, ppb	**Distance to Nearest Cleaner, feet**	**Direction of GW Flow & Direction from Cleaner to Well**	**SSR Rank**	**Start Year**	**Duration (years)**	**Notes**
10	605 ft	NNE, NE; Δ=7.5°	1707 M	1989	14	
4.5	750 ft	E & SE; Δ=45°	3648 H	1970	33	
4.1	1310 ft	NE, E; Δ=45°	672 ML	1967	36	6 other cleaners within ½-mile & > 25 years
3.3	> 2 miles	SW, NNE; Δ=157°	-	-	-	Source unknown; not from a dry cleaner
3	570 ft	E, NNE; Δ=67.5°	2400 MH	1969	21	2 other cleaners <1,500 ft & > 20 yrs
2.6	2,365 ft	NNE, NNE; Δ=0°	2053 MH	1989	33	(SLIC within 850 feet)
2.3	360 ft	E, SE; Δ=135°	1045 M	1968	1	2 other cleaners <1,500 ft & > 20 yrs
1.8	260 ft	NE, S; Δ=157.5°	1536 M	1964	2	Cleaner ½-mile upgradient operated 29 yrs
1.1	600 ft	NNE, WSW; Δ=225°	384 L	1975	4	SLIC within 350 feet; nearest upgradient dry cleaner is ½-mile

H = High; MH = Medium High; M = Medium; ML = Medium Low; L= Low.
SLIC = Spill or Leak Investigation and Cleanup that could also have released PCE

Table 18 displays proximity of wells with PCE detections to dry cleaners, and the SSR ranks for the nearest cleaners. Some of the supply wells with PCE detections are close to Regional Board SLICs (spills, leaks, investigations, and cleanups) which could be a source of PCE.

Summary of Simplified SiteRank Findings

77 dry cleaners were assigned the highest threat index, indicating that they should be prioritized for further investigation. 115 cleaners were given the Medium High rank; 326 were given the Medium rank; 344 were assigned Medium Low Rank; and 388 were assigned the Low Rank. Remembering that dry cleaning machinery may have been operated at only 2/3 of locations mapped for this study, there is an inherent overestimation of the potential impacts from dry cleaners. The goal for SSR is to pick those sites with the greatest potential to cause soil and groundwater contamination, and prioritize these for site-specific investigation to verify whether PCE releases have occurred.

Inherent limitations notwithstanding, SSR provides a useful means to integrate groundwater vulnerability, source strength, and well vulnerability, in order to prioritize cases for investigation. GIS is an important tool for both executing SSR and analyzing the ranks. For example, the higher ranked cleaners nearest wells serving drinking water may be considered for prioritized investigation. Water utility operators managing such wells may use this information to calibrate their approach to monitoring production wells with an increased potential for PCE contamination from dry cleaners. Knowing the locations and potential severity of threats from past dry cleaner operations can also be helpful for siting a new water supply well, planning groundwater remediation at a nearby fuel leak site, or planning a construction dewatering operation.

In addition to groundwater impacts, SSR may be beneficial for ranking potential human health risk from vapor intrustion into occupied buildings. Occupied residences that overly former dry cleaner operations within 15 feet of the water table may be good candidates for vapor intrusion risk assessments.

Recommendations for Next Steps in Applying Simplified SiteRank

The following efforts would greatly improve the value of prioritization estimates generated using SSR:

1. Add a capability to incorporate seasonal fluctuations in groundwater flow directions.
2. Add a capture zone evaluation function for supply wells to better simulate real world conditions. The WHPA[7] code for three-dimensional capture zone estimation using the groundwater mechanics approach may be adaptable to this purpose, or, the Bear equation can be applied using modeled aquifer parameters from the District's regional groundwater model.
3. Replace generalized regional shallow groundwater flow directions with measured or modeled local groundwater flow directions.
4. Further calibrate mass-release estimates (the age-duration surrogate) by analyzing several dozen well-investigated dry cleaner release sites from across the country and comparing age-duration rank with total mass recovered and estimated mass in the subsurface.
5. Incorporate the number, thickness, and competency of aquitards to more realistically address the degree to which drinking water aquifers are geologically isolated from surficial contamination, instead of relying only on DRASTIC groundwater vulnerability ratings.
6. Validate the assumptions and method for estimating well vulnerability through literature research and a survey of well integrity testing result.
7. Use monthly pump discharge and operating frequencies instead of annual discharge with an assumed operating frequency to incorporate seasonality of pumping.
8. Perform particle tracking modeling to validate rankings provided by SSR.

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[7] WHPA code uses analytic element models (AEM), using boundary conditions derived from the MODFLOW model. ModAEM, is the computational heart of the EPA WhAEM for Windows wellhead protection model, may be well-suited to this task.

CONCLUSIONS

This report presents ample evidence that past dry cleaner operations have a high potential to cause significant releases that can threaten groundwater supplies. In Santa Clara County and throughout the nation, there have been many soil and groundwater contamination cases resulting from past dry cleaner operations. In Santa Clara County, however, there has not been a corresponding realization of widespread PCE contamination in drinking water supply wells. PCE detections in 17 wells is certainly problematic; however, all but 2 of these wells have been managed such that water supplied from these wells is now free of PCE detections above the common reporting limit of 0.5 ppb. In general, smaller quantities of PCE have been released from dry cleaners than from large electronics and industrial production facilities; consequently, the largest PCE plumes impacting the largest aquifer volumes originate from facilities that used much more PCE than dry cleaners. The largest solvents plumes in Santa Clara County originated from electronics and industrial facilities, and many of these sites have been undergoing long-term cleanup in the Superfund program. PCE from dry cleaners is also not the most ubiquitous form of groundwater contamination in Santa Clara County. Nitrate contamination, primarily from past agricultural practices, remains the most widespread groundwater contaminant.

Current dry cleaner operations have significantly reduced the threat of soil and groundwater contamination from most of today's dry cleaning operations. Modern machinery equipped with vapor-detection activated door locks, improved solvent recovery, and a major effort by dry cleaning industry leaders and air quality regulatory officials to educate dry cleaner proprietors has led to substantial improvements in safe handling of PCE. The exception is operators of older equipment. Increased regulation and inspection provides protection against releases from older equipment at modern operations. A small potential for releases remains; however, the potential impact to water supplies from infrequent releases of small masses of PCE is greatly reduced in contrast to earlier decades of dry cleaner operations.

PCE contamination will become a more significant issue if the California Department of Health Services lowers the Maximum Contaminant Level, in response to the lower Public Health Goal issued by the Office of Environmental Health Hazard Assessment. It is unclear whether lowering the MCL is warranted; the toxicology literature includes pharmaco-kinetic modeling suggesting that PCE's toxicity and potential carcinogenicity may be less than reflected in California's revised Public Health Goal. At the same time, US EPA's lowering of the Preliminary Remediation Goal for trichloroethylene (TCE) may also affect regulation of PCE at contaminated sites.

This study did not review the adequacy of the current standard of practice by environmental investigators, or the state officials who regulate dry cleaner investigations. The complex behavior of PCE as DNAPL, dissolved phase, and vapor phase, requires a sophisticated approach to both investigation and remediation. Many dry cleaner investigations take place outside the regulatory framework. Phase II investigations are often performed for banks issuing loans for real estate transactions, or for buyers or sellers of commercial properties that were occupied by dry cleaning operations. These investigations are reported to the Regional Board when significant groundwater contamination is found, but may not be reported if results turn up no contamination. The Regional Board may therefore be deprived of the opportunity to judge the adequacy of the investigation.

The importance of understanding the *"contaminant archeology"*, i.e. the manner in which solvents were used at dry cleaners, and therefore the likely points of release, cannot be understated. Training may be appropriate to ensure that both environmental investigation practitioners and regulators are equipped with detailed knowledge so that likely points of release are not overlooked. Investigations that conclude the absence of dry cleaner impacts on the basis of the common practice of advancing only four soil borings are ineffectual and likely to miss contamination that could remain a threat to water quality. Regulators must insist upon a well-reasoned basis for the technical approach to dry cleaner investigations.

The "worst-case" combination of high groundwater vulnerability, high source strength, high well vulnerability, and direct pathway from the cleaner to the supply well is found in only 6¼% of the 1,250 dry cleaners ranked for this study (78 dry cleaners). This smaller percentage is more manageable for the purposes limiting the effort needed to confirm or rule out threats to groundwater. Should a large number of the top-ranked cases show evidence of significant contamination, the next tier of ranked dry cleaners should be listed for further investigation.

These conclusions are conditioned by uncertainty inherent in the data collection and estimation methods described. The largest uncertainly affecting the analysis presented herein lies with the inclusion of all listed cleaners, when surveys demonstrate that more than a third of listed cleaners were drop-off locations that did not operate machines. In order of their potential to diminish the validity of the ranking algorithm, additional sources of uncertainty include:

1. assuming Perchloroethylene was the solvent used at all cleaners, when our review of air district records show that in 2002, 1/8th of operating cleaners used petroleum or other solvents;
2. the empirical method for using an age-duration surrogate to represent potential mass released
3. Accuracy of mapped cleaner location
4. Distance-direction rank does not account for conveyance of PCE wastewater by sewer lines
5. Accuracy of data collection for determining duration of cleaner operations
6. Interpreting groundwater sensitivity from DRASTIC
7. Assigning a single groundwater flow direction value based on reports from fuel leak sites
8. Depth to groundwater based on interpolation of water level data from nearby fuel leak sites
9. Interpretations of potential well vulnerability from well construction information compiled in a legacy database

Because the Simplified SiteRank approach used here produces only a ranking and not a quantitative risk estimate, these sources of uncertainty are not likely to materially diminish the value of this ranking exercise.

REGULATORY RECOMMENDATIONS

The following general suggestions are provided for consideration by regulators regarding techncial and regulatory approaches to investigating and remediating past dry cleaners. In the course of conducting this study, several aspects of the sometimes overlooked features of dry cleaner release sites were identified. Dry cleaner releases of PCE to soil and groundwater often come to light only after a property transaction in which the lender requires a Phase I or Phase II site investigation. Releases may therefore go undetected and continue to degrade groundwater quality for extended periods of time until they are investigated. Because some accepted investigation approaches are not comprehensive, some releases may not be identified. The recommendations below are suggestions that could improve the detection of dry cleaner releases. Recommendations for methods to rank dry cleaners for prioritized investigations are provided at Page 68.

- Dry Cleaner investigations should apply the San Francisco Regional Water Quality Control Board's *Environmental Screening Levels* rather than the commonly applied 1 mg/kg detection of PCE in soil.

- RWQCB and DTSC should consider requiring that groundwater at all dry cleaner sites should be tested regardless of soil concentrations, given the difficulty of detecting PCE's tortuous path through the subsurface. Groundwater samples are more likely to detect PCE releases than soil, while soil vapor samples indicate presence but may not reveal location of contamination.

- DTSC's Green Chemistry Initiative or an Interagency Committee should be formed to review potential environmental impacts and health effects of alternatives to PCE now being developed and used; not all of the alternatives are free of toxicity or threats to groundwater resources.

- RWQCB should consider using 13267 letters to require that soil gas investigations be performed at high risk dry cleaner facilities.

- Develop a model directive letter for dry cleaner investigations and cleanup.

- RWQCB should request that industrial pretreatment programs report individual volatile organic compound concentrations measured in wastewater treatment plant influent in their periodic discharge reports to RWQCB (as opposed to total VOCs). The RWQCB recipient of that data should share it with groundwater/toxics division caseworkers. Unexplained occurrences, i.e. those that don't add up with permitted discharges, should be pursued to identify the origin. Annual RWQCB Executive Officer reports should summarize findings of VOCs in sewers and any recommended actions or solutions.

- Phase II investigations: RWQCB should require that all Phase II reports be copied and filed with RWQCB's GeoTracker system.

- Copy reports to DHS that show presence of VOCs in drinking water to the RWQCBs. In the Annual Executive Officer report for each region, RWQCB staff should analyze and report on trends in VOCs in public supply wells, and on any efforts to identify the sources of detected VOCs. VOCs should be reported with respect to a threshold of concern as a percentage of the MCL.

Funding Recommendations

- The State Water Resources Control Board should establish a dry cleaner cleanup fund, following the model provided by the State Coalition for Remediation of Drycleaners.

- A grant-funded project should be pursued to conduct a 20-case pilot study of passive or qualitative soil vapor surveys using methods such as Gore-Sorbers installed in holes drilled ~4' into sidewalks, planters, parking lots, or streets adjacent to highest ranked dry cleaners.

- Pursue grant funding to do a more complete implementation of SiteRank to weigh threats from Dry Cleaners against other threats to groundwater quality such as M*t*BE, solvents from other industries, and other contaminants such as nitrate or perchlorate.

Further Study

- Establish a methodology for estimating source strengths for past and present Potentially Contaminating Activities.
- Further develop the SSR methodology to compare and rank threats to groundwater from additional contaminants and industries.

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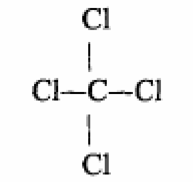
Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County

APPENDICES

Appendix A: Chemical And Physical Properties Of Dry Cleaning Solvents

Carbon Tetrachloride

Table 19: Chemical Identity of Carbon Tetrachloride

Characteristic	**Information**	**Reference**
Chemical Name	Carbon tetrachloride	IARC 1979
Synonym(s)	Carbona; carbon chloride; carbon tet; methane tetrachloride; perchloromethane; tetrachloromethane; benzinoform	HSDB 1993
Registered trade name(s)	Benzinoform; Fasciolin; Flukoids; Freon 10; Halon 104; Tetraform; Tetrasol	IARC 1979
Chemical formula	CCl_4	IARC 1979
Chemical Structure		IARC 1979
Identification Numbers		
CAS registry	56-23-5	NLM 1988
NIOSH RTECS	FG4900000	HSDB 1992
EPA hazardous waste	U211; D019	HSDB 1993
OHM/TADS	7216634	HSDB 1992
DOT/UN/NA/IMCO shipping	UN1846; IMCO 6.1	HSDB 1992
HSDB	53	HSDB 1992
NCI	No data	HSDB 1992

Source: Agency for Toxic Substances and Disease Registry, 1994.
CAS = Chemical Abstracts Services; CERCLA = Comprehensive Environmental Response Compensation Liability Act; DOT/UN/NA/IMCO = Department of Transportation/United Nations/North America/International Maritime Dangerous Goods Code; USEPA = United States Environmental Protection Agency; HSDB = Hazardous Substances Data Bank; HSIA = Halogenated Solvents Industry Alliance, Inc. NCI = National Cancer Institute; NIOSH = National Institute for Occupational Safety and Health; New Jersey Department of Health and Senior Services; OHM/TADS = Oil and Hazardous Materials/Technical Assistance Data System; RCRA = Resource Conservation and Recovery Act; RTECS = Registry of Toxic Effects of Chemicals Substances

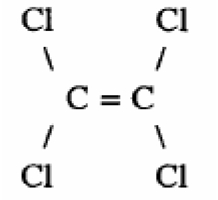
Table 20: Physical and Chemical Properties of Carbon Tetrachloride

Property	Information	Reference
Molecular weight	153.82	Lide 1992

Color	Colorless	Verschueren 1983
Physical state	Liquid	Verschueren 1983
Melting point	-23°C	Lide 1992
Boiling point	76.5°C	Lide 1992
Density	1.594 g/mL	Lide 1992
Odor	Aromatic, sweet	HSDB 1992
Odor threshold:		
Water	0.52 mg/L	IRIS 1993
Air	10-71,000 mg/m3	Verschueren 1983
	96 ppm (600 mg/m3)	Amoore and Hautala 1983
	60-1,500 mg/m3	Ruth 1986
Solubility:		
Water at 20 °C	800 mg/L	Verschueren 1983
Organic solvent(s)	Miscible	HSDB 1992
Partition coefficients:		
Log K_{ow}	2.64	EPA 1984
Log K_{oc}	2.04	Kenaga 1980
Vapor Density (Air = 1)	5.3	www.orcbs.msu.edu.....
Vapor Pressure at 20 °C	90 mmHg	Verschueren 1983
Henry's law constant:		
at 20°C	$2.04x10^{-2}$ atm-m^3/mol	Tse et al. 1992
at 24.8°C	$3.04x10^{-2}$ atm-m^3/mol	HSDB 1993
at 25°C	$2.94x10^{-2}$ atm-m^3/mol	Yaws et al. 1991
at 30°C	$3.37x10^{-2}$ atm-m^3/mol	Tse et al. 1992
Autoignition temperature	Nonflammable	HSDB 1992
Flashpoint	Nonflammable	HSDB 1992
Flammability limits	Nonflammable	HSDB 1992
Conversion factors		
ppm (v/v) to mg/m^3 in air (25°C)	1 ppm = 6.39 mg/m3	Verschueren 1983
mg/m^3 to ppm (v/v) in air (25°C)	1 mg/m3 = 0.16 ppm	Verschueren 1983
Explosive limits	No Data	

Perchloroethylene

Table 21: Chemical Identity of Perchloroethylene

Characteristic	**Information**	**Reference**
Chemical Name	Tetrachloroethylene	HSDB 1996
Synonym(s)	Carbon bichloride; carbon dichloride; ethylene tetrachloride; per; perc, perchlor; perchloroethylene; perk; 1,1,2,2-tetrachloroethylene; tetrachloroethene; PCE	HSDB 1996
Registered trade name(s)	Ankilostin; Antisal 1; Dee-Solve; Didakene; Dow-per; ENT 1860; Fedal-un; NCI-C04580; Nema; Perawin; Perchlor; Perclene; Perclene D; Percosolv; Perk; Perklone; PerSec; Tetlen; Tetracap; Tetraguer; Tetlen; Tetraleno; Tetravec; Tetroguer; Tetropil; Perawin; Tetralex; Dowclene EC; UN 1897	OHM/TADS 1990; USEPA Factsheet; JH Montgomery
Chemical formula	C_2Cl_4	ACGIH 1991
Chemical Structure		ACGIH 1991
Identification Numbers		
CAS registry	127-18-4	HSDB 1996
NIOSH RTECS	Kx3850000	HSDB 1996
EPA hazardous waste	U210	HSDB 1996
OHM/TADS	7216847	OHM/TADS 1990
DOT/UN/NA/IMCO shipping	UN1897; IMO 6.1	HSDB 1996
HSDB	49 403 55	HSDB 1996
RCRA Hazardous Waste Number	U 210	HSIA 1999
NCI	NCI-C04580	HSDB 1996

Sources: Montgomery J.H., 1996; US EPA, 2002; Agency for Toxic Substances and Disease Registry, 1997; Halogenated Solvents Industry Alliance, 1999

Table 22: Physical and Chemical Properties of Perchloroethylene

Property	**Information**	**Reference**
Molecular weight	165.83	Lide 1990
Color	Colorless	Sax and Lewis 1987
Physical state	Liquid (at room temperature)	Sax and Lewis 1987
Melting point	-19 °C	Lide 1990
Boiling point	250 °F	Lide 1990
Density at 20 °C	1.6227 g/ml	Lide 1990
Odor	Ethereal, sweet chloroform-like odor	HSDB 1996; NJDHSS 1996
Odor threshold:		
Water	0.3 ppm	EPA 1987b
Air	1.0 ppm	EPA 1987b
Solubility:		
PCE in water at 25 °C	150 mg/L	HSDB 1996
Water in PCE	105 mg/L	HSIA 1999
Organic solvent(s)	Miscible with alcohol, ether, chloroform, benzene, solvent hexane, and most of the fixed and volatile oils	HSDB 1996
Partition coefficients:		
Log K_{ow}	3.4	HSDB 1996
Log K_{oc}	2.2 – 2.7; low to moderate mobility in soil	Seip et al. 1986; Zytner et al. 1989a; USEPA Fact Sheet
Bioconcentration Factor	39 to 49 in fish	USEPA Fact Sheet
Vapor Density (Air = 1)	5.8	SCRD's MSDS
Vapor Pressure at 25 °C	18.47 mmHg	HSDB 1996
Henry's law constant at 25 ° C	1.8×10^{-2} atm-m^3/mol	Gossett 1987
Diffusivity in water (10^5 cm^2/sec)	0.87 at 20 °C using method of Hayduk & Laudie	JH Montgomery 1996.
Flashpoint	None	HSDB 1996
Flammability limits	Nonflammable	HSDB 1996
Conversion factors	1 mg/L = 147.4 ppm	HSDB 1996
ppm to mg/m3 in air	1 ppm = 6.78 mg/m^3	

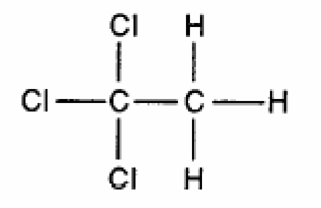
Table 23: Regulatory Limits and Water Quality Goals for Perchloroethylene

Governmental Agency	Exposure Pathway	Limits	Reference
ACGIH TLV:			
8 hr TWA	Air (workplace)	25 ppm	HSIA
15 min STEL	Air (workplace)	100 ppm	HSIA
DHS and EPA MCL	Water	5 ppb	DHS
EPA MCLG	Water	0	EPA
OEHHA PHG	Water	0.06 ppb (not a regulatory std)	OEHHA
OSHA PEL:			
8 hr TWA	Air (workplace)	100 ppm	NIOSH HC18
Ceiling	Air (workplace)	200 ppm for 5 min in any 3-hr period	NIOSH HC18
Peak	Air (workplace)	300 ppm	NIOSH HC18
Cancer Classification			
ACGIH		A3 = animal carcinogen	HSIA
IARC		2A = Probably carcinogenic to humans	HSIA
NTP		Reasonably anticipated to be a human carcinogen	HSIA

ACGIH = American Conference of Governmental Industrial Hygienists; DHS = Department of Health Services; Environmental Protection Agency; IARC = International Agency for Research on Cancer; MCL = Maximum Contaminant Level; MCLG = Maximum Contaminant Level Goal; NIOSH = National Institute of Occupational Safety and Health; NTP = National Toxicology Program; OEHHA = Office of Environmental Health Hazard Assessment; OSHA = Occupational Safety and Health Agency; STEL = Short Term Exposure Limit; TLV = Threshold Limit Value; TWA = Time Weighted Average

1,1,1-Trichloroethane

Table 24: Chemical Identity of 1,1,1-Trichloroethane

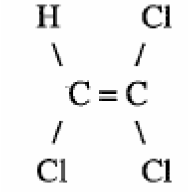
Characteristic	Information	Reference
Chemical Name	1,1,1-Trichloroethane	CAS 1994
Synonym(s)	Methylchloroform; Methyltrichloromethane; Trichloromethylmethane; alpha-Trichloromethane	CAS 1994 SANSS 1994
Registered trade name(s)	Chlorothene NU Aerothene TT	OHM-TADS 1994
Chemical formula	CCl_3CH_3	CAS 1994
Chemical Structure		
Identification Numbers		
CAS registry	71-55-6	CAS 1994
NIOSH RTECS	KJ2975000	RTECS 1994
EPA hazardous waste	U226	HSDB 1994
OHM/TADS	8100101	OHM/TADS 1994
DOT/UN/NA/IMCO shipping	UN 2831	HSDB 1994
HSDB	157	HSDB 1994
NCI	C04626	HSDB 1994

Source: Agency for Toxic Substances and Disease Registry, 1997.

Table 25: Physical and Chemical Properties of 1,1,1-Trichloroethane

Property	**Information**	**Reference**
Molecular weight	133.4	CAS 1993
Color	Colorless	Archer 1979; Sax and Lewis 1987
Physical state	Liquid	Merck 1989
Melting point	-30.4 °C -33.0 °C	Weast 1988 Archer 1979
Boiling point	74.1 °C	Merck 1989
Density		
at 20°C	1.3390 g/mL	Weast 1988
at 25°C	1.3299 g/mL	Riddick et al. 1986
at 30°C	1.32096 g/mL	Riddick et al. 1986
Odor	Ethereal, chloroform-like	Archer 1979; Aviado et al. 1976
Odor threshold:		
Water	No data	
Air	120 ppm 500 ppm	Amoore and Hautala 1983 Reist and Rex 1977
Solubility:		
Water at 20°C	0.1495% (wt/wt)	Horvath 1982
Organic solvent(s)	Soluble in alcohol, ether, chloroform; miscible with other chlorinated solvents; soluble in common organic solvents	Weast 1988; Archer 1979
Partition coefficients:		
Log K_{ow}	2.49	Hansch and Leo 1985
Log K_{oc}	2.03 2.02	Friesel et al. 1984 Chiou et al. 1979
Vapor Density (Air = 1)	4.54	Hillbrothers.com
Vapor Pressure at 20 °C	124 mmHg 16.4 1kPa	Boublik et al. 1984 Riddick et al. 1986
Henry's law constant		
at 20 °C	$6.3x10^{-3}$ atm-m^3/mol	Chiou et al. 1980
At 30 °C	$17.2x10^{-3}$ atm-m^3/mol	Gossett 1987
Autoignition temperature	537 °C	HSDB 1992
Flashpoint	None	Archer 1979
Flammability limits	8-10.5%	Archer 1979
Conversion factors:		
ppm (v/v) to mg/m3 in air (20 °C) mg/m3 to ppm (v/v) in air (20 °C)	1 ppm = 5.4 mg/m^3 1 mg/m^3 = 0.185 ppm	Chiou et al. 1980
Explosive limits:	7.5-12.5% in air	NIOSH 1990

Table 26: Chemical Identity of Trichloroehylene

Characteristic	Information	Reference
Chemical Name	Trichloroethylene	
Synonym(s)	Acetylene trichloride; 1-chloro-2,2dichloroethylene; 1,1-dichloro-2-chloroethylene; ethylene trichloride; trichloride; TCE; 1,1,2-trichloroethylene; trichloroethene	IARC 1979
Registered trade name(s)	Algylene; Anamenth;Benzinol; Blacosolv; Blancosolv; Cecolene; Chlorilen; Chloryles; Chlorylen; Chorylen; Cicosolv; Crawhaspol; Densinfluat; Dow-Tri; Dukeron; Fleck-Flip; Flock Flip; Fluate; Gumalgene; Germalgene; HI-TRI, Lanadin; Lethurin; Narcogen; Narkogen; Narkosoid; NEUTRI; Nialk; Perma-A-Chlor; Perma-A-Clor; Petzinol; Philex; Threthylen; Threthylene;Tretylene; Triad; Trial; Triasol; Trichloran; Trichloren; Triclene; Tri-Clene; Trielene; Trielin; Triklone; Trilen; Trilene; Triline; Trimar; Triol; TRI-plus; TRI-plus M; Vestrol; Vitran; Westrosol	IARC 1979
Chemical formula	C_2HCl_3	SANSS 1990
Chemical Structure		SANSS 1990
Identification Numbers		
CAS registry	79-01-6	SANSS 1990
NIOSH RTECS	KX4550000	HSDB 1994
EPA hazardous waste	U228	HSDB 1994
OHM/TADS	7216931	HSDB 1994
DOT/UN/NA/IMCO shipping	UN1710	HSDB 1994
HSDB	133	HSDB 1994
NCI	NCI-C04546	HSDB 1994

Source: Agency for Toxic Substances and Disease Registry, 1997.

Trichloroethylene

Table 27: Physical and Chemical Properties of Trichloroethylene

Property	Information	Reference
Molecular weight	131.40	HSDB 1994
Color	Clear, colorless	HSDB 1994
Physical state	Liquid (at room temperature)	HSDB 1994
Melting point	-87.1°C	McNeill 1979
Boiling point	86.7°C	McNeill 1979
Density at 20°C	1.465 g/mL	
Odor	Ethereal; chloroform-like; sweet	HSDB 1994
Odor threshold:		
Water	No data	HSDB 1994
Air	100 ppm	
Solubility:		
Water at 20°C	1.070 g/L	McNeill 1979
Water at 25°C	1.366 g/L	Tewari et al. 1982
Organic solvent(s)	Miscible with many common organic solvents (such as ether, alcohol, and chloroform)	McNeill 1979; Windholz 1983
Partition coefficients:		
Log K_{ow}	2.42	Hansch and Leo 1985
Log K_{oc}	2.03-2.66	Garbarini and Lion 1986
Vapor Density (Air = 1)	4.53	Global Chlorinated Organics
Vapor Pressure at 25°C	74 mmHg	Mackay and Shiu 1981
Henry's law constant		
at 20° C	0.020 atm-m^3/mol	Mackay and Shiu 1981
At 25°C	0.011 atm-m^3/mol	Hine and Mookerjee 1975
Autoignition temperature	None	McNeill 1979
Flashpoint	None	McNeill 1979
Flammability limits at 25°C (explosive limits) (volume % in air): % volume in air at 25°C	8.0-10.5	McNeill 1979
Conversion factors:		
Air at 20°C	1 mg/m^3 = 0.18; 1 ppm = 5.46 mg/m^3	Verschueren 1983
Water	1 ppm (weight per volume) = 1 mg/L	
Explosive limits:	No data	

Stoddard Solvent

Table 28: Chemical Identity of Stoddard Solvent

Characteristic	Information	Reference
Chemical Name	Stoddard solvent	Sax and Lewis 1989
Synonym(s)	Dry cleaning safety solvent, naphtha safety solvent, PD-680, petroleum solvent, spotting naphtha, varnoline, white spirits	Air Force 1989b; NIOSH 1989; Sax and Lewis 1989
Registered trade name(s)	Texsolve S, Varsol 1	Budavari et al. 1989; Hunter et al. 1982
Chemical formula	N/A[a]	
Chemical structure	N/A[a]	
Identification numbers:		
CAS registry	127-18-4	HSDB 1996
CERCLA RQ	100 pounds	HSIA 1999
NIOSH RTECS	Kx3850000	HSDB 1996
EPA hazardous waste	U210	HSDB 1996
OHM/TADS	7216847	OHM/TADS 1990
DOT/UN/NA/IMCO shipping	UN1897; IMO 6.1	HSDB 1996
HSDB	49 403 55	HSDB 1996
RCRA Hazardous Waste Number	U 210	HSIA 1999
NCI	NCI-C04580	HSDB 1996

[a] Stoddard solvent is a mixture of C_7-C_{12} hydrocarbons primarily containing straight and branched chain alkanes (30-50%), cycloalkanes (30-40%), and alkyl aromatic hydrocarbons (10-20%) (Air Force 1989b; McDermott 1975).

Source: Agency for Toxic Substances and Disease Registry, 1995b

Table 29: Physical and Chemical Properties of Stoddard Solvent

Property	Information	Reference
Molecular weight	144 (mean); 135-145 (range)	Air Force 1989b; Carpenter et al. 1975b
Color	Clear, colorless	Sax and Lewis 1989
Physical state	Liquid	Sax and Lewis 1989
Melting point	No data	
Boiling point	154-202°C; 160-199°C	Air Force 1989b Coast Guard 1985
Density at 20 °C	0.78 g/mL	NIOSH 1990
Odor	Similar to kerosene	NIOSH 1990
Odor threshold:	0.9 ppm (5.1 mg/m^3) 2 mg/m^3	Carpenter el al. 1975b Hastings et al. 1984
Solubility:		
Water	Insoluble	McDermott 1975
Organic solvent(s)	Absolute alcohol, benzene, ether, chloroform, carbon tetrachloride, carbon disulfide	McDermott 1975; Sax and Lewis 1989
Partition coefficients:		
Log K_{ow}	3.16-7.06	Air Force 1989b
Log K_{oc}	2.85-6.74	Air Force 1989b
Vapor Density (Air = 1)	<1	www.temarry.com/MSDS/...
Vapor Pressure at 25 °C	4-4.5 mmHg	Air Force 1989b
Henry's law constant at 20° C	$4.4x10^{-4}$-$7.4x10^{0}$ atm·m^3/mol	Air Force 1989b
Autoignition temperature	232°C	Sax and Lewis 1989
Flashpoint	37.8-60.0°C 38-43°C	Air Force 1989b
Flammability limits: % volume in air at 25°C	0.9-6.0	Carpenter el al. 1975b
Conversion factors:		
At 25°C and 760 mm	1 mg/L = 174.6 ppm; 1 ppm = 5.73 mg/m^3	Carpenter el al. 1975b
At 25°C	1 ppm = 5.77 mg/m^3	Air Force 1989b
Explosive limits:		
Lower limit	0.9%	
Upper limit	6%	

Source: Agency for Toxic Substances and Disease Registry, 1995b

Environmental Fate of PCE in Groundwater

PCE releases to the environment may occur in any of the following ways:

- as hot PCE vapor emissions to the atmosphere
- as PCE vapor sinking through the soil profile and partitioning into soil water and groundwater
- as dissolved phase PCE in floor cleaning wastewater and condensate discharged to the subsurface through leaking sewer lines
- as dissolved phase PCE discharged to surface water through storm drains
- as pure phase PCE drained from filters or other discarded PCE entering soil, groundwater, or surface water
- as adsorbed phase PCE on carbon cartridges or muck cooker solids sent to landfills or other waste disposal areas.

When released to air, PCE's vapor pressure of 18.5 mm Hg at 25 °C indicates that it persist as a vapor. Vapor-phase PCE is susceptible to reaction with photochemically-produced hydroxyl radicals; the half-life for this reaction in air is estimated to be 96 days. Direct photolysis is not an important environmental fate process since PCE absorbs light only weakly in the ambient UV spectrum (NLM, 2004).

PCE released to soil will usually have moderate mobility based upon its organic carbon partition coefficient (K_{OC}) values in the range of 200-237. PCE's mobility is demonstrated by the fact that it is among the most commonly detected anthropogenic contaminants detected in water supply wells. PCE will quickly volatilize from soil surfaces; it's air-water partition coefficient Henry's Law constant) is 0.0177 atm-m^3/mole. Volatilization half-lives in the range of 1.2-5.4 hrs were measured for PCE from a sandy loam soil surface and volatilization half-lives of 1.9-5.2 hrs were measured from an organic topsoil (NLM, 2004)

PCE may biodegrade slowly in soils under both aerobic and anaerobic conditions. Biodegradation half-lives of PCE in aerobic and anaerobic waters were reported as 180 and 98 days, respectively. PCE will volatilize readily from water surfaces, based upon its Henry's Law constant. Estimated volatilization half-lives for a model river and model lake are 1 hour and 5 days, respectively (NLM, 2004).

Bioconcentration of PCE in aquatic organisms is low to moderate; estimated and measured bioconcentration factors (BCF values) in fish range from 26 to 77. Hydrolysis is not expected to be an important environmental fate process based on a hydrolysis half-life of 9 months. PCE can undergo indirect photolysis in natural waters in the presence of dissolved humic acids (NLM, 2004).

Toxicology of Perchloroethylene

When individuals are exposed to a hazardous substance, several factors determine whether harmful effects will occur, and the type and severity of those health effects. These factors include the dose (how much), the duration (how long), the route by which they are exposed (breathing, eating, drinking, or skin contact), the other contaminants to which they may be exposed, and their individual characteristics such as age, sex, nutrition, family traits, life style, and state of health (California Department of Health Services, 1995). The scientific discipline that evaluates these factors and the potential for a chemical exposure to adversely impact health is called toxicology.

The two major routes of exposure to PCE are inhalation (i.e., breathing PCE-contaminated air) and oral (i.e., drinking PCE-contaminated water). Because PCE volatizes easily into the air, people living and/or working near PCE-contaminated hazardous waste sites may be exposed to PCE via the inhalation route. People living in apartment units located adjacent to dry cleaner may also be exposed to varying levels of PCE (0.04 ppm vs. 0.0003 ppm in a control apartment). Workers in occupational settings (e.g., dry cleaners, chemical plants, etc.) may be exposed to PCE via inhalation on a regular basis from performing job-related tasks. People may also be exposed to PCE via the oral route by drinking PCE-contaminated water. In addition, people can also inhale PCE volatizing from PCE-contaminated water.

As discussed in the regulatory section, DHS and US EPA have issued drinking water standards or Maximum Contaminant Level (MCL) for more than 80 contaminants, including PCE, in drinking water (USEPA). The MCL for PCE is 5 ppb. The MCLs are based on known or anticipated adverse human health effects (which also account for sensitive subgroups, such as, children, pregnant women, the elderly, etc.) the ability of various technologies to remove the contaminant, their effectiveness and cost of treatment.

Exposure to PCE may potentially cause adverse health effects; the main target organs are the central nervous system, kidney and the liver. Also, it may be linked to adverse reproductive and development health outcomes. Several public health agencies have classified PCE a possible human carcinogen.

Non-Cancer Effects

- Central Nervous System: The primary effect of PCE is upon the central nervous system. Short-term exposure (less than 2 hours) to high concentrations (1,000 to 1,500 ppm) of PCE has caused mood changes, slight ataxia (i.e., failure of muscle coordination), and dizziness. Exposure to lower level of PCE (100 ppm) for 7 hours produced symptoms of headache, dizziness, difficulty in speaking, and sleepiness.
- Kidney: In occupational settings, subtle kidney effects, such as, increased urinary lysozyme, fibronectin, albumin, brush border antigens, transferring, laminin fragments, and tissue-nonspecific alkaline phosphatase have been noted in workers.
- Liver: Human exposure to high concentrations of PCE resulted in enlarged liver, fatty changes, and elevated SGOT.
- Menstrual Disorders: Based on limited studies, they may be an association between menstrual disorders and spontaneous abortions in women exposed to PCE in occupational settings. Also, based on responses to questionnaires, it may take wives of dry cleaners slightly longer to get pregnant and they are more likely to seek help for infertility problems.

Cancer Effects

Based on a few epidemiological studies of dry cleaning workers, there may be a possible association between long term exposure to PCE and increased cancer risk. Two studies have reported a small number of cancers in their study population and no significant excess number of malignancy cases. However, there was an increase in several types of cancers, such as, esophageal cancer, cervical cancer and non-Hodgkin's lymphoma. However, these studies were confounded by concomitant exposure to other solvents, smoking and other lifestyle variables, and methodological limitations.

In animal studies, PCE has been documented to be carcinogenic to two animal species, the mouse and rat. Via both the inhalation and oral routes, mice exposed to PCE developed liver tumors (i.e., hepatocellular neoplasms). In an inhalation study, there were significantly increased incidences of mononuclear cell leukemia in both female and male rats and a low incidence of kidney cancer in male rates.

Based on sufficient evidence from animal studies and inadequate evidence from human studies, several governmental agencies have issued the following carcinogen classifications.

- U.S. Department of Health and Human Services = PCE may reasonably be anticipated to be a carcinogen;
- IARC = PCE is probably carcinogenic to humans (or a Group 2 carcinogen);
- USEPA = PCE is a probable carcinogen (or a Group B2 carcinogen).

Appendix B: The *SiteRank* Approach to Ranking Dry Cleaners for Threats to Groundwater Quality

With more than a 1,000 unique locations of past and current dry cleaners, determining which sites present the greatest threat to groundwater resources becomes a difficult task. By treating all dry cleaners equally, time, effort, and funds may be over-allocated to low risk cases, while high risk cases may not receive sufficient attention. Therefore, a methodology is needed to determine which dry cleaners pose the greatest risk to protecting the beneficial uses of groundwater in the Santa Clara Subbasins. A method was developed using geographic information system software (GIS) that accounts for which generation dry cleaning equipment was used, how long the dry cleaner operated, and the location of the dry cleaner relative to underlying groundwater vulnerability, groundwater flow direction, nearby supply wells, and nearby abandoned wells.

Numerous previous efforts have been conducted to categorize and prioritize contamination sites for investigation, and to establish the degree to which cleanup must be performed. Approaches considered in prior efforts by the Santa Clara Valley Water District to rank sites have included the following methods:

- fixed radius from a supply well,
- site location within the forebay or recharge zone,
- proximity to known abandoned wells,
- proximity to surface water,
- sensitivity of underlying groundwater as determined by applying EPA's DRASTIC methodology.

The Santa Clara Valley Water District developed criteria for ranking Operating Gasoline Underground Storage Tank (UST) facilities with respect to M*t*BE threat to groundwater using a combination of these approaches. The criteria were developed using the District's highly developed GIS data and spatial querying. Gasoline UST facilities were considered to be high threat if they met the following criteria:

- Located within 2,000 feet of an active drinking water supply well
- Located within 500 feet from a known abandoned well
- Located within 500 feet of a creek
- Located anywhere within a recharge zone
- Located within an area determined to have high groundwater sensitivity using the DRASTIC scale (see Appendix K for an explanation of the DRASTIC scale).

An approach suitable for contrasting risks posed by sites with a wide range of chemicals of concern that accounts for aquifer conditions, source strength, well vulnerability and pumping, and contaminant fate and transport was found in *SiteRank*. The *SiteRank* algorithm was developed by Matthew C. Small for his Ph.D. research at the University of California at Berkeley, and is presented in his dissertation, "Managing the Risks of Exposure to Methyl Tertiary Butyl Ether (M*t*BE) Contamination in Ground Water at Leaking Underground Storage Tank (LUST) Sites" (Small, 2003).[i] The *SiteRank* algorithm provides a simplified process-based, travel-time representation of contaminant fate and transport, combined with index-based scaling factors for chemical hazard and vertical migration. The *SiteRank* tool provides a dimensionally consistent screening tool that integrates both the relative strength of sources of contamination, and the vulnerability of water supply wells.

The input parameters for *SiteRank* include:

- Pumping Well Production: location, pumping rate, and days pumped per year
- Aquifer parameters: groundwater travel time from contaminant source to pumping well, and presence of intervening aquitards between source and well intake
- Source characteristics: location, estimated volume of release, and chemical(s) of concern
- Chemical properties: percent present in source (e.g. gasoline is 11% M*t*BE, dry cleaning solvent is 99% PCE), toxicity, retardation, solubility, half-life, and relative hazard

These parameters are converted to dimensionless factors, and then integrated into a ranking based on the sums of factors as follows:

$$\text{Rank} = \sum_{chemicals,k=1}^{n} \left(\frac{\mathrm{T}_{i,j,k}\ \mathrm{V}_{i,j}\ \mathrm{P}_{j,k}\ \mathrm{S}_{k}\ \mathrm{H}_{k}\ \mathrm{U}_{i}}{\mathrm{Z}} \right), \text{ where}$$

- Ti,j,k = Normalized inverse travel time for chemical k from source j to well i.
- Vi,j = Volume of source j divided by capture zone volume for well i.
- Pj,k = Percent of volume of chemical k in source j.
- Sk = Solubility factor for chemical k
- Hk = Hazard factor for chemical k.
- Ui = Usage factor for well i.
- Zi,j = relative vertical migration factor for source j with respect to well i.

The non-dimensional inverse travel time for chemical k from source j to the well is defined as:

Where:

- t½ is the reactive-half life for chemical k due to abiotic or microbial degradation,
- Rk is the retardation factor of chemical k, and ti,j is the travel time from source j to well i
- Ti,j,k is set to zero for dry cleaners or other sources found outside the capture zone of the pumping well of interest

The normalized release volume is defined as:

$$V_{i,j} = \frac{V_j}{Q_i t_{i,j}} \quad ;$$

and the percent by volume of chemical in the original release is defined as:

$$\mathrm{Pj,k} = \frac{\text{volume of chemical k}}{\text{release volume}} \times 100\,.$$

A value of 99% PCE is used for PCE content in dry cleaning solvent; the remaining 1% is assumed to be stabilizer compounds such as n-butyl glycidyl ether and cyclohexene oxide. This is a conservative assumption, because the actual composition of the released waste may also include a substantial proportion of water, as well as trace amounts of detergents, spot removal agents, soils, grease, and food waste, etc.

