PCBs in Caulk Project:

Estimated Stock in Currently Standing Buildings in a San Francisco Bay Study Area and Releases to Stormwater during Renovation and Demolition

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EXECUTIVE SUMMARY

In April 2007, the State Water Resources Control Board awarded the Association of Bay Area Governments/San Francisco Estuary Partnership (SFEP) a Proposition 50 Coastal Nonpoint Source Pollution grant known as the “Taking Action for Clean Water” project to further implementation of several Bay Area Total Maximum Daily Loads (TMDLs). One of the Taking Action for Clean Water projects is the PCBs in Caulk project, which will create a model management process to keep polychlorinated biphenyls (PCBs) in historic building materials, specifically uncontained materials like sealants and caulking, out of urban runoff as partial implementation of the TMDL for PCBs in San Francisco Bay (adopted by the Office of Administrative Law on February 15, 2010). Caulk is targeted because it is a building material that has been found in many studies to have high concentrations of PCBs and is used on the exterior of buildings, and thus exposed to the environment.

After the California bond project freeze in 2008-2009, the grant was transferred to the Clean Water State Revolving Fund under the American Recovery and Reinvestment Act of 2009 (ARRA). In October 2009, the San Francisco Bay Regional Water Quality Control Board (RWQCB) adopted the Municipal Regional NPDES Permit for Stormwater (MRP), which includes Provision C.12.b.ii (3) requiring that permittees “develop/select BMPs to reduce or prevent discharges of PCBs during demolition/remodeling.” SFEP contracted with SFEI to assist with the development of Bay-Area-specific estimates of PCB loadings to urban runoff from historic building materials as part of the PCBs in Caulk project.

This report follows preliminary work summarized in a July 16, 2007 memorandum to the Clean Estuary Partnership (Moran et al. 2007), which reviewed building materials containing PCBs that could potentially contribute PCB loads to stormwater. That memo recommended that “the grant project initially focus on building materials within the categories of: (1) caulking and sealants, and (2) paint and coatings, with the category of caulking and sealants being the higher priority of the two.” The memo also recommended focusing on concrete and masonry structures constructed or substantially remodeled between 1957 and 1977. Further information about the selection of these parameters may be found in Moran et al. (2007). Though the MRP addresses PCB-containing materials, caulk is the only building material addressed in this report.

The specific objectives of the present study and this report were to:

- estimate the PCB mass associated with caulk in currently standing commercial and industrial buildings constructed between 1950 and 1980 in the San Francisco Bay study area (Note the ‘San Francisco Bay study area’ corresponds to the area covered by the MRP: Alameda, Contra Costa, Santa Clara, and San Mateo Counties, and the cities of Fairfield, Suisun, and Vallejo. In 1980 (the end of the main use period for PCBs), this area accounted for 73% of the population of the nine-county San Francisco Bay Area. The Counties of San Francisco, Marin, Sonoma, Napa, and most of Solano are excluded from this area,

- estimate the PCB mass released to urban runoff during the renovation and demolition of these buildings using current practices (i.e., prior to any PCB in caulk best management practices [BMPs] implementation),

- compare the estimated PCB mass released to stormwater from building renovation and demolition to other PCB sources in the Bay Area,

- summarize the information available regarding the potential effectiveness of BMPs for preventing PCB release to stormwater from demolition and renovation of PCB-containing caulk, and

- recommend opportunities to refine the estimates of the PCB stock in building caulk in the study area and PCB loading to stormwater from caulk in these buildings during building renovation and demolition.

PCBs in Caulk in San Francisco Bay Area Buildings

Using a blind sampling approach, 25 caulk samples were collected from the exterior of ten buildings in the San Francisco Bay study area and analyzed for PCBs. The caulk samples were analyzed for PCBs using a traditional, congener-specific laboratory method (solvent extraction and GC-MS analysis) and were also screened for the presence of chlorine (Cl) using a portable x-ray fluorescence (XRF) analyzer.

