



## Dry Cleaner Releases and Forensic Considerations

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### ABSTRACT

Upfront consideration of historical operations and potentially valuable forensic information/data helps to ensuring the cleanup liability at dry cleaner sites can be equitably divided. While each site is different and requires site-specific evaluation, the associated environmental impacts from any given year of dry cleaning operations can vary significantly based on the interconnections related to the type of solvent and/or equipment used at a site as well as the solvent handling practices employed during that specific period of time.

### I. Introduction

Dry cleaning has been a routine part of American society for almost 100 years. Over that history, there are tens of thousands of locations where dry cleaners have operated.<sup>1</sup> Solvent handling by these facilities was vulnerable to numerous operational steps that permitted solvent releases to occur before and after regulations of hazardous waste handling procedures and reporting were established. At locations where solvent releases impact soils, groundwater, and/or indoor air, the necessary cleanup for protection of workers, the general public, and nearby residents at each site often costs hundreds of thousands of dollar or more.<sup>2</sup> Where solvent contamination has been discovered, the party or parties identified by the regulatory agency as responsible for these cleanup costs often look to previous dry cleaning owners and/or operators to contribute their equitable share to the overall costs. In order to evaluate the contribution of each party to the overall liability, environmental forensic methods can be employed to reconstruct the types and/or magnitude of a party's release and their attributable contribution to the overall site contamination. Over the many decades of dry cleaner operations numerous solvents were used for dry cleaning. This

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<sup>1</sup>USEPA. 1980. Perchloroethylene Dry Cleaners – Background Information for Proposed Standards. Table 8-4 for the period 1967 to 1976, which shows a maximum in 1967 of over 47,000 dry cleaning establishments (coin-operated, commercial, and industrial).

<sup>2</sup>Mohr, Thomas K.G. May 2007. "Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County." Santa Clara Valley Water District. Pages 6–7.

article focuses on the most prevalent dry cleaning solvent, tetrachloroethene (also commonly referred to as tetrachloroethylene, perchloroethylene, PCE, or Perc).

Legal liability for site contamination can extend beyond site dry cleaning operators and can include other parties who had some responsibility for the handling of solvents and solvent wastes. In addition to site operators, other liable parties may include property owners, solvent/waste transporters,<sup>3</sup> and municipalities responsible for sewers that service the dry cleaning operations.<sup>4</sup> These potentially responsible parties need to be accounted for in a forensics evaluation and an apportionment of overall cleanup liability.

## II. Changes in dry cleaning operations over time

Understanding the contribution of various potentially responsible parties to the overall site cleanup liability is made more complicated by the changes in dry cleaner operations and regulatory requirements and limitations. As a result, the associated impact from any given year of dry cleaning operations can vary significantly based on the type of solvent and/or equipment used at a site as well as the solvent handling practices employed during that specific period of time.

Dry cleaning operations occurred at various scales. According to the United States Environmental Protection Agency (“USEPA”), the most common types of dry cleaning operations in 1991 were commercial operations that “include[d] small independently operated neighborhood shops, franchise shops, and small specialty cleaners that clean leather and other fine goods.”<sup>5</sup> On the smallest scale were coin-operated dry cleaning machines that were “usually part of laundromats” where cleaning was done “on either a self-service or an over-the-counter basis.”<sup>6</sup> On the largest scale were industrial dry cleaning plants that “primarily suppl[ied] rental services of uniforms and other items...to business, industrial, and institutional customers.”<sup>7</sup> As shown in [Table 1](#), in 1991 there were approximately 28,000 PCE-based dry cleaning operations in the United States. Commercial-scale operations made of 89% of all PCE-based dry cleaning operations, coin-operated operations made up 11% of the PCE-based dry cleaning operations, and industrial-scale operations made up less than 1% of the PCE-based dry cleaning operations.<sup>8</sup>

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<sup>3</sup> Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) 42 U.S.C. §9601 et seq. (1980).

<sup>4</sup> *Adobe Lumber v. Hellman*, 658 F.Supp.2d 1188, (E.D. Cal. 2009).

<sup>5</sup> USEPA. November 1991. Dry Cleaning Facilities – Background Information for Proposed Standards. Page 3–2.

<sup>6</sup> *Ibid.*

<sup>7</sup> *Ibid.*

<sup>8</sup> USEPA. September 1995. Profile of the Dry Cleaning Industry. Exhibit 7 and citations therein.

**Table 1.** Number of dry cleaning facilities by process and industrial sector, USA, 1991.<sup>9,2</sup>

Process solvent	Industrial sector			Total
	Commercial	Industrial	Coin-operated	
PCE	24947	130	3044	28121
Petroleum	4548	195	0	4743
CFC-113	949	0	0	949
TCA	50	0	0	50
Total	30494	325	3044	33863

### A. Dry cleaning solvents

A wide array of solvents are used in the dry cleaning industry, but the most prevalent solvent in the context of environmental contamination is PCE. PCE has been used as dry cleaning solvent since the late 1930s due to its physical properties that allowed for faster and safer operations (relative to past usage of flammable petroleum-based solvents)<sup>9</sup> – properties that have also allowed operators to clean more clothes and generate more income. While the business side of the dry cleaning industry was focused on the efficiency of dry cleaning operations when PCE was first introduced as a solvent, there was limited focus on the impacts caused by a release of PCE to the environment. We now understand that when released to the environment, PCE is toxic in relatively low concentrations, mobile, and persistent<sup>10</sup> – all chemical characteristics that contribute to expensive environmental cleanups. For perspective, using the current drinking water Maximum Contaminant Level as a measure, a single drop of PCE reaching groundwater could result in the contamination of up to 7,000 gallons of water.<sup>11</sup> Among its most problematic properties, pure-phase PCE is denser than water (i.e. a dense non-aqueous phase liquid, or DNAPL) and is thus capable of sinking within groundwater and contaminating groundwater, soil, and bedrock hundreds of feet or more below a site.