The Solubility Factor S_k for each chemical is scaled based upon a range of solubilities. The range of solubilities chosen can be based upon the solubilities of interest for the chemicals of concern in an application of *SiteRank.* A relative indicator of solubility, i.e. high, medium, or low, is assigned because solubilities can vary over several orders of magnitude. The effective solubilities of chemicals within a mixed waste can be used in the *SiteRank* model.

An example application of the Solubility Factor S_k in a fuel leak context follows:

$$S_{benzene} = \frac{(S_{benzene} - S_{\mathrm{C34\,aromatics}}) \cdot 10}{(S_{MTBE} - S_{\mathrm{C34\,aromatics}})} = \frac{(1750\ \mathrm{mg/L} - 6\times10^{-4}\ \mathrm{mg/L})10}{(5\times10^{4}\ \mathrm{mg/L} - 6\times10^{-4}\ \mathrm{mg/L})} = 0.35$$

$$S_{MTBE} = \frac{(S_{MTBE} - S_{C\,34\mathrm{aromatics}})10}{(S_{MTBE} - S_{C\,34\,aromatics})} = 10$$

The hazard factor H_k compares the toxicity of each chemical of concern relative to a scale that encompasses all foreseeable contaminants in the groundwater subbasins for which sites are being ranked. *SiteRank's* hazard factor H_k for chemical *k* is scaled based upon the oral reference dose, ($\mathrm{RfD_o}$) for non-carcinogens, and the oral slope factor ($\mathrm{Sf_o}$) for carcinogens. Non-carcinogens are given a lower risk than carcinogens using two ranges of scaled rankings. An example application of hazard ranking in the dry cleaner context follows:

$$H_{PCE} = \frac{(SFo_{PCE}^{\ (1)} - SFo_{isophorone})(20-11)}{SFo_{dioxin} - SFo_{isophone}} + 11 = \frac{(5.1\times10^{-2} - 9.5\times10^{-4})(20-11)}{1.5\times10^{5} - 9.5\times10^{-4}} + 11 = 11$$

By providing a means of comparing the solubility and toxicity of multiple chemicals at a single site or several sites, *SiteRank* allows the severity of groundwater contamination from different types of sites to be contrasted.

The Well Usage Factor *U* simply quantifies how often the wells are pumping during a year, assuming a constant discharge rate. *U* = 1 for continuously pumped wells.

$$U = \frac{\text{(days well is used each year)}}{365}$$

The relative vertical migration factor *Z*, as originally formulated, is used to address the common situation where the source and the well are located in different hydrostratigraphic units separated by one or more aquitards.

Z = number of intervening aquitards + 1;
Z = 1 when source and well are in the same statigraphic unit.

The authors developed a "modified vertical migration factor" to address vertical conduits, well seal depth, length of gravel pack above the first perforated interval, and spatial density of known abandoned wells in the vicinity of the dry cleaner and nearby well for a given application of *SiteRank*. Well age was also incorporated into this modified Z factor, based on an assumed deterioration of well seals with age. Wells less than ten years old were considered to have intact well seals, and a deterioration factor was applied for each additional decade up to fifty years old.

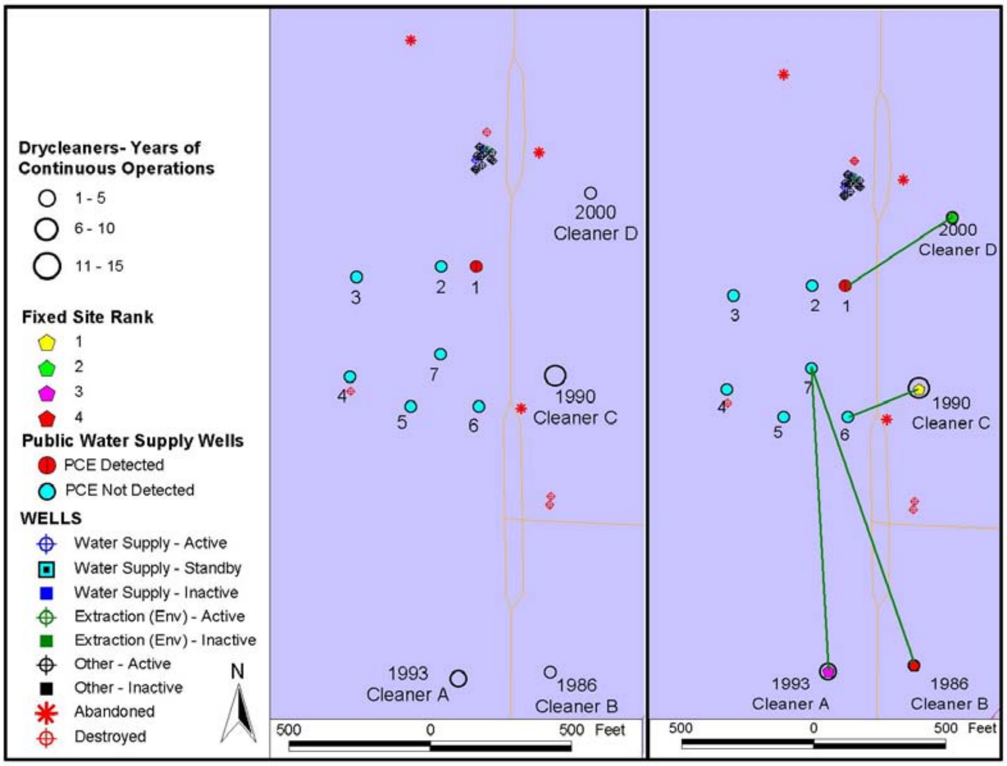


Figure 23 – Configuration of Wells and Dry Cleaners for *SiteRank* Pilot Calculations

__Example Application of SiteRank__

SiteRank was applied to a wellfield with seven public water supply wells in southwestern San Jose located within one-quarter mile of five dry cleaner locations; two dry cleaners are still in operation today. None of the dry cleaners is a known release site. Figure 23 shows the dry cleaners locations, duration of continuous operation, and start year, and their proximity to the well field and known abandoned wells. Groundwater flow directions measured at nearby fuel leak sites is generally to the north-northwest; some dry cleaners are upgradient while others are cross-gradient or even downgradient in the context of the shallow aquifer monitored at nearby fuel leak sites. One of the seven wells in the well field has historically had low level detections of PCE below the MCL. Table 30 presents the values assigned to the SiteRank parameters described above. The highest rank is assigned to Well 6, followed by Well 1, Well 7(A), and Well 7(B).

Table 30: Parameters Used for Pilot Site Rank Calculation

Parameters Used for Pilot SiteRank Calculation

Business Name	Min of Year	Associated Well ID
Cleaner A	1993	7
Cleaner B	1986	7
Cleaner C	1990	6
Cleaner D	2000	1

GWFL_Dir	Sensitivity
NNE	Med-High

Parameters	Well 1	Well 6	Well 7 (A)	Well 7 (B)
Well Age	43	41	41	41
Depth to 1st Perforation	359	321	454	454
Saturated Thickness	161	161	161	161
Regional Groundwater Velocity, ft/year	21.9	21.9	21.9	21.9
Darcy ft/day	0.07	0.07	0.07	0.07
Porosity	0.36	0.34	0.36	0.36
Number of aquitards between ground surface and top of 1st screen	5	8	12	12
Abandoned Well Density (Abandoned Wells per Square Mile)	28	28	56	56
Pumping rate, ft^3/year	16,148,563	53,230,320	16,148,563	16,148,563
Pumping rate, gallons per day	330,935	1,090,857	330,935	330,935
Pumping rate, ft^3/year	44,243	145,836	44,243	44,243
Travel time, days, from Bear equation	393	145	766	786
Transmissivity, ft/day	5616	5616	5616	5616
Release Volume	1000	1000	1000	1000
Volume of Water in Well Capture Zone, Acre-Feet	2989	1102	19195	19673
Percent of Target Chemical in Release (Commercial PCE is 99% PCE, 1% inhibitors)	0.99	0.99	0.99	0.99
Chemical	PCE	PCE	PCE	PCE
Retardation Factor	2	2	2	2
Biotic Half Life (years)	3650	3650	3650	3650
Solubility Factor	0.0015	0.0015	0.0015	0.0015
Chemical	PCE	PCE	PCE	PCE
Carcinogen	Yes	Yes	Yes	Yes
Cancer Slope Factor	0.1	0.1	0.1	0.1
Non-Carcinogenic H	1.00	1.00	1.00	1.00
Carcinogenic H	11.00	11.00	11.00	11.00
Hazard Ranking	11.00	11.00	11.00	11.00
Well Usage Factor	0.437	0.437	0.399	0.399
Vertical Migration Factor	5.37	8.05	7.89	7.89
SiteRank	3.31E-08	1.81E-07	2.36E-09	2.04E-09

Figure 24 represents the variability of lithology encountered in the installation of the seven wells, as interpreted from drillers' logs. The seven wells are all located within 500 feet of each other. The high degree of variability in lithologic units, as inferred from the lack of horizontal continuity in clays and gravels recorded in the drillers logs, suggests that either the sedimentary depositional processes in the forebay region result in a high degree of heterogeneity with very limited lateral continuity of water-bearing units, or, that the drillers logs available for these wells are not reliable for interpreting geologic features.

SiteRank produces a relative ranking for each source of contamination paired with each well in the area of interest. There are five former and operating dry cleaners within a quarter-mile of the well field. One well was determined to be downgradient and outside the zone of contribution for the seven wells. The four sources and seven wells generate 28 pairs, each of which is assigned a rank. This application of SiteRank assigned the highest rank to the Cleaner #A-Well #7 pair. The well with past PCE detections (#1) was not given a high rank in this application of SiteRank. Reasons for SiteRank's inability to predict which well had contamination may include:

- The impacted well pumps at only one-fifth the rate of the well that was predicted to be most vulnerable to PCE contamination.
- The high degree of geologic heterogeneity precludes accurate prediction of well vulnerability due to complex pathways.

Figure 24 - Lithologic Variability Among 7 Closely Spaced Wells in Wellfield for SiteRank Pilot Calculation

- Construction defects, such as in improper cement mix for the well seal leading to early cracking, cannot be predicted by SiteRank.
- Well logs may not accurately record well construction details.
- Pumping rates may be higher than assigned because of assumptions made regarding frequency of well operation. If a given well is pumped intensively only during peak summer demand and remains on standby the remainder of the year, then the role of pumping in that particular well will be underestimated.
- The mass of the source release cannot be predicted based on age and duration alone.

Release mass may vary by orders of magnitude depending upon:

- The practices of the dry cleaner operator
- the integrity of sewer lines
- the volume of cleaning business performed
- the soil conditions beneath each dry cleaner
- access to dry wells that can rapidly deliver pure PCE into the shallow aquifer
- the random occurrence of abandoned wells whose locations are unknown
- variable subsurface geochemical conditions that may favor reductive dehalogenation in one location and not at the next.

The full application of SiteRank across the entire study area (the Santa Clara Valley, Coyote, and Llagas Subbasins) requires data that enable prediction of capture zones and vertical migration. While much of the necessary data is available, the absence of a complete electronic database of well construction and lithology precludes estimation of vertical migration factors and reliable determination of whether a given dry cleaner resides within the zone of contribution to a given well. The three dimensional nature of determining the zone of contribution presents a challenge that is difficult to overcome without well-by-well analysis using modeling. To leverage SiteRank for screening level ranking, it is necessary to apply the SiteRank algorithm in a semi-automatic fashion. The rankings obtained from SiteRank can then be used to determine which source-well pairs warrant the significant effort required to establish three-dimensional capture zones, zones of contribution, and the lithologic and well construction integrity for each well.

The goal of evaluating capture zones and vertical migration factors through database and GIS spatial queries is attainable, and work is in progress to establish a digital database of lithologic data for the subbasins. A multi-layer three-dimensional MODFLOW groundwater flow model is available for the Santa Clara subbasin, and with additional effort, could help to predict capture zones for use with SiteRank. The example application described above represents a reasonable means of completing analysis of groundwater impacts from dry cleaners or other industries, as well as the comparative analysis of all types of groundwater impacts.

Appendix C: Dry Cleaning Operations & Methods

History of Dry Cleaning

The usage of non-aqueous substances for cleaning garments and fabric began in Mycenae, an ancient city, in southern Greece that flourished from about 1500 B.C. to about 1100 B.C. (Garfield, E., 1985; US EPA, 1995). Soiled garments and fabrics that were too delicate for laundering with water and detergents (e.g., lye and ammonia) were "dry" cleaned with a special type of grease-absorbent earth, known as fuller's earth. The special grease absorbing earth was coined "fuller's earth" because it was used by fullers (textile workers) who washed and brushed the earth into fabric to clean it.

In the 19th century, cleaners started using various organic solvents (e.g., camphene, benzene, benzol, naptha, and gasoline) to dry clean soiled garments. The first commercial dry cleaner, called Jolly Belin, was started in the mid- to late- 1800s by a French dye-works owner named J. Bapiste Jolly in Paris, France (Lyle, D., 1984). Jolly reportedly discovered dry-cleaning when he noticed that the grease stains on his table cloth magically disappeared after his maid accidentally overturned a kerosene lamp (Johnson, A.E., 1971). Through his dye-works company, he offered a new cleaning service and called it "nettoyage a sec" or dry cleaning. The term, "French Cleaning," is commonly used by many dry cleaners in the United States today because dry cleaning originated in France; however, it does not signify a specialized cleaning process.

Other dry-cleaning establishments also opened in Europe in the late 1800s. In 1869, the Pullars of Perth, Scotland (first founded in 1824 as a garment cleaning and re-dyeing business) manufactured the first power-driven dry cleaning machine. Benzene was probably used as the dry cleaning solvent. This dry-cleaning machine cleaned clothes faster and more efficiently.

The precise date of the first commercial dry-cleaner in the United States is unknown. However, by the early 1900s, the dry-cleaning industry was firmly established in the United States (DryClean USA, 2002). The first dry-cleaning solvent used was gasoline. It was later replaced by other petroleum distillates, such as, naphtha, kerosene, and benzene. There were several problems using petroleum distillates: disagreeable residual odor, highly flammable (i.e., dry cleaners exploded periodically), many city ordinances prevented dry cleaners from opening in highly populated urban cities, etc.

Development of Dry Cleaning Machines from 1930s to the Present

Over the years, the dry cleaning machine has evolved from 1st generation to modern state-of-the art 5th generation machines to reduce workers exposure to dry-cleaning solvents; to reduce amount of solvent needed to clean clothing, and to permit easier compliance with safety, health, and environmental regulations (National Institutional Occupational Safety and Health, 1998). There are two basic types of dry cleaning machines: transfer machines and the dry-to-dry machines. The transfer machines are older machines that wash dirty clothing in one unit and dry the clothing in a 2nd unit. The dry-to-dry machines are the newer machines that wash, extract and dry the clothing in one unit. Synthetic solvents plants can be either the transfer or dry-to-dry type facilities. All petroleum solvent machines are the transfer type.

1st Generation: Transfer machines

The transfer machines first appeared on the market in the 1930s and were used exclusively until the 1960s. In 1995, 34% of the dry cleaning machines in the United States were transfer machines. Transfer machines were largely banned in many California air basins by adoption of the California Dry Cleaning Airborne Toxic Control Measure on October 1, 1998 (BAAQMD, 2002).

Transfer machines usually composed of 2 units: a washer/extract unit and a dryer unit. Then, the clothing and solvent (either PCE or petroleum combined with a small amount of detergent and water) is agitated in the drum. After washing, the drum is spun at high speed to extract the solvent. An attendant must manually transfer the clothing to a dryer. The clothing is tumbled in re-circulating warm air to vaporize the residual solvent. After the drying cycle, cool air is circulated through the clothing to reduce wrinkling. Some transfer machines were composed of 3 units: a machine to wash the clothing; a machine to extract the solvent from the clothing using centrifugal forces; and a dryer (tumbler or reclaimer) to vaporize the remaining solvent and fumes (SCRD, 2002a).

The advantages of the transfer machine include: increased production since a new load of clothing can be washed while the previous load was drying; easier to repair because of its basic construction with less automation; less fabric damage because the drum remains cool after the previous load is removed. The disadvantages include: additional labor needed to manually transfer the solvent-soaked clothing from the washer/extractor to the dryer; worker exposure to the solvent vapors during the transfer of clothing; and can be difficult to find replacement parts because these are older machines. Another disadvantage of transfer machines is low solvent mileage.

To minimize vapor exposure during the transfer of clothing from the washer to the dryer, 2 vapor emission control technologies are used: hamper enclosure and room enclosure. The hamper enclosure is a hood or canopy made of an impervious plastic that encloses the clothing hamper and the open door of the washer when the clothing is transfer from the washer to the dryer. A room enclosure is composed of a metal frame covered with an impervious plastic that encloses both the washer and dryer units. During the transfer of clothing, a fan turns off and draws the solvent vapors through a vapor emission device (Hoenig, D.R., 2002)

1st generation machines had both the lowest solvent mileage and released the largest quantities of solvent to the environment. Based on survey data, PCE consumption was typically in the range of 78-100 kg per 1,000 kg of clothes cleaned, depending on the primary control technology, as well as operator and maintenance practices (California Air Resources Board, 1996).

2nd Generation: Vented Dry-to Dry machines

Improvement in dry cleaning machines started in the 1950s. The 2nd generation dry cleaning machines or the vented dry-to-dry machines were introduced in the late 1960s. One of the major improvements was the washing, extracting and drying was done in one unit; it was no longer necessary to transfer solvent-soaked clothing from the washer to the dryer. Other advantages include: they were smaller units, thus, saved space; less labor intensive-attendants no longer had to transfer heavy solvent-soaked clothing; reduced the amount of solvent escaping into the work room, thus, lower worker exposure; and higher solvent mileage. One disadvantage is lower production (since washing, extracting and drying takes place in one unit.

These were originally designed to emit residual vapors to the atmosphere. But, they could be retrofitted with a vapor control device such as, a carbon adsorbers and/or refrigerated condensers. In 1993, two thirds of dry cleaning machines used in the United States were dry-to-dry. One third of the dry-to-dry machines in use in 1993 were vented units designed to send residual vapors to the atmosphere or an external control device (US EPA, 1995).

Carbon adsorbers can be retrofitted to both transfer and vented dry-to-dry machines. Instead of venting solvent vapors directly into the atmosphere, retrofitted machines recover the solvent by directing the solvent-laden vapors through an activated carbon bed that adsorbs the solvent. The adsorbed solvent is recovered by passing low-pressure steam or hot air through the carbon bed; then the mixed steam and solvent vapor are passed through a water-cooled condenser and collected in a phase separator. The desorbed activated carbon bed is dried and reused while the recovered solvent is returned to the solvent tank. The removal efficiency is about 85% compared to non-controlled vented dry-to-dry machines (US EPA, 1995).

Like the carbon adsorbers, refrigerated condensers can be retrofitted to both transfer and vented dry-to-dry machines. The refrigerated condenser requires less maintenance than the carbon adsorbers, but it cannot be used to control low concentration of low vapor emission streams. It can achieve about 95% control of hazardous air pollutants (HAPs) compared to uncontrolled machines.

Effective April 1, 1996, the Bay Area Air Quality Management District (BAAQMD) prohibited the conversion of vented machines (i.e., transfer machines and vented dry-to-dry machines) into a closed-loop system (or a non-vented machine) with vapor emission control devices (carbon adsorbers and/or refrigerated condensers).

Based on survey data, PERC mileage was typically in the range 77-94 kg per 1,000 kg of clothes, depending on primary control technology used, and operator and maintenance practices (California Air Resources Board, 1996).

3rd Generation: Closed-Loop (non-vented) Dry-to Dry machines

The 3rd generation or closed-loop dry-to-dry machines with built-in refrigerated condenser came on the market in the late 1970s. It operates like the 2nd generation dry cleaning machine retrofitted with a refrigerated condenser. The closed-loop machines do not vent solvent vapors to the atmosphere but recycles it continually throughout the dry cleaning cycle. The only air exchange occurs when the attendant load and unload the machine. In 1993, one-third of dry cleaning machines in use were closed-loop dry-to-dry machines. The advantage of this dry cleaning machine is that it does not vent directly to the atmosphere. The disadvantage is that the complex design of the machine can result in higher maintenance costs and more frequent breakdowns. Dry-to-dry machines also use petroleum drycleaning solvent. Based on survey data, PERC mileage in dry-to-dry machines was typically 20 to 40 kg per 1,000 kg of clothes cleaned, depending on operator and maintenance practices (California EPA, 1996).

4th Generation: Closed-Loop (non-vented) Dry-to Dry machines

The 4th generation machine came on the market in the early 1990s. It is a non-vented closed-loop dry-to-dry machine with an additional internal vapor recovery device. It is basically a 3rd generation machine fitted with built-in carbon adsorbers in series with the refrigerated condenser. Another common feature is a spill pan below the machine to contain any potential accidental releases of PCE.

PERC mileage in 4th generation machines is nominally higher than 3rd generation machines (California Air Resources Board, 1996).

5th Generation: Closed-Loop (non-vented) Dry-to Dry machines

The 5th generation machines were introduced in the late 1990s. A 5th generation machine is a 4th generation machine fitted with a single beam infrared photometer to monitor the PCE concentration in the machine cylinder. An interlock on the machine door prevents the attendant from opening the machine door until the PCE concentration in the cylinder falls below 290 ppm. Although this is a highly sophisticated machine, it is not widely used in the United States because of the high cost (California Air Resources Board, 1996).

While new generation (4th or 5th) machines can achieve a solvent mileage factory design rating of 10kg/1,000 kg of clothes, operator and maintenance practices are critically important to achieve the design performance. During sustained commercial operation, however, an average solvent mileage of 20kg PERC/1,000 is a reasonable target for the sector as a whole if good operating and maintenance practices are adhered to.

Self Service Coin-Operated Dry Cleaning machines

Self-service coin-operated dry cleaners were introduced to the market in the early 1960s. Coin-operated machines were usually located in laundromats in rural areas and operated by consumers. The coin-operated machines are small dry-to-dry machines (i.e., 8 to 12 pounds clothing capacity) that used PCE. A few of the coin-operated drycleaning machines utilized Valclene (Freon 113), but, by far, most of the machines used PCE. Effective December 21, 1994, the BAAQMD prohibited coin-operated dry cleaning machines.

Table 31 summarizes the Perchloroethylene mileage for five generations of dry cleaning machines.

Table 31: PCE Mileage per 1000 kg of Clothing Cleaned

PCE Mileage per 1000 kg of Clothing Cleaned	
Generation	**PCE Consumption (kg)**
1st	78 to 100
2nd	77 to 94
3rd	20 to 40
4th & 5th	10 to 20

Source: CARB, 1996.

Dry-Cleaning Solvent Usage Pattern in the United States from the 1920s to Present

Stoddard Solvent

Over the decades, different solvents were used because of the increased understanding of the chemicals and the chemistry of cleaning. In the early 1920s, the development of a new solvent, Stoddard, was heralded as a major research breakthrough in the dry cleaning industry. In 1928, Stoddard solvent was adopted by dry-cleaners in the United States. It was a much safer petroleum product with a higher flash point (lowest temperature at which a solvent will become volatile and mix with air to form an inflammable gas) of 103° F than the previous petroleum solvents; and it was pure and odor free. Until 1962, Stoddard solvent usage exceeded chlorinated solvents; it is less commonly used today, but some dry-cleaners still use it to clean drapes, suedes and leathers. Stoddard solvent had several disadvantages, including building code restrictions, requirement for non-residential locations; low solvent mileage of transfer machines, high energy demands for distillation because of the high boiling point (310° F); photoreactivity, and the possible presence of benzene, a carcinogenic by-product of production.

Stoddard solvent is stilled in a partial vacuum in petroleum drycleaning machines (at approximately 100° F). Most petroleum drycleaners do not operate a distillation unit but rather rely strictly on filtration to purify Stoddard solvent. Another disadvantage of petroleum drycleaning solvent is that the presence of water in the system can result in solvent degradation with associated foul odors (Linn, W., 2005).

140° F Solvent

At the same time, another petroleum solvent was introduced, 140° F Solvent (it was named after its flashpoint of 140° F). It was safer than Stoddard solvent because of the higher flashpoint. It was permitted to be used in some places where Stoddard was prohibited. The disadvantages of 140° F Solvent are: longer drying times, more expensive and may also contain benzene.

Carbon Tetrachloride

Carbon Tetrachloride (CCl_4) was the first chlorinated solvent to be produced in the United States; large scale production started in the early 1900s. It was first used as a household cleaning agent and in fire extinguishers. In 1914, annual production was approximately 10 million pounds. By the 1920s, it was primarily used as a dry-cleaning solvent and in fire extinguishers. It was used by the majority of dry-cleaners in the United States during World War II (which started in 1939). CCl_4 was replaced by PCE and TCE as a dry-cleaning and degreasing solvent because: they were less toxic than CCl_4; absence of a good recovery technique for CCl_4; and CCL_4 needed to be shipped in special containers (e.g., lead lined containers) because it was corrosive to common metals [e.g., steel]. By the late 1940s, PCE replaced CCl4 as the leading chlorinated solvent used in dry cleaning (the ratio of PCE:CCl_4 was 3:1). In 1962, estimate use of CCl_4 in the dry-cleaning industry decreased to 2 - 3 million pounds. By the 1970s, the usage of CCl_4 as a degreasing and dry cleaning solvent was negligible. Today, CCl_4 is no longer used in the dry cleaning industry (Doherty, R.E., 2000).

Trichloroethylene

Trichloroethylene (TCE) was first used as a dry-cleaning solvent in Germany in the 1920s. In 1930s, TCE was introduced in the United States. TCE was highly effective. Its improved dry-cleaning properties: little disagreeable odors; cleaned more effectively; more easily reused and were faster and safer to use. The disadvantages of using TCE were: damaged certain types of fibers and synthetic substances, human toxicity and photochemical reactivity concerns. Today, TCE is no longer used as a primary dry cleaning solvent; however, it is a constituent of dry-side spot-removal agents.

Perchloroethylene

Perchloroethylene (PCE) was introduced in the late 1930s to early 1940s in the United States to the dry-cleaning industry. PCE became the solvent of choice for most small dry-cleaners because it can safely clean virtually all types of fabrics; it was nonflammable; and it was less toxic than CCl4. Large industrial dry-cleaners mostly used petroleum based cleaners (e.g., Stoddard solvent). As of 1952, the dry-cleaning industry used 80% of the PCE produced; the remaining 15% was used in the metal cleaning industry. Over the following decades, PCE usage by the dry-cleaning industry decreased; from 1972 to 1975, the usage of PCE decreased from 75% to 63%. The following developments had a major impact on the declining usage of PCE: improvement in dry-cleaning equipment and vapor recovery systems that resulted in the increase efficiency of PCE usage; increased popularity of washable fabric; and new environmental regulations. In 1975, one 55 gallon drum of PCE cleaned 8,000 pounds of clothing; whereas, in 1993, one 55 gallon drum of PCE cleaned 16,000 pounds of clothing. By 1990, only 50% of the PCE manufactured was used by the dry-cleaning industry; other uses included: 25% feedstock (mostly in the production of CFC-113), 15% in metal cleaning and degreasing, 10% others. In the United States today, 85 to 90% of dry-cleaners use PCE.

In 1991, the California Air Resources Board (CARB) estimated that 1,870,000 gallons of PCE was used in California by various industries. 60% or 1,100,000 gallons PCE was used in the dry cleaning industry, 20% in the degreasing industry, 8% in the paints and coating industry, 2% in the adhesive industry and 10% miscellaneous (i.e., aerosols, specialty chemical production, printing inks, silicones, rug shampoos, lab solvents, etc). During that same year, CARB conducted a mail questionnaire survey of 6000 potential PCE dry cleaners in California. Based on the 2,000 plus responses, CARB estimated that 4,800 dry cleaners used PCE; there are 5,300 PCE dry cleaning machines, 1,100,000 gallons (7,425 tons) of PCE is used to dry clean 247 million pounds of clothing annually; 742,000 gallons (5,008 tons) of PCE emitted/year and 60% of the existing dry cleaning machines are closed-loop, 33% vented machine and 8% transfer machines.

Table 32: 1991 Statewide Distribution of Machines & PCE Emissions by Machine Types as Determined by CARB

1991 Statewide Distribution of Machines & PCE Emissions by Machine Types as Determined by CARB			
Machine type	% of machines	Emissions (lbs/yr)	% of emission
Transfer	8	134,000	18
Vented	35	331,400	45
Converted	4	30,100	4
Closed-loop	53	246,500	33

1,1,2-Trichloro-1,2,2-trifluoroethane

In 1964, a fluorinated-chlorinated hydrocarbon solvent (i.e., 1,1,2-trichloro-1,2,2-trifluoroethane, or Freon 113) was introduced in the United States by E.I. Du Pont de Nemours & Company under the trade name Valclene [solvents R113 and R11 were also produced in Europe]. Valclene was milder than PCE; it evaporated from fabric at lower temperatures, thus, useful for cleaning delicate fabrics. Unlike PCE, it doesn't affect rubber, painted effects on fabrics, polystyrene, vinyl coated fabrics, polyvinyl chloride fibers, some pigment colors, furs and leathers. Although it is a better dry-cleaning solvent than PCE, its usage was not widespread and eventually banned (in 1996) because of its potential to deplete ozone and cause global warming.

1,1,1-Trichlorethane

In the early 1980s, Dow chemical introduced 1,1,1-Trichlorethane (TCA) as a dry cleaning solvent. It was not widely used in the dry cleaning industry as a primary dry cleaning solvent because it can damage delicate fabrics; and it is not very stable-when mixed with water. TCA will break down and form acidic compounds that will corrode typical dry cleaning machines (SCRD, 2002b). TCA was eventually banned (in 1996) because of its potential to deplete ozone and cause global warming.

Drycleaning Fluid 2000

In the late 1990s, Exxon introduced a new petroleum based solvent, Drycleaning Fluid-2000 or DF-2000. Its properties include: higher flashpoint (147° F) than Stoddard or 140° F Solvent, very little residual odor, relatively high permissible occupational exposure limit (300 ppm), and more favorable solvent cost and mileage compared to PCE. However, the disadvantages are: requires specially designed machines and facilities to prevent fires or explosions, a lower Kauri-Butanol value (cleaning ability) and longer cycle time. Other brands of higher flash point petroleum drycleaning solvents include EcoSolv (Chevron Phillips Chemical Co., flashpoint 142° F) and Hydroclene Drycleaning Fluid (Caled Chemical Co., flashpoint 145° F) (Linn, W., 2005).

Other Dry Cleaning Solvents –Rynex, GreenEarth, and PureDry

Four alternative dry cleaning solvents were introduced within the last 10 years: Rynex, GreenEarth, PureDry, and Impress. Rynex was developed as an alternative to PCE; its chemical name is dipropylene glycol tertiary-butyl ether or DPTB. GreenEarth is a silicon-based solvent;

its chemical name is decamethylcylcopentasilozane or D5. PureDry was developed by Niran Technologies; it is a "hybrid" solvent (i.e., composition of C9 – C12 hydrocarbons, hydrofluoroethanes (HFE) and perfluorocarbons) with a high flashpoint of 350° F. Impress Solvent is an aliphatic propylene glycol ether marketed by Lyondell Chemical Company. The following table summarizes the pros and cons for using alternative dry cleaning solvents:

Solvent	**Pros**	**Cons**
D5 and D4	Not volatile	Very lipophilic, potential to bioaccumulate, possible animal carcinogen and/or endocrine disruptor
Propylene glycol tert butyle ether	Member of less toxic propylene glycol ether family	Possible water contaminant; possible animal carcinogen
1-propyl bromide	Less volatile than PCE	Toxic to nervous and reproductive systems
Mineral spirits	Well known, toxicity well-studied	Flammable, VOC
HFE-7100 & HFE-7200	Relatively inert	Unknown environmental fate; potential Ozone Depleting Compound in stratosphere

Source: Howd, R., 2004.

Description of the Dry-Cleaning Industry

Initially, the dry-cleaning industry was composed of three main sectors: the commercial sector, the industrial sector and the coin-operated sector. In California, coin-operated dry cleaning machines have been banned since December 21, 1994. In 1995, a study conducted by the United States Environmental Protection Agency (USEPA), determined that nationwide, there were 30,494 commercial dry cleaners (cleaning approximately 630,520 tons of clothing annually), 1,379 industrial cleaners (325 of them had dry cleaning capacity cleaning 187,991 tons clothing annually), and 3,044 coin-operated dry cleaners (cleaning 4,914 tons of clothing annually).

The dry cleaning industry is not a high profit business. The estimate future growth rate is zero because more clothes are made of washable fabrics (e.g., polyester, blue jeans, etc.), the trend towards causal clothing in the workplace and the widespread availability of home washers and dryers. In 1993, the typical start-up cost was ~ $113,000. For 25% of the dry cleaners, their annual revenues were less than $28,000 and 6% had revenues greater than $564,000. The receipts must cover labor costs, rent, capital depreciation, solvent, and other supplies.

Commercial Dry Cleaning Sector

The development of nonflammable solvents in the 1930s permitted the decentralization of dry-cleaning plants. The use of nonflammable solvents allowed small dry-cleaners to be opened in metropolitan areas and shopping centers. Between 1919 and the late 1960s, the dry-cleaning business grew from a $5.5 million industry to approximately $2.8 billion. Post-1970, the commercial dry-cleaning industry begin to decline because of several factors, the increase in home washers and dryers; the introduction of easy to care for fabrics (e.g., polyester); the availability and lower cost of coin-operated laundries and self-service dry cleaners introduced in the late 1950s; and other factors.

The commercial dry-cleaning sector provides cleaning services for garments directly to the consumers. Dry-cleaners may have one or two dry-cleaning machines on-site or merely collect soiled garments to be cleaned at a central location. This sector is mainly composed of small independent neighborhood shops (i.e., "Mom and Pop" dry cleaners) and franchise dry-cleaners (e.g., One Hour Martinizing). They usually employ 2 or 3 full time employees (including the owner) and several part-time employees.

In 2002, there were 219 commercial dry-cleaners in the County of Santa Clara (BAAQMD, 2002). Approximately 84% of the dry-cleaners in Santa Clara County used PCE; the other solvents used are: 140F Solvent, Stoddard Solvent, Exxon DF2000, and D5 siloxane. In the last five years, a growing number of dry cleaners have switched to alternatives solvents. In 2007, the California Air Resources Board issued a ban on permits for new dry cleaning machines beginning in 2009. The ban includes a plan to phase out PCE from all dry cleaning operations by 2023.

In the past, two types of dry-cleaning machines were used: transfer and dry-to-dry machines. The typical dry-cleaning machine used in the commercial sector ranges from 30 to 60 pounds garment cleaning capacity (US EPA, 1995a). The majority of commercial dry cleaners use the cleaning solvent PCE. The amount of PCE used depends on the type of vapor control device fitted to the dry cleaning machine. Vented machines use the largest amount of solvent because there is no solvent recovery, whereas machines with vapor control devices use the lowest amount of solvents. A vented dry-to-dry machine with a clothing capacity of 30 to 190 pounds uses between 130 to 3,600 gallons of PCE per year, respectively. A dry-to-dry machine with a clothing capacity of 35 to 70 pounds uses between 70 to 100 gallons of PCE per year.
Table 32 lists the different models of dry cleaning machinery used in Santa Clara County dry cleaning businesses. Over the years, the usage of transfer machines in commercial dry-cleaners have began to decline because of stricter regulations protecting worker safety and health and the environment. As of October 1, 1998, transfer machines have been prohibited in the Bay Area.

Table 33: Types of Drycleaning Machines used in Santa Clara County

Types of Drycleaning Machines used in Santa Clara County	
Dry Cleaning Machine	**Clothing Capacity (lbs)**
Colombia Closed-loop	30, 50
Columbia Fugitive Control	40
Columbia Secondary Control	40, 80
Crown Closed-loop	35
Crown Petroleum Closed-loop	40
Crown Secondary Control	45
Fluormatic Closed-loop	37, 50
Fluormatic Secondary Control	37
Hoffman Closed-loop	30, 35, 45, 55
Hoffman Petroleum Closed-loop	30

Table 33: Types of Drycleaning Machines used in Santa Clara County (cont'd)

LCI (Union) Secondary Control	35 & 45
Lindus Closed-loop	40 & 55
Lindus Converted	40
Lindus Fugitive Control	30
Lindus Secondary Control	40, 60
Martin Converted	35
Miraclean Closed-loop	35, 50
Miraclean Converted	35
Moderna Nature Closed-loop	35, 40
Multimatic Converted Fugitive Control	35
Multimatic Closed-loop	25, 35, 45, 50, 75
Multimatic Converted	35, 40
Omega Closed-loop	20, 30
Omega Petroleum Closed-loop	60
Omega Secondary Control	30
Permac Closed-loop	30, 35, 40, 45
Permac Closed-loop, 40 lb./Firbimatic Secondary Control, 50 lb	
Permac Petroleum Closed-loop	35, 55
Permac Secondary Control, 35 lb.	35, 45, 55
Prestige Closed-loop	50
RealStar Closed-loop	40, 50
RealStar D5 Siloxane Closed-loop	75
Renzacci Closed-loop	25, 30, 35, 40, 48
Renzacci Secondary Control	45
Satec Petroleum Closed-loop	35, 45
Satec Petroleum Closed-loop, 45 lb./Multimatic Closed-loop, 35 lb	
Shin Sung Perfect Closed-loop	35, 40, 50
Spencer Closed-loop	50
Spencer Converted	60
Superstar Petroleum Closed-loop	35, 55
Suprema Closed-loop	30, 35, 40, 45
Suprema Converted	35
Union Petroleum Closed-loop	35, 40
Union Secondary Control	35, 80
VaporPress Closed-loop	35
VaporPress Secondary Control	35
VIC Closed-loop	35, 50
VIC Secondary Control	35
VIC Vented	55
Wasco/Donini Closed-loop	40
Wasco/Donini Converted	15
Zephyr Transfer Dryer, 100 lb./Zephyr Transfer Washer, 250 lb.	

Industrial Dry Cleaning Sector

The industrial dry cleaners are large operations that provide cleaning and rental services for uniforms, towels or other garments. They are usually located in small to medium sized cities because of the lower capital and labor costs. Approximately 50% of the industrial dry cleaners use the petroleum solvents. They are usually located in non-residential areas or shopping centers because of their high emissions and potential fire hazards (US EPA, 1978). A typical industrial cleaner may have a 500 pounds clothing capacity washer/extractor and three to six 100 pounds capacity dryers. There are large size dryers (e.g., 450 to 500 pounds capacities) but they are not very common. The solvent usage (e.g., PCE) ranges from 200 to 1,300 gallons/year.

Coin-Operated Dry Cleaning Sector

Coin-operated dry cleaning machines entered the dry cleaning market in the early 1960's. It was supposed to revolutionize the dry cleaning industry because it offered a low cost and practical alternative to professional dry cleaning services. In 1962, customers spent $100 million in the new self-service coin-operated dry cleaning machines, which was a 75% saving compared to using full service commercial dry cleaners By 1963, there were over 7,000 self-service coin-operated dry cleaning machines across the United States. They were usually located in coin-operated laundromats or full service commercial dry cleaning. Many were located in rural areas where commercial dry cleaners were not available. The coin-operated machines were small machines, usually 8 to 12 pounds clothing capacity. There were all dry-to-dry machines that used mainly PCE.

However, there were several major disadvantages to using the self-service coin-operated machines, including: the coin operated machines did only part of the job (e.g., no pre-spotting of water-soluble stains and spots, no presser, dyes can run and ruin the entire load of wash, etc.) and without a dry cleaner attendant on-site, they were not always properly supervised and maintained, thus, resulting in adverse health impacts. During this time, a new type of synthetic knit fabric with a spongy polyurethane foam lining came of the market; the solvent melted the bonding adhesive which stained the fabric and, in some cases, caused the foam to disintegrate. Consumers, without knowledge of textiles, dyes and dry cleaning techniques, could damage or ruin their clothing by tossing their garments into a self-service coin-operated machine. In the late 1960's and the early 1970's, the dry cleaning and laundry industries were severely impacted by the sudden popularity of polyester and other easy care fabric (e.g., blue jeans) and other causal styles. In 1996, in France, a baby died after being exposed to PCE vapors from curtains cleaned in a coin-operated machine that were hung in the baby's room (Chlorine Online Information Resource, 2002). In California, coin-operated machines were eventually phased out due to economic and other factors; they were banned on December 21, 1994.

Dry Cleaning Process

The dry cleaning process is fairly similar to cleaning garments at home in the washer and dryer. Instead of cleaning the garments with water, the garments are cleaned with PCE, petroleum solvents, or alternative solvents. There are many different brands and models of dry cleaning machines on the market, but they basically operate the same and have similar parts. There are 3 main cycles in dry cleaning: the wash cycle, the extraction cycle and the drying cycle.

First, a dry cleaning worker tags and inspects the soiled garments and treats stains with solvents. This process may also be repeated after the cleaning cycle (i.e., post-spotting) for residual and stubborn stains. The types of pre- and post- spotting chemicals include: acetic acid, amyl acetate, aqueous ammonia, bleaching agents, chlorinated solvents, diluted hydrogen peroxide, hydrogen peroxide, and oxalic acid (AIG Environmental, 2002).

Soiled garments are loaded into a rotating, perforated stainless-steel cylindrical basket with 3 or 4 ribs protruding horizontally. The clothing capacity of a dry cleaning machine varies from 20 to 100 pounds of clothes or fabrics. A typical dry cleaning machine has 2 PCE solvent tanks: one tank for pure solvent and the second tank for "charged" solvent (which is made up of used or distilled solvent plus a small amount of detergent and water to help clean water-soluble stains). Solvent is never discarded, it is continually recycled and as it is used up, fresh solvent is added to the solvent tanks.

First Wash Cycle

For the first wash, garments are completely soaked and tumbled in charged solvent for 8 to 12 minutes at a temperature ranging from 70 to 85° F. A typical machine may pump PCE into the rotating basket filled with soiled clothing at a rate of 1,500 gallons per hour (Cantin, J., 1992). For an 8 minute cleaning cycle, the soiled clothes would be soaked in 200 gallons of solvent. The charged solvent dissolves greases and oily stains. The charged solvent is continually filtered during the wash cycle. The dirty charged solvent is first pumped through the button trap which is the solvent "pre-filter" removing larger objects, such as, pins and buttons, from the solvent before they can reach and damage the pump. Next, the charged solvent is pumped either through a disposable cartridge filter, a spin-disc filter or a regenerative (or flex-tube) filters to remove soil, lint and other insoluble materials.