PCBs were detected in 88% of the caulk samples collected from the study area buildings, with 40% exceeding 50 ppm, the concentration at which caulk falls under U.S. Environmental Protection Agency (USEPA) regulations (Federal Register 2010). Detectable PCB concentrations ranged over six orders of magnitude, from 1 to 220,000 ppm (22%). These data suggest that PCBs are prevalent in currently standing Bay Area buildings constructed during the period of PCB usage. These data are consistent with previous studies in other cities that have identified relatively high concentrations of PCBs in concrete and masonry buildings built between 1950 and 1980. Portable XRF was not a good predictor of the PCB content in caulk and the results indicate that XRF may only be useful for identifying caulk that does not contain high concentrations of PCBs (≥10,000 ppm).

PCB Mass in Caulk in Study Area Buildings

A geographic information system (GIS)-based approach was used to estimate the number, area, and volume of currently standing buildings in the study area that were built during the era of PCB use in caulk. The GIS-based approach used historical imagery and modern land use, and involved characterization of randomly selected buildings within the area of interest, which was then scaled up to extrapolate total building counts and areas in municipalities regulated by the MRP. Various assumptions, including the frequency of anticipated PCB detection and PCB concentrations in the caulk, were then applied to calculate an estimate of the total PCB mass in building caulk in the study area.

The evaluation resulted in a medium estimate (i.e., the mid-range estimate) of 10,500 kg PCBs (low and high estimates were 767 and 46,000 kg, respectively) in caulk in buildings located in the study area, which equated to an average of 4.7 kg PCBs per building (low and high estimates were 0.6 and 16 kg, respectively). This estimate includes caulk located on both the interior and exterior of buildings.

PCB Loading to Stormwater from Building Renovation and Demolition

An estimate of the PCB mass released during the renovation and demolition of buildings with PCB-containing caulk was developed to assess the importance of these activities as a source of contamination to stormwater. A field study quantifying PCB losses during a demolition or renovation effort was not within the scope of this project; thus the estimate was developed using existing data, a series of factors known or thought to influence release using a spreadsheet (available upon request). The estimate was developed by considering releases due to currently used renovation and demolition practices only (i.e., prior to implementation of BMPs for specifically managing PCBs in caulk).

The medium estimate of PCB mass released per year from caulk to stormwater during building demolition and renovation activities in the San Francisco Bay study area was 0.04 kg (low and high estimates of 0.0008 and 0.6 kg, respectively). Approximately 50% of the total PCB mass released occurs during renovations, and 50% during demolitions.

Because PCB losses from caulk scraps that may be left behind at a demolition/renovation site were not included, the estimate of 0.04 kg reported here is likely an underestimate. However, because of the lack of data to quantify these potential losses (reporting of residual scrap material is generally anecdotal and only qualitative), it is not possible to determine the magnitude of the low bias but it might be as high as several kilograms on average, a portion of which could enter stormwater. These significant information gaps, together with the small data set of concentrations of caulk in Bay Area buildings used in the present study (n=25 samples from ten structures), leave considerable uncertainty in the release estimate made in this report for building demolition and renovation activities. All the elements of uncertainty in our calculations are biased low, and an estimate of mass released from residual scraps left on site appears to be a high priority data gap.

Effectiveness of BMPs for PCB-containing Caulk

A summary of available information regarding the effectiveness of BMPs designed to prevent the release of PCBs from caulk during the renovation and demolition of buildings was also included. The limited information available suggests that BMPs are highly effective for reducing the release of PCBs to the environment (>99% of PCBs in building caulk removed). The BMPs used in previous studies of BMP removal effectiveness include the removal of the caulk from the building, the use of vacuum attachments connected to tools used for grinding the concrete or masonry substrate formerly in contact with the caulk, and covering the ground adjacent to the building with plastic sheeting to collect dust and debris.

Recommendations for Refining Estimates

The following actions could be taken to increase the accuracy and refine the estimate of the PCB stock in caulk in the San Francisco Bay study area buildings.