There are a number of other solvents that have also been used since the beginning of the dry cleaning industry. Early dry cleaner operations conducted in the late 1800s and early 1900s used kerosene and gasoline to clean clothes.<sup>12</sup> While these solvents were effective, they often required longer times to clean clothes and resulted in other occupational hazards – explosion of dry cleaning equipment and/or fires – or consumer complaints associated with unfavorable odors.<sup>13</sup>

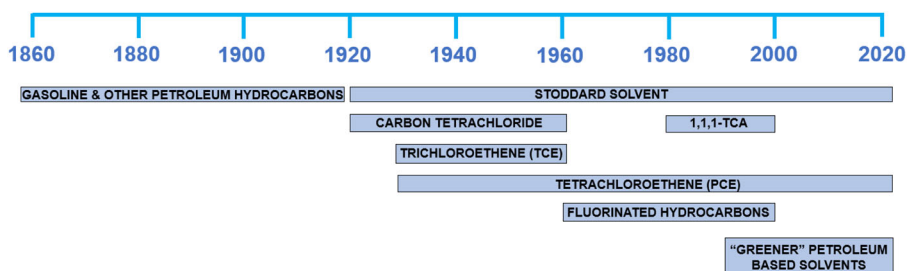
<sup>9</sup>Doherty, Robert, 2000. A History of the Production and Use of Carbon Tetrachloride, Tetrachloroethylene, Trichloroethylene and 1,1,1-Trichloroethane in the United States: Part 1 – Historical Background; Carbon Tetrachloride and Tetrachloroethylene.

<sup>10</sup>United States Agency for Toxic Substances and Disease Registry. 2019. Toxicological Profile for Tetrachloroethylene.

<sup>11</sup>Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.

<sup>12</sup>*Ibid.* Page 43.

<sup>13</sup>Doherty, Robert, 2000. A History of the Production and Use of Carbon Tetrachloride, Tetrachloroethylene, Trichloroethylene and 1,1,1-Trichloroethane in the United States: Part 1 – Historical Background; Carbon Tetrachloride and Tetrachloroethylene.



**Figure 1.** Timeframes for historical solvent use in dry cleaning operations.

Since the 1920s, less-flammable solvents have been introduced to the dry cleaning industry to provide a safer work environment for employees and to improve the efficiency of dry cleaning operations. These solvents include carbon tetrachloride; Stoddard solvent<sup>14</sup> and other hydrocarbons; trichloroethene (TCE); fluorinated hydrocarbons; and methyl chloroform (aka 1,1,1-TCA).<sup>15</sup> In recent times, dry cleaning operators have shifted away from using PCE due to the potential human health and environmental risk and have returned to using less hazardous petroleum-based solvents or alternatives.<sup>16</sup> An approximate timeline of the use of various solvents in the dry cleaning industry is provided in Figure 1.<sup>17</sup>

### **B. Dry cleaning equipment**

The evolution of PCE-based dry cleaning machines over the decades are typically described in terms of “generations.” First generation machines are often called transfer machines because they had separate units for washing and drying clothes that required the physical transfer of cloths wet with solvent between the two units. Later generations had solvent washing and drying in single self-contained units with varying degrees of sophistication for solvent recovery and recycling. The different types of machines are described in more detail below.

- *Transfer machines.* Transfer dry-cleaning systems are comprised of separate washing and drying units, hence involving a transfer of clothes wet with PCE (or other solvents) from the washer unit to the dryer unit.<sup>18</sup> Before drying, 100 pounds of clothes may contain 2–3 gallons

<sup>14</sup>The United States Agency for Toxic Substances and Disease Registry (ATSDR), specifies that Stoddard solvent is “a mixture of many chemicals” and “is a widely used, man-made organic solvent that comes from the refining of crude oil. It is a petroleum mixture made from distilled alkanes, cycloalkanes (naphthenes), and aromatic compounds. The chemicals in Stoddard solvent are similar to those in white spirits.” ATSDR. 1995. Public Health Statement, Stoddard Solvent.

<sup>15</sup>Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District. Page 43.

<sup>16</sup>*Ibid.*

<sup>17</sup>Note that it is possible that dry cleaner facilities may have used these solvents outside the time period shown in Figure A.

<sup>18</sup>USEPA. September 1995. “Profile of the Dry Cleaning Industry.” Page 14.

(approximately 27–40 lbs) of PCE.<sup>19</sup> A transfer dry cleaning system typically includes a dry cleaning washing unit (extractor) and PCE storage tank, a reclaiming (dryer), and may also contain a cooker and vapor condenser in later models.<sup>20</sup> Transfer dry cleaning machines, also termed “first generation machines,” were the only type of dry cleaning machine used until the late 1960s, when dry-to-dry machines (integration of washing and drying into the same unit) were developed.<sup>21</sup> Even after dry-to-dry machines were developed, transfer dry cleaning machines continued to be used for several decades since new machines represented a significant capital investment for small dry cleaning businesses. In fact, the USEPA documented that transfer dry cleaning systems still accounted for approximately 34% of dry cleaning machines in the United States in 1995.<sup>22</sup>

- *Dry-to-dry machines.* Dry-to-dry machines are closed-loop systems introduced in the late 1960s. These machines washed and dried clothes in a single unit, eliminating the need to transfer clothes wet with solvent to a separate dryer. Dry-to-dry machines are often identified as 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, and 5<sup>th</sup> generation, depending on how each system manages solvent emissions to the atmosphere.<sup>23</sup> As the generation of dry cleaning machines advanced, the solvent recovery systems progressed to minimize the vapor emissions of PCE, initially because PCE was one of a dry cleaner’s largest operating expenses and vapor losses resulted in significant cost to the business, and then later in order to protect dry cleaning workers from solvent vapors.<sup>24</sup> Specifically, 2<sup>nd</sup> generation machines typically sent residual vapors directly to the atmosphere unless they were retrofitted with some type of vapor recovery,<sup>25</sup> whereas subsequent generations have increasingly sophisticated mechanisms (e.g., condensers, carbon adsorbers) to enhance solvent recovery for reuse and decrease solvent emissions to the atmosphere.<sup>26</sup>

The dry cleaning machines that handled clothing only represent a portion of the equipment at a typical dry cleaner. Depending on the dry

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<sup>19</sup> Metropolitan Water District of Southern California and the Environmental Defense Fund. 1991. *Dry Cleaning of Fabrics*. Page 9–10.

<sup>20</sup> Izzo, Victor J. 1992. *Dry Cleaners – A Major Source of PCE in Groundwater*. California Regional Water Quality Control Board, Central Valley Region. Page 9.

<sup>21</sup> USEPA. September 1995. “Profile of the Dry Cleaning Industry.” Pages 14 & 16.

<sup>22</sup> Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District. Page 43.

<sup>23</sup> *Ibid.* Table 12.