Filtration

Disposable cartridge filters are used by 90% of dry cleaners (Cantin, J., 1992). There are three types of cartridge filters: carbon core, adsorption and polishing. The carbon core cartridge filters come with or without pleated paper. The paper filters out insoluble soils. Granular activated carbon removes dyes from the solvent. Adsorption cartridge filters contain activated carbon and activated clays, such as attapulgite or montmorillonite. Activated clay adsorbs water, alcohols, acids, aldehydes, ketone, olefins, natural esters, aromatics, cyclo-parrafins, and parrafins. Polishing filters are paper cartridge filters with resin-bonded paper that remove insoluble soil. As the cartridge filters soils and other contaminants from the solvent (e.g., dirt, sand, dust, lint, ashes and hair), pressure builds up on the cartridge. The disposable cartridge should be changed after cleaning 450 to 1,000 pounds of soil clothing, when the pressure reaches a certain level or as specified by the manufacturer. The used or spent cartridge should be drained for 24 hours (or 48 hours for adsorptive cartridges) before disposal at a hazardous waste treatment facility. Before draining overnight, a spent cartridge can retain as much as one gallon of PCE; after draining, from 1/8 to ¼ gallon of PCE remains in the spent filter.

A smaller number of dry cleaners use spin-disc filters. Spin-disc filters are made up of approximately 36 15-inch diameter finely woven double-walled circular polyester discs (approximately 85 square feet of surface area) in series mounted on a perforated hollow shaft to filter the dirty solvent (National Institutional Occupational Safety and Health, 1997). There are two types of spin-disc filters: powder spin-disk filtration system and powder-less spin-disc filtration system, both types can use activated carbon cartridges to improve the filtration process. The powder spin-disc filtration system has a pore size of approximately 60 microns and requires a coating of diatomaceous earth which builds a 5 micron filter over the disc; and the powder-less version has a pore size of 30 microns or less and no powder Hygnstrom, J., 1995). As the spin-disc filters collect soils, dirt and other insoluble impurities on the stationary discs and the pressure differential across the disc reaches approximately 22 pounds/square inch gauge, the filters are regenerated by spinning the discs and directing the solvent and the "caked" impurities through a drain value into a distillation still. The solvent is recovered after distillation. The spin-disc filters last longer and produce less waste (i.e., the powder generates about 1 pound of hazardous waste per 500 pounds of clothing cleaned) than the cartridge systems but skilled labor and frequent maintenance is required to operate properly.

A third type of filters is the regenerative or flex-tube filters. These are braid tubes coated with a combination of diatomaceous earth and activated carbon. After filtering soils, dirt and other insoluble impurities, the filter is cleaned by re-suspending the powder and dirt in solution by "air bumping" or back washing, creating a mixture which is then re-deposited back on the filter creating a highly porous "cake" resulting in a more uniform filter media and better removal of contaminants. The regeneration action is repeated with each cycle. When the pressure reaches a certain level and the solvent flow is impeded, the mixture of diatomaceous earth and activated carbon is drained to the distillation still to be recovered and the filter is re-coated. This filter system is more expensive than the spin-disc filters and requires skilled labor to operate properly.

Distillation

Approximately 90% of dry cleaners use distillation as a companion process to purify and recover used solvent. Distillation stills are built into most modern dry cleaning machines. Steam is used to heat the solvent to its boiling point or 250° F. Solvent and water vapors generated from the distillation process pass through a condenser where they are condensed to a liquid that passes to a water separator. Non-volatile residues (e.g., detergents, waxes, dyestuffs, sizing, oils and grease) called sludge or still bottom is removed for disposal as hazardous waste. The sludge or still bottom can contain as much as 50% to 70% PCE. A muck cooker is a type of distillation unit used to reclaim solvent from drycleaning operations that use a powder filtration system. The spent solvent mixed with the spent powder filtration material is known as muck. The muck cooker works like the still. After distillation, the still is cooled for at least 15 minutes, and water is added at the same volume as the still bottoms or sludge. The volume is then boiled down at 25 to 30 psi until the water from the water separator and solvent line stops flowing. The waste mixture is then cooled for 15 minutes and the process is repeated.

Water Separator

A water separator has been plumbed to solvent distillation stills since the early 1900s (Morrison, R.E., 2002). The distilled solvent and water mixture sits in a gravity separator unit. PCE is heavier than water, thus it will sink to the bottom of the water separator and is drained back to the solvent tank. Separated water was frequently drained to floor drains or onto the ground; until 1986, it was routed to the sanitary sewer system.

In the past, it was legal to discharge wastewater into the sanitary sewer system. Older model of dry cleaning machines were plumbed to discharge waste water from the water separator to the sanitary sewer system; the modern models do not have direct piping to the sanitary sewer system. High levels of PCE in the separator water were routinely discharged to the sanitary sewer system. For example, levels of PCE up to 1,120 mg/l, with an average of 152 mg/L were detected in samples of separator water; as much as 30% of the samples were pure solvent (Cohen, W.L., Izzo, V.J., 1992). Among older dry cleaning machines (circa 1986), discharges from PCE water separators were common cause of soil and groundwater contamination (Hoenig, D.R., 2002).

Today, both practices are prohibited in California. There are two acceptable separator water disposal methods: properly store and transport as a hazardous waste or evaporate the separator water. For the County of Santa Clara, the disposal method is governed by local rules or permits mandated by the cities' sanitary sewer districts.

Second Wash Cycle, Extraction and Drying

For the second wash, the clothing is rinsed in pure solvent for approximately 4 to 5 minutes to remove any detergent residue. Like the charged solvent, the pure solvent is filtered continuously by one of the three filtration systems mentioned above. Next, the rinsed clothing is rapidly spun to extract the solvent from the clothing. The spent solvent is drained to the charged solvent tank and is used for the first wash for the next load of soiled clothing.

Afterwards, the freshly cleaned clothing is heated to about 160° F (the temperature will vary depending on the types of garments) for approximately 40 minutes. The remaining PCE fumes and solvent are vaporized by the warm air and then condensed over cooling coils top recover the PCE. The residual amount of PCE remaining on the clothing ranges from 3 to 6 pounds for 100 pounds of clothing (Barr, J., 1962). The quality of the cleaning, the degree of soil removal, color brightness freshness, odor, softness is depended the cleanliness of the filter and the solvent. Most of the PCE is removed from the clothing via the last two cycles: extraction and drying; however, there are small levels of PCE in the dry cleaned clothing. See Table 33:

Table 34: Residual Amounts of PCE in Different Types of Fabric Immediately after Dry Cleaned

Residual Amounts of PCE in Different Types of Fabric Immediately after Dry Cleaned		
Type	**Texture**	**Residual PCE (mg PCE/g of fabric)**
100% wool	Twill weave	0.427
93% wool/7% nylon	Twill weave	0.119
100% polyester	Circular knitting	0.139
100% cotton	Knitted	0.202
100% acetate fiber	Plain weave	1.576
100% polyester	Twill weave	0.515

Source: Kubota, J., 1992.

Other Chemicals Used in the Dry Cleaning Industry

In addition to drycleaning solvents, there are 4 other types of chemicals are used in the dry cleaning industry. These are grouped into: Other Chemicals Used in the Dry Cleaning Machine, Pre-cleaning and Spotting Agents, Garment Treatment Chemicals, and Chemicals Used in Solvent and Equipment Maintenance.

Detergents

Detergents are used in the drycleaning process. They perform three different functions:

- carry moisture to aid in the removal of water soluble soils;
- suspend soil after it has been removed from the fabric;
- and act as a spotting agent to penetrate the fabric so that the solvent and water can remove stains.

Based on their charge and how they carry water, there are three classifications of detergents:

- anionic detergents – are negatively charged and carry water by means of solubilization;
- non-anionic detergents - carry no charge and carry water by solubilization;
- cationic detergents – are positively charged and carry water by means of an emulsion. Most cationic detergents are pre-charged with moisture.

Detergents are introduced into the drycleaning machine by two different systems:

- In charged systems, where detergent is added to the solvent or "charged" as a certain percentage of the solvent (normally 1 to 2%) to maintain a continuous concentration of detergent. Charged systems use anionic detergents. "Pre-charged solvent" (solvents containing the detergent) have been marketed in the industry – particularly for use in coin-operated drycleaning machines.

- In injection systems, also known as batched detergent injection, solvent is added to the wheel saturating the garments and then detergent is injected into the flow line or into the drum by a pump or dump method. Cationic detergents are used in injection systems.

The earliest drycleaning detergents were soaps. There were three different types: paste soaps, gel soaps and liquid soaps. Most of these soaps were composed of surfactants, Stoddard Solvent, free fatty acids and some moisture to create an emulsion. When filtration was first utilized in the drycleaning process, it was discovered that paste and gel soaps, also known as "true soaps", tended to plug or "slime" the filters, so the soaps became obsolete. The liquid soaps, also known as "filter soaps", sometimes contained a co-solvent such as butyl cellosolve, hexylene glycol, isopropanol, cyclohexanol, ethanolamine or n-butanol, which was used to disperse moisture. By the early 1950s, the industry trend was from liquid soaps to the use of synthetic detergents.

Synthetic detergents are surfactants or mixtures of surfactants with solvents. The following surfactants have been used in commercial drycleaning detergents: soap-fatty acid mixtures; "mahogany" or petroleum sulfonates; sodium sulfosuccinates; sodium alkylarenesulfonates; amine alkylarenesulfonates; fatty acid esters of sorbitan, etc; ethoxylated alkanolamides; ethoxylated phenols; and ethoxylated phosphate esters (Kirk-Othmer, 1965).

The constituents listed for the drycleaning detergents include surfactants: phosphate esters, linear alkylbenzenesulfonic acid salt, oxyethylated isononylphenol, diethanolamine, alkearyl sulfonate, sodium sufonate, and sulfosuccinate. They also include drycleaning solvents and co-solvents that function as carriers. These include perchloroethylene, petroleum solvents and the following cosolvents – butyl cellosolve, hexylene glycol, 2-propanol, isopropyl alcohol, 2-butoxyethanol, diethylene glycol monobutylether, dipropylene glycol monomethylether and glycol ether. The most common solvent contained in the drycleaning detergent mixtures listed is petroleum drycleaning solvent (petroleum naphtha blends).

Sizing

Sizing is a type of finish used in drycleaning to impart "body" to a fabric. Sizing is actually applied to fabrics when they are manufactured and is depleted after several fabric cleanings. Most sizing used in drycleaning operations today is composed of hydrocarbon resins. Alpha methylstyrene was reportedly used in sizing in the past. There are two forms of sizing used in drycleaning operations - a solid (in a powder or bead form) – and a liquid. The solid form of sizing - the bead form - is commonly used in PCE drycleaning systems. Most of the liquid sizing used today has a petroleum solvent carrier. It is not uncommon for liquid sizing to contain over 50% petroleum solvent (petroleum naphtha blends) by volume. Anti-static agents and optical brighteners are commonly added to sizing.

Sizing can be applied in three different ways: by a continuous bath in the drycleaning machine; by dipping garments in a tank of sizing; or by spraying sizing in an aerosol form (generally containing a propane/isobutane carrier) on the garments after they have been drycleaned.

In the continuous bath application method 0.5 to 1.5% charge of sizing is added to the drycleaning machine. The concentration of sizing used in the dipping method ranges from 1 to 4% (Eisenhauer).

Other Chemicals

Other chemicals used in the drycleaning machine include: optical brighteners, bactericides, fabric conditioners, and anti-static/anti-lint agents.

Optical brighteners, also known as fluorescent whitening agents, optical bleaches or optical dyes are used to "make white whiter". These chemicals are normally added to drycleaning detergents or sizing. Optical brighteners have been widely used in laundry detergents for many years. In recent years, they have been used in drycleaning.

One of the problems associated with petroleum drycleaning solvents is biodegradation. Bacteria introduced into the drycleaning system through the clothing being drycleaned or in water introduced into the system will feed on the petroleum solvent and degrade the petroleum compounds producing "sour smells". To combat this problem, bactericides or biocides are added to the system, normally in detergents. The biocides used today are reportedly similar to those used in shampoos, laundry products and cosmetics. In the past PCE was added to drycleaning soaps as a bacterial inhibitor.

Some fabric conditioners are added to the drycleaning process. These are used primarily to condition or restore luster and shine to suedes, leathers and silks. These products are typically solvent based – petroleum naphtha or perchloroethylene.

Anti-static agents and anti-lint agents (to prevent lint buildup and retention) are available for drycleaning operations.

Pre-Cleaning/Spotting Agents

The greatest number and variety of chemicals used in drycleaning operations are used in pre-cleaning and spotting operations. Prior to being placed in the drycleaning machine, heavily stained garments are usually pre-cleaned or pre-spotted with cleaning chemicals. The types of chemicals used depend on the type of stain and the type of fabric being cleaned. After they are drycleaned, garments that are still stained or soiled are spot cleaned using the same chemicals as in pre-cleaning. There are three types of pre-cleaning/spotting agents: wet-side agents, dry-side agents and bleaches.

Wet-side Spotting Agents

Wet-side pre-cleaning/spotting agents are used to clean water soluble stains from clothing. Wet-side agents can be subdivided into three different classes: neutral, alkaline, and acidic.

- Neutral Wet-Side Agents – Neutral spotting agents include water and neutral synthetic detergents (which contain surfactants). These agents are used to remove water-soluble stains, food, beverages and water-soluble dyes.
- Alkaline Wet-Side Agents – Alkaline spotting agents include lye, ammonia, potassium hydroxide, sodium hydroxide and so-called protein formula home detergents. Protein formula detergents contain digester enzymes - Amylase, Cellulase, Lipase and Protease. Digesters can be used to remove: starch, cellulose, fats and oils, and protein stains.
- Acidic Wet-Side Agents – Acid agents include acetic acid, hydrofluoric acid, oxalic acid, glycolic acid and sulfuric acid. Tannin or plant-based stains can be removed with wet-side spotting agents (known as tannin formula agents).

Dry-Side Spotting Agents

Dry-side pre-cleaning/spotting agents are used to remove oily-type stains, stains including fats, waxes, grease, cosmetics, paints and plastics. The primary constituents of dry-side agents are non-aqueous solvents and alcohols and include, or have included: perchloroethylene, trichloroethylene, 1,1,1-trichloroethane, carbon tetrachloride, methylene chloride, amyl acetate and petroleum solvents. In general, from a contamination and regulatory standpoint, dry-side spotting agents include some of the most toxic chemicals used in drycleaning operations.

Bleaches

Bleaches are used in stain removal when other spotting techniques have failed to remove a stain. This process is known as “spot bleaching”. Bleaches are also used in conventional laundry operations which are conducted at most drycleaning plants. Bleaches can be classified as either oxidizing or reducing.

Oxidizing Bleaches	Reducing Bleaches
Sodium Perborate	Sodium Bisulfite
Hydrogen Peroxide	Sodium Hydrosulfite
Sodium Percarbonate	Titanium Sulfate
Sodium Hypochlorite	Oxalic Acid

Garment Treatment Chemicals

A number of different chemicals are used to treat garments after they are drycleaned. The functions of these chemicals include waterproofing, flame retardants, refurbishing, deodorizing, stain repellents and pest control.

Waterproofing

Waterproofing of garments by the clothing manufacturer is a relatively recent development. Historically, much of garment waterproofing was performed by dry cleaners. The water proofing agent was usually a waxed-base product and the predominant carrying agent for waterproofing agents has been nonaqueous solvents – perchloroethylene and petroleum solvents. Several methods have been used to apply the waterproofing agent, including immersion in the waterproofing agent in a dip tank; spraying the waterproofing agent on the garments in a tank; applying the waterproofing agent in the form of an aerosol spray; and in some cases applying the waterproofing agent in an auxiliary tank in a drycleaning machine (Rising, 1997).

Flame Retardants

Flame retardants are normally applied to garments by the garment manufacturers. However, in the past, some dry cleaners have treated or re-treated garments with flame retardants. Some of the chemicals used in flame retardants include: decabromodiphenyl oxide (DBDPO), organo-phosphates, phosphate salts and phosphated esters. Dry-side application of flame retardants used drycleaning solvent as the carrying agent. The flame retardant chemicals were applied by immersion or dipping in a tank or by spraying the garment with the flame retardant (IFI, 1995).

Fabric Conditioner

Chemicals are applied to refurbish garments after drycleaning. Typically, these garments can include suedes, leathers, silks, wools and vinyls. These chemicals are usually applied by spraying the garment (using a spray bottle or aerosol spray). Plasticizers such as di-N-butyl phthalate and di-2-ethylhexyl adipate are used to re-condition vinyl garments.

Stain Repellents

Stain repellents are generally applied by the garment manufacturer, but some dry cleaners do apply stain repellents. Historically, these products have been silicone based and the carrying agent has been 1,1,1-trichloroethane (no longer used) or petroleum naphtha (IFI, 1994). Most stain repellents can be applied as an aerosol spray. Scotchgard^{TM} (no longer manufactured) was one of the most commonly used stain/water repellents.

Chemicals Used In Solvent & Equipment Maintenance

Solvent Maintenance & Treatment

From the early part of the twentieth century until the early 1950s, both alkalis and sulfuric acid were used to clarify spent petroleum drycleaning solvent. The most common alkali used was caustic soda (sodium hydroxide) in a 8-10% solution. The solvent was bubbled through or agitated with the caustic soda solution to help remove soap-fatty acid type detergents. Sulfuric acid was mixed and agitated with the spent solvent and then allowed to settle out (Martin, 1958).

Anti-foaming agents (such as glycol ether acetate) are sometimes added to the distillation unit to prevent contaminants in the spent solvents (pigments, fatty acids, filter powder, detergents water repellents and retexturing agents) from causing excessive foaming during the distillation process.

Chemical agents are sometimes added to prevent the formation of free fatty acids in solvents. Alkaline solutions are also added to buffer destabilized (acidic) perc. Detergents are sometimes added to the system to clean the drum and button trap of the drycleaning machine.

Filter Maintenance

Trisodium Phosphate was once used to clean tubular (regenerative) filters – used in powder filtration systems. It is doubtful that any of these tubular filters are still being utilized.

Detergent Maintenance

In charged systems, where anionic detergents are used, it is important to maintain a constant detergent concentration. Test kits are utilized to titrate solvent/detergent mixtures to measure the amount of detergent in the system. Chemicals used in these test kits can include: 1,2-dichloroethane, methylene chloride, and chloroform.

Boiler Maintenance

The use of untreated water in a boiler can cause scale buildup and corrosion. Treating the boiler water with chemicals - known as boiler feed water treatment - will increase the life of the boiler and reduce maintenance costs. Scale is formed from calcium and magnesium salts that are carried in solution in the water used in the boiler. Treatment of the boiler water by raising the pH with the addition of alkaline salts – such as sodium or potassium hydroxide – will prohibit most of the calcium and magnesium salts from precipitating and causing scale buildup in the boiler. Sodium sulfite is a constituent of some boiler feed water treatments. This constituent acts as an oxygen scavenger. The presence of oxygen in boiler water will lead to corrosion of the boiler (Faig). A chelating agent, sodium hexametaphosphate is sometimes added to boiler water to inhibit hard water salts from precipitating to form scale. Hydrochloric acid is sometimes utilized in acid boils to remove scale.

Appendix D: Groundwater Impacts From Dry Cleaning Operations

Overview

There are approximately 36,000 active dry cleaning facilities in the United States, including commercial, industrial and coin-operated facilities (US EPA, 1998). Most of these facilities have significant potential to cause soil and groundwater contamination by dry cleaning solvents. A recent survey of state dry cleaner programs estimates that 75% of dry cleaners have caused soil and groundwater contamination (Schmidt, R., et al, 2001). In addition to active or operating dry cleaning facilities, there is an unknown number of former dry cleaning sites that may also contaminated. A 1992 well investigation program conducted by the Central Valley Regional Water Quality Control Board identified 21 PCE impacted drinking water wells and found that dry cleaners were the likely source of PCE for 20 of those wells (Izzo, V.J., 1992). Contamination by perchloroethylene, the most common dry cleaning solvent, has impacted hundreds of public water supply wells in California and threatens many other wellfields. The source of perchloroethylene contamination in wells is often presumed to be dry cleaners; however, numerous other businesses have used perchloroethylene, including automotive shops, printing shops, and electronics manufacturing facilities.

The Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) lists 15 dry cleaners among the country's 1,300 superfund sites on the National Priorities List (NPL). Nationally, 141 of America's 36,000 dry cleaner facilities are listed in the CERCLIS database, with 32 in California (only 1 of which is listed on the NPL). Listing in CERCLIS usually signifies large magnitude releases or severe environmental impacts or risks to human health. CERCLIS listing is most often associated with large industrial and defense facilities; however, in some instances, dry cleaners have cause impacts of similar severity.

Summary of Known Dry Cleaner Releases in Santa Clara County

Active Dry Cleaner Cases in Santa Clara County

In this study, existing dry cleaner cases in Santa Clara County were reviewed to determine regulatory status, types of solvent used, concentration trends, and remedial technologies used. Contrasting this information with national dry cleaner cleanup statistics is helpful to determine the effectiveness of clean-up programs in Santa Clara County, and to evaluate the potential number of undiscovered cases that have not yet been investigated or remediated.

Table 34 lists the regulatory status of 38 known dry cleaner cases in Santa Clara County as of 2002. Of the 38 sites that the Regional Water Quality Control Board has opened as release cases, 19 percent (7 sites) are in the 'release confirmation' or 'remedial investigation' phase and 5 percent (2 sites) are under active remediation. 13 percent (5 sites) of the sites are considered inactive; 87 percent (33 sites) are either actively pursuing investigation and/or remediation, or have been closed.

Including 16 additional dry cleaners with known releases but whose regulatory status is unknown, there is at least limited information available for 54 sites in Santa Clara County, or approximately 4% percent of the nearly 1,250 dry cleaner sites identified in this study. Based on a recent study's estimate that up to 75 percent of dry cleaner sites may have caused soil and groundwater contamination (Schmidt, 2001), more than 800 additional uninvestigated solvent release sites could be present in Santa Clara County. RWQCB actively pursues investigation and remediation of dry cleaner release sites. Progress on cleanup is sometimes hampered by difficulties locating responsible parties and identifying financial resources to pay for cleanup. RWQCB has closed a third of the dry cleaning cases it oversees in Santa Clara County, and continues to oversee active remediation of most of the remaining cases.[8]

Table 35: Regulatory Status of Dry Cleaner Cases in Santa Clara County

Regulatory Status of Dry Cleaner Cases in Santa Clara County

Site Status	Number of Sites	Sites (%)
Inactive	5	13%
Release Confirmation - Preliminary Investigation	4	11%
Remedial Investigation/ Remedial Action Plan	3	8%
Active Remediation	2	5%
Verification Monitoring	2	5%
Closed	13	34%
Active - Unknown Status	8	21%
No Action	1	3%
Total	38	100%

Soil and groundwater sampling results show that, as expected, PCE is the most prevalent contaminant at Santa Clara County dry cleaning sites (Table 35). Of 26 sites with sampling results available, 77 percent had detections of PCE. Stoddard solvent and PCE were detected at 8 percent (2 sites) of the sites. Based on BAAQMD permits, 87% of active dry cleaning facilities use PCE.

Table 36: Chemical Use at Dry Cleaner Sites in Santa Clara County Based on Soil/Groundwater Sampling Results

Chemical Use at Dry Cleaner Sites in Santa Clara County Based on Soil/Groundwater Sampling Results

Contaminant Detected	Number of Sites	Sites (%)
PCE	22	85%
Stoddard Solvent	6	23%
Total	26	100%

(Two sites had both PCE and Stoddard solvent)

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[8] Santa Clara County is divided into two Water Board regions: the Central Coast Water Board oversees the Llagas groundwater subbasin south of Cochrane Road in Morgan Hill, while the San Francisco Bay Water Board oversees the Coyote and Santa Clara subbasins north of Cochrane Road and Metcalf Road, respectively.

Table 36 presents a summary of soil and groundwater sampling results at 26 dry cleaner sites in Santa Clara County. Table 37 compares the PCE detections in groundwater at dry cleaner sites in Santa Clara County with 90 other sites across the United States as listed in the Case Profiles on the SCRD website. Santa Clara County sites appear to be consistent with those in the SCRD case profiles as follows: 1) where groundwater is impacted, concentrations of PCE exceed the MCL, and 2) PCE exceeds 10,000 ppb in groundwater in approximately 2/3 of the cases.

Table 37: Summary of Solvent Detections at Dry Cleaner Release Sites in Santa Clara County

Summary of Solvent Detections at Dry Cleaner Release Sites in Santa Clara County

	Soil (ppm)		Groundwater (*ppb*)	
	PCE	Stoddard Solvent	PCE	Stoddard Solvent
Number of Results	7	2	14	3
Maximum Concentration	250	39,000	24,000	5,500,000
Mean	41	19,501	6,293	1,841,667
Median	41	19,501	1,100	14,000

Table 38: Comparison of PCE Concentrations in Santa Clara County Sites and National Case Profiles

Comparison of Groundwater PCE concentrations in Santa Clara County Dry Cleaner Remediation Sites and National Case Profiles on SCRD Website

Groundwater Concentrations	USA (SCRD)	Santa Clara County, USA
Number of Cases reviewed	*90*	*14*
% Above MCL	97%	100%
95th Concentration, ppb	105,240	4,171
Median Concentration, ppb	3,400	1,100
% Sites >10,000 ppb	38%	36%

The remedial technologies used at 9 dry cleaner sites in Santa Clara County are summarized in Table 38. The predominant technology in use for remediating groundwater contamination is groundwater extraction (5 out of 7 sites). Some sites perform both groundwater and soil remediation; one site is a soils-only site.

Table 39: Remedial Technologies Used at Dry Cleaner Release Sites in Santa Clara County

Remedial technologies used at dry cleaner release sites in Santa Clara County

Remedial Technology	Soil	Groundwater
Excavation	3	
Soil Vapor Extraction	2	
Groundwater Extraction		5
Bioremediation		1
Monitored Natural Attenuation		1
Free Product Recovery		1

Magnitudes of PCE Impacts

Because data is available for only a small number of dry cleaner investigations Santa Clara County, the range of impacts that can result from dry cleaner releases was estimated from a review of the 95 dry cleaner site summaries listed on the SCRD website. Profiles for each site list site name, location, description, hydrology, type and magnitude of contamination, remediation technology employed, results achieved, costs, lessons learned, and point-of-contact for further information. 92 of the SCRD sites had groundwater sample results listing the maximum detection for each chemical constituent.

Chemical concentration data provided presumptive evidence of DNAPL presence at 41 % of sites surveyed by SCRD. DNAPL was considered present when at least one sample had PCE concentration in excess of 10% of its aqueous solubility (i.e., greater than 15,000 ppb, because PCE's solubility is 150 mg/L); or in soil, at least one sample had PCE concentrations in excess of 10,000 mg/kg. 62 (67%) of the sites reported maximum PCE concentrations above 1,000 ppb in groundwater, while 34 (40%) of the sites reported maximum PCE concentrations of 10,000 ppb or above; the maximum PCE concentration from all sites was 8,700,000 ppb. Figure 23 illustrates the distribution of PCE concentrations listed in the SCRD site profiles.

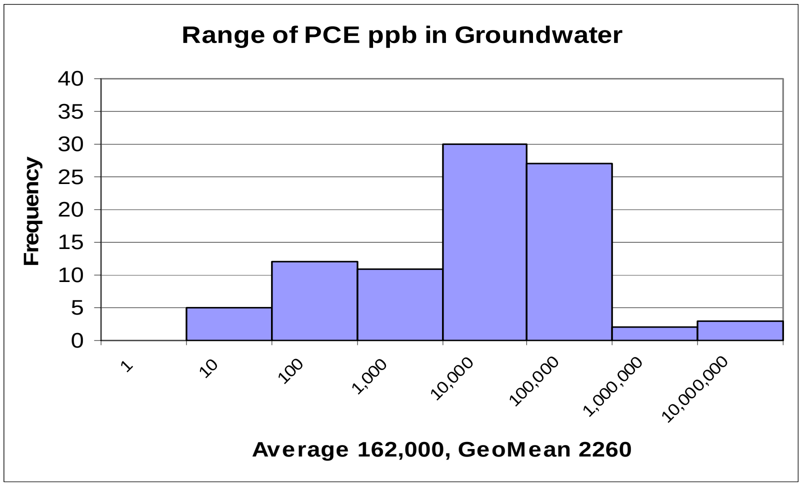


Figure 25 - PCE Concentration Distribution in Sites Profiled by SCRD

PCE groundwater plume length data was available for 62 of the sites profiled on the SCRD website. PCE plume lengths ranged from 25 feet to 14,200 feet (2.7 miles).

Maximum reported concentrations of PCE in soil and groundwater were compared to determine whether PCE concentration in soil predicts the severity of groundwater contamination. For sites with available soil and groundwater data, correlation is poor. A scatter-plot of SCRD site profile soil and groundwater data is provided in Figure 25. The authors' lack of detailed familiarity with the sites in question probably lead to some erroneous comparisons, and peak concentration in each medium is a less robust comparator than the median, mean, or 90th percentile. 12% of the sites with maximum groundwater concentrations above 10,000 ppb had a maximum soil concentration of less than 1 ppm. Conversely, 33% of sites with less than 1 ppm in soil had greater than 1,000 ppb PCE in groundwater. The data suggest that soil concentrations should not be used to estimate potential groundwater impacts.

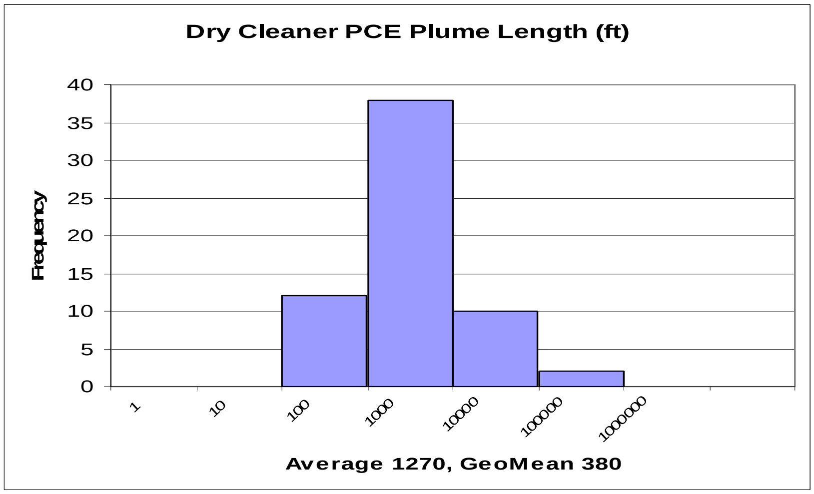


Figure 26 - PCE Plume Lengths at Sites in SCRD Survey

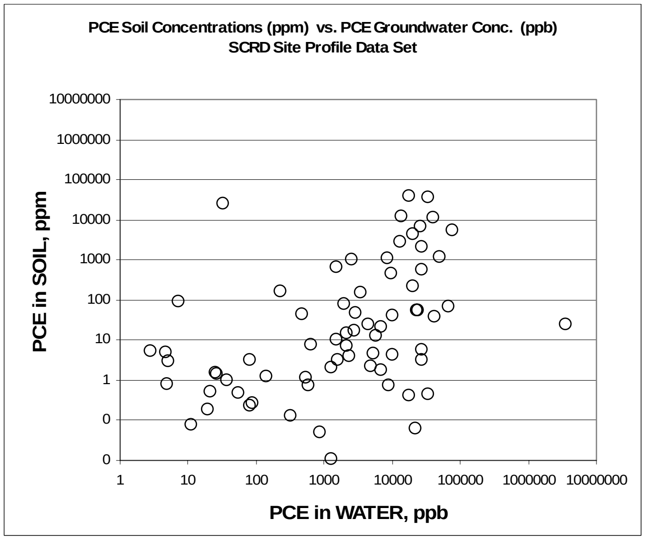


Figure 27 - SCRD Site Profile Data - Peak PCE Concentrations in Soil vs. Groundwater

Plume Length Comparison: PCE and MtBE

Plume length is a general indicator of the potential severity of contaminant releases to groundwater. Actual severity is established by the health risk created by the plume, whether to consumers of water from impacted water supply wells, or to occupants of buildings overlying shallow groundwater plumes of volatile contaminants who may breathe vapors from the plume.

To gauge the potential severity of PCE releases from dry cleaners relative to M*t*BE releases from leaking underground fuel tanks, plume length data from the SCRD site profiles was compared to published plume studies for M*t*BE and benzene, another volatile, mobile, and toxic constituent of gasoline. The M*t*BE plume studies used for this comparison were conducted in Southern California (Rong, Y., 1998) and Texas (Mace, R.E., Wan-Joo, C., 1998). Plume data collection methods for the SCRD profile sites are less rigorous than methods used in the two M*t*BE plume studies, but a general comparison remains useful nonetheless. Comparable plume attribute data for PCE plumes and M*t*BE and benzene plumes are contrasted in Tables 39, 40, 41 and 42.

Table 40: PCE vs M*t*BE Maximum Concentrations in Plumes from Selected Studies

	PCE	M*t*BE
Maximum Contaminant Level	5 ppb	[20 ppb]*
% Above MCL or USEPA Advisory*	97%	85%
95th Percentile Conc., ppb	105,240	100,000
Median Concentration, ppb	3,400	1,600
% Sites >10,000 ppb	38%	28%
Number of Cases reviewed	*90*	*465*
Source	*SCRD*	*Mace, R.E.*
Study Location	*USA*	*Texas*

*Note the USEPA Advisory Noted in this plume study was 20 ppb for M*t*BE. The Secondary MCL in California is 5 ppb. The Primary MCL for PCE is also 5 ppb.

Summary site statistics for PCE and M*t*BE at dry cleaners and gas stations are relatively similar. This generalization is somewhat counterintuitive, given the substantial differences in the chemical properties governing fate and transport of PCE and M*t*BE. M*t*BE is significantly more soluble in water than PCE, and it is much more volatile (i.e., M*t*BE has a higher air/water partitioning value, i.e. *Henry's Law Constant*, than PCE). M*t*BE also has a lower affinity to sorb to soil organic matter than PCE. The chemical characteristics of M*t*BE suggest it should be found at substantially higher dissolved concentrations than PCE. A variety of factors may contribute to the similarity in summary site statistics between PCE at dry cleaner release sites and MtBE at fuel leak sites. M*t*BE has been in use for a much shorter timeframe than PCE. In California, M*t*BE use is generally limited to the period from the late 1980s or early 1990s until 2004. While used in smaller quantities than M*t*BE, PCE was used from the 1940s through the present. Because PCE may move as a DNAPL, it continues to sink through the saturated zone, leading to a large surface area from which PCE may dissolve into groundwater. By contrast, M*t*BE is present at less than 15% of the total volume of gasoline, and is lighter than water. PCE has a specific gravity of 1.62 g/cm^3, while M*t*BE's specific gravity is 0.74 g/cm^3. Because M*t*BE is lighter than water, a small volume of the aquifer near the top of the water table will be impacted by M*t*BE in gasoline. Consequently, a smaller surface area will be available for dissolution of M*t*BE into groundwater.

Table 41: Chemical Properties of M*t*BE and PCE

Chemical Properties	**M*t*BE**	**PCE**
Molecular Weight	88.15 g/mol	165.83 g/mol
Melting Point/Boiling Point	-109 °C / 55.2 °C	-19 °C / 121 °C
Vapor Pressure	240 mm Hg at 20 °C	18.47 mm Hg at 20 °C
Density	0.74 g/mol at 20 °C	1.623 g/mol at 20° C
Solubility in Water	43,000 mg/L	150 mg/L
Henry's Law Constant	5.4×10^{-4} atm-m^3/mol	1.8×10^{-2} atm-m^3/mol
Log K_{OC}	0.55 – 0.91; high mobility in soil	2.2 – 2.7; low to moderate mobility in soil

Table 42: PCE vs M*t*BE and Benzene Plume Length - Mace Study

	PCE	M*t*BE	Benzene
99th percentile plume length	14,160	750	831
90th percentile plume length	2585	386	325
Median Plume Length	300	174	144
Geometric Mean Plume Length	378	182	155
Number of Cases reviewed	*62*	*58*	*289*
Source	*SCRD*	*Mace, R.E.*	*Mace, R.E.*
Study Location	*USA*	*Texas*	*Texas*

Table 43: PCE vs M*t*BE Plume Length - Rong Study

	PCE	M*t*BE
Average Plume Length, >10,000 ppb	981	125
% plumes >100 ft	89%	50%
Number of Cases reviewed	*62*	*51*
Source	*SCRD*	*Rong, Y*
Study Location	*USA*	*So. CA, USA*

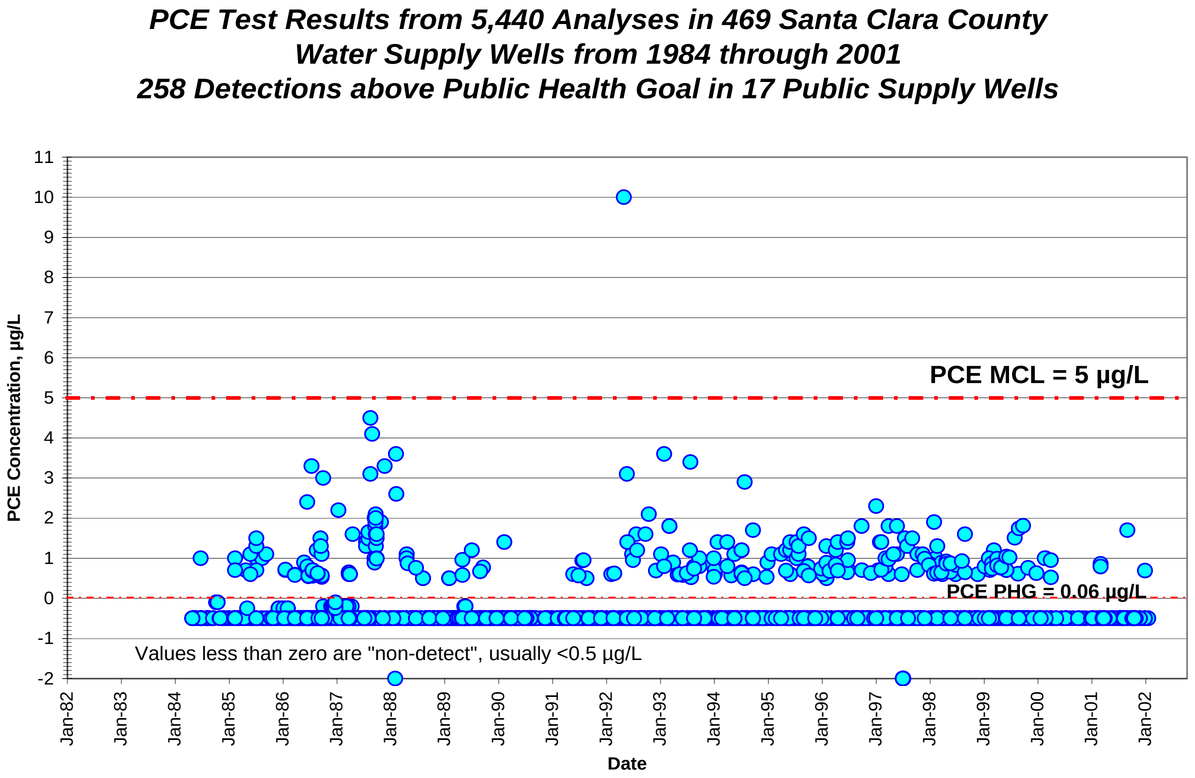
Comparisons of both gasoline plume studies to the SCRD site profile plume data reveal a considerable difference in plume lengths of PCE and M*t*BE. Because the 5 ppb MCL for PCE is lower than the 20 ppb US EPA Advisory level for M*t*BE, and because California's PCE Public Health Goal, 0.06 ppb, is lower still, longer PCE plume lengths are more likely to degrade water quality in municipal and domestic water supply wells. The number of facilities that use or used PCE and M*t*BE is also relevant for evaluating threats to groundwater. Approximately 2,000 gasoline facilities operated in Santa Clara County. While there have been far more gasoline facilities than dry cleaners, gasoline facilities have been aggressively monitored for leaks, and groundwater has been tested at most locations. There has not been a corresponding regulatory-mandated effort to monitor impacts from current and past dry cleaners that use or used PCE.

Gasoline facilities typically store thousands to tens of thousands of gallons of gasoline, with M*t*BE content ranging from 2 to 15% by volume. Typical dry cleaners today use only a few hundred gallons of PCE annually. Dry cleaners operating in earlier decades used a few thousand gallons of PCE each year. Nevertheless, the 90th percentile of PCE plume lengths from the studies contrasted here is an order of magnitude higher than M*t*BE plume lengths. Accordingly, the potential threat to groundwater resources from PCE releases appears greater than the threat posed by M*t*BE.

PCE Impacts to Water Supply

Water retailers in California are required by the California Department of Health Services (DHS) to regularly test water quality to ensure that groundwater pumped from wells meets health based standards. The regulatory compliance level for PCE in drinking water is 5 ppb. Santa Clara County groundwater pumped for drinking water supply has been tested for PCE since the 1970s or earlier. Data obtained from DHS in electronic format are available from 1982 through the present. During this time, 4.5% of the 5,440 analyses conducted on samples from public supply wells indicated PCE presence. Most of these detections resulted from repeat analyses in impacted wells, and many were at 1 ppb or less with a laboratory reporting limit of 0.5 ppb. Counting only detections greater than 1 ppb, the frequency of detection becomes 1.8%. The total number of wells in Santa Clara County with PCE detections listed in the DHS Database in the past 22 years is 17 wells out of 469 tested, or 3.6 %. The total number of wells with at least two PCE detections above 1 ppb is 8, or 1.7 %. Since 2000, only 3 wells have had reportable detections of PCE, at maximum reported values of 2.9, 1.1, and 0.56 ppb. In November 2006, 2 wells had detections, with the maximum PCE detection at 1.8 ppb. The maximum detected PCE concentration in any drinking water well was 10 ppb in 1992, representing the only MCL exceedance in the period of record[9]

In 2002, the State Water Resources Control Board's *Groundwater Ambient Monitoring and Assessment* program (GAMA) was implemented in Santa Clara County to test water supply wells for Volatile Organic Compounds (VOCs) using ultra-low level laboratory reporting limits. PCE was analyzed in 166 wells, and detected in 10 wells above the reporting limit, which ranged from 5 to 40 parts per trillion (ppt). Detected concentrations ranged from 5 to 59 part per trillion. The Public Health Goal is 60 parts per trillion. DHS data from 2002 showed only 2 wells with PCE detections, ranging from 690 ppt to 2,200 ppt (0.69 ppb to 2.2 ppb). Figure 26 displays the frequency of PCE detections in water supply wells from the DHS database. About 95% of tests (5,194 analyses) were non-detect. The common reporting limits for PCE in routine municipal well sample analyses are 0.5 and 0.1 ppb, both greater than the Public Health Goal.



PCE Test Results from 5,440 Analyses in 469 Santa Clara County Water Supply Wells from 1984 through 2001
258 Detections above Public Health Goal in 17 Public Supply Wells

Figure 28 - Frequency of PCE Detection in Santa Clara County Drinking Water Supply Wells - 1984 – 2001

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[9] This well is a municipal supply well located about three quarters of a mile downgradient from a large solvent release including PCE from three electronics facilities; it also located about one-quarter mile cross gradient from a dry cleaner that operated for 33 years, and less than three-quarters of mile downgradient from five other dry cleaners that operated from 5 to 30 years. The well is still in use today, but regular testing shows it is now free of PCE detections.