- Validate the estimates for the number of buildings that were constructed during the era of PCB use in building caulk.
- Validate estimates for the prevalence of PCBs in these buildings, including their prevalence in different building types (e.g. residential, commercial/industrial) and locations (e.g. between concrete blocks, around windows). Also, validate estimates for the PCB concentration distribution.
- Validate the estimate for the average mass caulk per volume of building.

The following actions could be taken to refine the estimate of PCB loading to stormwater from caulk during building renovation and demolition.

- Validate estimates of the annual number of demolitions and renovations in the Bay Area by building type and building construction year.
- Validate estimates for the amount of PCBs released from caulk during renovation and demolition. This information may be obtained by performing pilot studies of actual building demolitions and renovations in which PCB losses to air and soil are quantified.
- Conduct a study to develop an estimate for the amount of PCB released from caulk scraps that may be left behind at a demolition/renovation site.

1.0 INTRODUCTION

1.1 PCBs in San Francisco Bay Area Urban Runoff

Urban runoff has been identified as one of the major pathways of polychlorinated biphenyl (PCB) loading to San Francisco Bay, where elevated PCB concentrations threaten the heath of people and wildlife consuming fish (RWQCB 2008). In addition to past PCB releases that have contaminated soil and sediments, PCB-containing materials such as sealants, caulking, and paint used in buildings have been identified as potentially significant sources of PCBs to urban runoff in the Bay Area (Larry Walker Associates et al. 2006; Moran et al. 2007; RWQCB 2008, 2009). Although the processes are not well understood, PCB residues associated with the degradation and renovation of these building materials may be transported away from the buildings by wind or during rainstorms, through landscape irrigation overflows, or by pavement washing (e.g., forecourts and sidewalks surrounding the buildings), and enter the stormwater drainage system. In addition, when buildings are demolished, PCBs may be released onto the ground and can be washed off into stormwater drains by rainfall.

The San Francisco Bay TMDL for PCBs (RWQCB 2008) called for a load reduction in stormwater from the current estimate of 20 kg down to 2 kg over the next 20 years, with an interim target of 10 kg in 10 years. In this context, the municipal regional stormwater NPDES permit issued in October 2009 (MRP) (RWQCB 2009) called for an improved understanding of the mass of PCBs associated with a range of sources and pathways including PCB-containing building materials. Specifically, provision C.12.b.ii.(3) states that permittees shall develop/select BMPs to reduce or prevent discharges of PCBs during demolition/remodeling. The BMPs will focus on methods to identify, handle, contain, transport and dispose of PCB-containing materials, especially caulking and sealants (herein collectively referred to as “caulk”).

There have been several previous efforts to quantify the potential contribution of PCBs in building materials to Bay Area stormwater loads. Larry Walker Associates et al. (2006) estimated the number of buildings demolished in the Bay Area annually using national data. They assumed about 10% of demolished buildings were constructed between 1950-1975, applied estimates of release per building to soils and stormwater based on European studies, and doubled the resulting estimate to account for remodeling and maintenance on a much greater number of buildings. They noted very high uncertainty surrounding their resulting estimate of 4.1 kg/year. McKee et al. (2006) commented on the difficulty of estimating the PCB mass entering stormwater from various sources. They estimated a PCB mass associated with plasticizers in general (inclusive of caulk) entering stormwater of 1.1 kg/year scaled from national use estimates, dissipative loss estimates from Belgium and Norway, and rainout from the atmosphere, and also noted high uncertainty.

The uncertainties of these previous estimates indicate a need for better data. San Francisco Bay Area-specific information about the presence of PCBs in building materials and data to estimate potential losses to urban runoff need to be updated and better quantified. These kinds of data will be useful during the first permit term, when BASMAA agencies will be planning, prioritizing, and optimizing methods to achieve TMDL targets.