<sup>24</sup> USEPA. 1980. *Perchloroethylene Dry Cleaners – Background Information for Proposed Standards*; USEPA. September 1995. *Profile of the Dry Cleaning Industry*. Page 14; California Environmental Protection Agency Air Resources Board. 2006. *California Dry Cleaning Industry Technical Assessment Report*. Table VII-5.

<sup>25</sup> USEPA. September 1995. *Profile of the Dry Cleaning Industry*. Page 16.

<sup>26</sup> *Ibid.* Page 14.

cleaning equipment generation, various auxiliary processes handled the solvent, solvent vapors, and wastes inherent in the dry cleaning process. The unit processes with the most significant handling of PCE are described below, including the waste streams that they generated.

- *Filtration System.* After washing was complete, the used solvent in the machine is passed through a filtration system to remove the solids that were generated in the cleaning process (e.g., dirt, lint, etc. from dirty clothing) and prepare the solvent for reuse. Typically, the filters can be reused regularly for a period of time, but once they have reached their useful life they must be disposed. Historically, filters were often collected outside a facility's service door<sup>27</sup> and disposed in the regular trash,<sup>28</sup> but now are required to be disposed as a RCRA hazardous waste because of the residual PCE in the filter.<sup>29</sup>
- *Vapor Recovery System.* Once solvent is removed from clothing via physical means (e.g., centrifugal forces) the clothes are dried, often using heat to evaporate the remaining solvent. Dry cleaning machines with vapor recovery systems capture the solvent vapor through a carbon adsorber (sometimes called a "sniffer")<sup>30</sup> or a condenser that cools most of the vapor back into a liquid for recovery and reuse. Some vapor recovery systems include both a carbon absorption unit after a condenser to further decrease the amount of PCE discharged to the atmosphere. Depending on the system configuration, the carbon adsorber can also be dry heated or steam can be passed through it to recover PCE, which is condensed and recovered in the phase separator.
- *Distillation System.* Distillation was used for both solids and liquids. The solids recovered by the filtration process are transferred to a muck cooker, which heats up the wet solids and volatilizes the PCE. PCE recovered from the muck cooker is recovered in a condenser and reused.<sup>31</sup> In addition, as part of the cleaning process, the PCE itself can become dirty with the material it dissolves from clothing. Dirty PCE is cleaned in a distillation process that separates out the PCE by boiling it off, leaving behind nonvolatile residue in the bottom of the still. The boiled-off PCE is recovered in a condenser and reused. The residual solids from the distillation process still contain appreciable quantities of PCE: in one report, still bottoms were 75% PCE by weight and muck

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<sup>27</sup> Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Dry cleaning Sites.

<sup>28</sup> Mohr, Thomas K.G. May 2007. "Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County." Santa Clara Valley Water District. Page 43.

<sup>29</sup> USEPA. 1999. RCRA in Focus, Dry Cleaning.

<sup>30</sup> Metropolitan Water District of Southern California and the Environmental Defense Fund. 1991. Dry Cleaning of Fabrics. Page 61.

<sup>31</sup> USEPA. November 1991. Dry Cleaning Facilities – Background Information for Proposed Standards. Page 3-8

(the residual solids from muck cookers) was 56% PCE by weight.<sup>32</sup> Historically muck solids and still bottoms were disposed in the regular trash,<sup>33</sup> but now are required to be disposed as a RCRA hazardous waste because of the residual PCE content.<sup>34</sup>

- *Phase Separator.* The dry-cleaning process mixes solvent and water at various stages of the process (e.g., in the washer/extractor, from a condenser). The phase separator allows PCE-and-water mixtures to separate and the PCE to be removed for reprocessing. The process is intended to separate PCE from the water, but the water in contact with PCE contains dissolved PCE (PCE's solubility limit in water is approximately 150 mg/L) and soaps and other surfactants can keep separate phase PCE suspended in the water. While the intent of the phase separator is to only discharge water with dissolved PCE, in practice both separator failures and surfactant suspended separate phase droplets can result in the discharge of separate phase PCE. Historically, separator water was disposed of on the ground outside of the building or into sewers or septic systems.<sup>35</sup> Now, contact water from phase separators typically contains enough PCE to be classified as a hazardous waste and requires handling and disposal accordingly.<sup>36</sup>

### **C. Regulatory framework**

Dry cleaning handling practices and the solvents and equipment used evolved over time. The evolution of solvent handling practices was driven by technical advances and business optimization, but was also pushed by government regulations.

Regulations for the proper handling of solvents and solvent wastes in dry cleaning operations were established relatively recently in the history of dry cleaning operations. Dry cleaner regulations were driven by the increased knowledge of each of the on-site processes performed by even the smallest plants.

#### **1. Standard of care before state and federal regulation**

Dry cleaning was first reported in the United States in the late 1800s. During the time when dry cleaners typically used flammable solvents (1880s to 1940s), local building regulations required dry cleaners be located away from populated areas. Other historical building codes required early dry cleaners to construct

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<sup>32</sup> State Coalition for Remediation of Dry Cleaners. 2010. Conducting Contamination Assessment Work at Dry Cleaning Site. October. Page 14.

<sup>33</sup> Mohr, Thomas K.G. May 2007. "Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County." Santa Clara Valley Water District. Table 54.

<sup>34</sup> USEPA. 1999. RCRA in Focus, Dry Cleaning.

<sup>35</sup> Mohr, Thomas K.G. May 2007. "Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County." Santa Clara Valley Water District. Table 54.

<sup>36</sup> USEPA. September 1995. Profile of the Dry Cleaning Industry. Page 55.

thick-walled buildings to house the operations in order to protect the public from explosions, which were reportedly not uncommon.<sup>37</sup>

Some of the earliest monitoring of dry cleaning sites was done by the Sanborn Map Company. Started in 1867 as the D. A. Sanborn National Insurance Diagram Bureau, Sanborn produced U.S. town maps for fire insurance purposes.<sup>38</sup> Because dry cleaners used flammable and hazardous substances, Sanborn included dry cleaner buildings on their maps. Similarly, as early as the 1950s and 1960s, many local fire departments began inspecting and monitoring dry cleaners due to their use of flammable and hazardous substances.<sup>39</sup> This information was primarily used for the safety of firefighters responding to a structure fire.

Since, most “regulation” of dry cleaners during the period from the late 1800s to the early 1970s was local, Sanborn maps, and municipal building and public works permitting documents can be some of the only documentation of historical dry cleaning operations.