Investigation Methods and Remedial Technologies for Dry Cleaner Sites

Proper investigation of dry cleaner releases generally includes research into the dry cleaner operating history for investigation planning, sampling at release and discharge locations, and using investigation methods appropriate for DNAPL where chlorinated solvents have been used. The paper written by members of the State Coalition for Remediation of Dry cleaners, *'Conducting Contamination Assessment Work At Drycleaning Sites'* (Linn, W. et al., 2004), provides a highly useful and detailed guide to conducting dry cleaner investigations. Key recommendations from SCRD's Dry Cleaner Assessment guidance are summarized in the following section.

Assessment Planning/Site Conceptual Model

Investigation of dry cleaner releases must begin with research of the history of the facility and operations. This is critical in determining the location of source area investigations. Research can include:

- environmental and facility inspection and compliance records
- environmental property audits
- licenses, business, and building permits
- historical aerial photographs
- review of nearby site assessment and remedial work (particularly service stations or other investigations that include groundwater sampling for volatile organic compounds)
- facility as-built drawings
- underground utility locations, utility records, including videos of sewer lines and sewer line pressure testing
- water well surveys

Preliminary research allows the investigator to determine the dry cleaner location, potential points of release, and potential conduits and receptors, all of which are necessary to establish the Site Conceptual Model and direct the investigation.

In addition to research, site reconnaissance will aid in developing the Site Conceptual Model and determining sources. Reconnaissance should include:

- interviews with past and current operators about operations, waste generation and storage, and historical chemical usage
- documentation of current and past machinery types and equipment location(s)
- review of equipment repair logs
- location of solvent storage (indoor and outdoors, including above ground or underground tanks)
- location of solvent transfer (including location of service doors)
- location of distilling equipment (separate room or outdoors at older facilities)
- use and location of septic tanks, drainfields, and floor drains
- observation of expansion joints and cracks in the slab near equipment and solvent storage areas
- document historical waste management practices
- former locations of dumpsters and trash cans

If the facility is no longer in operation, but vacant, the investigator should look for sawed-off lag bolts or concrete or mortar patches in the flooring as evidence of former equipment locations. Staining on the floors or walls indicates where spills of still bottoms or cooked powder residues occurred during removal from the still or muck cooker. Brown stains on walls indicate still boilovers.

If the dry cleaner operation is no longer present, aerial photos can be used to find the former location of a facility, for example, identifying which unit within a strip mall was leased by a dry cleaner by noting locations of characteristic roof vents. Most dry cleaning operations and equipment were located at the rear of the shop. Photos should therefore be researched, and interviews conducted to locate the rear of the facility to direct sampling locations. Current or former horizontal conduits (e.g. buried utility trenches) connecting to the rear of the facility should be mapped to guide placement of borings and monitoring wells. Results of research and reconnaissance should be documented in writing and on facility maps for use in the Site Conceptual Model.

Assessment Approaches, Technologies and Tools

Dense Non-Aqueous Phase Liquids (DNAPL) – Concerns and Considerations

Assessment strategies will differ between a chlorinated solvent release and a petroleum solvent release. At some sites, both chlorinated and petroleum solvents have been used. PCE, TCE, carbon tetrachloride, TCA and Freon 113 are dense non-aqueous phase liquids (DNAPLs), and petroleum dry cleaning solvents are light non-aqueous phase liquids (LNAPLs) (US EPA, 2004). This section focuses on the predominant chlorinated solvent cleaner, PCE. Some environmental assessment practitioners erroneously approach dry cleaner investigations in much the same way they approach petroleum investigations (EPA 2004). Consideration must be given to the likely presence of DNAPL beneath dry cleaner facilities.

DNAPL may be present in the vadose alone, or present in both the vadose and saturated zones. Because DNAPL flows under its own density, sampling at same locations may reveal DNAPL in the saturated zone but not in the vadose zone. Approaches for assessing DNAPL presence differ between the two media. DNAPL movement can be very difficult to predict and DNAPL presence is difficult to detect in the field. The depth of NAPL penetration is difficult to predict and is dependent on a number of factors that may not be known to the investigator. Several experiments have shown that estimating penetration is difficult in both the vadose and saturated zones. These factors include geologic features that may increase lateral spreading, volatilization, source/release characteristics, soil permeability, residual saturation, and hydraulic conductivity (Feenstra, S. et al., 1996).

Dry Cleaner Assessment Technologies

Site assessment is extremely important in understanding how contaminants enter the subsurface and move in the soil and water matrixes. Site assessment planning must take into consideration the most useful and cost effective methods for data collection needed to develop the Site Conceptual Model (Jurgens et al, 2004). Assessment technologies include:

- DNAPL Detection – Direct and presumptive evidence of DNAPL presence
- DNAPL Assessment – Delineation of nature and extent of DNAPL
- Geophysical Techniques
- Non-Geophysical Techniques
- Field screening (i.e. photo-ionizing detectors, organic vapor analyzers, etc)
- Sampling
- Monitoring
- Miscellaneous – Aquifer Testing, Tracers, Sewer Line Video

Most dry cleaner assessments apply non-geophysical techniques such as field screening and direct push sampling technologies, while only 18% of dry cleaner site assessments use geophysical techniques (Jurgens, B., and Linn, W., 2004).

DNAPL Detection

As noted in the 'Magnitudes of PCE Impacts' section of Appendix D, direct and presumptive evidence indicated 41% of the 95 sites surveyed in the 2002 SCRD Survey had evidence of DNAPL. A Texas study revealed a similar percentage, 45% of 80 dry cleaner sites, with presumptive evidence of DNAPL presence in groundwater (Rifai, H.S., et al, 2001.). A Livermore National Laboratories study of chlorinated solvent plumes from a variety of sources including dry cleaners revealed 12 of the 32 PCE plumes studied had PCE concentrations in groundwater at more than 1% of PCE's solubility (McNab, W.W., et al, 1999).

The wide variety of release scenarios from dry cleaner sites suggests a multitude of pathways for DNAPL entry into the subsurface. DNAPL identification is critical at the beginning of an investigation. Confirmed or suspected DNAPL requires precautions to minimize unwanted DNAPL migration (Cohen, W., 1993). Non-invasive techniques such as geophysical surveys and shallow soil gas surveys can be used to minimize the risks of unwanted DNAPL migration that can occur if borings are advanced through low permeability horizons that until penetrated were effective for impeding downward migration of DNAPL.

Older geophysical methods are not well-suited for delineating the actual distribution of PCE DNAPL in heterogeneous environments; however, they are suitable to assess stratigraphic and hydrogeologic conditions, detect and map buried utilities, and to identify potential migration pathways (Cohen, R.M., and Mercer, J.W., 1993). Ground Penetrating Radar is an effective tool for detecting DNAPL in uniform high permeability units. Electrical Resistance Tomography (ERT, also known as electrical *impedance* tomography), Vertical Induction Profiling (VIP), and Cross-Well Radar, can be effective in other soil types. New and innovative geophysical techniques for DNAPL delineation are profiled in the Interstate Regulatory Council's *Review of Emerging Characterization and Remediation Technologies for DNAPLs*, (ITRC, 2000) and the EPA's guidance for *Site Characterization Technologies for DNAPL Investigations* (US EPA, 2004).

Chlorinated DNAPLs have a relatively high vapor pressure and will volatilize to form a vapor plume around the source. Soil gas sampling can be used to quickly and inexpensively obtain large amounts of data on subsurface PCE vapor distribution. However, subsurface heterogeneities can affect soil vapor gradients. Soil gas data reflect vapor migration, and not necessarily dissolved source contamination. Some controlled studies have shown that dissolved plumes more than a meter below the groundwater table may not be detected by soil gas surveys. The saturated soil vapor of PCE at 20 degrees Celsius is 19,300 parts per million by volume (ppmv in air (Feenstra, S.,1996). If DNAPL is present in the vadose zone, soil vapor will be present at saturated vapor concentrations. Soil sampling probes have a better chance of detecting DNAPL, but the depth of investigation must be considered to avoid cross-contamination or creating vertical conduits that may remobilize trapped DNAPL.

Data obtained from research and reconnaissance of a dry cleaner operation can be combined with the geochemical, geologic and screening data to form the next stage of the Site Conceptual Model.

Where noninvasive methods such as geophysics suggest possible DNAPL presence, invasive techniques should be employed to detect DNAPL and improve the Site Conceptual Model. Invasive techniques also help define the subsurface geologic features controlling contaminant migration.

Failure to detect DNAPL by noninvasive methods does not necessarily rule out DNAPL presence (Cohen, R.M., and Mercer, J.W., 1993). Direct observation of DNAPL can be accomplished through:

- Careful analysis of properly preserved soil samples
- Induced laser ultraviolet fluorescence – screens for hydrocarbons while drilling
- Soil-water shake methods – clear centrifuge of soil sample and water for visual DNAPL observation
- Ribbon NAPL Sampler (RNS) – downhole sampler with a reactive liner that turns red in the presence of NAPL
- Sampling of appropriately screened monitoring wells
- Membrane Interface Probe (MIP)
- Hydrophobic Dye Testing and Membranes - hydrophobic dye to determine the presence of DNAPLs in ex-situ soil samples
- Diffusion samplers (e.g. passive diffusion bags)
- Optical viewing (optical tele-viewers are used to examine the walls of an open borehole for visual observation of DNAPL)
- Partitioning Inter-well Tracer Tests (PITT), an in-situ technique for estimating the volume and percent saturation of DNAPLs)

These methods and other innovative and emerging technologies are described in detail in ITRC 2000 and USEPA 2004.

Presumptive evidence of DNAPL can be based on comparisons of soil, soil gas and groundwater concentrations to partitioning coefficients, vapor pressure and effective solubilities. Cohen and

Mercer, 1993, and others have concluded that groundwater concentrations above 1% of the pure phase or effective solubility, soil concentration above 10,000 mg/kg or soil vapor in excess of 100 to 1000 ppmv is presumptive evidence of DNAPL. However, groundwater concentrations in excess of 1% of the DNAPL solubility does not always mean that DNAPL is present at, or traveled through, the sampled location. Horizontal flow may cause high dissolved concentrations to migrate a significant distance from the residual DNAPL. Other anomalous field conditions may exist that would indicate the presence of DNAPL include:

- unexplained increases in groundwater concentrations in the vertical profile
- erratic and localized groundwater contamination
- concentration increases hydraulically upgradient of sources
- significant rebound in concentrations after remediation is stopped

DNAPL Assessment/Delineation

Soil gas surveys, soil sampling, and groundwater monitoring are generally effective in assessment of the dissolved plume. Methods discussed above can also be useful in determining the *presence* of DNAPL; however more specialized technologies are generally required to *locate* and *quantify* the DNAPL source. Ground water extraction may recover some DNAPL; however, the amount recovered is often very small compared to the amount of DNAPL sorbed to soil, or pooled beneath the surface of the source area (ITRC, 2000).

Direct-push technologies are used to extract groundwater and core samples for *ex situ* analysis. Direct-push methods can also be used to obtain continuous real-time information on soil stratigraphy and contaminant distribution when coupled with flexible membranes fitted with absorbent liners to detect DNAPL (ITRC, 2000). A number of the detection technologies described above can be used with direct-push technologies to assess the extent of DNAPL. In particular, the Membrane Interface Probe (MIP) is useful for characterizing relative VOC concentrations in the vertical profile.

The most common approach used in dry cleaner investigations, advancing soil borings and installing monitoring wells, is not best-suited for DNAPL detection. As described above, direct push techniques with sampling and screening technologies are generally preferred for assessing DNAPL presence, and for expedited site assessment. Assessing DNAPL with monitoring wells can be very difficult, if not futile. Monitoring wells must be properly screened and constructed to detect DNAPL, and even then it is generally not feasible to relate the DNAPL thickness measured in the well to the thickness of DNAPL presence in the formation. The exception may be areas of pooled DNAPL. DNAPL migrates along permeable zones; therefore, the sand used to install a monitoring well filter pack must be at least as permeable as the surrounding formation. Monitoring well installation may remobilize DNAPL, causing it to descend deeper into the aquifer if DNAPL enters the sand pack and migrates vertically, where it can escape at the bottom of the well if the formation is highly permeable. Well screen position must also account for DNAPL properties. If the bottom of the sand pack is below the well screen, there may not be sufficient accumulation of DNAPL to enter the well. Some of these problems can be avoided by installing a cement basket and sump at the bottom of the well (described in Feenstra, S.,1996).

To detect DNAPL, groundwater samples should be retrieved from the bottom of the well. Monitoring well interface probes should be used to determine the presence of accumulated DNAPL.

Other technologies useful for assessment of dissolved solvent or DNAPL assessment include (US EPA, 2004):

- CPT- Cone Penetrometer Testing
- Direct Push methods– e.g. GeoProbe, Hydropunch
- MIP – Membrane Interface Probe
- Soil Gas Surveys
- Micro-wells – Small diameter short-screen wells installed by direct push
- Groundwater Monitoring Wells
- Color-Tec Screening - combines the use of colorimetric gas detector tubes with sample purging
- Passive Diffusion Bag Samplers (PDB) for vertical profiling of dissolved concentrations along monitoring well screens

Remediation of Dry Cleaner PCE Contamination

A 2002 survey conducted by SCRD summarized cleanup technologies used at dry cleaner sites at 533 sites in 26 states. Many sites still have significant soil contamination 40 years after the dry cleaner business closed. (Jurgens, B., and Linn, W., 2004). Until removed or remediated, soil contamination continues to contribute to groundwater contamination and plume growth. Soil excavation was reported as the most common soil cleanup technology; soil vapor extraction was the second most commonly used soil cleanup technology. Table 43 depicts the breakdown of responses.

Table 44: SCRD 2004 Survey - Soil Remediation

Soil Remediation Technologies	**% Sites Using this Method***
Soil Excavation and Disposal	79%
Soil Vapor Extraction	68%
Chemical Treatment	46%
Bioventing	21%
Ex-situ treatment	18%
Thermal	14%

*(most sites used multiple methods for soil remediation)

The SCRD 2004 survey found that Pump and Treat and Chemical Oxidation were the most common methods in use for groundwater remediation. Bioremediation, Monitored Natural Attenuation, and Air Sparging were also used at more than half the sites surveyed. Table 44 profiles groundwater remediation technologies employed at dry cleaner sites.

Table 45: SCRD 2004 Survey - Groundwater Remediation

Groundwater Remediation Technologies	% Sites Using this Method*
Pump and Treat	75%
Chemical Oxidation	64%
Bioremediation	54%
Monitored Natural Attenuation	54%
Air Sparging	54%
Multi-phase Extraction	29%
Thermal Treatment	14%
Recirculating Wells	14%
Flushing	7%
Permeable Reactive Barrier	4%

*(most sites used multiple methods for groundwater remediation)

The 95 SCRD site profiles were reviewed to see what soil and groundwater remediation technologies were being employed. Considering soil and groundwater remediation methods jointly, the review found that soil vapor extraction is by far the most frequently used technology. Figure 27 provides a breakdown of the number of sites utilizing a particular technology.

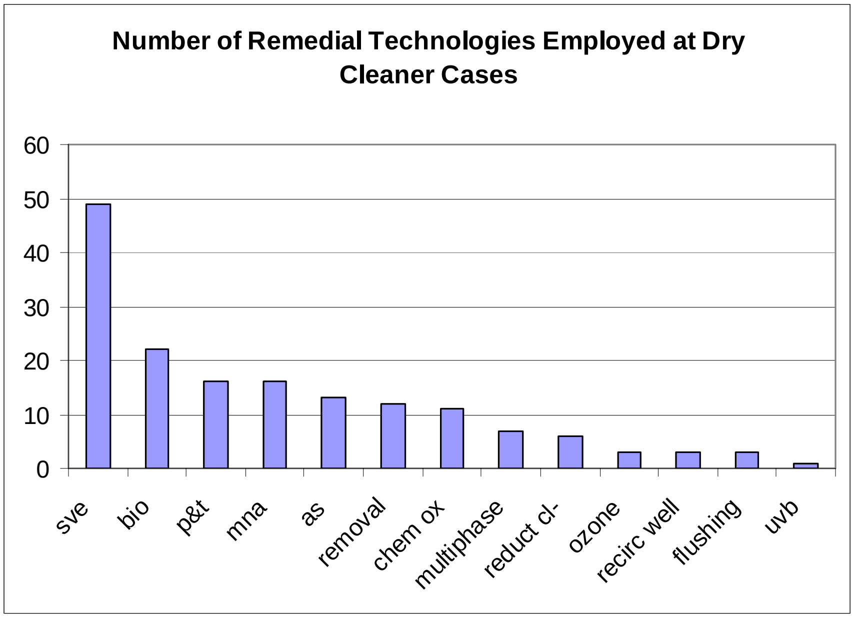


Figure 29 - Prevalence of Soil and Groundwater Remediation Technologies among Sites Profiled by SCRD.

Key: sve = soil vapor extractionl; bio = enhanced bioremediation; p&t = pump and treat by various ex situ treatment technologies, most commonly air stripping; mna = monitored natural attenuation; as = air stripping; removal = soil excavation; chem ox = in situ chemical oxidation of solvents in soil or groundwater; multiphase = combined sve, p&t, and NAPL removal; reduct cl- = reductive dechlorination by enhanced bioremediation and innoculation with microbes; ozone = use of ozone to oxidize solvents in groundwater; recirculation wells = in-well air stripping; flushing = flushing solvents out of vadose zone into saturated zone where they can be treated using p&t; uvb = ex situ ultraviolet light treatment to breakdown PCE.

At most sites, several different technologies had been utilized, sometimes in combination, but often in succession, after the first attempt did not achieve remedial goals. Remedial technology combinations utilizing Soil Vapor Extraction were the most common among methods listed in the SCRD site profiles. Figure 28 illustrates the distribution of remedial technology combinations.

Remedial technology selection must be based on site conditions and subsurface characteristics. Successful deployment of remedial technologies therefore depends on a good understanding of contaminant and subsurface characteristics such as chemical properties, source zone location, DNAPL presence, and geologic features controlling movement of DNAPL and groundwater. Not all technologies work well at all sites. Dry cleaner remediation sites with long histories have seen a progression from the pump and treat approach to the eventual application of in situ techniques such as chemical oxidation and enhanced bioremediation. Newly initiated dry cleaner remediation efforts are less likely to employ pump and treat techniques for remediation, favoring in situ techniques instead, but may deploy pump and treat to establish groundwater containment. In situ technologies involving injection of substances into the subsurface are improving with increased ability to mix chemical oxidizing agents or bioenhancement agents into the subsurface. Air sparging and recirculating wells are examples of technologies that can improve mixing.

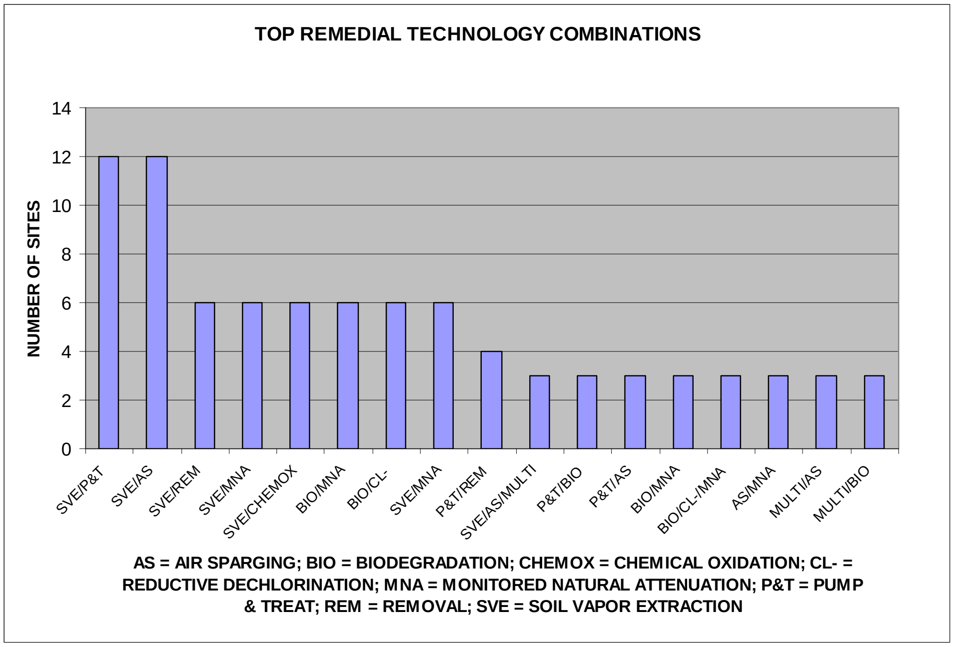


Figure 30 - Prevalence of Remedial Technology Combinations among Sites Profiled by SCRD

Innovative technologies for DNAPL remediation are showing some success. The ITRC report discusses four innovative/emerging technologies for DNAPL remediation:

- In Situ Flushing: a system of injection and extraction wells capable of hydraulically sweeping the entire volume of the impacted aquifer

- Dynamic Underground Stripping: a process of heating the subsurface by injecting steam, combined with extraction technologies
- Six-Phase Heating: electrical resistive heating combined with extraction technologies
- In Situ Chemical Oxidation: oxidation-reduction (redox) reactions

The 2000 ITRC report presents these methods in more detail, and discusses pros, cons, and site studies. Technologies that change a contaminant's phase (DNAPL to vapor) or involve injection (flushing) may unintentionally cause further contaminant spreading. With these technologies, it is compulsory that practitioners have collected enough data to formulate a detailed model of subsurface characteristics.

Economics and Logistics of Dry Cleaner Site Assessment and Remediation

The 2002 Survey by SCRD contacted environmental regulatory officials in 28 states to compile investigation costs at dry cleaner sites that have been in remediation for one year or more, and to inventory technologies used and obstacles to cleanup (Jurgens, B., and Linn, W., 2004). Responses accounted for 1,229 dry cleaner cleanup sites.

Site assessment costs reported in this survey are summarized in Figure 29. Remediation costs were not summarized in the 2002 survey report; remediation cost data was interpreted from the SCRD site profiles.

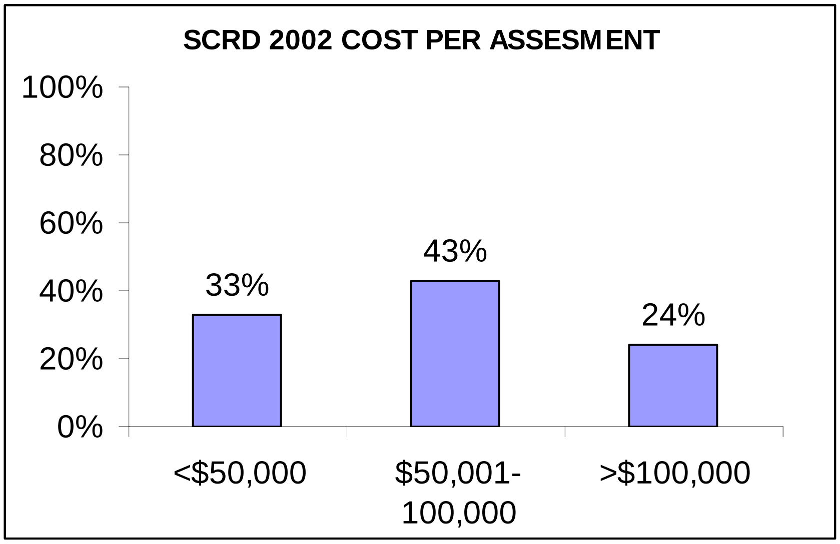


Figure 31 - Cost to Complete Site Assessment, SCRD 2002

Investigation and remediation costs are dependent on a number a factors, including:

- solvent type
- source strength – total mass of contaminant released
- geologic and hydrogeologic conditions
- risk – potential for drinking water impacts or vapor intrusion into buildings
- assessment and remediation technologies
- local or state regulations and laws
- cleanup funding approaches

Obstacles to a successful cleanup effort included the following challenges:

- on- and off-site access from uncooperative tenants, landowners, or independent third parties in commercial areas
- physical access to source areas due to buildings, utilities, streets, etc.
- space limitations and access problems due to operating businesses
- off-site migration of contamination
- incomplete site assessment, particularly with respect to vertical delineation of contamination
- finding an effective technology for unfavorable geologic or hydrogeologic conditions
- permitting requirements
- remediation waste disposal
- noise from system operation
- lack of funding for corrective action

Survey data indicate that the time required to complete site assessment was six months or less at 12% of sites, 50% took from 6 to 12 months, and 38% of sites took more than 12 months (Jurgens, B., and Linn, W., 2004).

We reviewed the 95 site profiles on the SCRD web site and made the following observations of Investigation and Remediation costs.

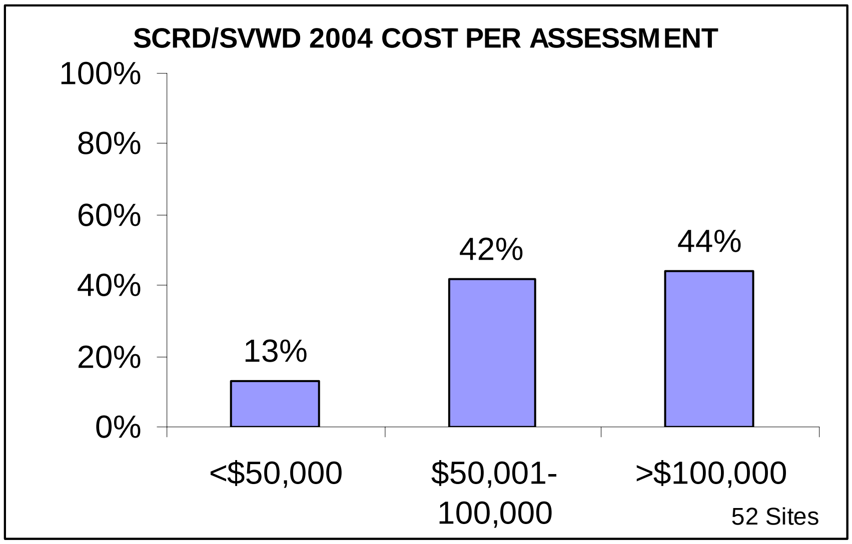


Figure 32 - Range of Completed Site Assessment Costs, SCRD 2002

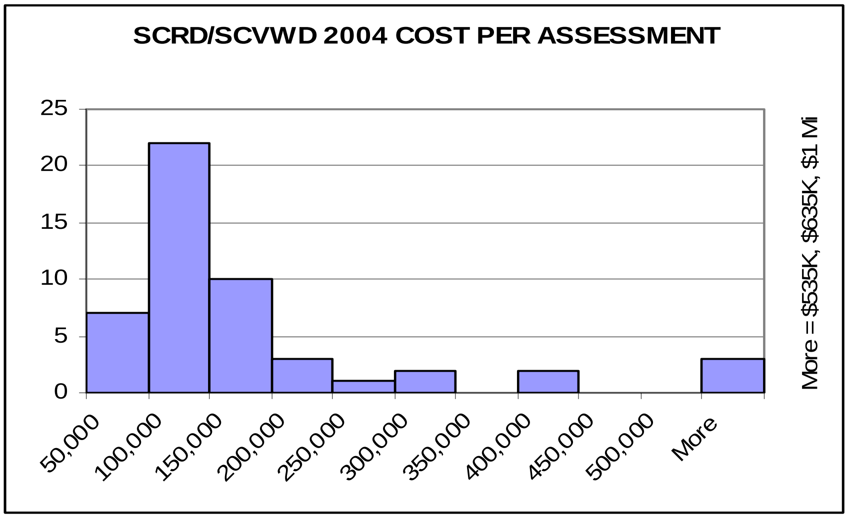


Figure 33 - Detailed Range of Completed Site Assessment Costs in SCRD Site Profiles

The percentage of sites reviewed from SCRD site profiles with investigation costs from $50,001 to $100,000 was similar to the SCRD 2002 figures. However, SCRD Site Profile data show an increase in the percentage of sites with investigation costs in excess of $100,000. The increase may be attributable to SCRD's criteria for including sites in the Site Profiles. Sites selected for SCRD site profiles were chosen because detailed information is available. Sites with detailed information have generally been in cleanup for a longer time. Therefore, costs associated with sites included in the SCRD site profiles are expected to be higher. The minimum assessment cost was $2,000 and the maximum was reported at $1,000,000.

A similar review of the SCRD site profiles was conducted by the authors for remediation installation and design costs, which are summarized in Figure 32. The minimum remediation design and installation cost was $18,000 and the maximum was reported at $7,037,000. The site summary for the site $7 million remediation costs notes: “Contamination spread over a 10-block area and impacted two municipal wells before it was detected. Remedies included extraction wells along the heart of the mile-long plume and granular activated carbon treatment of contaminated water, soil vapor extraction at the source, and water supply replacement. Also, most affected private wells were abandoned, and residences were put on city water.” Three other sites reported remediation costs in excess of $1,000,000. One of these reported PCE contamination in a private water supply well shared with adjacent commercial tenants; a total of 16 private wells were contaminated with PCE concentrations greater than the MCL, requiring carbon filter treatment. The other two cases with remedial costs in excess of a million dollars had to abate vapor intrusion into occupied buildings.

Additional cost parameters can be discerned from the SCRD site profiles. Table 45 depicts average and median costs for investigation, remediation design and installation, and remediation operating costs for all dry cleaner site profiles, and compares costs for sites with water supply well impacts (high priority sites) to those with no water supply well impacts.

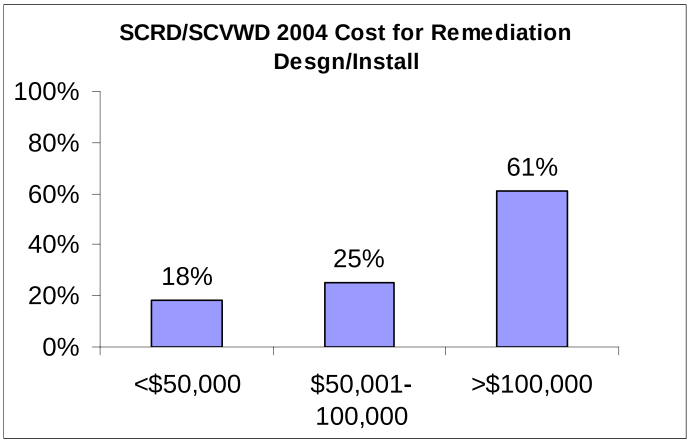


Figure 34 - Range of Completed Remediation Costs, SCRD Site Profiles

Table 46: Investigation, Remedial Design and Installation, and Operating Costs

	COST	CASES
Average Assesment Cost	147,061	50
Median Assesment Cost	94,000	
Max Cost	1,000,000	
Average remediation design/install Cost	363,396	57
Median remediation design/install Cost	132,000	
Max Cost	7,037,000	
Average O&M Cost/YR	103,986	40
Median O&M Cost/YR	50,000	
Max Cost	1,400,000	

Water Well Impact Case Costs - 8 cases

Average Assesment Cost	222,800	5
Median Assesment Cost	52,000	
Max Cost	635,000	
Average remediation design/install Cost	1,404,079	6
Median remediation design/install Cost	251,552	
Max Cost	7,037,000	
Average O&M Cost/YR	116,600	5
Median O&M Cost/YR	54,000	
Max Cost	300,000	

Non-Water Well Impact Case Costs -

Average Assesment Cost	138,646	45
Median Assesment Cost	96,000	
Max Cost	1,000,000	
Average remediation design/install Cost	214,727	51
Median remediation design/install Cost	130,000	
Max Cost	1,700,000	
Average O&M Cost/YR	102,016	35
Median O&M Cost/YR	49,000	
Max Cost	1,400,000	

The average, median and maximum costs of remediation design and installation were higher for the water well impacted cases. The average and median costs/year for Operation & Maintenance at sites with water supply well imply impacts were similar to those without.

The average assessment costs were higher for the water well impacted cases, but the median and maximum costs were lower than cases without water well impacts. The average cost is skewed due to the small number of sites with water supply impacts (8 cases). Figure 33, below, graphically contrasts the range of costs for sites with and without water supply well impacts.

Data from the 95 case profiles was reduced further to test for a relationship between PCE concentration and cleanup costs, or for plume length and cleanup. These comparisons are presented graphically in Figures 34 and 35 through 38 and 39.

The expected correlation between plume length and investigation cost, or between maximum PCE concentration and investigation cost, is not evident in these scatter plots. A few outliers are observed in Figure 34. The two longest plumes have relatively low assessment costs. One of these sites, with a $15,000 assessment cost, was a shallow plume more than two miles long. The plume was in clean sand and investigators used direct push sampling methods. Monitoring well installations were included in the remediation costs.

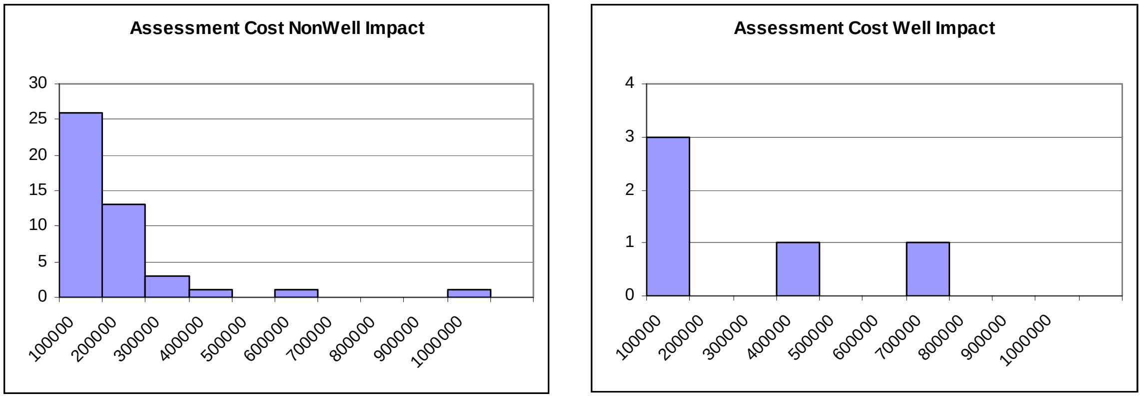


Figure 35 - Comparison of Assessment Costs between Sites with and without Water Supply Well Impacts (Number of Cases vs. Cost in Dollars)

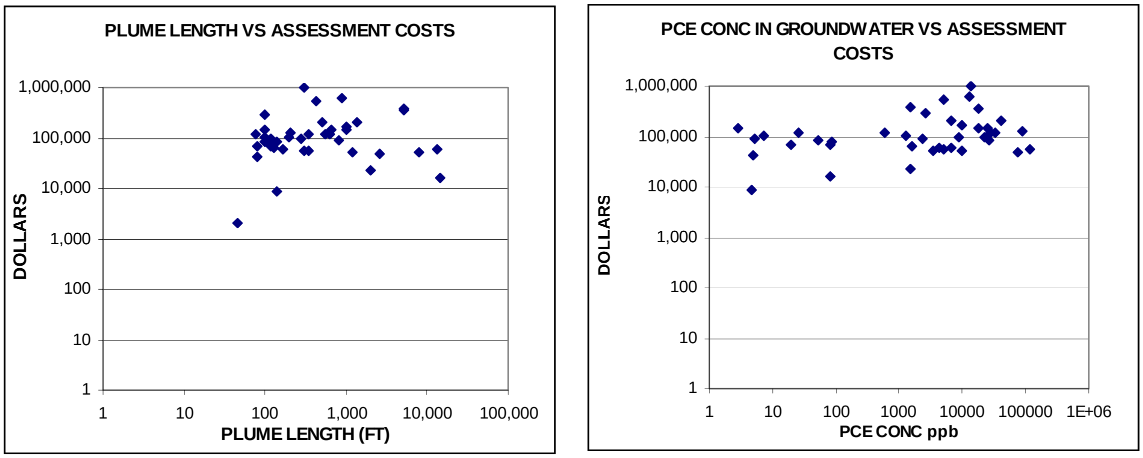


Figure 36 and Figure 37 – Cost for Site Assessment vs. Plume Length and PCE Concentration

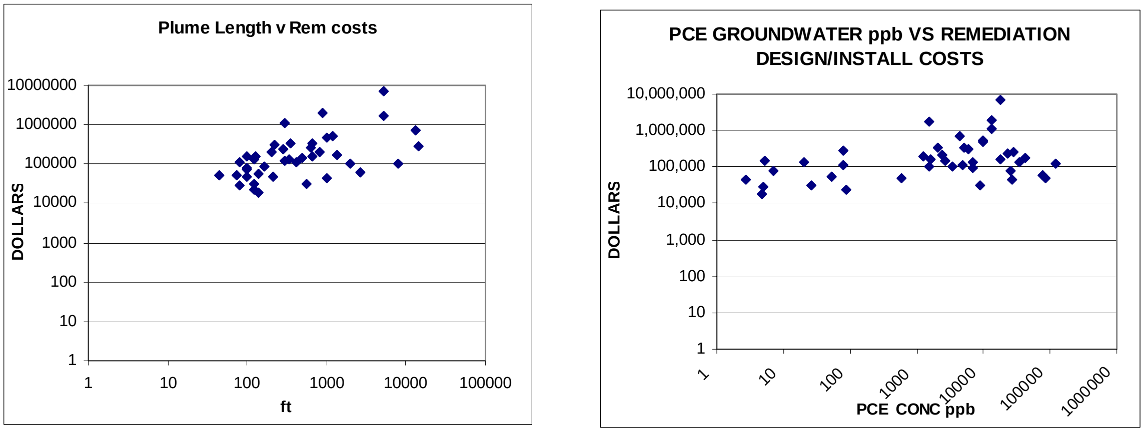


Figure 38 and Figure 39 - Remediation Costs vs. Plume Length and Maximum PCE Concentrations

Figure 36 depicts a moderate degree of correlation between remediation costs and plume length. The correlation between remediation costs and maximum groundwater concentration is poor.

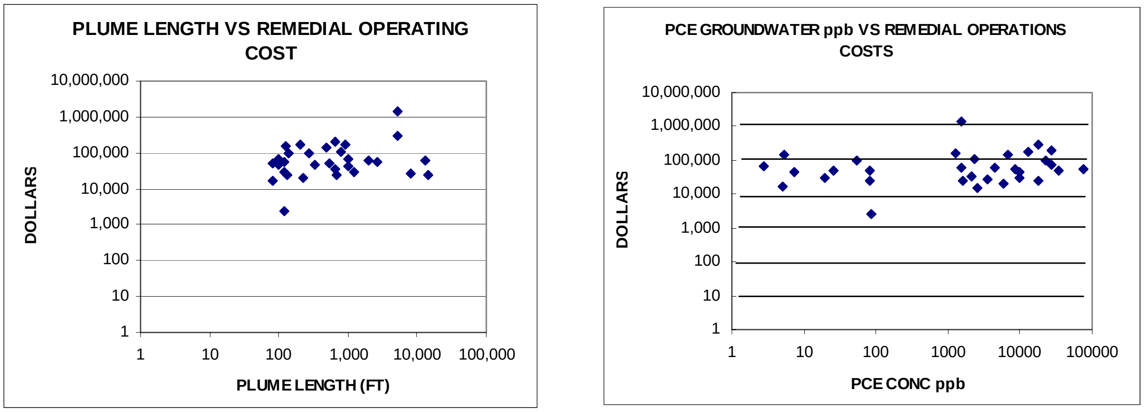


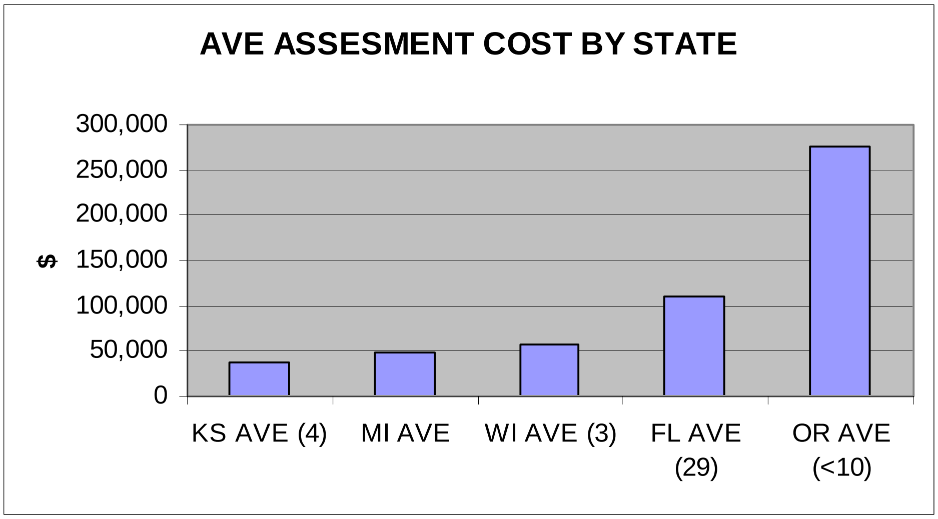
Figure 40 and Figure 41 – Annual Remediation Operating Costs vs. Plume Lengths and Maximum PCE Concentrations

Remedial operating costs (shown in Figures 38 and 39) are weakly correlated with plume length and poorly correlated with maximum PCE concentration.

In summary, groundwater concentrations do not appear to be a good indicator of potential costs. Further, it is unrealistic to assume that sites with relatively low concentrations at which cleanup is nevertheless required will be small or low-cost cases.

While there is a better correlation between plume size and remediation costs, the correlation is not strong enough to make generalizations. The highest costs have been associated with sites requiring abatement of drinking water well impacts or indoor air exposure pathways.

Costs from the profile sites were also broken down by State. Factors that may contribute to assessment and remediation costs being higher in one state than another include states' risk management practices, public risk perception, agency requirements, groundwater use or sensitivity, and governing regulations and policy decisions. Figures 40 and 41 illustrate differences in average investigation and cleanup costs among States. The number of sites reporting costs for each state is shown parenthetically next to the State name.