1.2 PCBs in Caulk

About 9% of the PCBs sold in the US were used in plasticizers, of which an unknown portion were used in caulk (Erickson and Kaley II 2011). The addition of PCBs to permanently elastic, polysulfide joint caulk used in building construction was a significant use from the late 1940s to 1979, when PCB sale and production were banned. However, given the voluntary phase out of sale for open applications (i.e., applications where PCBs were not used in sealed containers) starting about 1971, it is likely that use in caulk started declining before 1979. Similarly, because the use of existing stock of these materials likely occurred after the ban, the addition of PCBs to caulk may have continued for a limited number of years after 1979.

PCBs were added to joint caulk to improve the flexibility of the material, increase the resistance to mechanical erosion, and improve adherence to other building materials (Andersson et al. 2004; Erickson and Kaley II 2011). Locations on buildings where PCB-containing caulk has been found include outdoor seams between concrete blocks (Astebro et al., 2000; Priha et al., 2005; Sundahl et al., 1999) and around windows and doorframes (Astebro et al., 2000; Persson et al., 2005). The application of caulk in this manner appears to have been common across Europe and North America (Sundahl et al. 1999; Astebro et al. 2000; Persson et al. 2005; Priha et al. 2005; Kohler et al. 2005; Herrick et al. 2004; Robson et al. 2010; Erickson and Kaley II 2011). Most studies have focused on PCB-containing caulk on building exteriors, but PCB-containing caulk has also been found indoors in Europe (Balfanz et al. 1993) and the US (Coghlan et al. 2002; Robert Herrick, personal communication, 2011; Lexington, MA Public Schools 2011).

A few surveys have documented the presence of PCBs in caulk. In the largest survey conducted to date, caulk samples were collected from 1,348 buildings in Switzerland constructed between 1950 and 1980 (Kohler et al. 2005). This study reported that almost half of the buildings contained PCBs in caulk (detection limits 20 ppm for total PCBs), with most samples containing concentrations > 100 ppm and 20% of samples containing 10,000 ppm (1%) or more PCB by weight. Less rigorous surveys have been conducted in Boston and other locations in Europe with comparable findings (Herrick et al. 2004; Sundahl et al 1999; Astebro et al. 2000). In a more recent survey of 95 buildings in Toronto, 14% of buildings sampled had detectable concentrations of PCBs in caulk, with concentrations ranging from 570 ppm to 82,000 ppm (mean 4600 ppm or ~0.5%) (Robson et al. 2010). PCBs have also been detected in caulk at a number of schools in New York and Massachusetts (http://www.pcbinschools.org) in a similar range of concentrations. PCBs in caulk in California buildings have not been reported, with the exception of an article documenting the discovery of PCBs in the caulk lining a drinking water reservoir in Northern California in the 1990s (Sykes and Coate 1995). The caulk lining the reservoir contained PCBs at concentrations of 15-20%, but has since been replaced.

PCBs in caulk in buildings may serve as an ongoing source of PCBs to the environment. Studies have indicated that PCBs can volatilize from the caulk into surrounding air (Kohler et al. 2002; Robson et al. 2010) and spread to indoor dust and soil surrounding the buildings outdoors via natural weathering and deterioration (Sundahl et al. 1999; Herrick et al. 2007). Studies have also indicated that significant quantities of PCBs can be released into soil and water runoff during activities associated with the renovation of building caulk, such as concrete grinding and power washing (Sundahl et al 1999; Astebro et al. 2000). It is also suspected that, without appropriate containment, PCBs may also be released to the environment during the demolition of buildings.

Management practices have been developed that can prevent PCB releases from structural materials into urban runoff. Both the Swiss and Swedish governments have developed active programs to manage PCB-containing building materials in response to public health concerns, which relate to both direct exposures and adverse effects on Europe’s fisheries. In the United States (US), the US Environmental Protection Agency (USEPA) has developed guidance for managing PCBs in caulk and tools to help minimize possible exposure (http://www.epa.gov/pcbsincaulk/). The guidance includes precautionary measures and best work practices to follow when conducting a repair or renovation in older buildings where PCB-containing caulk could be encountered, and specifically addresses steps that can be taken to minimize the generation of dust and heat to prevent release of PCBs to the air and surrounding area (USEPA 2009a; 2010a). Though the USEPA recommends BMPs for PCBs in caulk, it is suspected that BMPs specifically for this purpose are not routinely used during the renovation and demolition of buildings in the San Francisco Bay Area.