From the beginning of dry cleaning in the United States until the early 1970s, there was no Federal or State regulations for the proper handling and disposal of dry cleaning solvents. Dry cleaner operators bought and used solvents to operate their facility. Prior to enactment of regulations, many chemical distributors often delivered their products in either tanker truck or drums, and possibly via railroad tank cars.<sup>40</sup> For historical tanker truck or railroad tank car deliveries, solvent was transferred either directly to the dry cleaning machine or onsite storage tanks using a pump and a hose outfitted with a discharge nozzle.<sup>41</sup> More often than not, these trucks/tanks would not be equipped with controls to prevent accidental leaks or discharges of solvents to the ground in the dry cleaner facility or “out the back door.” Releases of solvents have been reported to have occurred: (1) at uncoupled hoses, valves, or fittings; (2) when reeling a hose back into the truck or railroad car; (3) overfilling the onsite solvent storage tanks or dry-cleaning machines; or (4) spills during drum deliveries (e.g. drum rupture).<sup>42</sup>

In more modern times, dry cleaning solvents are delivered in drums using “direct-couple or closed-loop” solvent delivery systems.<sup>43</sup> These

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<sup>37</sup> Michelsen, E.M. 1957. *Remembering the Years 1907–1957*, Silver Spring, MD, National Institute of Dry cleaning.

<sup>38</sup> Chris Nehls. 2003. “Sanborn Fire Insurance Maps, a Brief History”. Geostat Center and Department of History, University of Virginia.

<sup>39</sup> National Fire Protection Association. [nfpa.org](http://nfpa.org)

<sup>40</sup> State Coalition for Remediation of Dry Cleaners. 2010. Conducting Contamination Assessment Work at Dry Cleaning Site.

<sup>41</sup> State Coalition for Remediation of Dry Cleaners. 2010. Conducting Contamination Assessment Work at Dry Cleaning Site; Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Drycleaning Sites.

<sup>42</sup> State Coalition for Remediation of Dry Cleaners. 2010. Conducting Contamination Assessment Work at Dry Cleaning Site; Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.

<sup>43</sup> Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.



systems are designed to prevent leaks and capture PCE vapors during solvent delivery.<sup>44</sup>

Historically, solvents were stored in either aboveground storage tanks (ASTs), underground storage tanks (USTs), drums, or within the dry cleaner machine itself.<sup>45</sup> If not stored within the machine, the solvent would often be pumped by hand into the dry cleaning machine or into a bucket or other container, which was used to transfer solvent and fill the machine.<sup>46</sup> In the early days, solvent was often added to the machine through the front door and into the drum of the washer, or through the button trap lid.<sup>47</sup> The new closed-loop dry cleaning machines used today include dedicated solvent filling ports, which are directly connected to a pump in a drum.<sup>48</sup>

Prior to regulation, the state of the art for disposal of solvent and solvent wastes can be understood from dry cleaning solvent Safety Data Sheets, and the installation and operation manuals for the various trade equipment available and in operation during that period of time.

Equipment performing the various post-cleaning processes (filtration, distillation, etc.) within dry cleaning facilities, each had their own instruction for use. Many included instructions for practices that today are known to have caused PCE contamination of soil and groundwater, including:

- Disposal of large solvent spill via flushing to ground or burial away from water supply,<sup>49</sup>
- Disposal of solvent-laden wastewater (e.g., separator water and vacuum/mop water) to the ground, sanitary sewer or septic field;<sup>50</sup>
- Disposal of solvent-laden solid waste (e.g., filters, lint, still bottoms, cooked powder residues or “muck,” etc.) in the trash or dumpster;<sup>51</sup> and

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<sup>44</sup> Oregon Department of Environmental Quality (ODEQ), 2018. Fact Sheet: Dry Cleaners: Delivery of Perchloroethylene Solvent.

<sup>45</sup> Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.

<sup>46</sup> Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Drycleaning Sites.

<sup>47</sup> Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.

<sup>48</sup> Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Drycleaning Sites.

<sup>49</sup> Dow MSDS for Perchloroethylene instructs users in “disposal” for “large spill” to “flush spill to ground and let evaporate” ... and “bury away from water supply or allow to solvent to evaporate [on ground].”

<sup>50</sup> Manufacturing Chemists Assoc., Chemical Data Safety Sheet. Includes only two small paragraphs on “waste disposal.” Instructs to obtain “good advice” from supplier, and that “distillations ... may be poured on ... dry sand, or earth ... and allowed to evaporate.”; Izzo, Victor J. 1992. Dry Cleaners – A Major Source of PCE in Groundwater. California Regional Water Quality Control Board, Central Valley Region.; Norge Sales Corporation, 1961. Installation and Operating Instructions for the Norge Dry Cleaning System, Model 013-323-3; 1979 Hoyt Sniffer Manual Instructs dry cleaner to connect separator water outlet pipe to “open sewer” because “in excess of 12 gallons of [waste] water will be generated on each operation.”

<sup>51</sup> Norge Sales Corporation, 1961. Installation and Operating Instructions for the Norge Dry Cleaning System, Model 013-323-3; Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Dry cleaning Sites; Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.

- Emission of solvent in the vapor-phase solvents before and after the installation of spent carbon adsorbers or misting devices.<sup>52</sup>

Given the above as the standard of care prior to regulation, USEPA noted in 1980 that well-operated and well-controlled facilities “do not represent the norm in the industry.”<sup>53</sup> Over time, as Federal and State regulators learned more and more about the processes that occurred in dry cleaning plants, existing regulations were enforced and new regulations were implemented to deal with dry cleaner wastes.

## **2. Clean air act**

The first regulatory actions related specifically to dry cleaning solvent handling were aimed at air quality, not waste handling or water quality. In 1963, Congress enacted the Clean Air Act<sup>54</sup> that allowed states to establish their own agencies to regulate air emissions. However, it was not until 1983 that the California Air Resources Board (“CARB”), which oversees local and regional air pollution control districts throughout California, began enforcing permitting of PCE dry cleaning machines as part of CARB’s Industrial Sources permitting procedure. At the time, PCE was targeted because of its high volatility and carbon emissions, which affected air quality. Permitting of all PCE dry cleaning machines became statewide law pursuant to Health & Safety Code Section 39666. H&S Code section 39666 required dry cleaning machines using PCE to be permitted and required emission mitigation controls. Local Air Management Control Districts established annual inspection programs. This regulation reduced air emissions in the workplace and to the outdoor environment, but did not address any liquid waste discharges or solid waste handling.