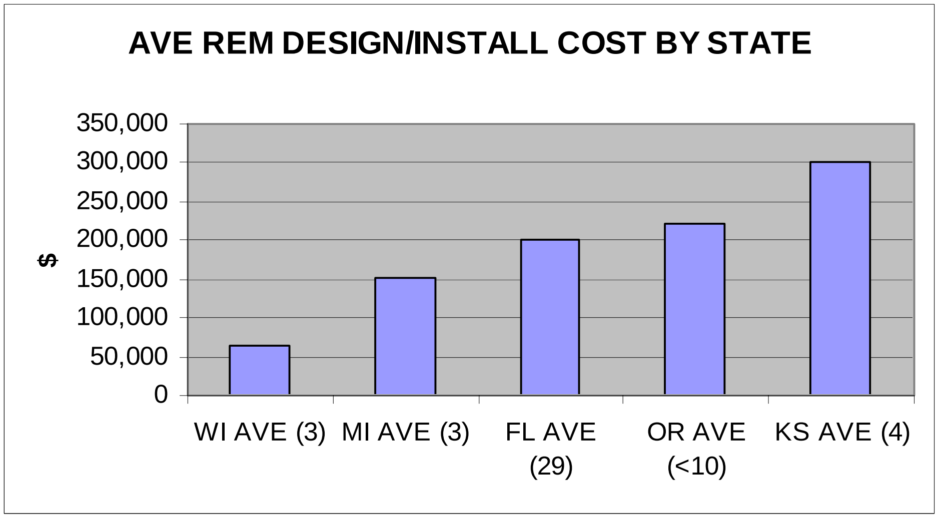


Figure 42 (top) and Figure 43 (bottom) - Comparison of Assessment and Remediation Costs by State

Appendix E: Regulations Governing Dry Cleaning Operations

Air

The California Air Resources Board (CARB) under the jurisdiction of the California Environmental Protection Agency (Cal-EPA) is responsible for developing safe levels of a wide gamut of chemicals in the ambient air for the State of California. These regulations are adopted, implemented, and enforced by 34 local air pollution control and air management districts throughout the state (Marvin, C., 1992). The local air districts are responsible for permitting and regulating all stationary sources of air pollutant. They have the ability to adopt and enforce stricter air toxic regulations than the CARB. Two local air districts, the Bay Area Air Quality Management District (BAAQMD) and the South Coast Air Quality Management District (SCAQMD), have adopted stricter air toxic regulations.

The BAAQMD had jurisdiction over the permitting and regulating process of all stationary sources of air pollutants for the County of Santa Clara. All dry cleaners using PCE and synthetic solvents must follow the rules mandated in Regulation 11, Hazardous Pollutants Rule 16, Perchloroethylene and Synthetic Solvent, Dry Cleaning Operations. The purpose of the regulation is to limit the emission of synthetic solvents and PCE, which has been determined to be a toxic air contaminant from dry cleaners into the ambient air. The regulation can be found on BAAQMD's website at http://www.baaqmd.gov/regs/rg1116.pdf.

Currently, all dry cleaners must use dry-to-dry, non-vented machines equipped with a refrigerated condenser and a drying sensor. The table below summarizes all prohibited equipment and operations.

Table 47: Prohibited Equipment/Operation

Prohibited Equipment/Operation	
Prohibited on:	Equipment/Operations
October 1, 1994	Any washing, drying or treatment (excluding pre-cleaning of spots) outside of approved equipment
October 1, 1994	Any installation of a vented machine or a transfer machine
December 21, 1994	A separate washer or drying tumbler used with dry-to-dry equipment is prohibited; wet materials shall not be transferred to or from dry-to-dry machines except from dip tanks or to a drying cabinet.
December 21, 1994	Any self-service dry cleaning machine
April 1, 1996	Conversion of any vented machine to a closed-loop system
April 1,1997	For co-residential facilities: any vented machine, transfer machine, or closed-loop machine without a secondary control system or fugitive control system
October 1, 1998	Any vented machine
October 1, 1998	Any transfer machine is prohibited except a drying cabinet

Drinking Water

Before drinking water is distributed to the public, the water must meet the standards mandated in the California Health and Safety Code, Title 22. The drinking water supply is monitored for organic chemicals (e.g., volatile organic chemicals, such as DCA, DCE, PCE, and TCE; and non-volatile synthetic organic chemicals, such as pesticides), inorganic chemicals (e.g., asbestos, barium), minerals (e.g., chromium, magnesium), microorganisms (e.g., giardia and crytosporidium), and radiological parameters (e.g., radium-226, radium-228, tritium, and uranium). According to Title 22, water purveyors must follow a specific monitoring schedule; however, they can waive or decrease the sampling frequency for specific chemicals, if they can provide justification that it is no longer necessary to sample for them. For example, a water purveyor can apply for a monitoring waiver for volatile organic compounds (VOCs), if their monitoring records show that no VOCs were detected in their water system for three consecutive years.

As stated in Title 22, the levels of contaminant detected in the drinking water may not exceed the Maximum Contaminant Levels (MCLs). DHS and USEPA have issued drinking water standards or Maximum Contaminant Level (MCL) for more than 80 contaminants, including PCE, in drinking water (USEPA). The MCL for PCE is 5 ppb. MCLs are set based on known or anticipated adverse human health effects the ability of various technologies to remove the contaminant, their effectiveness and cost of treatment.

Wastewater

The federal Clean Water Act prohibits discharge of wastewater to surface water and to municipal and industrial sewers. USEPA has jurisdiction over both the National Pollutant Discharge Elimination System (NPDES) program for surface water discharges and the pretreatment program for sewer discharges. In California, USEPA has delegated the NPDES program over to the State Water Resources Control Board (SWRCB) and sewer districts (Bunte, B.L., 1992).

For the County of Santa Clara, wastewater disposal is governed by local rules or permits mandated by the cities and the sanitary sewer districts.

Table 48: Acceptable Disposal Levels of Industrial Wastewater

Publicly Owned Treatment Works	**Jurisdiction**	**Acceptable Disposal Levels of Industrial wastewater**
South County Regional Wastewater Authority (SCRWA)	Gilroy and Morgan Hill	All industrial effluent must meet the effluent limitation which has been set at "trace" mg/l for total identifiable chlorinated hydrocarbons.
Mountain View	Los Altos, Los Altos Hill, Mountain View, Saratoga	1 mg/L for total CVOCs
San Jose	Campbell, Cupertino, Los Gatos, Milpitas, Santa Clara, San Jose	1 mg/L for total CVOCs
Sunnyvale	Sunnyvale	1 mg/L for total CVOCs

Appendix F: PCE Releases to the Environment

Summary of Release Mechanisms

Five Potential Methods on how Perchloroethylene Contaminated Separator Water from Dry Cleaning Operations may have Impacted Soil and Groundwater via the Sanitary Sewer Pipes

In 1984, a state law required all municipal water systems using groundwater and serving more than 5 connections to test their water for volatile organic compounds. The Central Valley Regional Water Quality Control Board (CVRWQCB) tested 21 Central Valley groundwater wells and discovered that 20 of the 21 groundwater wells were impacted by PCE. The source of the PCE contamination was most likely the local dry cleaners because they were the only large quantity users of PCE (Cohen, W., 1992).

The CVRWQCB's study determined that there are 5 potential mechanisms by which PCE migrated out of the sewer lines and impacted the surrounding and underlying soil and groundwater. The first 4 pathways are associated with PCE-contaminated liquids and sludges settling in low spots in the sewer lines.
The 5 potential mechanisms are summarized in Table 49 below:

Table 49: Five Potential Mechanisms for PCE Migration from Leaking Sewer Lines to Soil and Groundwater

Mechanism/Pathway	Detailed Explanation
1. Through breaks or cracks in the sewer pipes.	
2. Through pipe joints and other connections.	
3. By leaching in liquid form directly through sewer lines into the vadose zone, because:	a. Sewer pipes aren't impermeable to water or PCE; b. Liquid PCE settles in low spots in the sewer pipe and causes an increase in hydraulic head which moves PCE downward through the pipe; c. PCE's viscosity is less than water, so PCE will flow through a pipe wall more easily than water;
4. By saturating the bottom of the sewer piper with high concentrations of PCE-containing liquids, PCE will volatilize from the outer edge of the pipe into the soils:	a. PCE will turn into a gas at the liquid-soil vapor interface at the outer edge of the pipe. Since PCE's vapor density is almost 6 times greater than air, the PCE vapor will sink and migrate downwards to the groundwater.
5. By penetrating the sewer pipe as a gas:	a. Concentration of PCE gas in the pipe usually is greater than in surrounding soils which causes a dispersion through the sewer pipe to the less concentrated area; b. Gas can penetrate the pipe due to pressure; and/or c. Vapor pressure increase to above atmosphere which causes a pressure gradient that forces PCE gas through the pipe into the vadose zone. Once outside the pipe, the PCE gas tends to sink downwards towards the groundwater.

Solvent Releases due to Leaks, Spills and Discharges

In 1994, the Florida legislature created the Florida Dry Cleaning Solvent Cleanup Program in order to clean up over 1,400 contaminated sites impacted by dry cleaners in the State of Florida. In the application process, all active dry cleaners were required to complete a questionnaire that included questions about facility history, operational and waste management practices. A key question was, "Describe any spilling, leaking, pouring, emitting, emptying, dumping, or misapplication of dry-cleaning solvents that has occurred at any time during the operation of the facility prior to this application." (Linn, W., 2002).

Approximately 32 % of the active facilities surveyed (334 dry cleaners and 14 dry-cleaning wholesale supply facilities) reported at least one leak, spill or discharge of dry-cleaning solvent or solvent-contaminated wastes at their facility for a total of 530 incidents. These are briefly summarized in Table 50 (Linn, W., 2002):

Table 50: Dry-Cleaning Solvent Spills and Discharges at 334 Dry-Cleaning Facilities in the State of Florida

Spills and Discharges Associated with:	**Number (Percent) of Incidents**	**Detailed Description of Reported Incidents**
Equipment Failure	208 (40%)	Joints/Seal/Gasket; Door Gasket; Piping/Hose; Solvent Pump; Still/Cooker; Button/Lint Trap; Filter; Condenser & Value; Chiller
Equipment/Machine Operation	111 (21%)	Still Boil-over; Machine Door Open; Valve Open
Solvent Transfer & Storage	81 (15%)	
Equipment Maintenance	73 (14%)	Change/Clean Filter; Clean Out Still; Service Solvent Pump; Drain Filter Tank
Waste Discharges	50 (9%)	
Other Spills	7 (1%)	
Total	**530 (100%)**	

Equipment Failure

Approximately 25% of solvent emissions are due to equipment leaks as a result of equipment wear and corrosion due to general usage; expansion and contraction of the metal parts of the dry cleaning machine from changes in temperature during operations; and the vibration of the equipment. These are summarized in Table 51 below:

Table 51: Types of Equipment Failure

Types	**Due to:**
Failed seals or leaks at the cartridge filter housings	• Soil build-up in cartridge filters causes the filters to rupture due to excessive pressure. • Excessive moisture in the filter cartridge or the build-up of water repellent agents or fabric finishers can cause rapid pressure increase resulting in filter failure.
Leaking door gaskets[1]	• Failure of the button trap lid gasket resulting in solvent discharge from the button trap.
Leaking piping and hoses	• Failure at pipe joints. • Coupling failures (hose clamps & piping joint failures). • Rupture of piping and hoses.
Leaking distillation units	• Failure of pressure values. • Leaking gaskets on the distillation still door.
Leaks/discharges associated with the condenser coils	• Pinhole leaks in coil due to corrosion and pitting from acidic lint and dirt build-up.
[1] Most common reported source of solvent leakage.	

Equipment and Machine Operation

Discharges due to equipment and machine operation are usually the result of operator’s error. These are summarized in 52 below:

Table 52: Discharges due to Equipment and Machine Operation

Types:	**Due to:**
Boilover of solvent/distillation residues from distillation units:	• Mostly due to overfilling the distillation units • Sometime due to excessive operating temperatures
Machine door not closed before starting machine or door opened while machine still operating:	• Clothing caught in the door
Loose cartridge filter housing	•
Water separator overflowing:	• Plugging of the air vent, or solvent or water outlets w/lint or dirt • Values left open.

Solvent Transfer and Storage

85% of the reported spills are related to the transfer of solvent during delivery to the dry cleaning facilities or filling the dry cleaning machines. In the past, dry cleaners used more PCE. According to the Textile Care Allied Trades Association, in the last 10 years, there has been a 75% decrease of PCE usage in the United States. In the late 1970s, the dry cleaning industry used 360 million gallons of PCE; by 2000, the amount decreased to 59 million gallons. This trend is due to the transition from old transfer machines to the usage of the new state-of-the-art dry-to-dry closed-loop dry cleaning machines with efficient vapor recovery technologies.

In the past, PCE was delivered to dry cleaners by tanker trucks. The solvent was pumped from the tanker trucks directly to the dry cleaning machines or to an above ground storage tank (AST) located either inside or outside the dry cleaner. Leaks and spills were due to filling the ASTs or the dry cleaning machines (due to leaking values); over-filling the ASTs or the dry cleaning machines; and from solvent leaks as the solvent delivery hose is reeled back to the tank truck. Another method of solvent transfer was to fill a bucket with PCE from the solvent AST, carry the bucket from the AST to the machine and pour the solvent into the machine, either directly into the drum or through the button trap door. Spills occurred during the filling of the bucket, transporting of the bucket and filling the machine (Linn, W., 2005). Spills can occur during the filling, transferring and/or pouring of the PCE into the dry cleaning machine.

Today, most PCE is delivered to drycleaners in drums, generally in the so-called direct-couple or closed-loop solvent delivery systems. The PCE is pumped directly from the drum into the drycleaning machine. In the past, there have been instances where the drums full of solvent have been dropped or spilled (Linn, W., 2005).

Equipment & Machine Maintenance

PCE can be spilled during the equipment and machine maintenance. These are summarized in Table 53.

Table 53: PCE Spilled during Equipment and Machine Maintenance

PCE Spilled during Equipment and Machine Maintenance	
Spillage Incident During or when:	**Results:**
Filter Change (spent cartridge filters can contain up to 1 gallon of PCE)	Must be drained at least 24 hours. If not, PCE will be spilled when the un-drained spent cartridge filters are removed from the filter cartridge. In the past, un-drained spent filter cartridges were collected and stored outside the dry cleaner's service door. PCE drained directly to the ground or the pavement.
Improperly seated or wrong sized gaskets used.	Solvent discharge from the cartridge filters.
Clean-out of distillation units or muck cookers	• Spills of still bottom (can contain up to 75% of PCE, % by weight) • Spills of cooked powder residues (can contain up to 56%, % by weight).
Servicing of solvent pump (i.e., replacing failed seals or packing; or cleaning out the pump strainer)	

Waste Management

Poor waste management practices can lead to the spillage of solvent contaminated waste from contact water (e.g., separator and mop water), still bottom, cooked powder residues, filters, lint and spotting residues. These are summarized in Table 54:

Table 54: Spillage of Solvent Contaminated Dry Cleaning Wast due to Poor Waste Management Practices

Spillage of Solvent Contaminated Dry Cleaning Waste due to Poor Waste Management Practices	
Type	**Disposal location**
Contact water	• Sanitary sewer • Storm sewer • Pavement • Ground
Still bottom residue	• Storm sewer • Sanitary sewer • Ground • Dumpsters • Trash containers
Spent filters	• Trash containers • Dumpsters

Other Discharges

In addition, other discharges not associated with day-to-day operations can occur. These are summarized below:

- Solvent and solvent contaminated waste spilled during the dismantling of a decommissioned dry cleaning machine.
- Spills during the removal of decommissioned dry cleaning machines.
- Solvent and solvent contaminated waste released during a fire.
- Solvent discharge from a vandalized solvent AST.

Solvent Spills and Discharge Volume

The reported volume of solvent spilled at dry cleaners ranged from a few ounces to over 500 gallons. The largest average spill volume is associated with solvent transfer/storage and equipment failure. But, the greatest number of reported discharges was due to equipment maintenance/operations.

Table 55 below provides a list of reported spills of solvent of 10 gallons or more and their source.

Table 55: Reported Spills of Solvent of 10 Gallons or More and their Source

Reported Spills of Solvent of 10 Gallons or More and their Source		
	Reported Spill (gallons)	**Source**
Solvent storage/Transfer	10	Delivery truck spill
	25	Tanker truck hose coupling failure
	30	Drum spill during solvent delivery
	50	Spill during delivery
	55	Drum of solvent ruptured
	62	Spill near machine
	275	AST hose coupling failure
Equipment maintenance	10	Filter gasket not secured
	10	Filter change
	20	Filter gasket not secured
	25	Filter change
Equipment failure	15	Filter gasket failure
	20	Pipe burst
	20	Hose coupling failure
	100	Filter system failure
	150	Filter gasket failure
Equipment operation	20	Tank overflow
"Other" spills	20	AST vandalized
	110	Recovered from catch basin, origin unknown
	500	Pumped from storm sewer, origin unknown

Conclusion

In 1988, the International Fabricare Institute (IFI) conducted an equipment and plant operation survey. Based on the surveys, over 70% of the dry cleaners in the United States discharged separator water either down the sewer or into a septic system. Despite this fact, the discharge of dry cleaning solvent discharges during solvent transfer, solvent storage, dry cleaning machine and still operation and maintenance may be a more important contaminant source. For example, a solvent leak dripping at a rate of one drop/second results in one gallon of solvent discharged during an 8 hour work day. And, one gallon of PCE contaminating a 200,000,000 gallon drinking water reservoir will result in the MCL of 5 ppb (Hoenig, D.R., 2002).

Based on the results of the Florida study, the soil beneath the floor slab in the vicinity of the dry cleaning machines and distillation units was identified as the most frequently contaminated area. These areas are identified by the presence of coffee-colored stains (due to boil-overs or still bottoms/cooked powder residues spillages during clean-out) on the floor. Additional areas where contamination were detected included: area near the service door where solvent deliveries were received; area where solvents and spent cartridge filters were stored; and areas where solvent contaminated wastes were discharged. The 10 most commonly reported sources of solvent discharges are summarized in Table 56.

Table 56: Ten Most Commonly Reported Sources of Solvent Discharges

Ten Most Commonly Reported Sources of Solvent Discharges	
Solvent Discharge	**Reported Incidents**
Button/lint trap cleanout	15
Still cleanout	15
Still leaks	18
Filter changes	25
Leaking solvent pump	29
Leaking pipers/hoses	28
Leaking door gasket	36
Still boil-over	37
Leaking joint, seal, gasket	41
Solvent transfer	69

The Florida study concluded that sampling activities during contamination assessments to identify contaminant source areas should be focused in the following areas:

- Current/former locations of drycleaning machines and distillation units - both front and back of the machine. Former machine locations can often be identified by the presence of cut off lag bolts (used to anchor the machines) in the floor slab or concrete patches in the floor slab where the lag bolts were formerly located. The presence of coffee-colored stains on the floor denotes the former location of distillation units where boilovers occurred or still bottoms or cooked powder residues were spilled during still cleanouts. When choosing soil sampling locations, for samples to be collected beneath the facility floor slab, look for cracks and expansion joints located near solvent use, solvent storage and solvent transfer areas. These joints and cracks acted as pathways for solvent migration into the soil.
- Current/former solvent storage areas (ASTs & USTs). Find out how solvent is/was delivered to the facility; where it was stored and how it was transferred to the drycleaning machine.
- Area around the service door of facility
- Along sanitary sewer lateral lines, particularly near the junction of the facility sewer line with the sewer lateral.
- Septic tanks/drainfield systems
- Floor drains
- Waste storage/disposal areas. Interview employees regarding disposal practices – especially past disposal practices.

Appendix G: Pollution Prevention Strategies

Over the years, the dry cleaning industry has made major strides in pollution prevention. Several factors have contributed to this trend: occupational health and environmental regulations, the import of state-of-the-art German-made dry cleaning machines, and environmental stewardship initiatives such as Design for the Environment (a voluntary program sponsored by US EPA to work with businesses to incorporate health and environmental concerns/issues into their business plans), etc. In addition, the high cost of PCE has encouraged dry cleaners to improve their pollution prevention strategy. Purchasing smaller quantities of PCE saves money and lowers waste management costs and potential financial liability.

Dry cleaners are required to keep a copy of the manufacturer's operating manual on site and to perform routine maintenance operations. One of the best dry cleaner pollution prevention strategies is to practice "good housekeeping". A few basic housekeeping rules are: inspect dry cleaning machinery often, promptly replace worn or cracked gaskets, store solvents in tightly closed containers, check for leaks and promptly mitigate, store liquids within secondary containment, minimize fugitive emissions, handle waste carefully, remove any lint build-up on steam or cooling cools and keep accurate up-to-date records. Additional pollution prevention techniques recommended by the Department of Toxic Substance Control, the Bay Area Air Quality Management District, the State Coalition for the Remediation of Drycleaners, and others are provided in Table 57. Pollution prevention techniques avoid violations of hazardous materials storage regulations and Air District permit conditions, but more importantly, they are also critical to the prevention of cumulative or sudden releases of PCE to soil and groundwater.

Table 57: Pollution Prevention Techniques

Pollution Prevention Techniques		
Category	**Pollution Prevention Tip**	**Purpose**
Button and Lint Traps	Open the trap doors only during cleaning the button and lint traps (i.e., perform the task as efficiently & quickly as possible).	• To decrease solvent losses through evaporate via the trap doors. • To minimize worker exposure to the solvent vapors.
	Clean lint traps at least once per working day and store lint in a tightly sealed container.	• To prevent clogging the fans and condensers. • To allow efficient drying. • To allow the steam coils to heat to proper temperatures for solvent vaporization. • To allow the cooling coils to condensed the vaporized solvent.
	Clean button trap after each working day and store lint in a tightly sealed container.	• To prevent solvent back-up and possible over-flow onto the floor.

	Inspect gaskets on button and lint traps for cracks. Promptly mitigate, if necessary. Keep traps door securely closed.	• To minimize vapor release. • To minimize worker exposure.
Conservation (i.e., energy and water)	Replace un-lagged and undersized pipes with lagged pipes of proper size to meet production demands and to allow for capacity expansion, if needed.	• To improve energy efficiency.
	Operate equipment over a staggered period of time.	• To reduce peak electricity demands.
	Monitor the drying temperature (i.e., 135°F in the lint traps usually indicates the clothing is dry)	• To converse energy
	Ensure that the temperature rise over the condenser coil is only 10°F	• To conserve water.
Filter Cartridge	Wear personal protective gear (i.e., goggles, Viton gloves, aprons and respirators) when changing cartridge filters.	• To protect worker.
	Filter cartridge should be changed after cleaning between 700 to 1,000 pounds of clothing.	• To ensure that the filter cartridge to remove impurities effectively.
	Drain the filter cartridges for 24 hours in their canisters or 48 hours for adsorptive cartridge filters. Use filter cooker to extract additional solvent. Or, use a cartridge stripper to remove as much as solvent as possible (i.e., more efficient than drainage or filter cooker). Place drained or stripped filter in a tightly sealed container for disposal as hazardous waste.	• To extract as much solvent as possible.
	Replace cartridge filters with spin disc filters	• Last longer than cartridge filters.
Gasket and Seals	Inspect all gaskets at least on a weekly basis. Replace promptly, if necessary (e.g., brittleness or hardening, cracks, gouges, or splintering). • Visually inspect all gaskets (e.g., filter cover and still-	• Routine maintenance will help prevent leaks; • Reduce worker exposure to PCE; • Maintain solvent mileage.

	clean-out-door gaskets) • Use a portable halogenated hydrocarbon detector to check the gaskets (e.g., loading and lint door gaskets).	
Solvent	Monitor solvent mileage, that is, record the amount of clothes washed and the amount of solvent used per week.	• Changes in mileage can indicate leaks in the equipment.
	Size the garment loads according ton the machine’s manufacturer specifications.	• Overloading the machine results in excess solvent in garments and reduces the effectiveness of solvent recovery equipment. • Under-loading the machine decreases the solvent mileage.
	Next to the equipment, post a chart which clearly shows the correct amount of detergents or solvents required per garment or load.	• To ensure the correct amount of solvents or detergent, thereby, reduce the amount used.
	Use low temperature laundering instead of dry cleaning.	• Reduces the use of cleaning solvents.
	Filter the solvent	• To extend the “life” of the solvent.
	Replace hazardous and toxic pre-spotters, if possible, with safer aqueous-type pre-spotters.	• To minimize exposure to workers and customer.
	Pre-wash garments, if possible, to remove dusts and oils	• Increases solvent and filter life.
	Use solvent leak detectors at least on a weekly basis.	• To monitor vapor losses.
Stills and Muck Cookers	Add water to still bottom after final boil down.	• To recover more solvent. • To decrease solvent content in the still bottom.
	Do not operate still and/or muck cookers when contents are greater than 75% of its capacity.	• To prevent boil-over.
	Cool to 100°F or lower before emptying and cleaning the still and muck unit.	• To minimize worker exposure.
	Keep steam coils clean of scale and hardened residues.	• To maximize operating conditions
	Use steam pressures recommended by the	• To maximize operating conditions

	manufacturer.	
	Ensure that the condenser water is on and that the condenser is at the operating temperature when beginning distillation.	• To maximize operating conditions
	Ensure that the condenser water flow is countercurrent to the solvent vapor flow.	• To maximize operating conditions
	Always keep solvent over the coils.	• To maximize operating conditions
	Check steam coils for build-up and cleaned, if necessary.	• To maximize operating conditions
Storage, Dispensing, and Transferring materials	Containers closed with tight fitting lids and bungs when not in use.	• Reduce evaporation spills. • Reduce chance of spills. • Minimize worker exposure.
	Use spigots and pumps for dispensing new materials	• More precise dispensing and less waste. • Reduce chances of spills and splashes.
	Use funnels for transferring wastes to storage containers	• Reduce chances of spills and splashes.
	Use tightly closed containers for collections & storage of new, recovered or spent solvent	• To minimize vapor release. • To minimize worker exposure.
Vapor Recovery Devices	Refrigerated Condensers: • inspect for dust/lint build-up and corrosion at least once per year, clean accumulated dust/lint with a stiff brush or use compressed air to rid; • ensure that the exit air temperature at the end of the cool down; cycle reaches 45°F or below with each load.	• To ensure that the cooling coils are able to condense the vaporized solvent back into a liquid form. • To prevent dirt/lint build-up which can restrict airflow and decrease the amount of solvent recovered. • To prevent dirt/lint build-up which can become acidic and cause tiny pin holes to form in the coil.
	Carbon Adsorbers: • desorb carbon bed & dry at a frequency set by ARB (check that there is proper steam pressure & air flow during desorption) or replace regularly; • attach a carbon adsorber on an induction door fan.	• Must desorb or replaced regularly to prevent PCE breakthrough. • To draw residual levels of PCE within the drum through the carbon adsorber before venting to the atmosphere or workroom.

Miscellaneous	At least one employee has attended an ARB-approved environmental training course for PCE dry cleaning operations.	• To enable dry cleaners to understand and comply with ARB's dry cleaning ATCM. • To be able to operate their facility more efficiently, thus, reducing cost, PCE emissions and worker exposure. • To learn about other pertinent regulations- water, worker exposure, emergency response & hazardous waste disposal.
	Operating equipment procedures are written in clear, concise and understandable language. Translated into the staff's native language, if necessary (i.e., Korean, Spanish, Chinese, etc.)	• Workers can safely operate the equipment.
	At all time, keep all doors, lids, or parts of the dry cleaning machine closed where PCE is kept, except when access is needed during maintenance or repairs.	• To minimize vapor emissions. • To minimize worker exposures.

Sources: Australian DEH, 2002; SCRD, 2002.

As part of the pollution prevention strategy, dry cleaners should maintain accurate and up-to-date operations and maintenance records. Using checklists is one of the most efficient and simple way to accomplish routine operations and maintenance tasks. The CARB provides 5 useful checklists: Pounds of Clothes/Load; Annual Report; Operations and Maintenance Checklist; Weekly Leak Inspection Checklist; and Service and Repair Log. These are available on CARB's website: http://www.arb.ca.gov/toxics/dryclean/etpmanul.pdf. In practice, the tables are tailored to a dry cleaner's specific operations (i.e., dry cleaning machines may have a specific timeline for various maintenance operations).

In addition to dry cleaning, there are alternative "greener" cleaning methods using state-of-the-art technology, such as, wet-cleaning and cleaning with carbon dioxide. Because of growing health, environmental, and regulatory concerns with PCE use, there has been a cooperative effort between the USEPA and the professional garment and textile industry since the early 1990s. At this time, there are limited numbers of professional cleaners offering both services: wet-cleaning and cleaning with carbon dioxide. For a list of wet-cleaners, see http://www.tpwn.org and for carbon dioxide cleaners, see http://hangersdry cleaners.com.

Wet-Cleaning

Wet-cleaning is a specialized cleaning technique that enables trained professional cleaners to wet clean many garments which were traditionally dry-cleaned only (e.g., silks, woolens, linens, suedes, and leather). The main elements to a professional wet-cleaner are: computer-controlled washers and dryers; specialized detergents (that are milder than home laundry products); and trained and skilled staff. Wet-cleaning differs from laundering with water because clothes are cleaned in computerized washers and dryers that can be programmed for various settings such as mechanical action, water and drying temperatures, moisture levels in the dryer and water and detergent volume. And, unlike dry cleaning, the wet cleaning process does not generate hazardous waste, air emissions, greenhouse gases, or ozone depleting gases; thus, compliance with governmental regulations is eliminated (US EPA, 1999).

Carbon Dioxide Cleaning

A dry-cleaning process using carbon dioxide and specialized equipment known as the Micare System was introduced in 1995 by Micell Technology in Raleigh, NC. The Micare system is very similar to a standard front-load PCE dry cleaning machine. It features both a wash and extract cycle, but no heating cycle since this cleaning technology operates at room temperature. Carbon dioxide is naturally occurring and generally a safe compound (i.e., Micare system uses liquid carbon dioxide which is stored under pressure, which can pose a hazard from a pressure standpoint). However, the system has been designed and constructed in accordance with the American Society of Mechanical Engineers code for pressurized vessels and systems; and have met the requirements mandated by the National Fire Protection Association and Occupational Safety and Health Administration (US EPA, 1999b).

The cleaning process is similar to the PCE cleaning one. Instead of PCE, liquid carbon dioxide is the solvent used along with specially formulated detergents. Unlike cleaning with PCE, the distillation fluid produced by the Micare system is not a hazardous waste, thus, compliance with governmental regulations (under the Resource Conservation and Recovery Act) is eliminated. The benefits of the Micare System are: eliminates exposures to PCE, cleans effectively with no unpleasant odors; treats garments gently, eliminates the risk of groundwater contamination from conventional dry-cleaning solvents; and eliminates the time and money that operators must spend to comply with environmental and safety regulations associated with the use of PCE and petroleum.

Appendix I: Water Supply in Santa Clara County

Overview

The Santa Clara Valley Water District is a special district, governed by a seven-member board of directors, and is responsible for water supply, flood protection and watershed management in Santa Clara County, California. The district encompasses all of the county's 1,300 square miles and serves the area's 15 cities, 1.7 million residents and more than 200,000 commuters. The District's responsibilities include: providing high quality water and to manage flood and storm waters along the county's 700 miles of creeks and rivers in an environmentally sensitive manner.

The district supplies water to local water retail agencies, which in turn provides it to their customers. In order to maintain maximum efficiency and flexibility, the District's water supply comes from a variety of sources. Nearly half the water comes from local sources, such groundwater, and more than half is imported from the Sierra Nevada through pumping stations in the Sacramento-San Joaquin River Delta. Both imported water and groundwater is sold to the 13 water retail agencies that supply most of the communities in Santa Clara County.

As the water resource management agency for the entire County, the District provides a reliable supply of high-quality water to 13 private and public water retailers, and to private well owners who rely on groundwater. The District operates and maintains a county-wide conservation and distribution system to convey raw water for groundwater recharge and treated water for wholesale to private and public retailers. The components of this distribution system are described in detail below.

Reservoirs

Local runoff is captured in reservoirs within the County with a combined capacity of about 170,000 acre-feet. The stored water is released gradually for beneficial uses including groundwater recharge, habitat preservation, and irrigation.

Treatment Plants

The District operates three water treatment plants (WTPs) known as Rinconada, Penitencia, and Santa Teresa. These facilities are connected by five major raw water conduits, which also connect the two imported raw water sources from the State Water Project (SWP) and the Central Valley Project (CVP). Two pumping plants (Coyote and Vasona) provide the lifts required for conveyance during peak usage.

Recharge Facilities

The Districts operates and maintains 18 major recharge systems, which consist of a combination of off-stream and in-stream facilities. These systems have a combined pond surface recharge area of more than 390 acres, and contain over 30 local creeks for artificial in-stream recharge to replenish the groundwater basin. The total annual average recharge capacity of these systems is 157,200 acre feet.

Groundwater Basins

The groundwater basin is divided into three interconnected subbasins that transmit, filter, and store water. The Santa Clara Subbasin in the northern part of the County extends from Coyote Narrows at Metcalf road to the County's northern boundary. The Diablo Range bounds it on the east and the Santa Cruz Mountains on the west. These two ranges converge at the Coyote Narrows to form the southern limits of the subbasin (SCVWD, 2001).

The three subbasins serve multiple functions. They transmit water through the gravelly alluvial fans into the deeper confined aquifer of the central part of the valley. Aquifers filter water, making it suitable for drinking and for municipal, industrial, and agricultural uses. They also have vast storage capacity, together supplying as much as half of the annual water needs of the County. In 2000, the groundwater basin supplied 165,000 acre-feet of the total water use of 390,000 acre-feet.

Santa Clara Subbasin

The Santa Clara Subbasin is approximately 22 miles long and 15 miles wide, with a surface area of 225 square miles. The water storage volume is 2½ to 3 million acre-feet and is located approximately 10 to 310 feet below ground surface (bgs). There are three aquifers located in the Santa Clara Subbasin: the forebay, the upper and lower aquifer zones. The aquifers are divided into nine plains (San Jose Plain, West Side Alluvial Apron, Saratoga Upland, Berryessa Alluvial Apron, Evergreen Alluvial Apron, Santa Teresa Plain, Alamitos Alluvial Apron, San Francisquito Cone, and Plain). See Table 58.

The forebay area occurs along the elevated edges of the southern basin in the upper alluvial fan area. The forebay consists predominantly of aquifer material with discontinuous or leaky aquitards. Here groundwater occurs unconfined, or under water table conditions. Within the interior portion of the basin the aquifers sloping from the forebay become distinctively divided into numerous separate aquifers within a predominantly clayey section. The upper aquifer zone encompasses aquifers located from the surface to approximately 150 feet bgs. In this zone, the groundwater is unconfined and leaky due to either the low compaction or discontinuities of the aquitards. The lower aquifer zone includes aquifers located beneath 150 feet bgs. This confined zone is separated by an extensive and thick compacted aquitard that is essentially impermeable (Iwamura, T.I., 1995).

Table 58 provides detailed information on the nine plains (Singh, R., 1987).

Table 58: Detailed information for the Nine Plains Located in the Santa Clara Valley Groundwater Subbasin

Detailed information for the Nine Plains Located in the Santa Clara Valley Groundwater Subbasin

Plains	Zones or Aquifers (ft)	Unconfined Zone (ft)	Confined Zone (ft)	Usage	Well Depths (ft)	Comments
San Jose Plain	0 – 150’; 150’- 350’, 35’0-550’ & > 550’	100’ – 300’	200’ – 500’	In use	12’ – 275’ (U); 125’ – 960’ (C)	None of these zones are completely separated from each other, substantial leakage between zones
West Side Alluvium Apron	500’ - 1,000’	Mostly unconfined.		In use	30’ – 955’	
Saratoga Upland		200’ – 400’ in the west		In use	175’ – 710’	
Berryessa Alluvial Apron		400’ – 500’ (greater thickness in the southern part)		In use	55’ – 816’	
Evergreen Alluvial Apron		500’ – 800’		In use	82’ – 760’	
Santa Teresa Plain		Less than 400’		In use	40’ – 445’	
Alamitos Alluvium Apron		30’ (in the south) – 130’ (in the north)		In use	40’ – 325’	
San Francisquito Cone	400’ (in the north) and > 1,000’ (in the south near the Bay)	Mostly unconfined	Confined in the southwest corner.	In use	15’ – 592’	
Bay Plain		Upper 1000’ is unconfined & highly saline	200’ to 500’ below mean sea level & contains various layers of aquifers underlying the Bay.	Not recommended	N/A	

U = Unconfined Zone. C = Confined Zone. N/A = Not Applicable.

Coyote Subbasin

The Coyote Subbasin extends from Metcalf Road south to Cochrane Road, where it joins the Llagas Subbasin at a groundwater divide. The Coyote Subbasin is approximately 7 miles long and 2 miles wide and has a surface area of approximately 15 square miles. Groundwater level ranges between 16 to 33 feet bgs (Singh). The aquifer is 170 feet thick at the Coyote Narrows to over 500 feet thick at Cochrane Road at the boundary of the Llagas Groundwater Subbasin (Singh). The storage in the aquifer is estimated to be 76,000 acre-feet between depths of 25 to 300 feet (Singh). The subbasin is generally unconfined and has no thick clay layers. The alluvial fill consists predominantly of coarse-grained materials with lesser interbeds of clayey and silty aquitards. This subbasin generally drains in a northwesterly direction into the Santa Clara Subbasin.

Llagas Subbasin

The Llagas Subbasin extends from Cochran Road, near Morgan Hill, south to the County's southern boundary. It is connected to the Bolsa Subbasin of the Hollister Basin and bounded on the south by the Pajaro River (the Santa Clara - San Benito County line). The Llagas Subbasin is approximately 15 miles long, 3 miles wide along its northern boundary, and 6 miles wide along the Pajaro River. The groundwater storage is estimated to be about 300,000 acre-feet between 25 to 200 feet bgs (Singh). A series of interbedded clay layers, which extend north from the Pajaro River, divides this subbasin into confined and forebay zones.

Groundwater Quality

Natural interactions between water, the atmosphere, rock minerals, and surface water control groundwater quality. Anthropogenic (man-made) compounds released into the environment, such as nitrogen-based fertilizer, solvents, and fuel products, can also affect groundwater quality. Groundwater in the Santa Clara Subbasin is generally high quality. Drinking water standards are met at public water supply wells without the use of treatment methods.

A few water quality problems have been detected. High mineral salt concentrations have been identified in the upper aquifer zone along San Francisco Bay, the lower aquifer zone underlying Palo Alto, and the southeastern portion of the forebay area of the Santa Clara Subbasin. Nitrate concentrations in the South County (Coyote and Llagas Subbasins) are elevated and high nitrate concentrations are sporadically observed in the Santa Clara Subbasin. Low levels of perchlorate, an oxidizing salt used in the manufacture of highway safety flares and solid rocket motors, and occurring as a natural constituent of fertilizer and impurity of bleach and chlorate herbicides, have been detected in the Llagas groundwater subbasin. The plume extends ten miles from Morgan Hill to Gilroy. The source of perchlorate is the former Olin Corporation highway safety flare manufacturing plant. Although Santa Clara County is home to a large number of Superfund sites, there are few groundwater supply impacts from the chemicals at these sites; volatile organic compounds (VOCs) are intermittently detected at trace concentrations in a few public water supply wells at concentrations below health and regulatory levels. In four wells, such contamination has been severe enough to cause the wells to be destroyed.

In 2001 and 2002, Lawrence Livermore National Laboratory (LLNL), under contract to the State Water Resources Control Board, completed a vulnerability study of the groundwater basins in Santa Clara County (the GAMA Study, for Groundwater Ambient Monitoring and Assessment). The goal of the study was to provide a probabilistic assessment of the relative vulnerability of groundwater used for public water supply to contamination by surface sources such as dry cleaners. This assessment of relative contamination vulnerability was made based on the results of two types of analyses that are not routinely carried out at public water supply wells: ultra low-level measurement of volatile organic compounds (VOCs), and groundwater age-dating.

PCE was detected infrequently above the ultra-low laboratory reporting limits. Twelve public water supply wells had detections of PCE, 10 of which were less than or equal to 58 parts per trillion (the Public Health Goal, PHG is 58 ppt or 0.06 ppb). The other two PCE concentrations detected were greater than 0.5 ppb (both in public water supply wells in the Llagas subbasin that have previously shown PCE contamination in the 1 to 2 ppb range), but none exceeded the state and federal maximum contaminant level (MCL) of 5 ppb for drinking water. Most of the detections occurred in the forebay area of the Santa Clara subbasin.

VOC analyses conducted for the 2001/2002 GAMA Study show only four solvent detections in the confined zone.. These sporadic detections of VOCs in the confined part of the basin could be due to abandoned wells, or natural geologic features serving as vertical conduits. The widespread absence of VOC detections in the confined zone may be related to groundwater management practices. After severe overdraft, the large volume of recent recharge in the forebay area and continued intense pumping in the confined zone may have induced an upward gradient in the confined zone that inhibits widespread downward contaminant transport. Figures 44 and 45 presents PCE results from the 2001/2002 GAMA Study.