1.3 The PCBs in Caulk Project

In April 2007, the State Water Resources Control Board awarded the Association of Bay Area Governments/San Francisco Estuary Partnership (SFEP) a Proposition 50 Coastal Nonpoint Source Pollution grant known as the “Taking Action for Clean Water” project to further implementation of several Bay Area Total Maximum Daily Loads (TMDLs). One of the Taking Action for Clean Water projects is the PCBs in Caulk project, which will create a model management process to keep PCBs in historic building materials, specifically uncontained materials like sealants and caulking, out of urban runoff as partial implementation of the TMDL for PCBs in San Francisco Bay (adopted by the Office of Administrative Law on February 15, 2010). Caulk is targeted because it is a building material that has been found in many studies to have high concentrations of PCBs and is used on the exterior of buildings, and thus exposed to the environment.

After the California bond project freeze in 2008-2009, the grant was transferred to the Clean Water State Revolving Fund under the American Recovery and Reinvestment Act of 2009 (ARRA). In October 2009, the San Francisco Bay Regional Water Quality Control Board (RWQCB) adopted the MRP, which includes Provision C.12.b.ii (3) requiring that permittees "develop/select BMPs to reduce or prevent discharges of PCBs during demolition/remodeling." SFEP contracted with SFEI to assist with the development of Bay-Area-specific estimates of PCB loadings to urban runoff from historic building materials as part of the PCBs in Caulk project.

This report follows preliminary work summarized in a July 16, 2007 memorandum to the Clean Estuary Partnership (Moran et al. 2007), which reviewed building materials containing PCBs that could potentially contribute PCB loads to stormwater. That memo recommended that "the grant project initially focus on building materials within the categories of: (1) caulking and caulk, and (2) paint and coatings, with the category of caulking and caulk being the higher priority of the two." The memo also recommended focusing on concrete and masonry structures constructed or substantially remodeled between 1957 and 1977. Further information about the selection of these parameters may be found in Moran et al. 2007. Though the MRP addresses PCB-containing materials, caulk is the only building material addressed in this report.

1.4 Project Objectives and Report Organization

The objectives of the present study and the report were to:

- estimate the PCB mass associated with caulk in currently standing commercial and industrial buildings constructed between 1950 and 1980 in the San Francisco Bay study area,
- estimate the PCB mass released to urban runoff during the renovation and demolition of these buildings using current practices (i.e. prior to any PCB in caulk BMP implementation),
- compare the estimated PCB mass released to stormwater from building renovation and demolition to other PCB sources in the study area, and
- summarize the information available regarding the potential effectiveness of BMPs for demolition and renovation of PCB-containing caulk.

The report is organized into the following four main sections:

Section 2	describes the results of a field assessment in which caulk samples from San Francisco Bay Area buildings were analyzed for PCBs. Caulk samples were analyzed using a traditional laboratory approach (solvent extraction with gas chromatography-mass spectrometry (GC-MS) analysis), as well as a portable screening approach (portable X-ray fluorescence detector (XRF)).

Section 3	provides the results of an effort to estimate the PCB mass associated with caulk in buildings in the study area.
Section 4	presents an estimate of the PCB mass released to urban runoff during the renovation and demolition of these buildings using current practices and compares it to other PCB sources to urban runoff in the Bay Area.
Section 5	discusses information available regarding the potential effectiveness of BMPs for demolition and renovation of PCB-containing caulk.

In the last section (Section 6), a summary of the results of the project and recommendations for future work are provided.