## **3. RCRA**

In 1976, Congress enacted the Resource Conservation and Recovery Act (“RCRA”).<sup>55</sup> Amended in 1980 and the promulgation of regulations thereafter, RCRA provides the framework of regulations regarding the generation and disposal of non-hazardous solid wastes and hazardous wastes. Manufacturer-provided Safety Data Sheets produced after the implementation of RCRA show changes in the spill and disposal instructions for PCE and PCE-containing solid wastes. Whereas prior to RCRA some Safety Data Sheets instructed disposing of waste solvent on the ground (e.g. one

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<sup>52</sup> Hoyt MFG. Corp, 1979. Installation, Operating & Service Instructions for Hoyt Sniff-O-Miser. Model 1A-4A-8A and 12A. April 15; Plain English Guide for Perc Dry Cleaners.

<sup>53</sup> USEPA. 1980. Perchloroethylene Dry Cleaners – Background Information for Proposed Standards. Page 3–7.

<sup>54</sup> 40 CFR Parts 50 to 99.

<sup>55</sup> 42 USC Sec. 6901.

1975 Material Safety Data Sheet for PCE states that “in some cases it can be transported to an area where it can be placed on the ground and allowed to evaporate safely”<sup>56</sup>), after the promulgation of RCRA, the Safety Data Sheets instruct that users should “take precautions as necessary to prevent contamination of ground and surface waters” and to “comply with all local codes.”<sup>57</sup>

#### 4. California regulators

In the late 1980s and early 1990s, California was one of a handful of states that started specific monitoring, inspections, and permitting of PCE dry cleaners. In 1991, CARB declared PCE a “toxic air contaminant” and codified it under Health and Safety Code section 39650 et. Seq. This allowed for stricter regulation of PCE and required dry cleaners to create a daily record of PCE usage and report it annually to local air boards. Interestingly, regulations of PCE air emissions from dry cleaners generated an additional liquid waste stream via the use of the vapor adsorbers and condensers that initially led to additional discharges to PCE laden wastewater to the sewers.

In March 1992, the California Central Valley Regional Water Quality Control Board (“RWQCB”) published its report first recognizing the widespread environmental impacts that dry cleaning wastewater generated during the PCE recycling, distillation, and steam stripping processes.<sup>58</sup> This report took a closer look at the post-cleaning processes inside more than twenty-five dry cleaners from Sacramento to Bakersfield, California. The investigation found that main discharge point of large volumes of wastewater generated by dry cleaning operations is the sewer line.

[T]he discharge from most dry cleaning units contains primarily water with dissolved PCE, but also contains some pure cleaning solvent and solids containing PCE. Being heavier than water, PCE settles to the bottom of the sewer line and exfiltrates through it. This liquid can leak through joints and cracks in the line. PCE, being volatile, also turns into gas and penetrates the sewer wall. Sewer lines are not designed to contain gas. The PCE then travels through the vadose zone to the ground water.<sup>59</sup>

In 1993, the State of California enacted separate regulations specifically for PCE dry cleaners that are codified into the California Code of Regulations (Title 17 CCR section 93109). Among other restrictions, these regulations prohibited the discharge of dry cleaner wastewater to the sewer.

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<sup>56</sup>Dow Chemical, USA. January 31, 1975 (effective date). Material Safety Data Sheet, Dowper (95% PCE, minimum).

<sup>57</sup>1984 PPG MSDS for Perchloroethylene.

<sup>58</sup>Izzo, Victor J. 1992. Dry Cleaners – A Major Source of PCE in Groundwater. California Regional Water Quality Control Board, Central Valley Region.

<sup>59</sup>*Ibid.* Page 2.

This is the first explicit regulation of so-called “separator water.” Thus, permitting of dry cleaning operations after 1980 could include documentation of facility operations from State and local Air Boards, and local public works departments (sewer permitting, design, and maps).

From a solvent use and equipment standpoint, regulators required that no new transfer machines were allowed to be installed in the United States as of 1993,<sup>60</sup> and New York State required the complete phase-out of transfer dry cleaning machines in 1996.<sup>61</sup> USEPA noted in 1995 that “coin-operated dry cleaners are gradually being phased out of the dry cleaning market... new coin-operated equipment is reported to be no longer available on the market.”<sup>62</sup> Furthermore, the State of California is in the process of pushing the phase out of PCE-based dry cleaning machines: installation of new PCE-based dry cleaning machines was prohibited in 2008, and all PCE-based dry cleaning machines must be removed from service by 2023.<sup>63</sup> In 2007, a study found there were 3,400 dry cleaners in California, of which 70% were using PCE as the main solvent.<sup>64</sup> As PCE-based machines are phased out they are replaced with machines that use the new generation of solvents that claim to be less environmentally impactful than PCE.

### III. Numerous identified sources of dry cleaner releases

There are numerous solvent handling steps in dry cleaning operations that can result in releases of solvents to the environment. Numerous studies have investigated the nature, extent, and frequency of various types of releases from dry cleaning operations.

According to a study that assessed over 300 dry cleaner or solvent handling facilities in Florida, 39.2% of solvent releases were associated with failure of equipment associated with a machine.<sup>65</sup> The types of releases reported were due to leaky seals, gaskets, piping, hoses, valves, etc.<sup>66</sup> The cause of these leaks may be attributable to:

1. equipment wear and corrosion, the expansion and contraction of metal components from temperature changes, and the vibration of dry cleaning equipment;<sup>67</sup> and
2. As the dry cleaning machines evolved over time, so did the complexity of these machines. While the early evolution of these machines was

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<sup>60</sup> National Emission Standards for Hazardous Air Pollutants for Source Categories - PCE Dry Cleaning Facilities, Final. Rule (58 FR 49354).

<sup>61</sup> USEPA. September 1995. Profile of the Dry Cleaning Industry. Page 56.

<sup>62</sup> *Ibid.* Page 6.