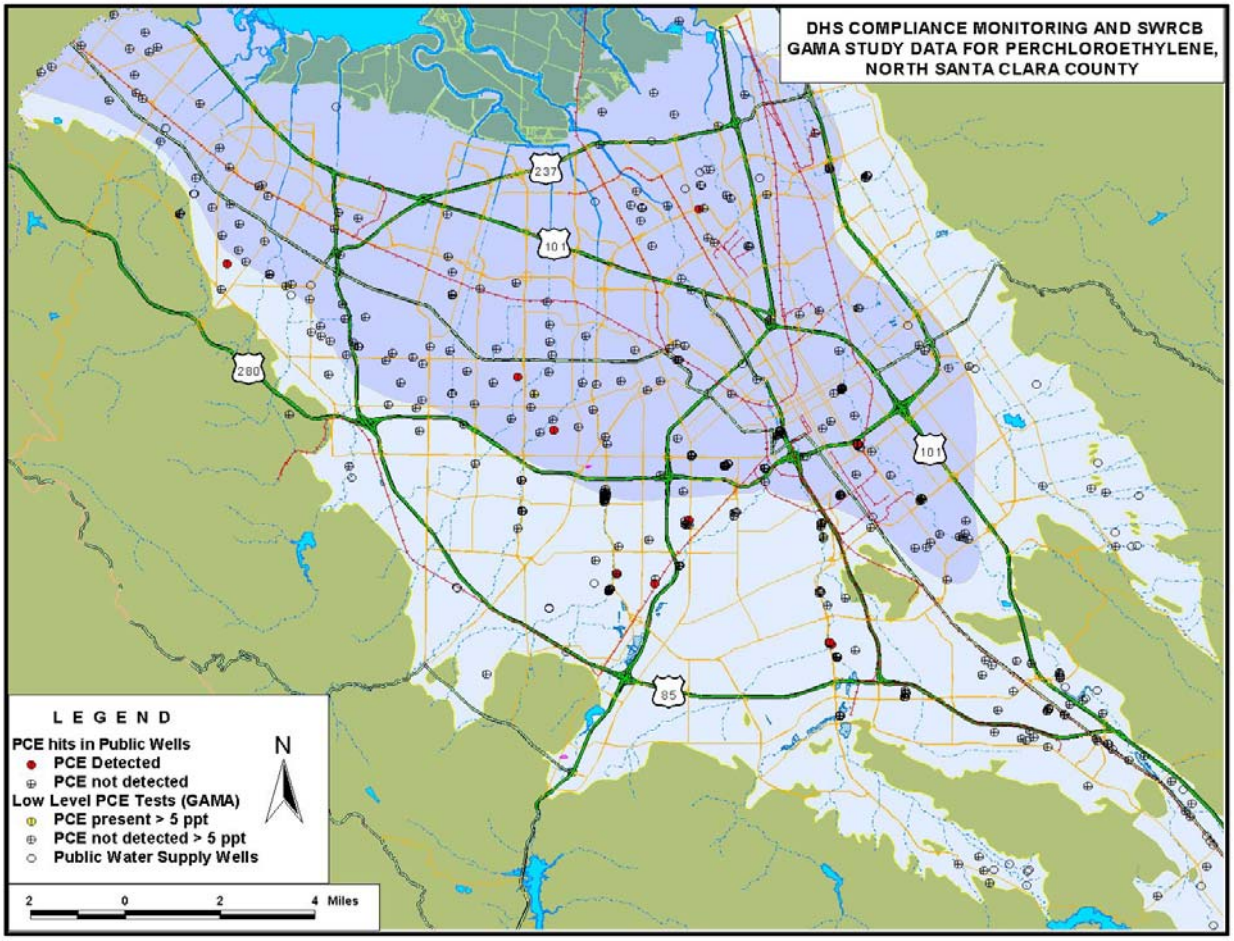


Figure 44 - DHS Compliance Monitoring and SWRCB GAMA Study Data for Perchloroethylene, North Santa Clara County

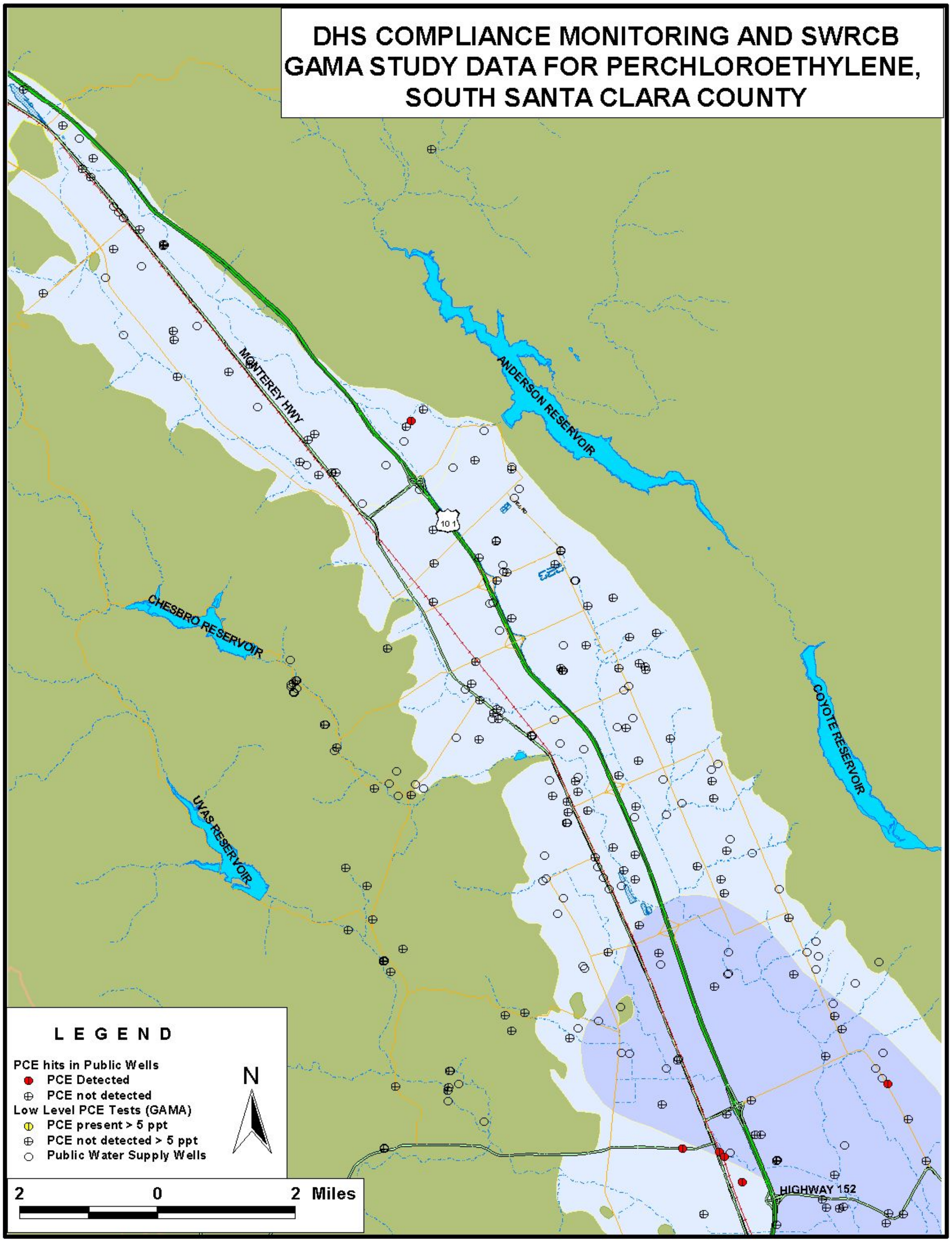


Figure 45 - DHS Compliance Monitoring and SWRCB GAMA Study Data for Perchloroethylene, South Santa Clara County

The District's groundwater protection programs, including its well permitting, well destruction, former leaking underground storage tank oversight program, and the solvents and toxics liaison program have been effective in protecting the groundwater basin from contamination.

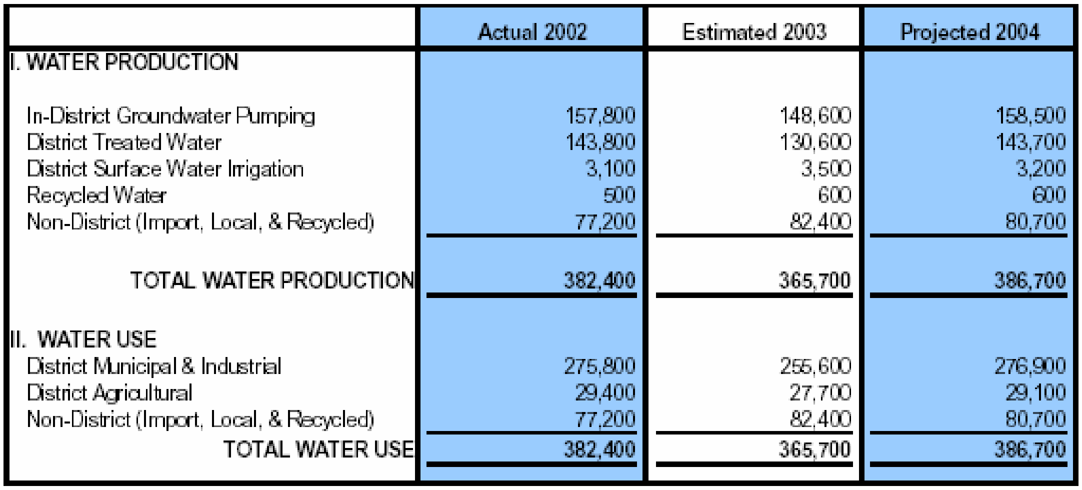
Water Supply from the Santa Clara Groundwater Basin

Since the 1930s, the Santa Clara Valley Water District has managed groundwater basin in Santa Clara County. The District conducts numerous groundwater management programs and works in conjunction with local retailers, the Regional Water Quality Control Board, and other agencies to manage the basin and to ensure a safe and healthy supply of groundwater.

Groundwater is critical to the water supply needs of Santa Clara County, and the District's success at managing the groundwater supply is critical. Increased demands and the possibility of reduced imported water in the future make effective and efficient management of the groundwater basin essential. The mission of the District is a healthy, safe, and enhanced quality of living in Santa Clara County through watershed stewardship and comprehensive management of water resources in a practical, cost-effective, and environmentally-sensitive manner. The goal of the District's groundwater management efforts is to ensure that all groundwater resources are sustained and protected for current and future beneficial uses.

In 2002, the groundwater basin supplied nearly half of the total water used in the County (382,400 acre feet (AF)). Table 59 presents a summary of in-county water demand.

Table 59: Santa Clara County Water Demand



	Actual 2002	Estimated 2003	Projected 2004
I. WATER PRODUCTION			
In-District Groundwater Pumping	157,800	148,600	158,500
District Treated Water	143,800	130,600	143,700
District Surface Water Irrigation	3,100	3,500	3,200
Recycled Water	500	600	600
Non-District (Import, Local, & Recycled)	77,200	82,400	80,700
TOTAL WATER PRODUCTION	382,400	365,700	386,700
II. WATER USE			
District Municipal & Industrial	275,800	255,600	276,900
District Agricultural	29,400	27,700	29,100
Non-District (Import, Local, & Recycled)	77,200	82,400	80,700
TOTAL WATER USE	382,400	365,700	386,700

Appendix J: Groundwater Vulnerability

Unconfined Aquifers

The upper aquifers in all three groundwater subbasins are sensitive to accidental, incidental or intentional contamination because they are unconfined; however, drinking water production in most part of the subbasins is from deeper aquifers that are generally isolated from surficial contamination by one or more confining clay layers, or aquitards. The lower aquifer zone within the interior portion of the Santa Clara Valley and the southern portion of the Llagas subbasin are under confined conditions and produce artesian wells under some wet season conditions.

In the unconfined forebay, accidental hazardous materials spills of sufficient volume can leach directly into the groundwater. Depth to groundwater is relatively shallow over most of the forebay, within 50 feet below ground surface (feet bgs). Stratification in the forebay is usually not well defined, and permeabilities are relatively high. Contaminants can potentially migrate laterally from the forebay toward the basin interior into both the upper aquifer zone and the confined lower aquifer zone.

In the Santa Clara Valley basin interior, the upper aquifer zone encompasses shallow aquifers at depths between 30 to 150 feet bgs. Much of the area within this zone is covered by a clay horizon of varying thickness, usually about 20 feet. Semi-perched groundwater often occurs within the clay cap. As noted in past studies, the clay horizon and intervening aquitards that separate the individual aquifers within the upper aquifer zone are leaky. Thus, past contaminant spills over the upper aquifer zone have quickly migrated and contaminated the various aquifers in that zone.

Most of the Coyote and Llagas Subbasins are unconfined. For both subbasins, the depths to groundwater are also fairly shallow. The groundwater level ranges between 16 to 33 feet bgs for the Coyote subbasin. For the latter, the groundwater ranges between 25 to 200 feet bgs. Contaminants spilled within either subbasins can easily migrate downwards and adversely impact both subbasins.

Vertical Conduits

Vertical conduits are pathways that allow groundwater to move between a shallow water-bearing zone and a deeper water-bearing zone or vice versa. Vertical conduits can be manmade (abandoned wells, improperly sealed wells, elevator shafts, or hollow piles, for example), or they can be naturally occurring (root holes, facies changes, or liquefaction-caused structures, for example). This discussion focuses on understanding the nature of vertical conduits, locating and mitigating their effects, and how searches for these conduits are conducted. Pollutants that contaminate shallow groundwater may have found their way into the deeper drinking-water zones through various vertical conduits.

Manmade Conduits

Water Wells. A well that penetrates more than one aquifer may allow water from one aquifer to contaminate another aquifer if the well is not properly constructed or was constructed before current well standards were established. Water may leak along the outside of the well casing if the well is not properly sealed, or the casing may deteriorate and develop holes that allow water and chemical movement inside the casing. As a result, water from one aquifer can mix with one or more other aquifers. A very small amount of contaminated or low-quality water can degrade a very large volume of clean groundwater to the point that it no longer meets drinking-water standards. Intra-borehole flow is another cause of transmitting shallow contamination to deeper aquifers. Intra-borehole flow describes flow from a shallow perforated zone within a production well either during pumping, or when the well is turned off.

Water supply wells constructed to modern standards may be screened across multiple deep water-bearing zones. If shallow contaminated groundwater can affect even the shallowest of these screened zones through manmade or natural conduits, then even a properly constructed water supply well can act as a vertical conduit to transport contaminants. In addition, although not typical, vertical conduits can allow movement of contaminated deeper water to migrate to less-contaminated shallow water. An example of this occurs is the Evergreen Area in the Santa Clara subbasin, where drilling deep wells could pierce areas of highly saline connate water under pressure, which could rise into and contaminate overlying aquifers.

Rapid urban expansion has taken place in the South Bay study area. Unfortunately, many agricultural and domestic wells up to 100 years old have been built over with no record of proper destruction. These lost wells are likely to be screened across several water-bearing zones and to have rusted or otherwise-damaged steel casings. In downtown San Jose, redevelopment or new construction projects commonly uncover three to five wells for each recorded well. Identification and proper destruction of these potential conduits is critical in any groundwater protection program.

Notable examples of abandoned wells that have led to cross-aquifer contamination are the IBM Superfund site (San Jose) and the Middlefield-Ellis-Whisman Superfund site (Mountain View). Solvents released at these facilities contaminated municipal wells to a depth of 510 feet. Fate and transport studies have shown that the mechanism for the vertical movement of contaminants was through improperly abandoned wells.

Cathodic Protection Wells. Most large manufacturing facilities, tank farms, and pipelines have some sort of cathodic protection wells. Although California does have well standards for the construction of these wells, these standards mainly protect against the introduction of water from the surface. Cathodic protection wells typically have shallow seals without casing and are not properly destroyed at the end of their useful life. Cathodic protection wells generally have not been constructed to prevent cross-aquifer contamination from occurring, especially at older facilities. It is imperative that the locations and construction logs for cathodic protection wells be incorporated into the wells database. Many cathodic protection wells were never located on well maps. State well numbers may not be assigned to older cathodic protection wells.

Structural Pilings. Structural pilings for large projects, such as bridges and high-rise buildings, may penetrate aquitards between shallow and deeper water-bearing zones. The Uniform Building Code and the S.F. Bay Regional Water Quality Control Board have guidelines to prevent pilings from acting as conduits between the water-bearing zones, but they are not yet part of standard construction techniques. This issue is of particular importance in urban areas. Because of the move to redevelop inner cities via brownfields initiatives, construction projects will inevitably encounter residual soil and shallow groundwater contamination.

Naturally Occurring Vertical Conduits

Stratigraphy. Stratigraphic or facies changes play an important part in the vertical transport of groundwater and its associated contaminants. Discontinuous and leaky aquitards are common in the heterogeneous alluvial sediments of the study area. A relatively impermeable silt or clay layer may change laterally, in a matter of yards, into a more permeable silty sand or sand. For example, a paleo-stream channel may have eroded through low-permeability strata to connect two higher-permeability strata. Continuous core from drilling, along with hydrogeologic data from the site and from nearby sites, are necessary to evaluate the potential for stratigraphic pathways and are a vital part of any contaminant-transport study, especially near public water supply wells.

Root Holes. It is not uncommon to find root hole features in paleosols cores taken up to 100 feet below the surface. These root holes provide unhindered access for shallow groundwater to reach deeper water-bearing zones. Before the introduction of non-native grasses to California landscapes, California native bunch grasses had root systems up to 27 feet long to take advantage of a fluctuating water table. Few of these grasses remain in California today, but their legacy is apparent in the root holes seen in deeper sediments than today’s grass roots can reach.

Liquefaction-caused Structures. Liquefaction, a phenomenon that takes place during earthquakes, causes sand boils (venting) and lateral-spreading fissures. These features generate sand bodies that short-circuit across finer-grained, low-permeability materials. Sand boils cause an irregular feeder pipe of sand from the liquefied zone up to the ground surface at the time of the earthquake and deposit a circular or oval sand body up to a few feet thick. These structures will be repeated through the stratigraphic sequence and can connect permeable zones, allowing substantial vertical migration of contaminants. Lateral spreads cause fissures that then fill (or partially fill) with upwelling sand from the liquefied zone. Lateral-spreading fissures as long as 650 feet have been observed. The sand-filled fissure can intercept a significant width of a contaminant plume and move it downward as much as 50 feet.

Santa Clara Valley Water District’s Well Search Program

The District has a fairly comprehensive wells search protocol. It has a GIS-based database of all known wells, including active, inactive, and destroyed supply, monitoring, and cathodic protection wells. The responsible party must complete the vertical conduit study with an air photo search; careful review of historical publications, documents, and maps; and a house-to-house canvass for existing unregistered wells.

Appendix K: The DRASTIC Spatial Index of Groundwater Sensitivity

AN ANALYSIS OF THE SENSITIVITY TO CONTAMINATION OF THE SANTA CLARA VALLEY GROUNDWATER AQUIFERS BASED ON THE USEPA DRASTIC METHODOLOGY

By:

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December 1999

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December 1999

TABLE OF CONTENTS

ABSTRACT **1**

INTRODUCTION **1**

METHODOLOGY

Overview 2
Depth to Water layer **3**
Recharge of Groundwater Layer **4**
Aquifer Media **4**
Soil Media **5**
Topography **5**
Influence of the Vadose Zone **6**
Hydraulic Conductivity **7**

RESULTS **7**

DISCUSSION **7**

CONCLUSIONS & RECOMMENDATIONS **8**

REFERENCES **9**

TABLES

Table 1: DRASTIC Rating and Weights 10

FIGURES

Figure 1: Groundwater Sensitivity Map
Figure 2: Depth to Groundwater
Figure 3: Recharge
Figure 4: Aquifer Influence
Figure 5: Soil Influence
Figure 6: Topography Influence
Figure 7: Vadose Protection Potential
Figure 8: Hydraulic Conductivity
Figure 9: Salt Water Intrusion

ABSTRACT

Approximately half the water used in Santa Clara County (County) is groundwater. Many areas in the groundwater basin are assumed to be highly sensitive to contamination, but a basinwide, comprehensive quantitative comparison of the relative sensitivities of these distinct groundwater areas has not previously been performed. The inconsistent level of knowledge of groundwater sensitivity throughout the County probably leaves large sensitive portions of the basins with little or no oversight or protective measures. Using a geographic information system (GIS), the United States Environmental Protection Agency's (USEPA) DRASTIC methodology was employed to develop a numerically-based map of the sensitivity of areas in the County’s groundwater basins to contamination. This map is an amalgam of the seven principal parameters that affect water and contaminant movement to and within aquifers. It, therefore, can represent the potential for pollution movement from the surface to potable groundwater. The seven parameters are Depth to water (dtw), net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity of the aquifer. These seven factors form the acronym DRASTIC.

The DRASTIC map created by this project provides information on the sensitivity of the groundwater to contamination originating at the ground surface. This map covers each of the groundwater subbasins at a resolution of approximately 50 acres. By using a GIS to layer a reference map over the DRASTIC map, a location of interest can be identified and the relative pollution sensitivity of that area in the groundwater basin can be instantly determined. In using this map, one must keep in mind that it represents relative sensitivity; it does not indicate the absolute sensitivity of any area. To validate the DRASTIC map and determine its real world usefulness, areas in the map were compared with several areas of known sensitivity. This comparison shows that the map appears to represent basin sensitivities accurately and should, therefore, be useful in depicting areas of high sensitivity. The map thereby highlights areas where groundwater protection efforts are needed and will help Santa Clara Valley Water District (District) staff focus on those areas. It will also be useful to planners when they review development proposals. As an additional benefit of this project, many individual GIS data layers were obtained or created that are useful in and of themselves.

INTRODUCTION

About half the water used in Santa Clara County comes from groundwater. All of the water used in southern Santa Clara County is derived from groundwater. These groundwaters are pumped primarily from alluvial confined and unconfined aquifers. Both types of aquifers, but especially the unconfined aquifers, are sensitive to contamination from activities on the land surface. Unconfined aquifers have little natural protection from surface contamination since a significant aquitard (low permeability zone) is not present above them. The confined aquifers are sensitive to contamination due mainly to the presence of poorly constructed wells and abandoned wells. The poorly constructed wells, those with inadequate seals or with perforations above and below the major aquitard, and abandoned wells act as conduits capable of carrying contamination past the aquitard to the drinking water aquifers. The threat posed by abandoned wells cannot be overstated since thousands of them are thought to exist in the County at unknown locations.

Activities which threaten groundwater quality include fuel storage, dry cleaning, solvent storage, auto repair, and agriculture. Any activity using synthetic or refined organic chemicals threatens groundwater quality. Most organic chemicals are soluble to some degree in water, some are highly soluble. These chemicals either leach directly to the groundwater aquifer or they dissolve in infiltrating water which then carries them to the aquifer. Agriculture contributes nitrates, fertilizers, pesticides, and fecal material to the aquifers, though the fecal material is usually broken down before it reaches a well. These agricultural contaminants are very water soluble and travel relatively quickly to the aquifers. Rural development also poses threats to groundwater quality and these threats may differ from the prior agricultural based threats.

Although much is known about the County's groundwater basins and how to protect the groundwater from contamination, questions still exist about the relative sensitivity of many areas. There are areas in the County that have been the subject of various hydrogeological studies and other areas that have received little or no analysis. Also, few of the areas studied have received similar types of analysis. This lack of a uniform and in-depth study of the entirety of each basin leaves the question of the sensitivity of some areas in the basins unanswered.

The goal of this study was to create a numerically-based map depicting the relative sensitivity of the groundwater to surface and near surface contamination for any area in the groundwater basins. The USEPA DRASTIC methodology is particularly well suited for this task. DRASTIC uses generalized subregional data which is relatively easy to obtain. It also assumes that the contaminants move with water, which is a worst case scenario. Major drawbacks to using DRASTIC are its inability to be used at the site level and the number of assumptions required at each step. The sensitivity map thus created is most applicable to water soluble contaminants such as nitrate and Methyl tert-Butyl Ether, though, by the mechanism described earlier, it is usable for most organic chemicals as well. The final map provides new information to aid in groundwater protection efforts.

Sensitivity, as used in this document, refers to how well an aquifer is protected from surface contamination based on its intrinsic, or hydrogeologic characteristics. Vulnerability, which is another common term, takes into account both the sensitivity of an aquifer and the potentially contaminating activities occurring at the land’s surface. DRASTIC is concerned solely with aquifer sensitivity.

METHODOLOGY

Overview

The final map in Figure 1, showing the sensitivity of the groundwater to surface contamination, was created by combining the values of seven pertinent hydrogeological parameters. These parameters are (1) Depth to groundwater, (2) amount of Recharge, (3) Aquifer media type, (4) Soil type, (5) Topography (slope), (6) Influence of the vadose zone, and (7) hydraulic Conductivity. Each of the seven parameters is represented in an individual GIS layer. Rating values are assigned to each subarea in the layers based on recommendations in the DRASTIC guidance document (USEPA, 1987). Then the values in each layer were multiplied by a weighting factor also recommended by the DRASTIC guidance document, see Table 1. To create the final map, a GIS was used to combine the various weighted values of these polygon (area) layers for all points in the groundwater basins. The creation of each of the seven initial layers will be described individually in the following sections.

Depth to Water Layer

Rationale

The depth to water is important because it determines the distance a contaminant must travel to reach groundwater. This distance indicates the amount of contaminant attenuation possible prior to it reaching the aquifer. The dtw layer, shown in Figure 2, was created from the depth to first water records for leaking underground storage tank (UST) cases as reported to the District's Leaking Underground Storage Tank Oversight Program (LUSTOP). This data is stored in LUSTOP's Felix database. This data was used for both the confined and unconfined aquifer zones. The depth to first water is the suggested data for use in the unconfined zones. However, for the confined zones, the DRASTIC manual suggests using the top of the aquifer as the dtw. We decided to use the depth to first water for confined aquifer areas as well because the prevalence of abandoned wells in the confined zones may effectively connect the shallow first water to the deeper drinking water.

Method

Leaking UST site location and dtw data was downloaded from the Felix database in May 1999. Initially, all of the sites with dtw information were plotted in the GIS as points. Then, for clusters of sites where the sites were closer than about 500 feet, the site with the smallest dtw was chosen and the other sites were deleted so they would not be included in the analysis. This filtering of the data was required because there are frequently large, greater than 50 feet, differences in the dtw between neighboring fuel leak sites. When dtw contours are generated with unfiltered data, the resulting contours have many unrealistically steep gradients. For the readers information, the differences in dtw between adjacent sites are due to water depths being measured at different times, the construction of the wells being different, or the geologic differences between the sites.

Contours, or more precisely depth ranges, were then generated using Arc/Info's TIN and GRID modeling programs. TIN was first used to create a network of lines and surfaces connecting each point to its nearest neighbors. A grid was then created, using GRID, from the tin layer. This grid had a grid spacing of 100 feet to provide adequate smoothness of the final layer for typical uses of the map. This method of going from points to tin to grid reduces the number of anomalous contours created by GRID in areas with sparse data. Then GRID was used with the range option to create polygons representing the ranges of depths specified in the DRASTIC manual, see Table 1. This range layer was then screened and edited by hand to eliminate any anomalous polygons which were created. Finally, the DRASTIC ratings and weights were applied to each depth range based on the values in Table 1.

Recharge of Groundwater Layer

Rationale

Recharge, actually net recharge, is the total amount of water that reaches the aquifer. It equals rainfall less runoff, evapotranspiration, and waters retained by the soil. The amount of groundwater recharge is important because it is recharge from precipitation that is the dominant vehicle carrying the contamination from the land surface to the aquifer. The groundwater recharge layer, shown in Figure 3, was created by combining the average rainfall for Santa Clara County with a land use map for the County from the Association of Bay Area Governments (ABAG). The rainfall map was originally developed by Mr. Abdullah Saah, of the District, and was digitized for this project. The ABAG map shows land use and land cover down to the parcel level and was augmented with storm water retention values that were based on the land use or cover. We did not take into account evaporation, transpiration, or soil wetting in this study. This minor deviation from the suggested guidance was made because rainfall here is concentrated in the four months of December, January, February, and March and there is little evapotranspiration during this cold time of year. Also, evapotranspiration does not vary greatly (+/- ½ inch, Pruitt et.al. 1984) across the valley and, therefore, trying to pinpoint an exact value for every point in the basins would be very time consuming without a concomitant improvement in map accuracy.

Method

The average rainfall map was first digitized using Arc/Info and our digitizing board. Each contour line was digitized using sufficient nodes to accurately represent its general shape. A polygon layer was generated from the lines and then labels of rainfall range, in inches, were added as a descriptive attribute. For land use and cover, a digital copy of ABAG's map for Santa Clara County was obtained from ABAG. This map contains the County's land use codes for each parcel. Rainfall retention attributes were then added to each polygon. The value added was determined by the land use code that can be used to estimate the percentage of land covered with impermeable material. The rainfall retention factors range from 0.2 (20 percent) to 0.8 (80 percent) (Rau and Wooten, 1980). Finally, the rainfall and land use layers were combined using Arc/Info and the appropriate ratings and weights were added from Table 1, to create the polygons shown in Figure 3.

Aquifer Media

Rationale

Aquifer media is the type of rock that makes up an aquifer, that unit of the subsurface that can yield usable quantities of water. The aquifer media type is important because it provides an indication of the path length a contaminant must travel once it reaches an aquifer. This in turn signifies the contact time a contaminant has with the media prior to reaching a well and, therefore, the attenuation potential. All of the significant aquifers in the Santa Clara County groundwater basins are of the sand and gravel type. These individual aquifers differ in the size distribution of their media and how well washed they are of fine-grained clay and silt. The hydrographic unit GIS layer, described in the Hydrographic Unit Delineation Report (Parton, 1996), provides outlines of these distinct aquifer units and descriptions of the geologic material in the aquifers in each unit. The aquifer media layer shown in Figure 4 was created by combining the general aquifer type with information on individual hydrographic units.

Method

The DRASTIC rating for sand and gravel aquifers provides a range of rating values to use based on how clean an aquifer is and its predominant particle sizes. This range is from four to nine. To determine the value to use for a particular subarea, the Hydrographic Unit Delineation Report was consulted. Values from its Table 1 were assigned to each polygon subregion in the hydrographic unit GIS layer, based on the description of that subregion in the report. Lines between regions assigned the same values were dissolved, leaving larger polygons. These polygons now represent the different aquifer subregions, forming the aquifer media layer.

Soil Media

Rationale

Soil media refers to that portion of the earth that is generally within six feet of the surface. Soil significantly effects the rate and amount of recharge and the rate of contaminant movement from the surface to groundwater. Some soils have high organic content causing some contaminants to adsorb to the soil, thus limiting the contaminant's movement and allowing more biochemical degradation of pollutants. Other soils may be rich in clays, which again limit contaminant movement. Still others may have little organic or fine-grained materials, allowing rapid movement of contaminants to the aquifer. The soil media layer in Figure 5 is derived from a Soil Conservation Service map.

Method

A digitized copy of the soil map developed by the United States Soil Conservation Service was obtained from District files. The soil classifications were analyzed and rating values from Table 1 were assigned to each area based on best professional judgment. The boundaries between areas with the same ratings were dissolved, leaving the final layer.

Topography

Rationale

Topography refers to the slope of the land surface. Topography is important in determining pollutant infiltration potential because it greatly influences whether or not water or a pollutant will run off or sit on a particular spot long enough to infiltrate the ground. The topography layer in Figure 6 is the result of processing United States Geological Survey (USGS) Digital Elevation Models (DEM). These are 30-meter DEMs which means that the points defining elevations are 30 meters, or about 100 feet, apart. This level of accuracy, aside from it being the most accurate available at the time, is appropriate for this type of study since this study will not provide site level information.

Method

DEMs from the USGS were used to create the topographic layer. Separate DEMs were obtained from the USGS web site, each having elevation points 30 meters apart. They were joined to create one large DEM for the County. Arc/Info was then used to create the slope layer. Lastly, ratings for each percentage of slope were added as an attribute based on values in Table 1.

Influence of the Vadose Zone

Rationale

The vadose zone is the unsaturated material between the ground surface and the aquifer. It generally includes the soil zone. Nevertheless, the soil has effects distinct from the rest of the vadose zone and so was considered separately. The type of vadose media determines its contaminant attenuation characteristics. Biodegradation, filtration, chemical reactions, volatilization, and dispersion are processes that may occur in the vadose zone. Santa Clara Valley groundwater basins consist of principally two types of vadose materials, those that inhibit vertical water movement and those that allow relatively free movement of water from the surface. The confined areas are dominated by clay aquitards that effectively prevent significant vertical water movement. The area of relatively free water movement, the forebay, is considered unconfined and is represented by interbeded layers of gravels, sands, silts, and clays. The silt and clay layers in the forebay are generally discontinuous and do not provide important confining properties to the aquifer. Since the forebay areas vary greatly from one point to another, bore hole information was used to define and subdivide these areas. The vadose layer is shown in Figure 7.

Method

The confined zones are reasonably well defined and, accordingly, these boundaries were used in the DRASTIC analysis. All that was required for the confined zones was the assignment of the rating factor for confined aquifers. The unconfined zones were first determined by subtracting the confined zones from the entire groundwater basin. Then this area was further subdivided by using geologic information from well logs in these areas. These logs provided details on the thicknesses of high and low permeability materials in the immediate areas of the wells. The features of the predominant or controlling vadose material were added to the well attribute table of the Allwells well GIS coverage. The controlling material would be clay if there was a significant, generally greater than 10 feet thick, clay deposit that would restrict water movement. If little clay or silt were present, meaning no 10 feet thick or thicker silt or clay zones, then the area would be defined as having a relatively porous vadose material. Theissen polygons were created around each well in the unconfined zones and assigned values based on the controlling geologic parameter. Then Arc/Info was used to dissolve the boundaries between adjacent polygons with the same values as assigned to the areas based on Table 1. Finally, the confined and unconfined zones were joined to create one vadose layer.

Hydraulic Conductivity

Rationale

Hydraulic conductivity is a measure of the ability of a geologic formation to transmit water. It is important in this study because the rate at which water flows controls the rate at which contaminants also flow. The hydraulic conductivity layer is shown in Figure 8.

Method

The hydraulic conductivity for the North County aquifers was determined by CH2MHill in1992 as a part of their development of the District's groundwater model (CH2MHill, 1992). The conductivities of the South County aquifers were determined by associating them with similar aquifers in the North County. By using the hydrographic units information (Parton, 1996) and consulting with District geologist Mr. Tom Iwamura, areas in the South County were defined. Then similarities between areas in the North and South County were identified. Areas in the south were then assigned the conductivities of the corresponding areas in the north. Lastly, values from Table 1 were assigned to each conductivity zone.

RESULTS

The final DRASTIC map is shown in Figure 1. Several areas in the County of known sensitivity were compared with the sensitivity portrayed in the final map and in each case the map agreed with what is known about the groundwater sensitivity in that area. The Great Oaks/Santa Teresa area is known to be highly sensitive and the map shows them as such. The western forebay of Los Altos, Mountain View, and Cupertino are known to have low sensitivity due to deep groundwater and the map agrees with this knowledge. The map also confirms that the areas in the County with large toxic contamination problems also have highly sensitive groundwater while low sensitivity areas do not have large scale contamination.

Areas in the northern confined zone along Coyote Creek, where saltwater intrusion has occurred, see Figure 9, were compared to the sensitivity map. These areas are assumed at first glance to have low sensitivity due to the confining layer. But when the presence of thousands of unknown abandoned wells is factored in, this northern area then has many highly sensitive areas, since the saltwater contamination is due to abandoned wells. That these areas, which are intruded with saltwater, actually are highly sensitive reinforces the decision to use the depth to first water in these confined zones.

DISCUSSION

This map has a higher resolution than the strict DRASTIC methodology maps due to the use of GIS and high resolution base data. The map is applicable to areas greater than 50 acres. Of all the factors used to create the final map, the vadose zone and the dtw have the greatest effects on the ratings. This is because they have larger weighting multipliers than the other factors. The vadose zone layer was created from well accepted geologic data with little subjectivity involved. The dtw layer in the confined zone uses the depth to first water and not the depth to the bottom of the aquitard. This was done to account for both the presence of unknown abandoned wells and for wells with multiple screens that may interconnect aquifers. Another approach could have been to use the District's abandoned well GIS layer and draw buffers around the wells with no or unsatisfactory sealing. Then only these buffered areas would use the depth to first water and the other areas in the confined zone would use the depth to the bottom of the aquitard. Because there are an unknown number of abandoned wells in unidentified locations, the safest approach is to assume these wells are ubiquitous and raise the sensitivity of the entire area.

Limitations to the map include accuracy at its periphery, at internal boundaries, and the usable resolution. At the edges, from the edge to about 1000 feet into the map, the map may not have sufficient justification for the designated sensitivity. This is due to the probability that the base data was extrapolated from a point up to 1000 feet from the edge. Regarding adjacent areas with different sensitivities, sites in areas with lower sensitivity near the border of high sensitivity areas should be considered to be in the higher sensitivity area and given heightened scrutiny. The practice of using the higher sensitivity near borders is needed because the 50-acre resolution limit of the map creates an inherent inexactness in the locations of the boundaries between different zones.

The DRASTIC map cannot be used to replace site-specific investigations. This is due to the regional character of the base data from which the map is derived. It does highlight areas that are sensitive, but even areas with lower indicated sensitivity should be investigated on a site basis to verify their suitability to particular potentially contaminating activities (PCA).

CONCLUSIONS AND RECOMMENDATIONS

Pollution prevention is a prerequisite to the availability of sufficient quantities of potable water. The groundwater sensitivity map created by this work provides essential information on groundwater protection needs to District staff, water retailers, and to city and county planners. The map accurately contrasts the more and less sensitive areas in the County and should be used during the review of development plans. By comparing the current knowledge of the basins to information in the map, the map also highlights areas in the County where further groundwater study may be needed. Finally, since the map shows sensitive areas, it will be instrumental in the development of source water protection areas.

This map should be presented to city and county planning departments to educate their members on the sensitivity of groundwater in the hope that they will direct new PCAs to less sensitive areas. These presentations should include the locations of wells, hazardous material storage tanks, major roads, and other potential contaminant sources to show how vulnerable the groundwater is. Also, undeveloped areas, such as north Coyote Valley, could be overlaid on the map to identify zones that should have restricted types of development.

The finalized groundwater sensitivity map based on the DRASTIC methodology is available for use with GIS. It is located on the District's GIS server under groundwater protection.

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TABLE 1

DRASTIC RATINGS AND WEIGHTS

1. Depth to Water (ft.)

Range	Rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
71-100	2
>100	1

2. Recharge (in)

Range	Rating
0-2	1
2-4	3
4-7	6
7-10	8
>10	9

3. Aquifer Media

Type	Rating
Sand & Gravel	4-9

4. Soil Media

Type	Rating
Gravel	10
Sand	9
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Massive Clay	1

5. Topography (%)

Range	Rating
0-2	10
2-6	9
6-12	5
12-18	3
>18	1

6. Vadose Zone Media

Type	Rating
Silt/Clay	2-6
Sand & Gravel with fines	4-8
Clean Sand & Gravel	6-9

7. Hydraulic Conductivity(gpd/sqft)

Range	Rating
1-100	1
100-300	2
300-700	4
700-1000	6
1000-2000	8
>2000	10

DRASTIC Weightings

Rating x Weight =

1. ____ x 5 =
2. ____ x 4 =
3. ____ x 3 =
4. ____ x 2 =
5. ____ x 1 =
6. ____ x 5 =
7. ____ x 3 =