2.0 PCB CONCENTRATIONS IN CAULK IN SAN FRANCISCO BAY AREA BUILDINGS

2.1 Approach

A field assessment was conducted to establish whether caulk in the San Francisco Bay Area contains PCBs at concentrations similar to other parts of the county and the world, and to understand the relative importance of PCBs in caulk among other potential sources of PCBs that may enter runoff to San Francisco Bay. The assessment specifically aimed to determine PCB concentrations in a small sampling of currently standing buildings, along with the construction type and year of these buildings. The objective of the field assessment was not to identify specific buildings that contained PCBs but rather to characterize concentrations found in exterior building caulk from the target decades (1950s, 1960s, 1970s, and 1980s). Therefore a blind sampling approach was used in which information that identifies sample locations was not retained. Details of the blind sampling approach used in the project are available in the Field Sampling and Chemical Analysis Plan (SFEI 2010).

The field sampling element was also conducted so that the PCB concentrations in caulk could be used to estimate the total PCB mass associated with caulk in currently standing commercial and industrial buildings in the study area (Section 3), and to estimate the mass of PCB released to stormwater runoff during renovation and demolition of these buildings (Section 4). The collection and analysis of caulk samples was also intended to fulfill MRP requirement C.12.b12.b.ii.(2).

In addition to PCB analysis using a traditional, congener-specific laboratory method (GC-MS), the caulk samples were screened for the presence of chlorine (Cl) using a portable XRF analyzer. In 2009, a pilot study was conducted to determine if a portable XRF analyzer, which estimates the elemental composition of a substance (e.g., chlorine or Cl, not PCBs specifically) could be used as a reliable screening tool to estimate PCB concentrations in caulk. In this study, 20 caulk samples were obtained from buildings predicted to have measurable concentrations of PCBs and analyzed for Cl content using XRF and PCBs using GC-MS. The results indicated that portable XRF may only be useful for identifying caulk that does not contain high concentrations of PCBs (≥1% or 10,000 ppm), because when XRF did not detect Cl (detection limit average ~0.1%), any PCBs detected were present at concentrations less than ~0.1% in the caulk. However, in general, the pilot study results suggested that use of portable XRF alone is not a good indicator of PCB content due to a high rate of 'false positives'. That is, when XRF detected elevated Cl (~>0.1%), PCBs were present in only ~20% of the samples (i.e., 20% specificity), indicating the presence of other types of chlorinated compounds in the caulk samples. XRF analysis was included in the present study to gain additional information in support of its possible use as a screening tool for PCBs in caulk.

2.2 Methods

2.2.1 Sample Collection

In 2010 and 2011, 29 caulk samples were collected from the exterior of ten buildings in the San Francisco Bay Area. Caulk samples were collected and processed in accordance with the project Field Sampling and Chemical Analysis Plan (SFEI 2010) and Quality Assurance Project Plan (SFEI 2011). Project partners identified buildings for possible inclusion in the project and secured permission from the building owner, a consultant, or contractor prior to any collection or analysis of caulk samples. Samples received by SFEI for the project included archived samples provided by a consultant. The buildings represented a variety of construction types and were constructed during the 1950s, 1960s, 1970s, or 1980s with the exception of one building with an unknown year of construction. From one to seven caulk samples were taken from the exterior of each building, with each sample representing a specific caulk type or function (e.g., caulk around window, between concrete blocks, etc). A maximum of one sample per caulk type/function was collected from each building. Caulk samples were collected from buildings known or suspected to contain original caulk.

For most caulk samples, collection entailed removing at least a one-inch strip (or minimum of 3 g) of caulk from the structure using a utility knife with a solvent-rinsed, stainless-steel blade and placing it in a labeled, chemically-clean glass jar. However, a portion of samples were collected by the building owner, a consultant, or a contractor and transferred to an SFEI employee for use in the project. When this occurred, the samples were not collected with pre-cleaned instruments or containers. Once collected or received by SFEI, samples were refrigerated until analysis.