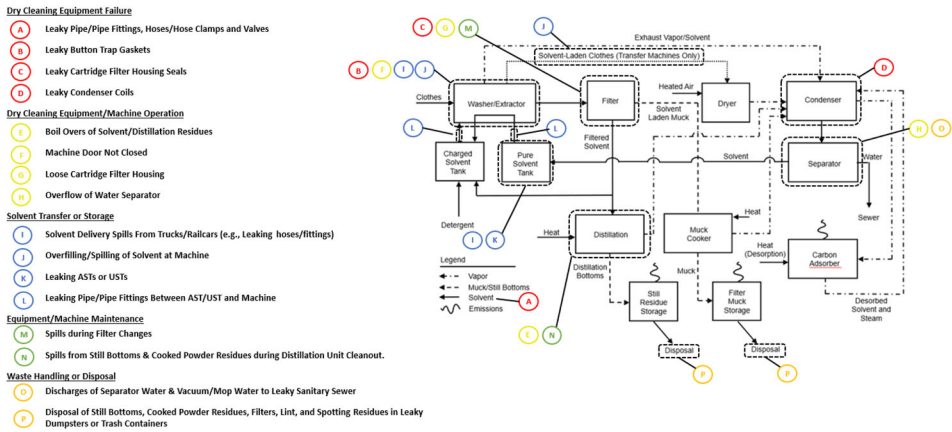
<sup>63</sup> California Environmental Protection Agency, Air Resources Board. March, 2007. Amended Dry Cleaning ATCM Requirements Fact Sheet.

<sup>64</sup> Halogenated Solvents Industry Alliance (“HSIA”). Perchloroethylene White Paper. 2008.

<sup>65</sup> Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Drycleaning Sites.

<sup>66</sup> *Ibid.*

<sup>67</sup> *Ibid.*



**Figure 2.** Process flow diagram the dry cleaning operations and locations of identified point of solvent releases.

driven by the desire to consume less solvent per unit weight of washed clothes (more profit for the operator), the additional components added to the machine also added to the many failure points in the machine, resulting in the release of solvents (as discussed further below).

A process flow diagram the dry cleaning operations and locations of identified points of solvent releases is shown in Figure 2.

Numerous studies and guidance documents have identified a wide range of sources of soil and groundwater contamination originating from dry cleaners. The most common sources identified by nine studies/guidance documents are summarized in Table 2. The sources represent broad groupings and are described in detail as follows:

- **Sewer Lines.** Typical sources of contamination originating from sewer lines include PCE-water separators, cooling water,<sup>68</sup> and the improper disposal of water and solvent in sinks or floor drains.<sup>69</sup> Discharges of solvent-laden wastewater to the sanitary sewer often leaked to the underlying soil and groundwater through leaking pipe joints or cracks.<sup>70</sup> Discharges to sewer lines can result in dry cleaner-related contamination that is not on the dry cleaner property. Releases through sanitary sewers have been observed hundreds of feet from a dry cleaning facility.<sup>71</sup>

<sup>68</sup> Izzo, Victor J. 1992. Dry Cleaners – A Major Source of PCE in Groundwater. California Regional Water Quality Control Board, Central Valley Region. Pages 9–10.

<sup>69</sup> State Coalition for Remediation of Dry Cleaners. 2010. Conducting Contamination Assessment Work at Dry Cleaning Site. October. Page 19.

<sup>70</sup> Izzo, Victor J. 1992. Dry Cleaners – A Major Source of PCE in Groundwater. California Regional Water Quality Control Board, Central Valley Region.

<sup>71</sup> *Ibid.*



**Table 2.** Sources of soil and groundwater contamination originating from dry cleaners.

Year	Publisher	Soil and groundwater contamination release mechanisms							
		Sewer lines	Septic systems	Interior spills or releases	Exterior spills or releases	Vapor discharge	Improper solid waste management	Storage tanks	
1992	California Regional Water Quality Control Board <sup>93</sup>	x							
1995	USEPA <sup>94</sup>	x	x	x				x	
2000	State of Georgia <sup>95</sup>	x	x	x	x	x		x	x
2006	Colorado Department of Public Health and Environment <sup>96</sup>		x	x	x			x	x
2006	State of California Air Resources Board <sup>97</sup>			x					
2007	Santa Clara Valley Water District <sup>98</sup>	x	x	x	x	x		x	x
2011	California State Water Resources Control Board <sup>99</sup>	x		x					x
2012	State Coalition for Remediation of Drycleaners <sup>100</sup>	x	x	x	x			x	x
2013 (rev. 2017)	Indiana Department of Environmental Management <sup>101</sup>	x	x	x	x			x	x

- *Septic Systems.* The sources to septic systems are the same as the sources to sewer lines, but the contamination is typically distributed on the property through the septic tank or leach field.<sup>72</sup>
- *Interior Spills.* Interior spills can originate from a wide range of locations, as discussed above, including: during transfer of wet clothing to the drying unit in first generation machines, clogged lint or button traps, overfilling of machines, leaks from solvent recovery systems, and inadequately sealed equipment (e.g., due to failed gaskets).<sup>73</sup> In 1998, the International Fabricare Institute reports solvents loses of 1.5 gallons per 1000 pounds of clothing can be anticipated from interior leaks and spills.<sup>74</sup> Many guidance documents recommend measures to absorb the spills typical to dry cleaning operations, oftentimes recommending use of rags or absorbent pads to absorb PCE and then re-washing the absorbing material to recovery the PCE. However, spills of PCE can permeate through the concrete and impact the underlying soil even in the absence of cracks in the concrete floor.<sup>75</sup> Several state guidance documents, including those from Colorado and Georgia, note that concrete is porous and allows for PCE transmission. Specifically, Georgia recommended in 2000 to “coat [the] floor with a non-porous material to keep any spills from seeping through the concrete slab. Contact your dry cleaner supplier for the type of epoxy coating to use.”<sup>76</sup> For these reasons, guidance documents often recommend investigating the soil immediately below where dry cleaning machines were previously located.<sup>77</sup>
- *Exterior Spills or Releases.* Exterior spills and releases include: both small and catastrophic events during delivery (for example, small drips from hosing during tank filling and drum failures, respectively), intentional pouring of solvent or contaminated water “out the back door,” and draining of filter cartridges outside the service door of a facility.<sup>78</sup> These spent filters have been reported to have contained up to a gallon of solvent.<sup>79</sup> According to the study conducted in Florida, 15% of the

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<sup>72</sup> State Coalition for Remediation of Dry Cleaners. 2010. Conducting Contamination Assessment Work at Dry Cleaning Site. October. Page 28.