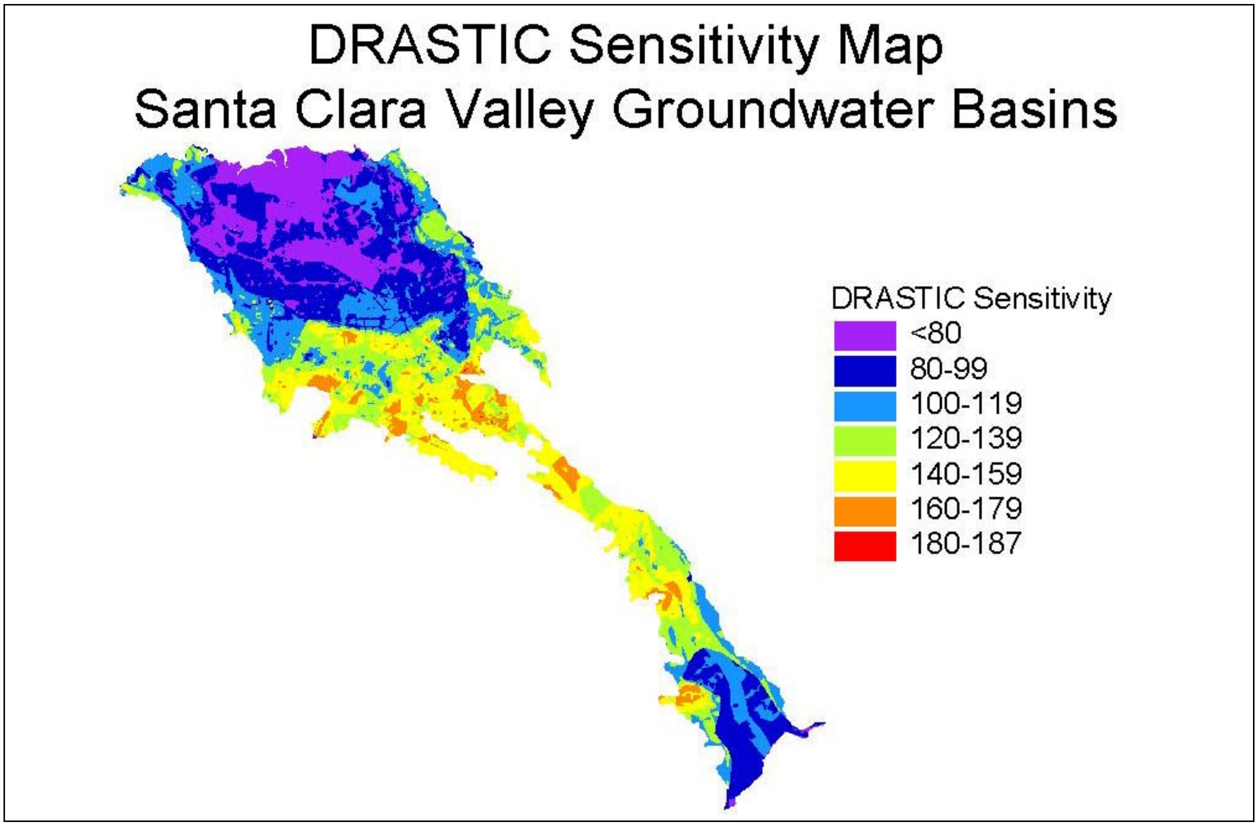

Figure 1 – Groundwater Sensitivity Map

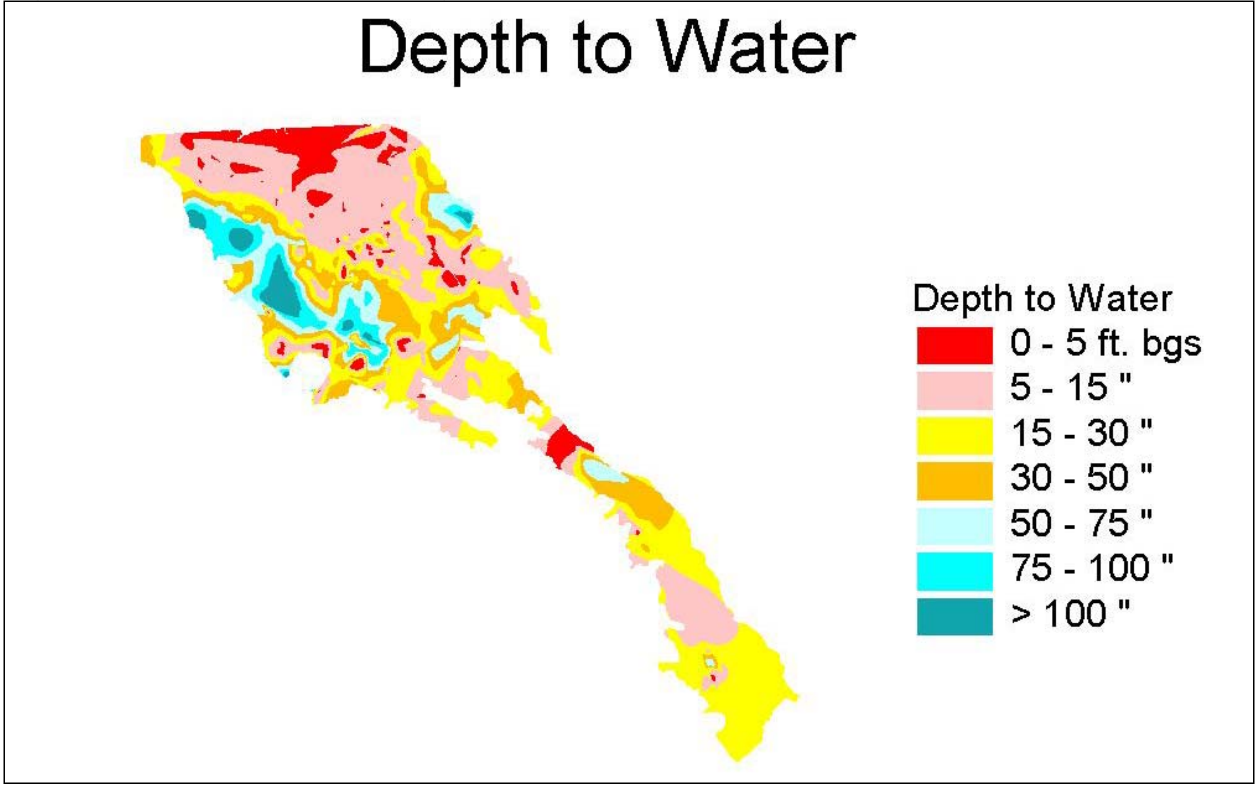

Figure 2 – Depth to Groundwater

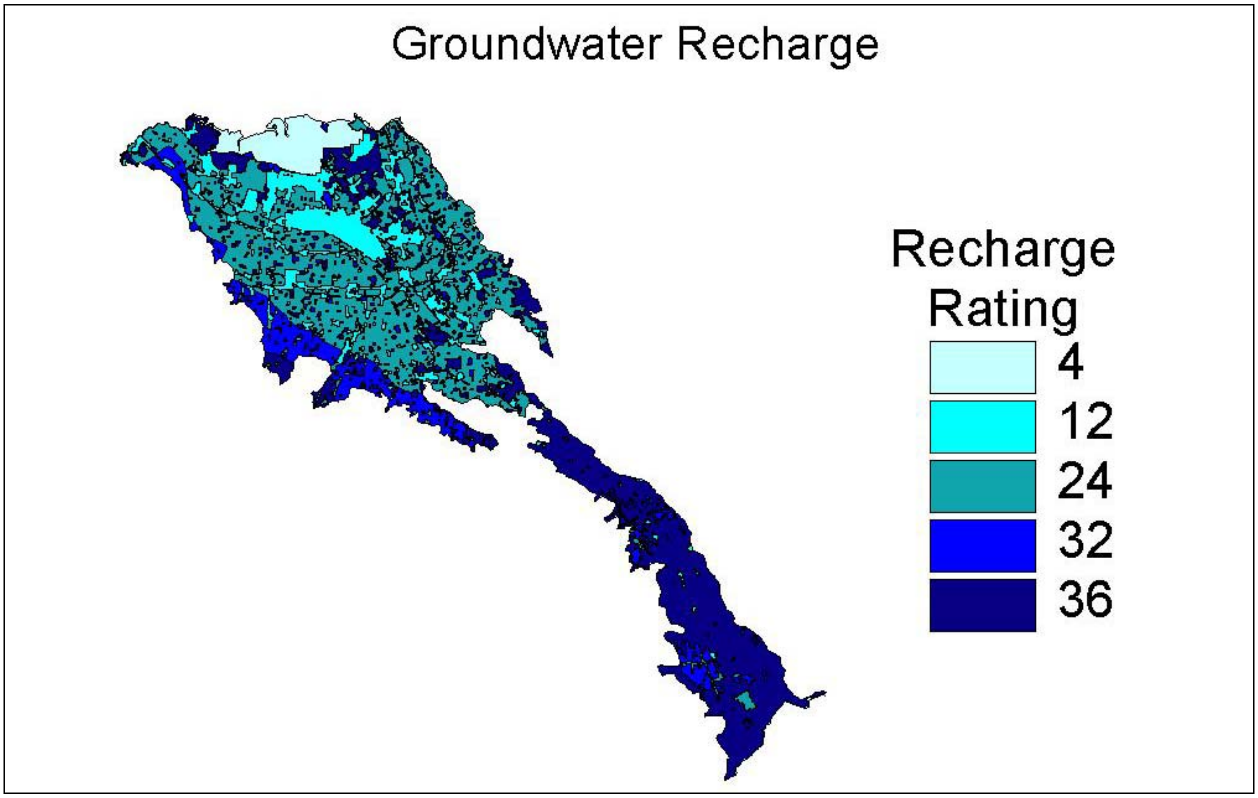

Figure 3 – Basemap for Recharge Rating

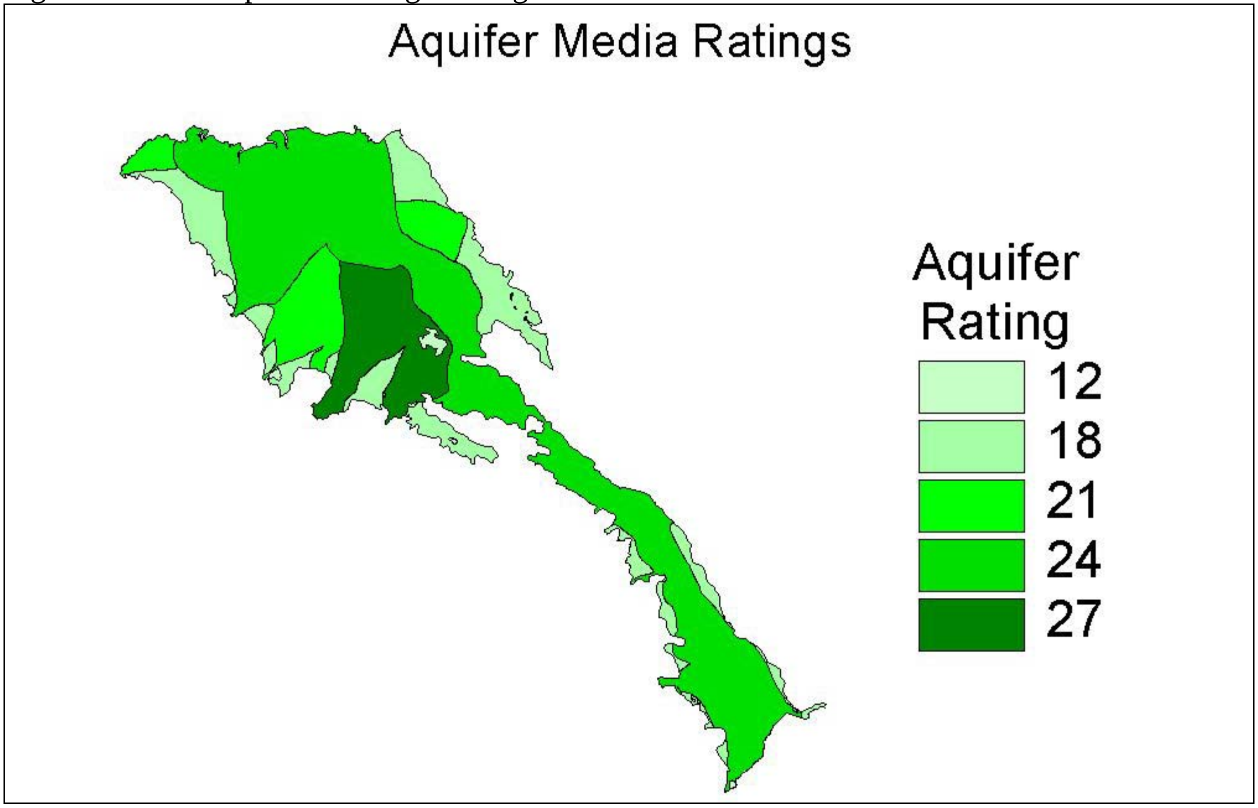

Figure 4 – Aquifer Influence

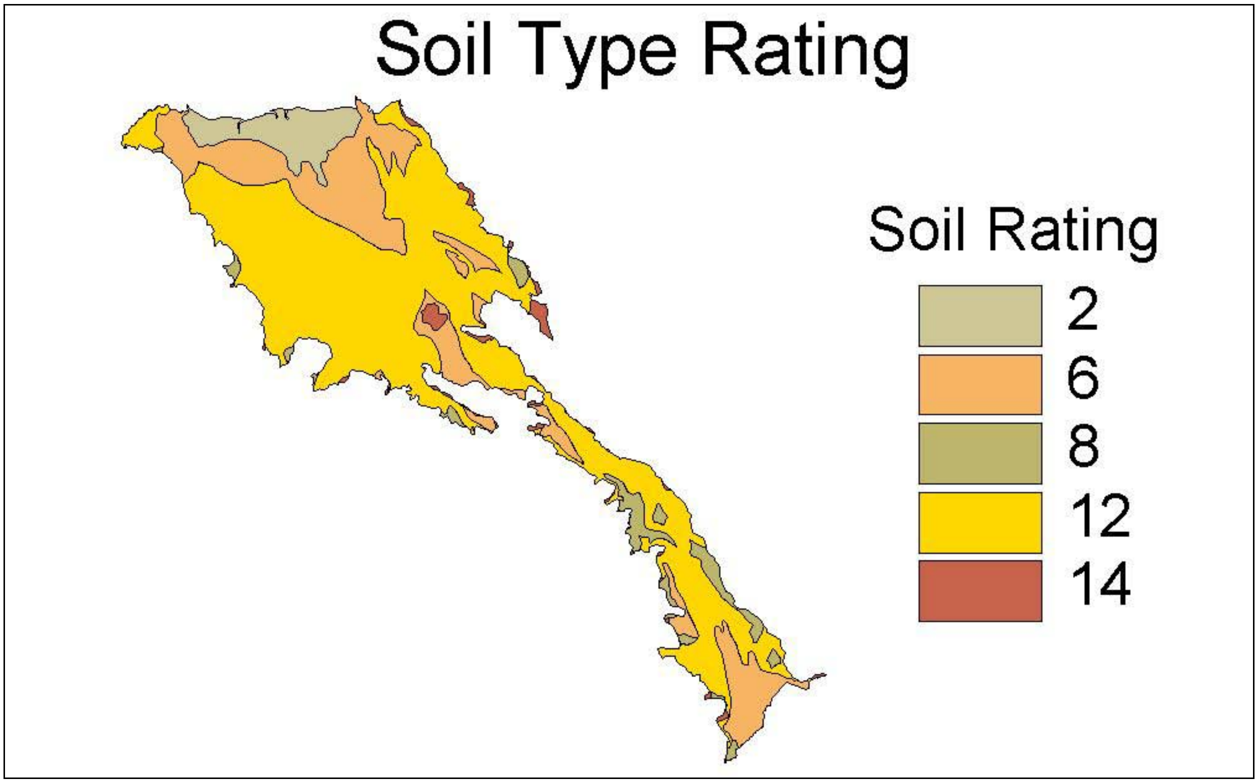

Figure 5 – Soil Influence

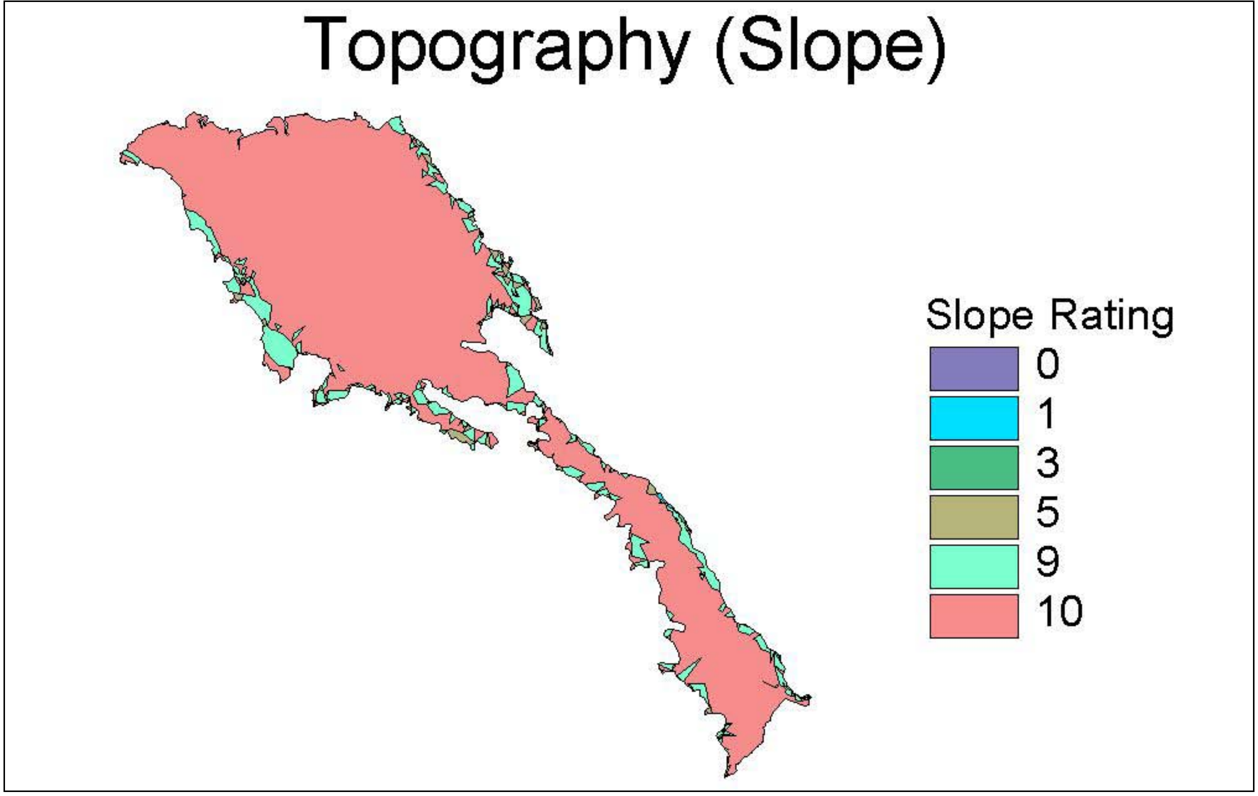

Figure 6 – Topography Influence

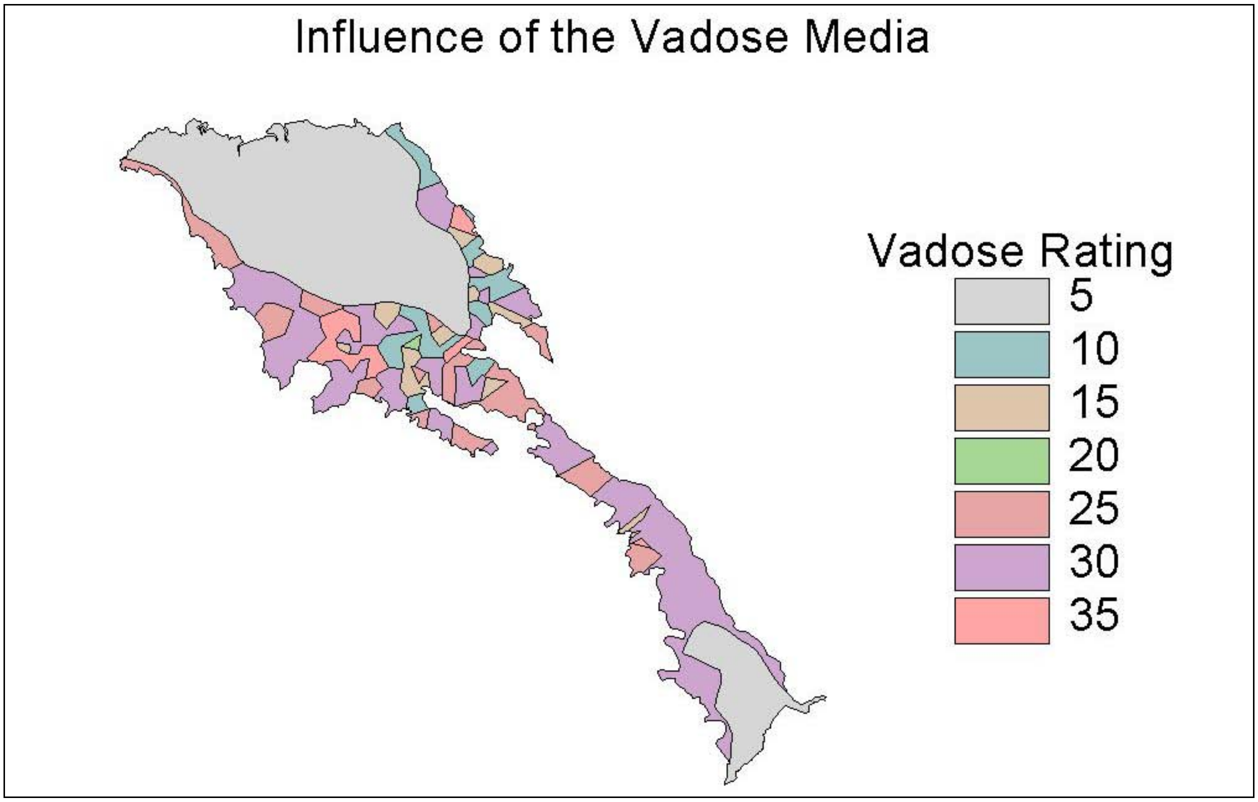

Figure 7 – Vadose Protection Potential

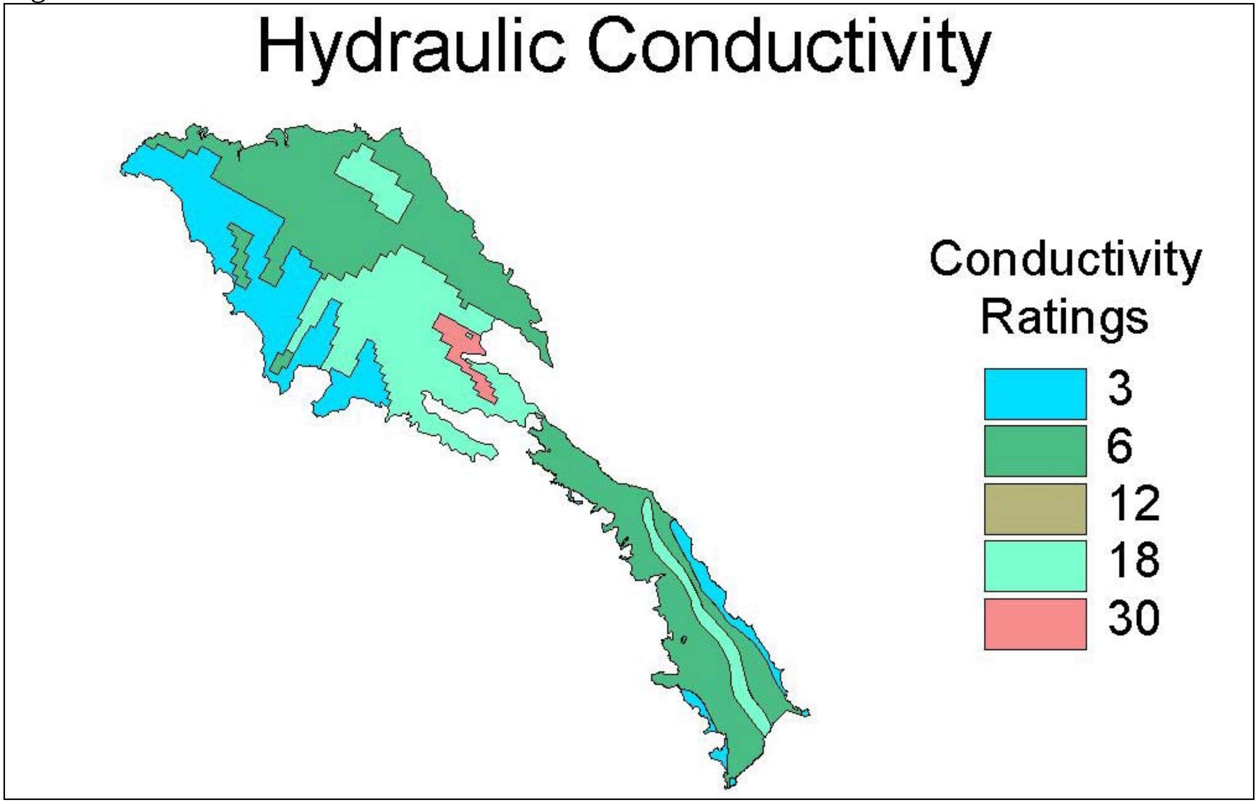

Figure 8 – Hydraulic Conductivity

Appendix L: Sewer Exfiltration

An Evaluation of the Potential for Exfiltration from the City of Sunnyvale Sewer System

(Originally Published as Appendix H of "A Comprehensive Groundwater Protection Evaluation for South San Francisco Bay Basins, RWQCB, May 2003)

L.1 City of Sunnyvale Sewer System

The city of Sunnyvale lies in northern Santa Clara County, in the medial and distal portions of the Stevens Creek fan, and in the Basin interior. The city obtains 90 percent of its water from treated surface-water sources; 10 percent is supplied by groundwater. Depth to groundwater ranges from greater than 100 feet at the southern edge of the city to 15 feet at the Central Expressway. Figure M1 presents geographic and groundwater features of the city of Sunnyvale. North of the Central Expressway, groundwater is less than 15 feet below ground at most locations. North of the rail line, many wells penetrating the lower aquifer are artesian, and north of the Central Expressway, nearly all wells penetrating the lower zone are artesian.

In an analysis of shallow groundwater sensitivity to surface contamination conducted by the Santa Clara Valley Water District using EPA's "DRASTIC" methodology, Sunnyvale's aquifers ranged from "low" sensitivity to "medium high," with the less-vulnerable zones lying in the southern half of Sunnyvale, and the more vulnerable zones lying in the shallow groundwater zone in the northern half of the city (Pierno, 1999).

The Sunnyvale sewer system is primarily a residential sanitary sewer system, but also includes five commercial lines serving commercial and industrial facilities. A majority of the sewer system is fewer than 50 years old. Construction details usable in ascertaining the physical potential for exfiltration were not obtained for this evaluation. In the shallow groundwater zone, infiltration is known to occur to a limited extent.

Sunnyvale is home to a large number of high-tech industries, including manufacturers of computer chips, printed circuit boards, and related products. There are also several chemical companies and metal-plating shops in Sunnyvale. To ensure safety from fire and explosion, these industries were required to store solvents in underground tanks. Solvent tanks leaked to soil and groundwater at many installations, resulting in a substantial number of releases in Sunnyvale. The S.F. Regional Board's database of Spills, Leaks, Investigation, and Cleanup (SLICs) lists 119 cases in Sunnyvale as of 2001. The high incidence of solvent use and spills in Sunnyvale suggests an increased potential for past illegal or unregulated discharge to sewers.

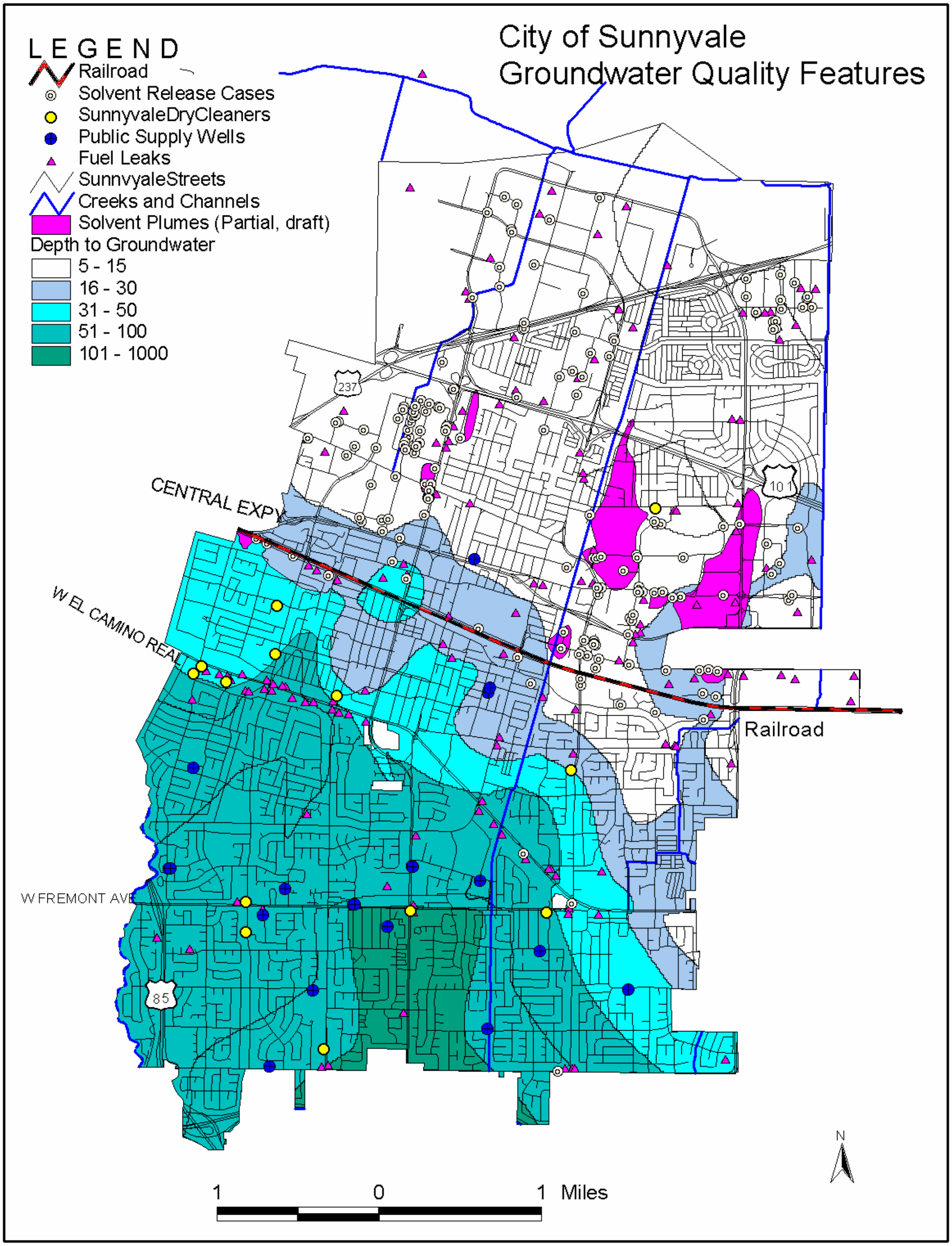

Figure L1. City of Sunnyvale Groundwater Quality Features

Sunnyvale's Industrial Pretreatment Program.

The former manager of Sunnyvale's pretreatment program was interviewed in June 2000 to learn the extent to which illegal discharges are now or have previously been a problem. Through this discussion, the following aspects of Sunnyvale's program and the dry-cleaner issue were explained.

- All dry cleaners in Sunnyvale are required to be zero discharge. These facilities are self-contained. In the past, there were three ways that solvent waste was generated from dry cleaners: from condensate (water and perchloroethene vapor condensate collected in a bucket and often dumped to sinks and drains), from exchanging the perchloroethene in the system, and from exchanging the solids accumulated on filters. All of these wastes were presumably manifested and disposed of appropriately, as verified by Sunnyvale's pretreatment program. In the 1970s and earlier, direct discharge of dry-cleaner wastes to the sewer was legal and commonplace.
- Not all dry cleaners in Sunnyvale perform the dry-cleaning process on-site; several dry cleaners take the work to another location outside of Sunnyvale.
- There are no centralized dry cleaners, such as large industrial uniform cleaning facilities, in Sunnyvale, nor do staff members recall any in the past.
- In 1992 and 1993, Sunnyvale's pretreatment inspectors conducted an intensive review of dry cleaners' activities, beyond routine inspections, and concluded that all were in compliance and none were discharging. One facility had installed a pilot treatment system to handle condensate rather than changing out equipment so it could become self-contained. Inspectors verified that the system worked properly.
- Today, the city's Industrial Pretreatment Program inspects significant industrial users annually, and requires a Solvents Management Plan for facilities using solvents on-site. City pretreatment staff experienced with these facilities contends that significant industrial users are unlikely to be the source of the influent concentrations of solvents (Gallo, 2000).

From a brief review of the City's Industrial Pretreatment Program reports the following features of Sunnyvale's program history are evident.

- Sunnyvale has aggressively pursued industrial discharge to the sewer system for as long as staff there can recall (all joined the city after 1990). The following examples obtained from reports confirm a history of proactive enforcement.
    - In 1985, six industries were referred to the city attorney for prosecution; court action on one case resulted in a 10-day jail term.
    - In 1986, the Sunnyvale Pretreatment Program led an interagency committee managing groundwater treatment issues and developing criteria to permit discharge from groundwater treatment systems, aquifer pump tests, etc.
    - In 1987, routine sampling efforts produced 1,307 samples.
    - In 1987, of 71 industrial dischargers, 57 achieved consistent compliance, seven were found to be in violation of federal regulations, two were referred to the city attorney, legal action was pending on four, and monetary penalties were assessed on one.
    - In the 1986-87 fiscal year, $393,211 was budgeted for the pretreatment program, including 13,542 inspector hours. In 1987-88, $412,000 was budgeted.
- Sunnyvale does not routinely sample and analyze for VOCs in trunk lines and laterals. VOCs are sampled and analyzed quarterly on influent. This is because the VOC concentrations on influent are well below the local limit for total toxic organics established for its facility. VOC concentrations have typically ranged from non-detect at reporting limits of five parts per billion (ppb) or less to approximately 10 ppb, while the local limit is one part per million (i.e.,

1,000 ppb). Sunnyvale does routinely sample trunk lines and laterals for metals, which in the South Bay present a greater permit-compliance challenge.

- Sunnyvale has an Incident Response Plan in place, and staff is trained to implement this plan. Because the Sunnyvale Water Pollution Control Plant is staffed 24 hours a day, seven days a week, any large release of solvents bearing a distinct odor would alert operators, and the Incident Response Plan would be implemented. Inspectors would work their way up trunk lines and laterals sampling manholes with GasTechs and PIDs to locate the source.
- Sunnyvale has had ample capacity, and aggressive identification of infiltration and inflow problems has not been a priority. Plans are nevertheless being made to assess the magnitude of these problems in light of increased daily flows. A rough estimate of infiltration is considered to be 3 to 5 percent of daily flow, which today may mean up to 900,000 gallons per day. At the Sunnyvale landfill, adjacent to the Water Pollution Control Plant, significant infiltration into the main trunk line creates a sufficient cone of depression to capture groundwater from beneath the 90-acre landfill.
- The Sunnyvale sewer system is considerably newer than San Jose’s, due to the relatively recent boom in development Sunnyvale experienced in the 1960s and 1970s. There have been relatively few structural problems with the system.

L.2 Implications of Influent Concentrations

A cursory review of current and past data for HVOCs detected on influent sewage was performed. Data from a few years was reviewed to get a general sense of the extent to which these parameters are monitored. HVOC concentrations on influent were reviewed on a few reports, and their implications were discussed with City staff. Before embarking on a more comprehensive data collection and compilation effort, a framework must be developed for using the data and arriving at meaningful interpretations. In a somewhat random sampling, the following values provide a sense of the relative historical presence of solvents in the Sunnyvale sewer system.

Table L1. Selected Historical HVOC Influent Concentrations At Sunnyvale Water Pollution Control Plant

Year	Compound	Influent Conc.	Dry Season Flow, Million Gallons per Day	Mass and Volume per Day	Pounds per Year
1999	TCE, PCE, 1,1,1-TCA	all nd	18 mgd	-	-
1998	TCE	6 μg/l	17.4 mgd	0.87 lb; 0.27 l	317
1994	PCE	nd	~15 mgd	-	-
1986	TCE	17	11 mgd	1.5 lbs; 0.46 l	547 lbs/yr
	PCE	40		3.7 lb; 1.03 l	1,350 lbs/yr
	1,1,1-TCA	28		2.6 lb; 0.87 l	949 lbs/yr

Assumptions: Concentrations are for dry season flow; storm season flow does not increase mass discharged and can be ignored; mass of solvents arriving at POTW in vapor form or adsorbed to solids not accounted for; dry season daily flows are estimated.

There are at least three possible interpretations to the influent concentrations. These are:

- **Direct Discharge Scenario.** An illegal discharge of concentrated solvents is causing the resulting influent concentration.
- **Infiltration Scenario.** Sewer lines in the northern half of Sunnyvale are likely to be at or below the water table, allowing infiltration where loose joints, holes, or other avenues exist. There are numerous large solvent plumes in Sunnyvale. Where sewer lines in which infiltration occurs intercept these plumes, contaminated groundwater may be entering the system and contributing the solvents.

- **Background Scenario.** The influent concentrations may represent the sum of all discharges in the system. Instead of a single discharger illegally dumping a large quantity of solvent, many dischargers may contribute small amounts. Homeowners may be a source of solvent discharge, particularly in older homes equipped with garage sinks. Home auto-maintenance work, home dry cleaning, leather conditioning, stain removal, pesticide disposal, hobbyists, home auto and other specialty painting, and other sources of solvents may contribute a background level similar to that observed in 1998. Home-based service businesses for which equipment is maintained and cleaned in the home, such as painting, exterminating, and janitorial services may also be contributors of solvents to the sewer system. Conscientious homeowners wanting to properly dispose of household hazardous waste should follow container instructions before rinsing contents into home drains and discarding containers in the trash.

The city of Sunnyvale encourages its residents to dispose of their household hazardous waste properly through an intensive public outreach program and conducts monthly household hazardous waste collection events at a facility adjacent to the Sunnyvale Water Pollution Control Plant. The participation rate for Sunnyvale residents is currently about 5 percent, compared to a 3 percent countywide participation rate (Bowers, 2001). In 1999-2000, approximately 900,000 pounds of household hazardous waste was collected throughout Santa Clara County. Households tend to participate on an as-needed basis, typically when moving, so a 3 percent participation rate does not imply that the balance of households are mishandling their hazardous waste. Nevertheless, some solvents may enter the sewer system through container rinsing, parts washing, and direct dumping.

Of these three scenarios, the largest quantities of solvents can be expected from the point-source scenario. This scenario is also the least likely threat today, due to the well-run permitting and inspection program implemented by the Sunnyvale Pretreatment Program. To the extent that point sources may have been a past issue, this scenario represents a possible continued threat to groundwater for the following reasons:

- Pure-phase solvent discharged to the sewer system is much denser than water; consequently, it sinks to the bottom of the sewer main, settling at sags or pooling at lift stations, and escaping at joints.
- It is likely that a few gallons of pure-phase solvent discharged to the sewer may escape notice by operators at the Water Pollution Control Plant because it would be retained in sags or escape through joints, so it would not arrive at the POTW headworks. Only a soluble fraction would be carried to the headworks. Because the city’s National Pollutant Discharge Elimination System (NPDES) permit requirements call for only semi-annual influent monitoring for VOCs, a discharge event may escape notice if peak concentrations of soluble solvents are flushed out between sampling events.

The above interpretation of the possible threat to groundwater is entirely speculative; no direct evidence was encountered to substantiate these scenarios. To determine whether this speculation is reasonable, it would be useful to obtain several case histories from other POTWs in which documented pure-phase solvent releases have been observed to be retained in the sewer mains, and to find out what the corresponding dissolved phase concentrations were at the influent sampling point. The city of Davis experienced an apparent illegal discharge of dry cleaning solvent to the sewer system, which resulted in groundwater contamination. However, perchloroethylene was not detected in wastewater influent (Hanzo, 2001).

The infiltration scenario represents removal of solvents from groundwater. For at least one plume, the sewer system substitutes for an engineered remedial action. VOCs imparted to groundwater at the adjacent Sunnyvale Landfill by landfill gas and leachate are captured by groundwater infiltration into the sewer and headworks. Where sewer mains are entirely below the water table, substantial inflow at faulty joints can be expected. At least some of the numerous solvent plumes in Sunnyvale can also be expected to be intercepted or redirected by sewer mains. In areas of shallow groundwater (north of the Central Expressway), sewer mains may act to redirect plumes by conducting flow in the sand and gravel backfill.

The background scenario represents a continued potential source and threat to groundwater, and is also the most difficult to address. In addition to the city's aggressive Industrial Pretreatment Program, the city operates an active outreach program with a full-time public education specialist conducting programs throughout the year to increase public awareness about the need to restrict inappropriate wastes from the sewer.

Absent better evidence, all three sources can be assumed to play a role. The trend of decreasing concentrations of HVOCs in influent can probably be attributed to improved education, permitting, and enforcement, along with dilution, exfiltration, biodegradation, improved industrial practices, and awareness of the consequences of mishandling solvents.

L.3 General Review of Perchloroethylene and Sewer Lines

A 1992 document, titled "Dry Cleaners – A Major Source of PCE in Groundwater," prepared by Victor J. Izzo of the Central Valley Regional Board, presents a detailed review of the mechanisms by which PCE from dry cleaners enters and leaves sewer lines. Izzo's report profiles how PCE in pure phase may exit a sewer pipe as vapor, liquid, or a combination of both, either through permeating clay and concrete sewer pipes, or by leaking through joints and cracks in the lines. PCE is considerably more dense than water (1.63 g/cm^3), allowing it to continue to sink once it encounters the saturated zone. PCE in vapor form is nearly six times denser than soil air, allowing it to sink down to the water table and partition into the liquid phase due to a concentration gradient.

Izzo's report presents several case studies from Central Valley cities in which PCE contamination of soil and groundwater, facilitated by sewer lines, has created plumes extending more than half a mile distant from the dry-cleaner source.

The South Bay has also experienced PCE contamination of groundwater from dry cleaners. There were approximately 345 dry cleaners within the study area in 1998, according to permit records maintained by the BAAQMD. There have been about 42 cases involving release of PCE from dry cleaners to soil and groundwater within the study area, of which about 24 are currently open and undergoing investigation or remediation.

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Appendix N : Dry Cleaner Ranking Maps by City

San Jose Page 191
Santa Clara Page 192
Sunnyvale Page 193
Mountain View Page 194
Palo Alto Page 195
Los Altos Page 196
Saratoga Page 197
Los Gatos Page 198
Cupertino Page 199
Campbell Page 200
Milpitas Page 201
Morgan Hill Page 202
Gilroy Page 203

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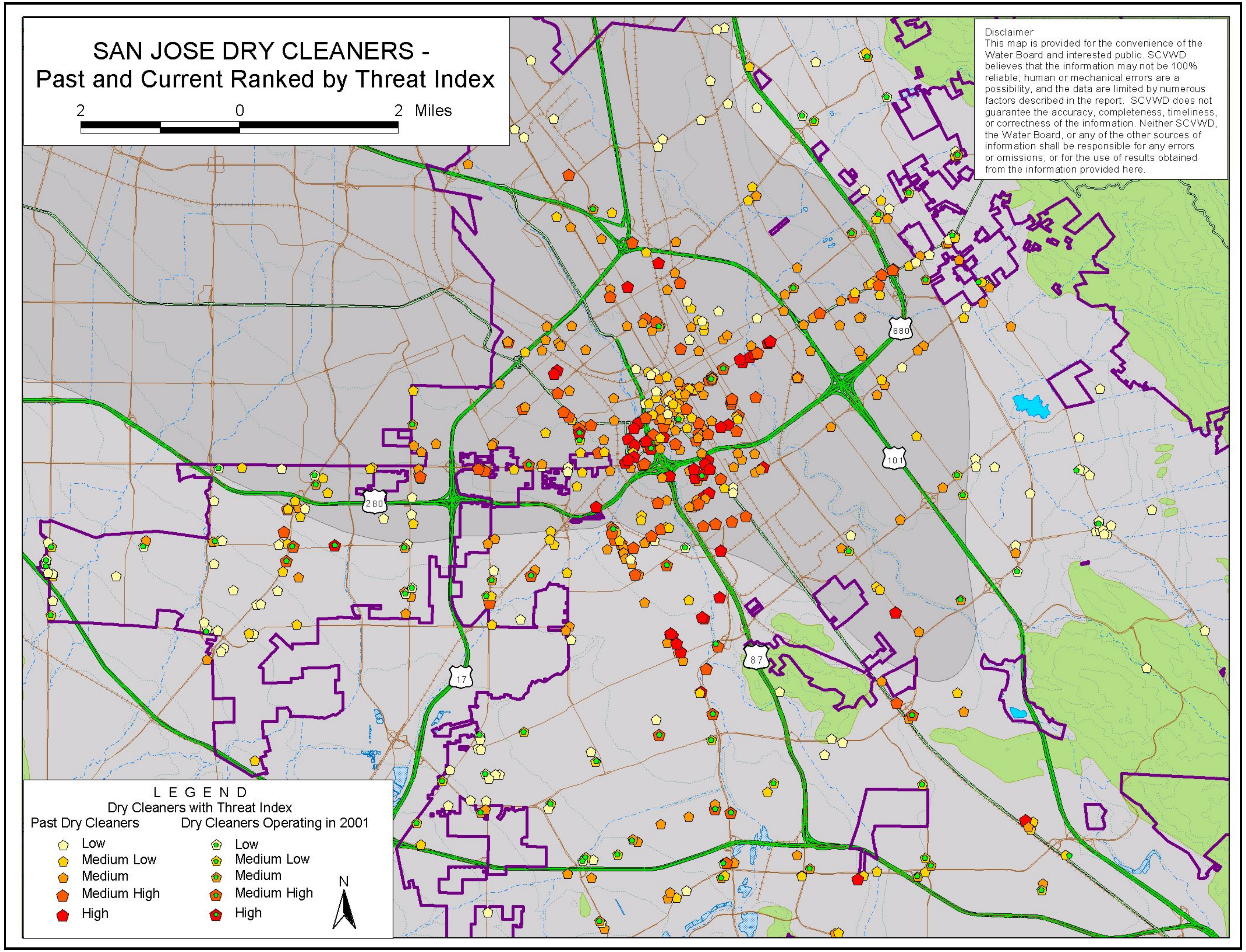

SAN JOSE DRY CLEANERS -
Past and Current Ranked by Threat Index

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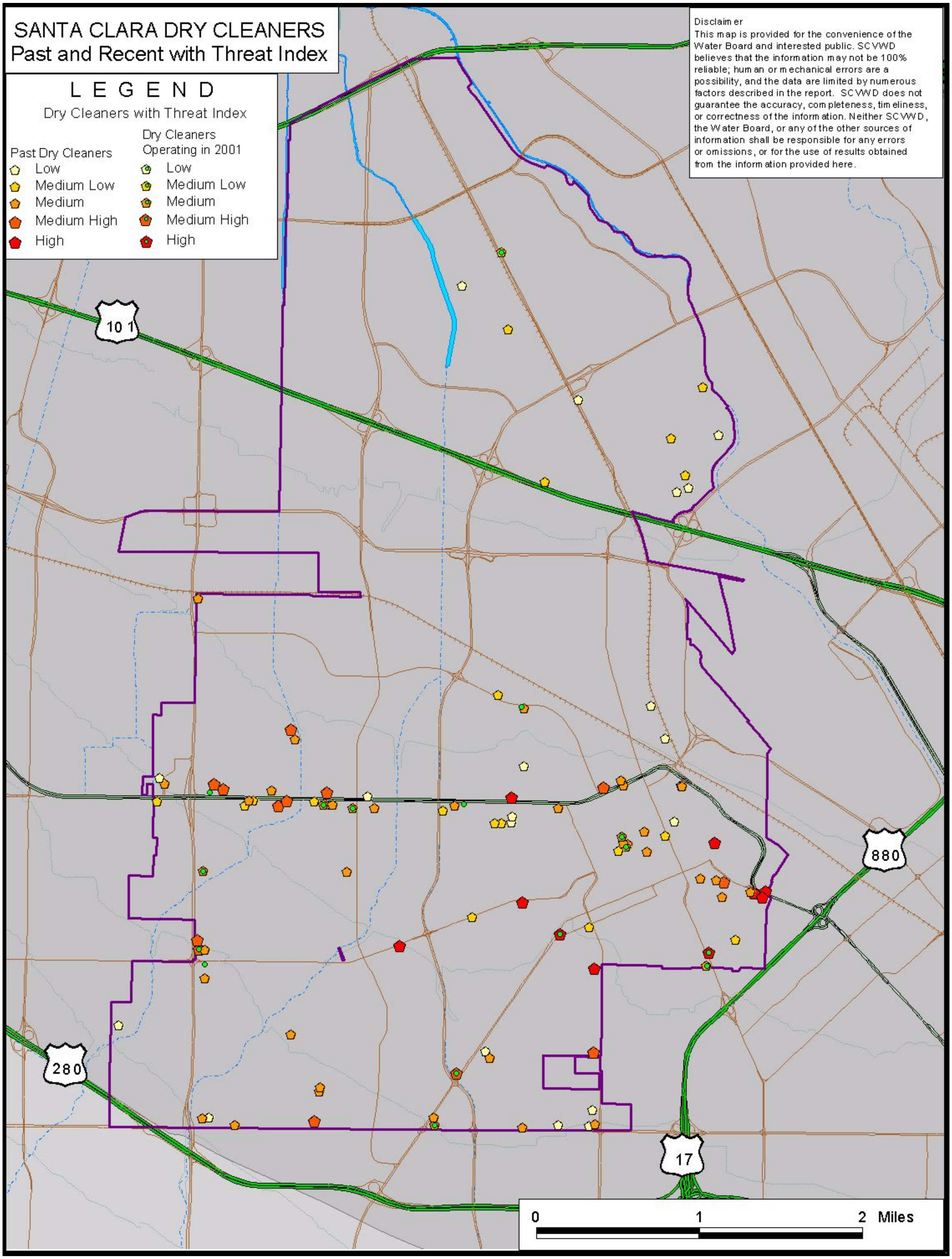