<sup>73</sup> Lohman, J. 2002. A History of Dry Cleaners and Sources of Solvent Releases from Dry Cleaning Equipment. *Environmental Forensics*, 3, 35–58.

<sup>74</sup> Morrison, R. 2003. PCE Contamination and the Dry Cleaning Industry. *Environmental Claims Journal*. 15:1. Page 97.

<sup>75</sup> Fong et al. (State of California Air Resources Board). California Dry Cleaning Industry Technical Assessment Report. Page VI-2.

<sup>76</sup> Georgia Environmental Protection Division. 2000. Environmental Guide for Georgia Dry Cleaners. Page 18.

<sup>77</sup> For example: Colorado Department of Public Health. 2006. Dry Cleaner Remediation Guidance Document. Page 6.

<sup>78</sup> Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.

<sup>79</sup> *Ibid.*

studied cases indicated that solvent releases were related to either the transfer or storage of solvents.<sup>80</sup> Although many of these releases may have occurred on concrete or asphalt, they may still be able to reach soil and groundwater. For example, the State of Colorado notes that “The major concern with filter cartridges is that they were often allowed to drain inside, or outside the service door of the dry cleaning facility prior to disposal in a trash dumpster ... a large percentage of the solvent may have migrated to the soil beneath these drainage areas due to the propensity of PCE to flow right through asphalt and concrete.”<sup>81</sup>

- *Vapor Discharge.* This release mechanism involves the initial discharge of PCE as a vapor, which then either condenses into a liquid and drips on the ground (e.g., at the vent of a dry cleaning system without a vapor recovery unit) or sinks to the ground surface because PCE vapor is denser than air and partitions to soil.<sup>82</sup> Solvent vapor has also been discharged to the atmosphere when transferring clothes (first generation machine) or during the drying process.<sup>83</sup> Refrigerated condensers or carbon adsorbers were installed on 2<sup>nd</sup> generation machines to capture solvents for reuse; however, these devices, when installed, would only recover 85% to 95% of solvent mass for the reuse – the remaining mass was discharged to the atmosphere.<sup>84</sup> In addition, following the ban on disposing of solvent-laden wastewater to the sewer, waste water would be discharged to the atmosphere through a mister.<sup>85</sup> While the mister would be outfitted with a carbon adsorber, the discharge of solvent-laden wastewater through a spent carbon adsorber (if not changed per a manufacturer’s recommendations) would result in the discharge of untreated solvent vapors to the atmosphere.<sup>86</sup>
- *Improper Solid Waste Disposal.* PCE-containing solid wastes from dry cleaners, including still bottoms and spent filter cartridges/media can be a source of contamination to soil and groundwater. The disposal of solvent-laden solids wastes in the trash can or dumpster often leaked to the underlying surface and eventually migrated to the underlying soil and groundwater over time.<sup>87</sup>
- *Storage Tanks.* Depending on the size of the facility, some dry cleaners stored new or waste PCE in above ground or underground storage tanks.

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<sup>80</sup> Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Dry Cleaning Sites. Page 5.

<sup>81</sup> Colorado Department of Public Health. 2006. Dry Cleaner Remediation Guidance Document. Page 7.

<sup>82</sup> Izzo, Victor J. 1992. “Dry Cleaners - A Major Source of PCE in Ground Water.” California Regional Water Quality Control Board, Central Valley Region. Page 3.

<sup>83</sup> USEPA, Plain English Guide for Perc Dry Cleaners

<sup>84</sup> Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.

<sup>85</sup> USEPA, 1996. Multimedia Inspection Guidance for Dry Cleaning Facilities.

<sup>86</sup> *Ibid.*

<sup>87</sup> Mohr, Thomas K.G. May 2007. “Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County.” Santa Clara Valley Water District.



Releases from storage tanks could be catastrophic (e.g., complete tank failure) or small and extended over long periods of time (e.g., slow drips). A number of studies have reported discharges of solvent during filling, or from overfilling, ASTs, USTs, drums, or the machine itself.<sup>88</sup> Furthermore, leakage from underground tanks may go unnoticed for long periods of time. For example, a leak rate of 1 tablespoon per day for a time period of 10 years would result in a solvent loss of 194 pounds of solvent, some fraction of which may be released to soil and groundwater.

Thus, there is no universal source of solvent releases to soil and groundwater at all sites with dry cleaning operations. Instead, there are a wide array of mechanisms, each of which requires consideration and possible investigation when developing a conceptual site model. Often, multiple release mechanisms are relevant.

#### **IV. Forensic considerations**

Determination of what releases occurred, when such releases occurred, and the magnitude of historical releases often requires a forensic investigation. Forensics data requirements should be considered during the site investigation phase in order to avoid duplicative investigation costs and prevent the loss of valuable site-specific information and/or data. Forensic investigations typically require piecing together multiple lines of evidence in order to develop technically defensible conclusions regarding the contributions from various operators on the site.

##### **A. Site operations**

Understanding any evolution of the facility layout over time and the areas of specific dry cleaning operations can be important for reconstructing which operator(s) contributed to solvent releases. If different areas of site contamination are identified, matching the release locations to the associated facility layout, solvent use, and handling practices can provide a technical basis for both geographic and temporal divisibility of the site contamination. For example, understanding the locations of various pieces of dry cleaning equipment, solvent storage areas, waste disposal areas, location of solvent deliveries, sewer lateral and sewer main locations all aid with associating site contamination more specifically with facility operations.

In addition, while dry cleaning operations did not typically measure and document solvent or solvent waste releases, there are various measures for

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<sup>88</sup> Mohr, Thomas K.G. May 2007. "Study of Potential for Groundwater Contamination from Past Dry Cleaner Operations in Santa Clara County." Santa Clara Valley Water District; Linn, B., Mixell, K. 2002. Reported Leaks, Spills, and Discharges at Florida Dry Cleaning Sites.

the intensity of solvent use for various operators over time and the likelihood of solvent releases. These measures include years of operation, type of equipment, volume of dry cleaning business, regulatory requirements and inspection records during the period of operations, records of solvent deliveries, and solvent and waste disposal records (or lack thereof).

In general, the earlier a dry cleaner operated at a facility, the greater the potential is for contaminant contributions for those early operators and the greater the contribution percentage to the overall contamination beneath a facility.<sup>89</sup> The greater likelihood results from the difference in older solvent handling practices relative to more modern standards of practice. For example:

- Solvent deliveries were often performed by a tanker truck, which contained multiple release points (e.g., leaky hoses, valves, hose fittings, etc.) as opposed to the delivery of solvent in sealed drums;
- Earlier operators used significantly greater amounts of solvent per unit weight of clothes cleaned, which indicates that they likely handled and released more solvent than later operators
- Early solvent handling and disposal practices were guided by the machine manufacturers and not by any environmental regulatory agency, which did nothing to prevent (and in some cases directed) the direct releases of solvents to the environment.

### **B. Data evaluation**

In addition to the qualitative evaluations of dry cleaning operations described above, there are quantitative data analysis techniques that have the potential to inform the source, timing, and relative contribution of historical releases to the overall site contamination. The techniques take advantage of the understanding of both the physics of the transport of contaminants through environmental media and the chemistry of the solvents themselves and their degradation in the environment.

The spatial distribution pattern of contamination and calculation of the estimated total mass of solvent released to soil and/or groundwater from each area of contamination can be useful for assessing if the suspected release mechanism matches the extent and magnitude of environmental impact. Depending on the nature and duration of the suspected release(s), the total solvent mass and the locations where it is found must fit within the framework of the local geology and hydrogeology and be consistent with the fundamental laws of chemistry and physics.

The dry cleaning solvent itself may be chemically unique in ways that can be used to differentiate different operators or distinguish on-site contribution

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<sup>89</sup> *Ibid.*

from other off-sources of solvents. The chemical uniqueness may result from the solvent molecule itself through its chemical structure (changes in solvent type like from Stoddard solvent to PCE) or isotopic ratio (among the same solvent type). There may also be chemical uniqueness through solvent additives or other chemicals used contemporaneously in dry cleaning operations which are not used specifically in the dry cleaning process.

For PCE, the specific isotopic weights of the chlorine and carbon molecules contained in the PCE molecule can potentially be used to distinguish different sources of PCE. Most dry cleaner operators at a given site used the same regional PCE supplier, and when the same supplier was utilized there is rarely any isotopic uniqueness among successive dry cleaner operators. Even where there may be some differences in the compound specific PCE isotopes among different suppliers or over different time periods, without original PCE samples from the specific suppliers or prior isotopic characterization it is difficult to make a definitive fingerprinting match. If different suppliers were utilized, there may be an observable difference in isotopic ratios within the site contamination that is not a result of degradation. Although isotopic ratios may be utilized to distinguish between different suppliers and time periods, compound specific PCE isotopes are typically more useful for distinguishing chlorinated solvent groundwater contamination from dry cleaning operational releases from other off-site sources of chlorinated solvents releases to groundwater originating from fundamentally different operations.

Dry cleaning solvents may also contain other chemicals that have the potential as a diagnostic of the time period when the solvent was used. These other chemicals can include a whole spectrum of chemical additives from different manufactures and for different dry cleaning facility operations, or they can include chemicals extracted from the cleaned materials that are unique to the cleaning business' clientele. There are other chemicals that are part of dry cleaning operation that may be diagnostic of specific operator processes: (1) detergents, surfactants, and stabilizers infused into the dry cleaning solvent, (2) pre- or post- fabric treatment applications such as bleaches, spotting agents, sizing chemicals, flame retardants, and water/stain repellents.<sup>90</sup> In practice, these chemicals have not demonstrated much utility since they typically are added to solvents at much lower concentrations than the solvents themselves and thus can easily drop below a laboratory's detection limits when they are dispersed and/or degraded in the environment. In addition, few of these dry cleaning associated chemicals are included in standard environmental testing methods, therefore detection would need to be specifically instructed to the laboratory, and associated costs incurred.

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<sup>90</sup>Morrison, R.D. and Murphy B.L. 2015. Chlorinated Solvents: A Forensic Evaluation. Chapter 8 – A Forensic History of Dry Cleaning.

Assuming site assessment data established a complete pathway from the facility into soil and through groundwater, the extent of the solvent groundwater plume reflects the amount of time the solvent releases have been in the environment and can be used to reconstruct the timing of initial solvent release. The extent of groundwater solvent contamination is controlled primarily by (1) flow rate of groundwater near, and within the vicinity of, the release area and (2) surface sorption of solvents to the solid matrix in the water bearing groundwater zone. This analytical technique is most effective at sites with homogenous geologic, hydrogeology, and biogeochemical conditions and has the potential to assign a narrow bracket (+/- a few years) around the aging of solvent release at a site. While this technique has the potential to provide beneficial results, many contaminated sites are underlain with heterogenous and complex geological, hydrogeological, and biogeochemical conditions that can expand the possible solvent release timing to a more uncertain timeframe (e.g. >10 years).

For chlorinated solvents, the ratio of PCE to TCE and other degradation products (through the reductive dechlorination of PCE) is also a measure of how much time released solvent has been in the environment. The more time in the environment, the more PCE degrades and the ratio of PCE to degradation products (TCE and DCE) decreases. At sites where the reductive dechlorination rate is known, this ratio can be used as another method for reconstructing the timing of the initial solvent release. Otherwise, the degradation ratios can be used qualitatively to assess whether the release has been in the environment for a relatively long or short period of time. PCE ratios with TCE and/or DCE also have the potential to be used to distinguish solvent contributions between on-site sources and possible off-site groundwater sources. Abrupt changes in molar ratios of PCE to TCE or TCE to DCE are typically indicative of multiple unique solvent releases,<sup>91</sup> as degradation is expected to result in gradual changes in such ratios as the contaminant plume migrates away from the source area.

## V. Conclusion

The overall evolution of dry cleaner operations over time, as well as site-specific history and operations, is important to consider when assessing the divisibility and apportionment of site contamination. Forensics need consideration during the site investigation phase in order to ensure all the information that can be used to reconstruct historical releases is available to figure out an equitable division of liability. Given the complexity of historical dry cleaning operations, considering forensics *after* investigation

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<sup>91</sup> Morrison, R. 2003. PCE Contamination and the Dry Cleaning Industry. *Environmental Claims Journal*. 15:1. Page 101–102.

and/or remediation is complete can result in duplicative costs and possibly loss of valuable information and/or data needed for a robust technical analysis utilizing multiple lines of evidence. Instead, incorporating an understanding of historical dry cleaning operations early in the site-specific technical analysis can help target the overall investigation of solvent impacts and can ultimately lead to a more robust, defensible and equitable apportionment of contaminant contribution at the site.

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