SANTA CLARA DRY CLEANERS
Past and Recent with Threat Index

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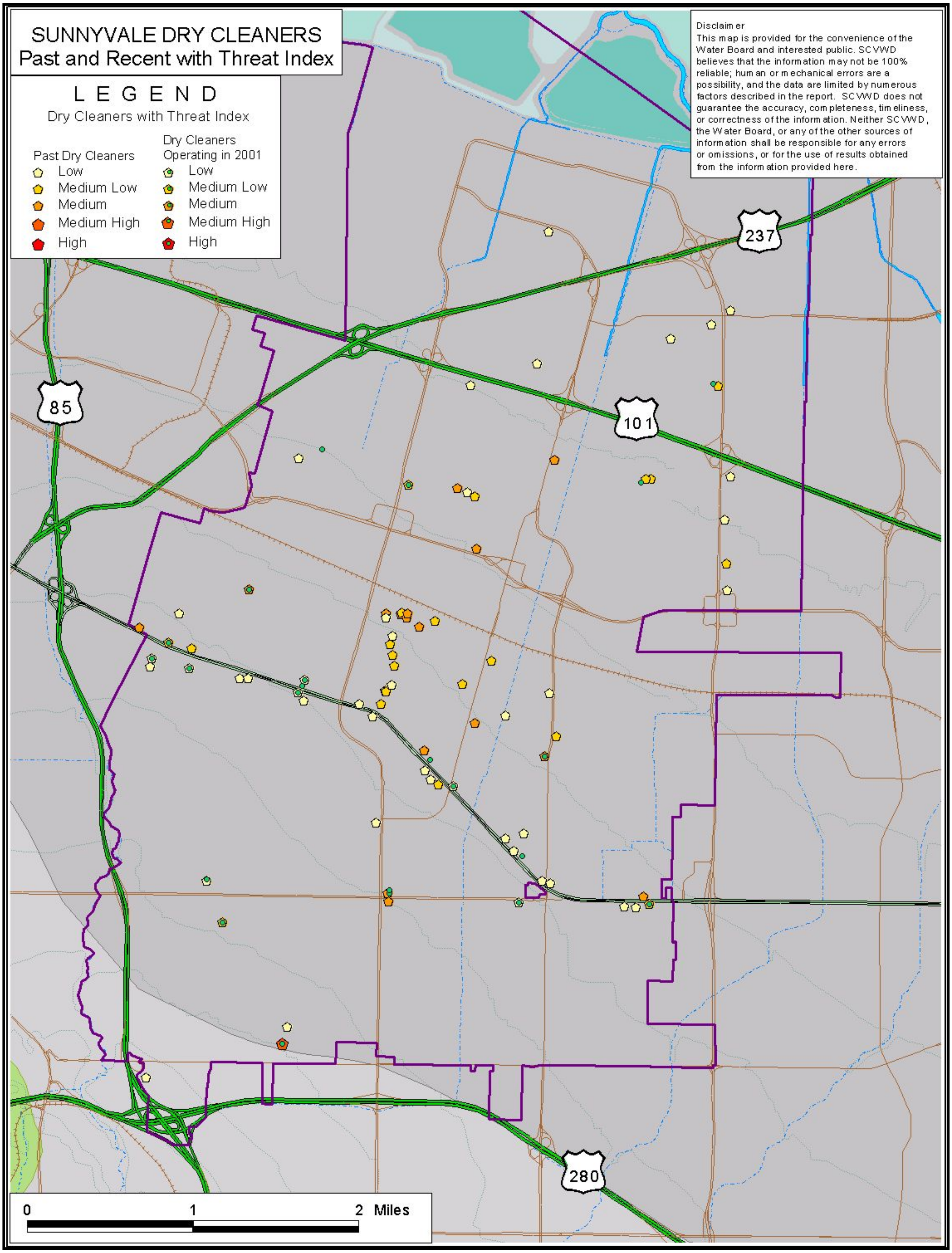

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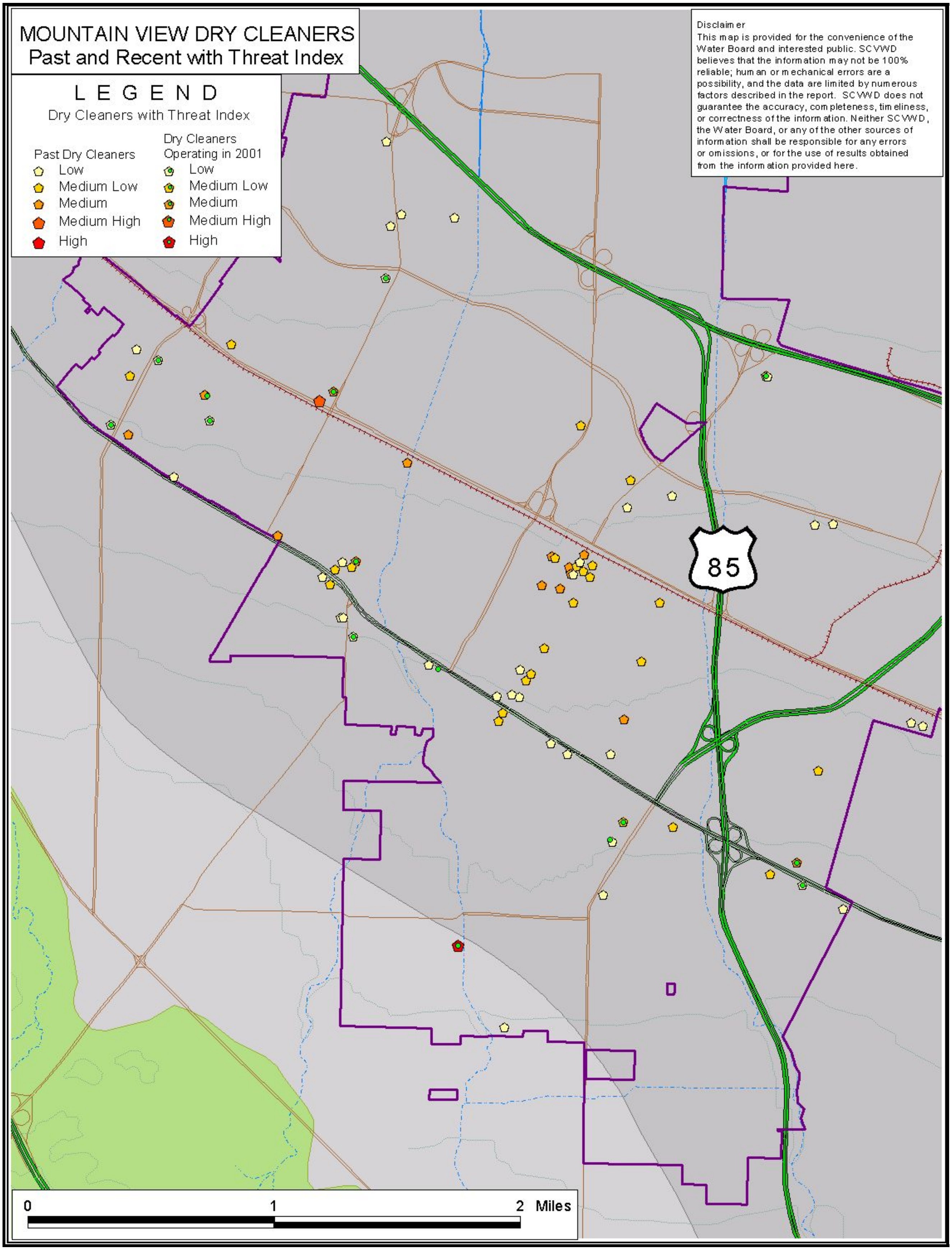

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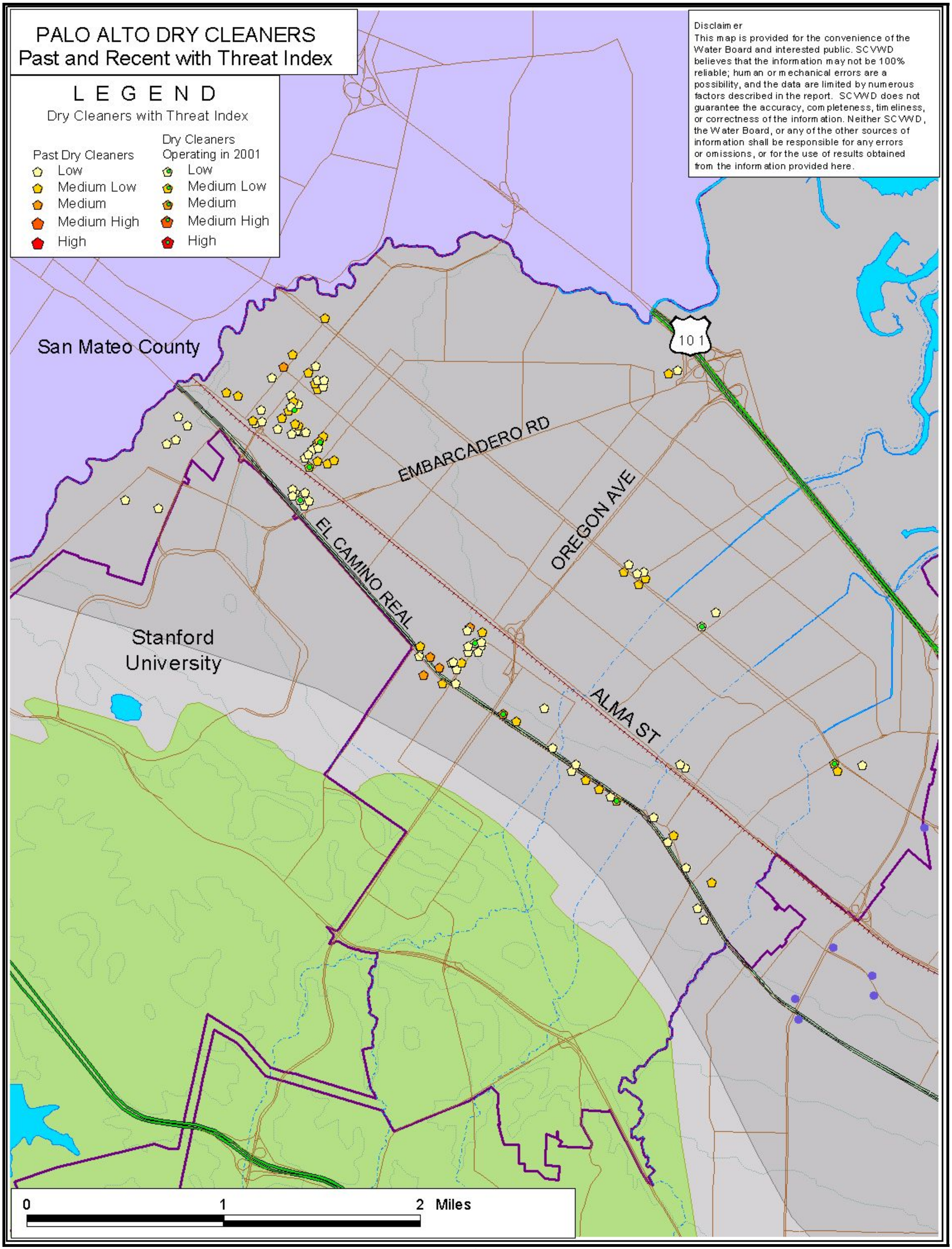

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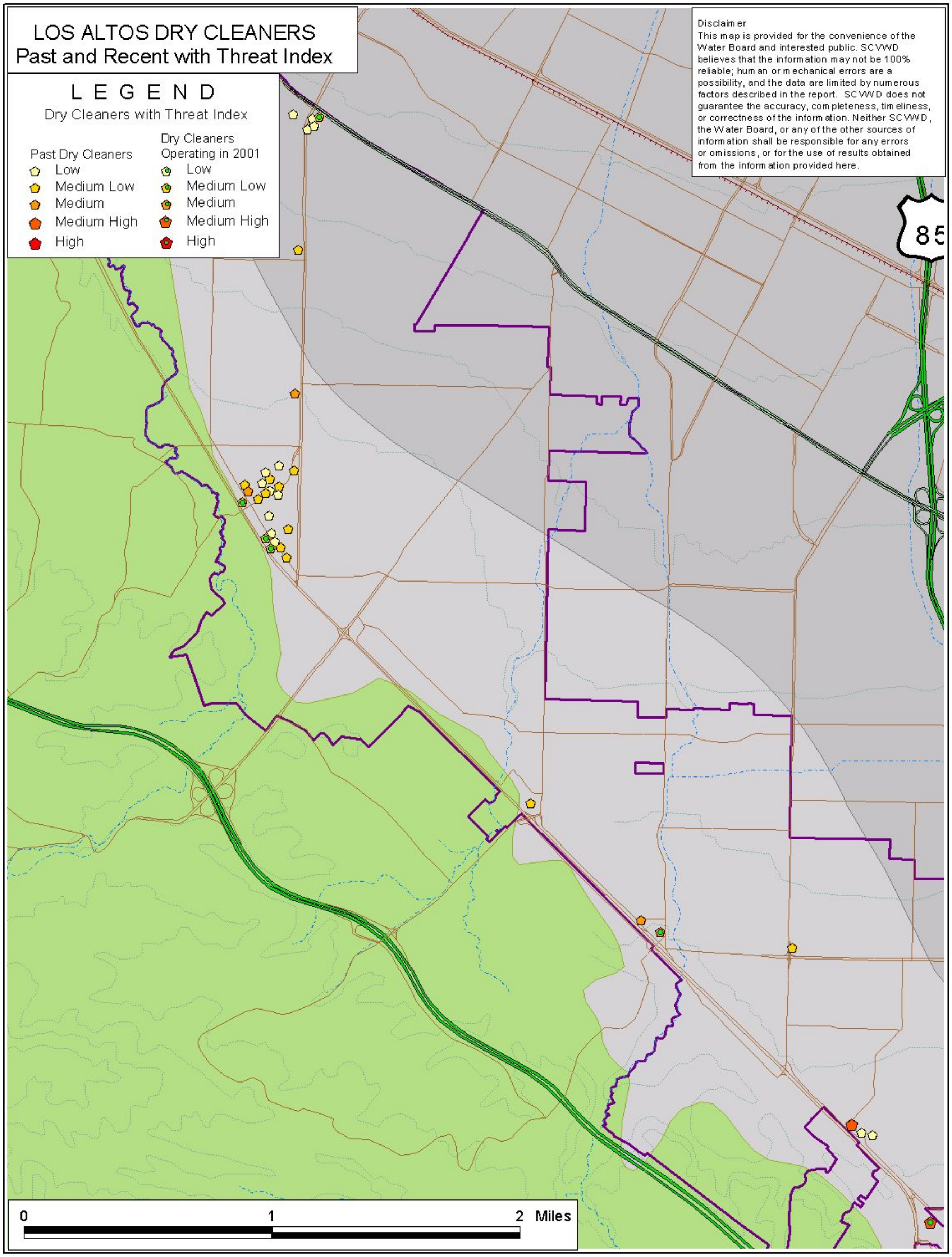

LOS ALTOS DRY CLEANERS
Past and Recent with Threat Index

L E G E N D
Dry Cleaners with Threat Index

Past Dry Cleaners	Dry Cleaners Operating in 2001
⬟ Low	⬟ Low
⬟ Medium Low	⬟ Medium Low
⬟ Medium	⬟ Medium
⬟ Medium High	⬟ Medium High
⬟ High	⬟ High

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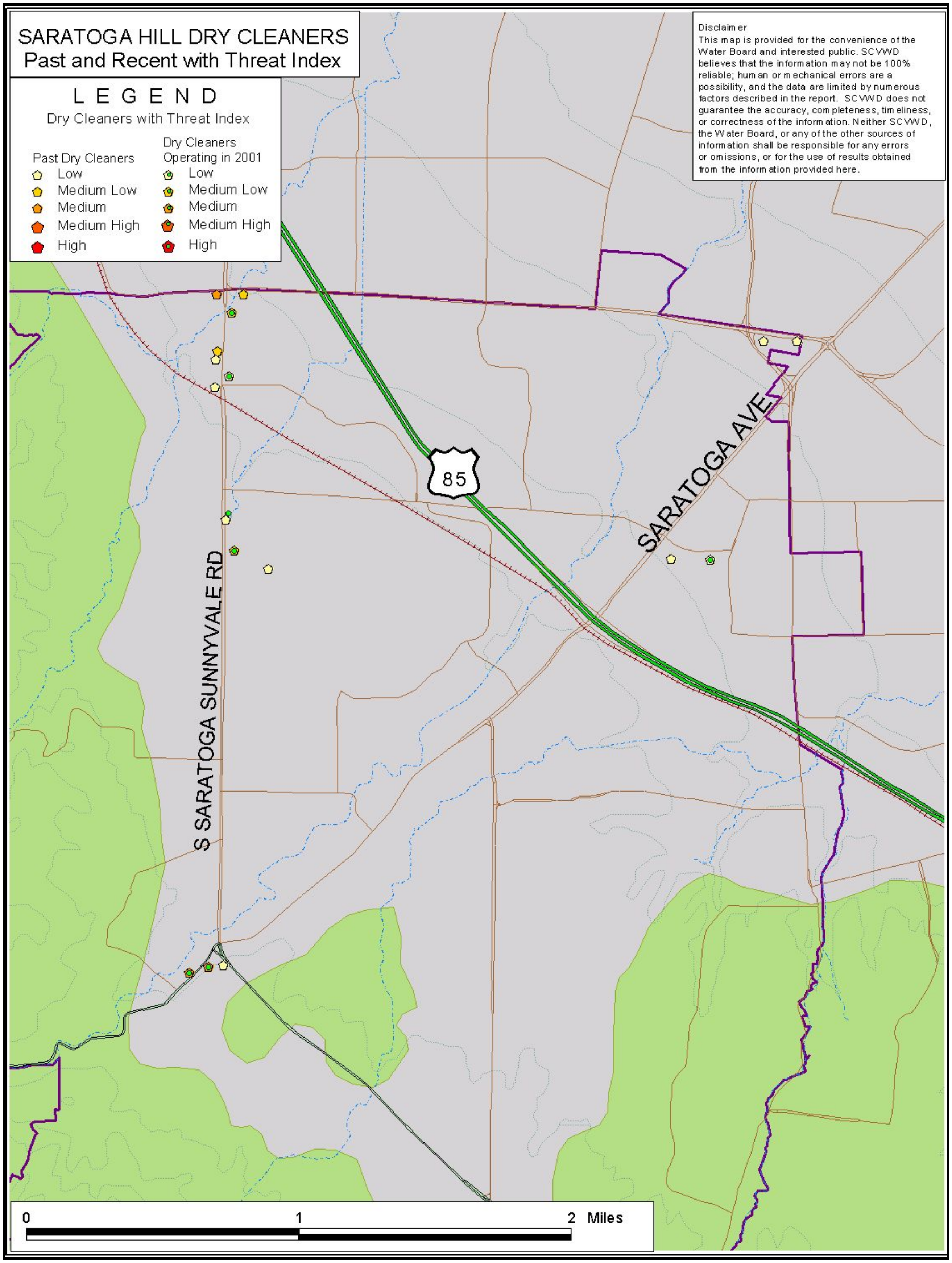

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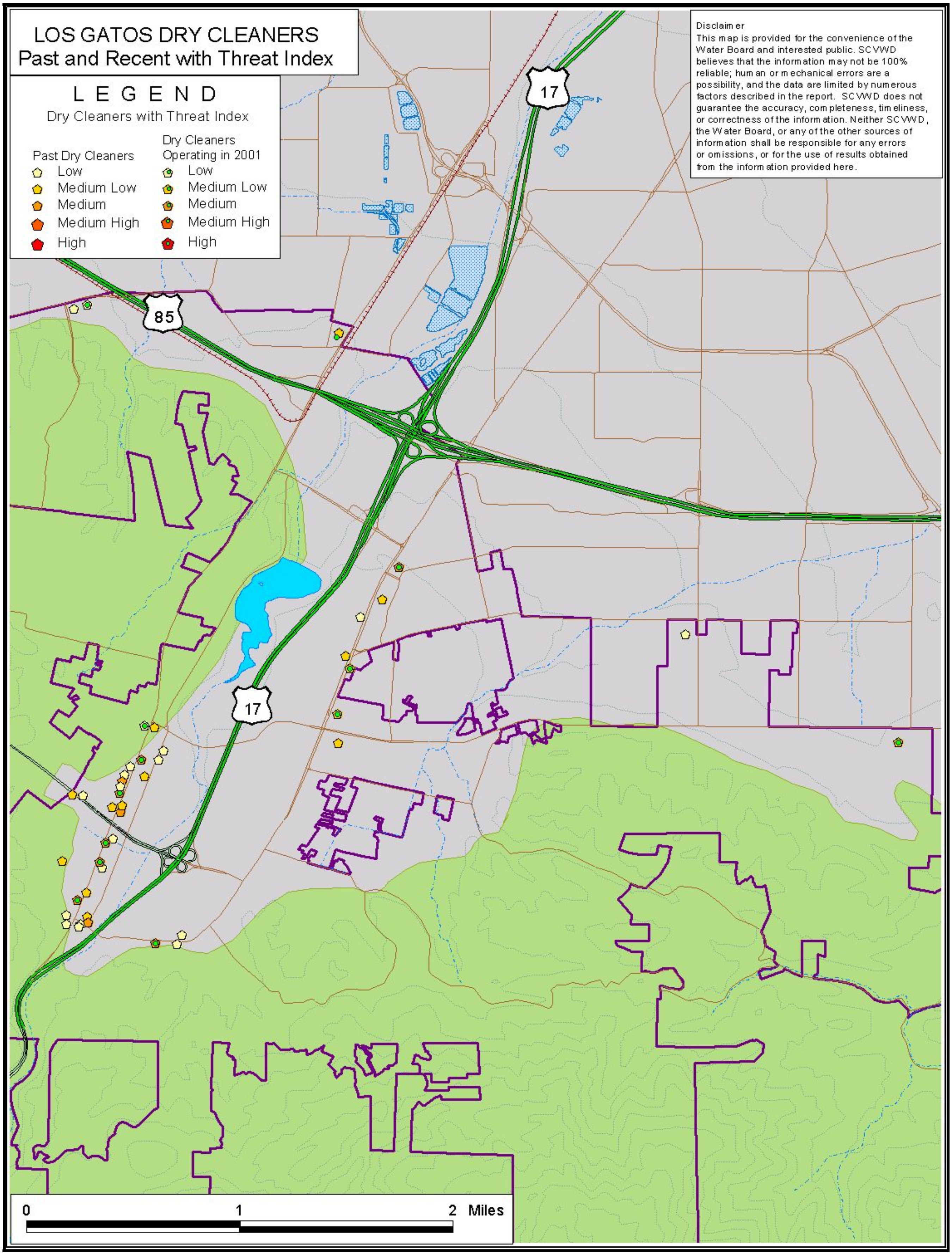

LOS GATOS DRY CLEANERS
Past and Recent with Threat Index

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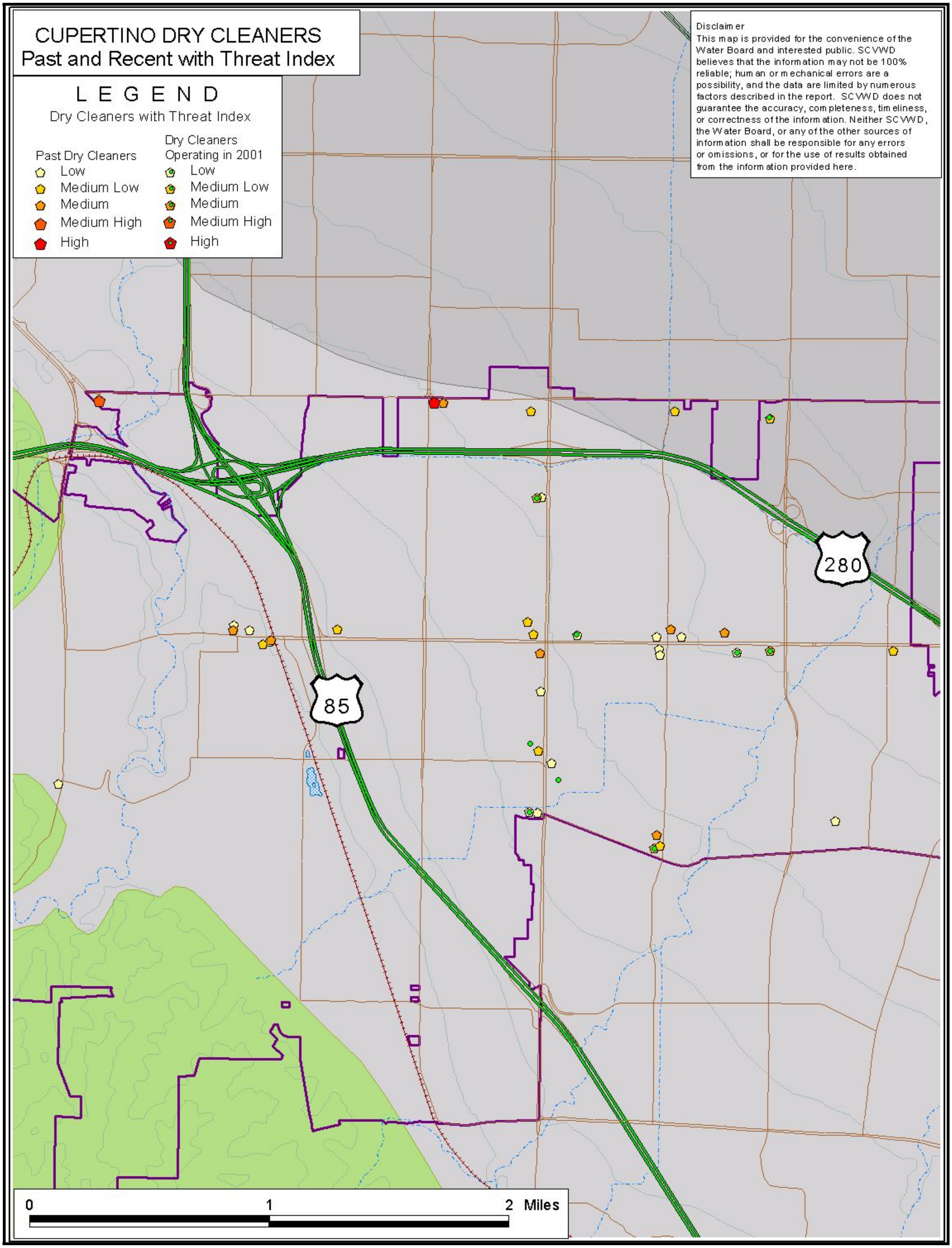

CUPERTINO DRY CLEANERS
Past and Recent with Threat Index

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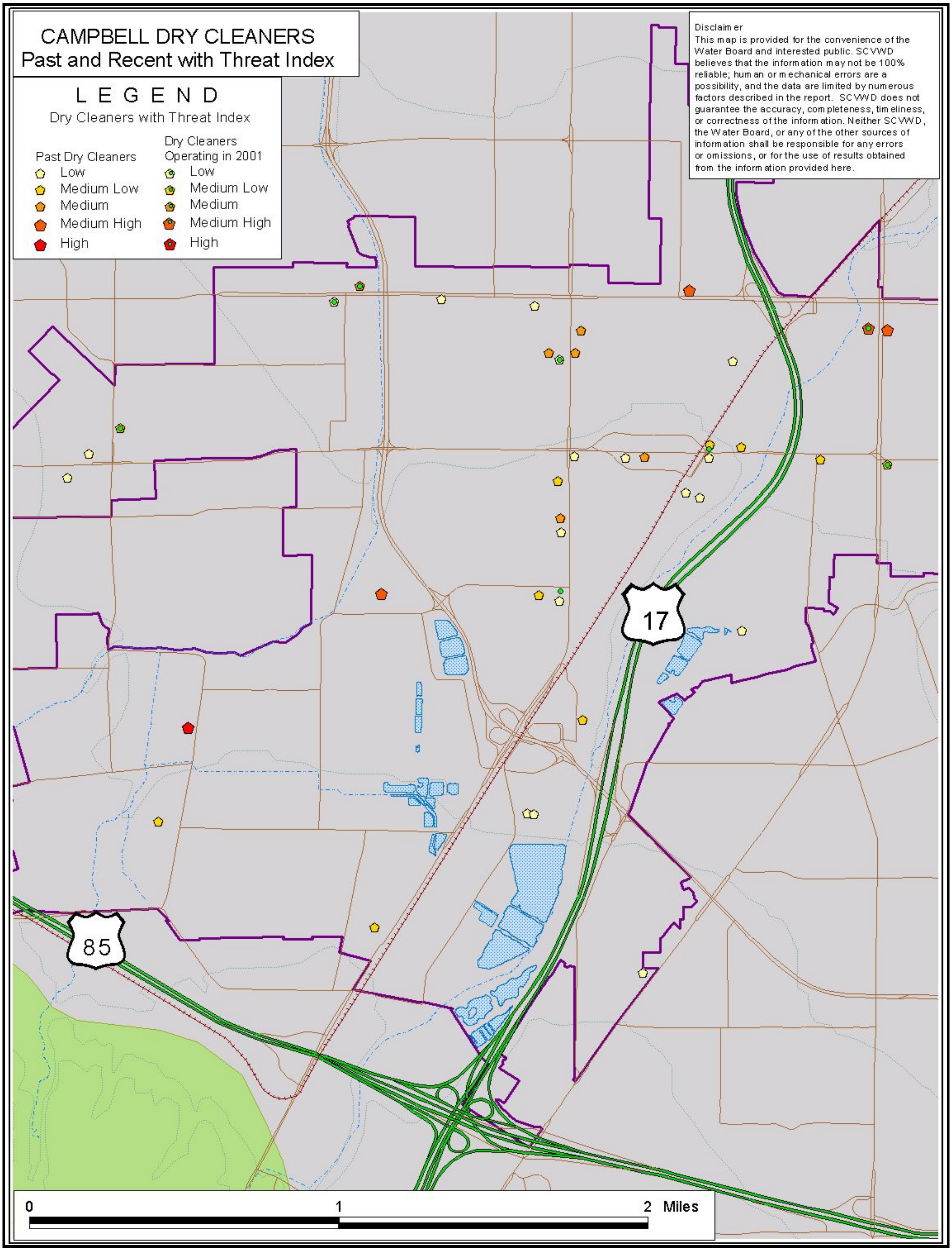

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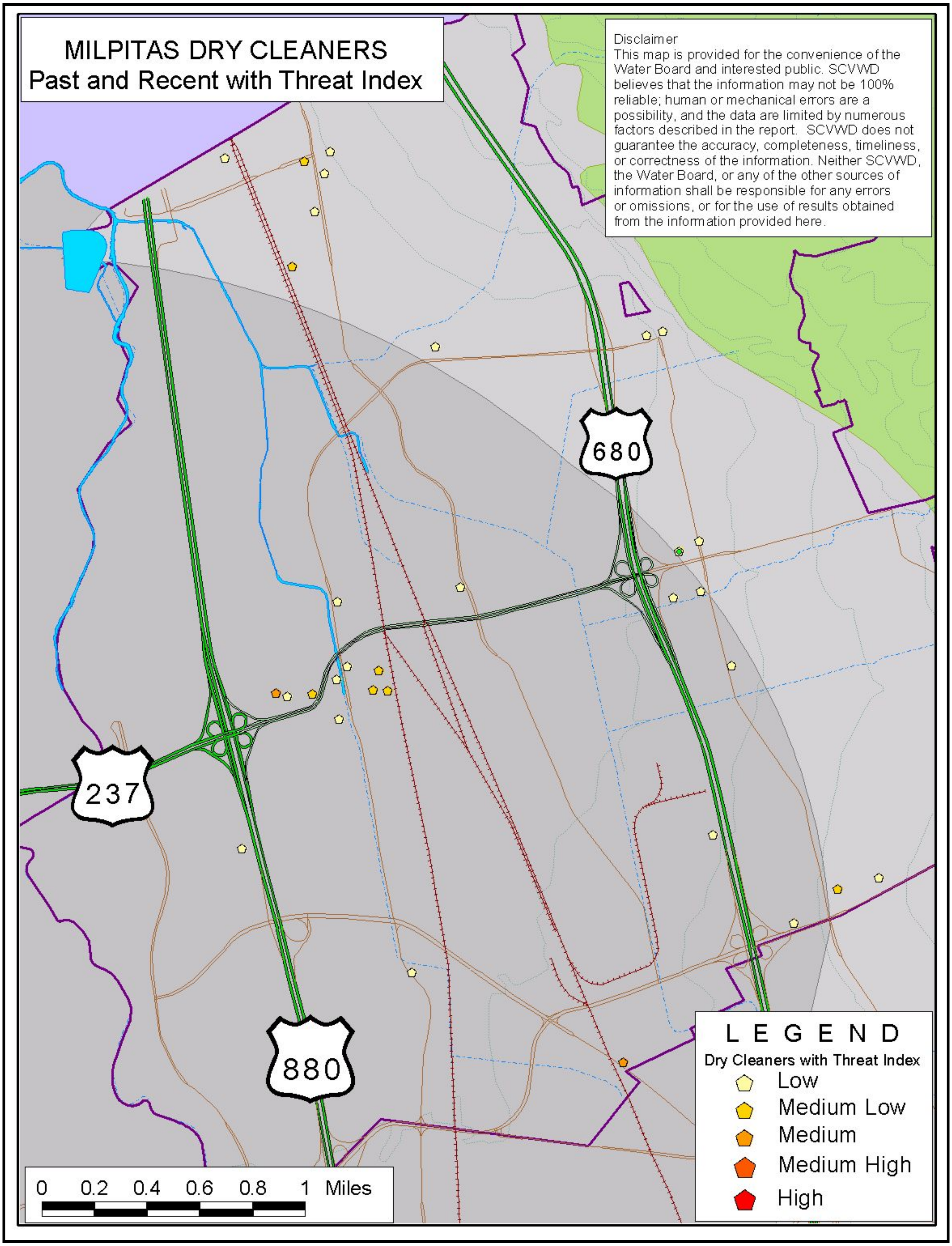

MILPITAS DRY CLEANERS
Past and Recent with Threat Index

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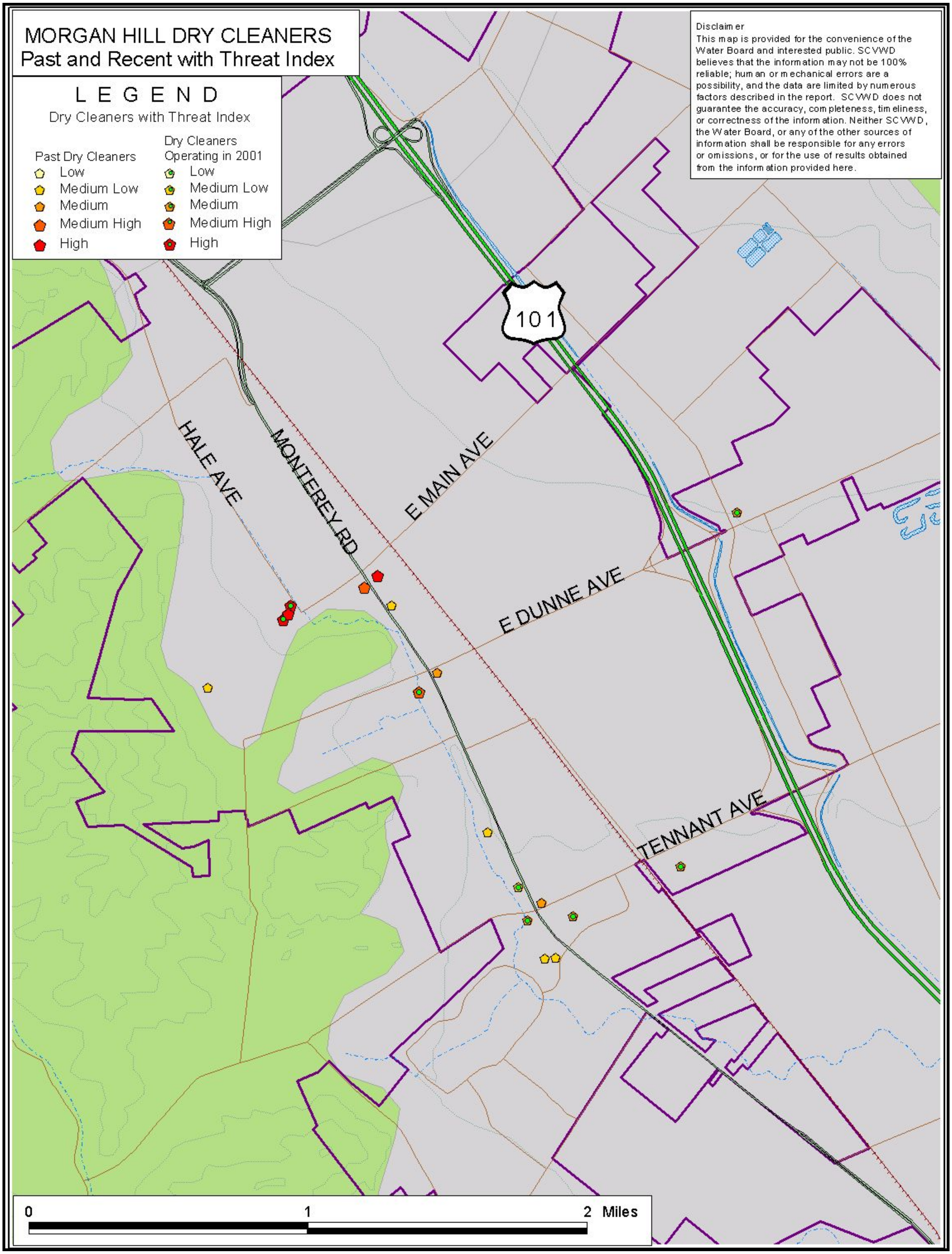
LEGEND

Dry Cleaners with Threat Index

- Low
- Medium Low
- Medium
- Medium High
- High



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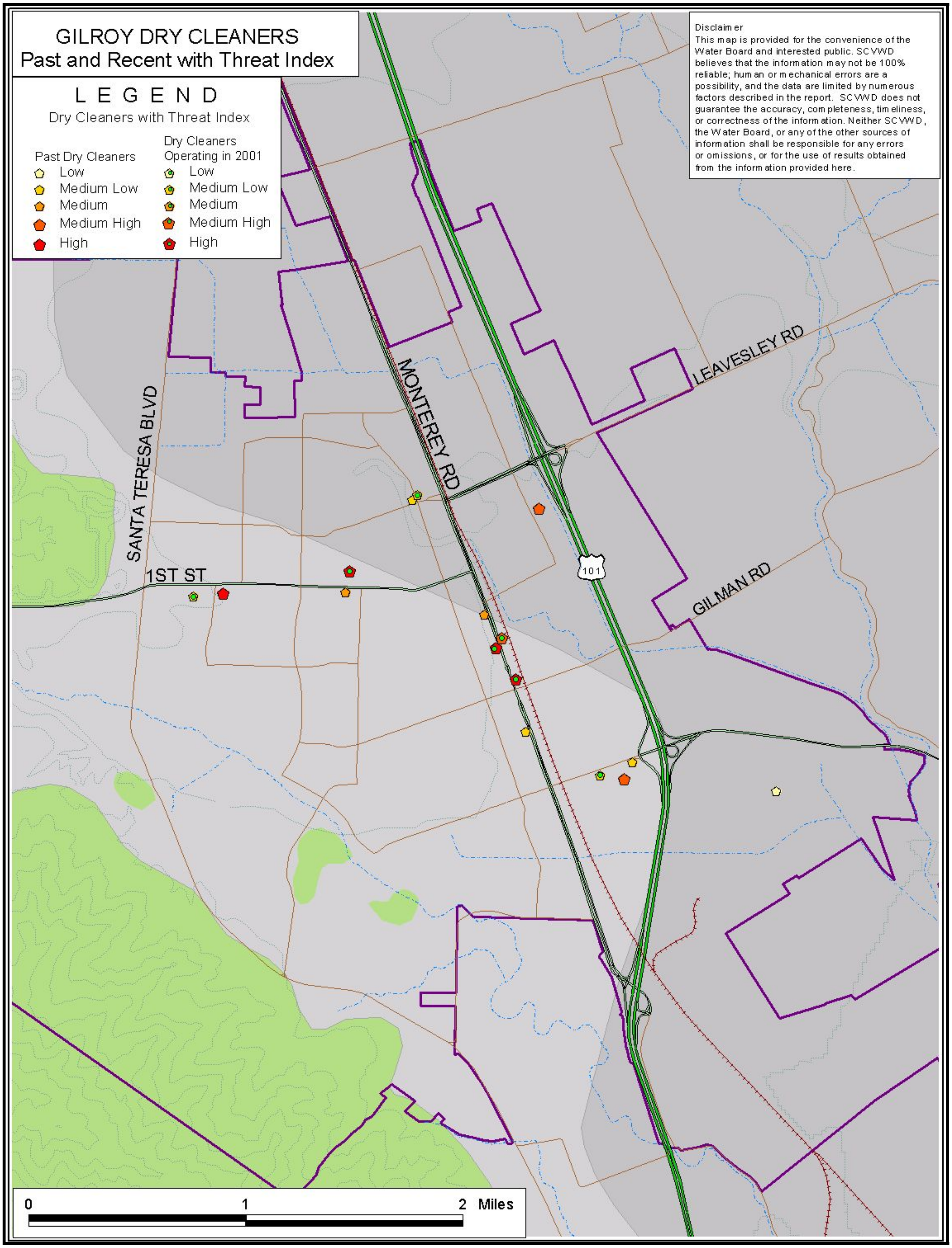

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