2.2.2 PCB Analysis

As part of the blind sampling scheme, 25 of the 29 samples collected were randomly selected and analyzed for PCBs using a modified EPA 8270 method protocol (semi-volatile organic compounds by GC-MS) by the East Bay Municipal Utility District (SFEI 2011). Each sample was sub-sampled for PCB analysis by cutting a small cross section of the sample (approximately 0.1 g or 2 mm in length). The samples were further cut into smaller pieces and homogenized to the extent possible prior to extraction.

Because of the complex nature of the caulk matrix and the potential for percent concentrations of PCBs in the samples, only 0.1g of caulk was extracted and a de facto dilution of 1:100 was applied. It should be noted that most of the caulk materials analyzed were soluble in the extraction solvent and, consequently, no more that 0.1 g of caulk sample could be concentrated into a 1 ml extract. Using a larger sample size would have required a larger final extract volume and would not have resulted in better detection limits. It should also be noted that the improved representativeness of a larger sample would have been offset by the problems associated with potential sample cross-contaminations that could be associated with extracting very high masses of PCBs in the analytical train. Some of the samples also required further dilutions to bring the analytes within the GC-MS calibration range.

The following PCB congeners were analyzed:

- the 40 congeners routinely monitored by the RMP (PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, l05, 110, 118, 128, 132, 138, 141, 149, l51, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203),
- PCB 11, a non-Aroclor congener commonly detected in wastewater effluent and environmental samples (Rodenburg et al. 2010),
- the coplanar PCBs 77, 126, and 169, ‘dioxin-like’ congeners which contribute substantially to the dioxin toxic equivalents observed in San Francisco Bay sport fish.

Quality assurance procedures included the analysis of laboratory method blank samples, duplicate samples, and a laboratory-fortified matrix spike (SFEI 2011). Congener-specific method detection limits (MDLs) were initially determined according to 40 CFR 136 Appendix B and ranged from 0.6 to 7 ppb for a nominal sample of 10 g. These were based on a nominal 10 g sample size. Actual MDLs ranged from 60 to 284,000 ppb because only 0.1 g for each sample was extracted and analyzed. GC-MS method detection limits are discussed further in Section 2.3.3. Only three out of the 25 samples analyzed had PCB concentrations below detection.

2.2.3 XRF Analysis

A portable XRF analyzer (Delta model, Innov-X Systems, Woburn, MA) was used as a screening tool to estimate the Cl content in each caulk sample. The analysis was performed on the sample remaining after GC-MS analysis using a test stand compatible with the instrument and provided by the Innov-X Systems representative. The analyzer was calibrated for Cl using plastic pellet European reference materials (EC680 and EC681) upon first use, and standardized each time the instrument was turned on and prior to any caulk monitoring. The standardization procedure entailed analysis of the metal disk provided with the XRF analyzer. A 30 second measurement in 'three beam soil' mode was used (Cl factor = 0.5). Analyses were conducted in triplicate on each sample and the mean was used for comparison to GC-MS results.

2.3 Results and Discussion

2.3.1 PCB Concentrations

Of the 25 caulk samples analyzed in the present study, 22 (88%) contained detectable concentrations (> 25 ppm; see Section 2.3.3) of PCBs and 10 of these (40% of all samples) exceeded 50 ppm, the concentration at which caulk falls under U.S. EPA PCBs regulations (Table 1). It was not possible to determine the number of buildings with PCB-containing caulk because blind sampling procedures prevented the association of samples with a particular building (SFEI 2010) and more than one sample per building may have been analyzed for PCBs. In previous surveys of caulk in buildings in Boston (Herrick et al. 2004), Switzerland (Kohler et al. 2005), and Toronto (Robson et al. 2010), the frequency of detection of samples containing greater than 50 ppm PCB was comparable to this study, although the overall frequency of PCB detection in those studies was lower (Table 2). Compared to the previous surveys, a higher proportion of samples in the present study contained detectable concentrations of less than 50 ppm. Analysis of a larger number of congeners in the present study may have contributed to this difference.

Detectable PCB concentrations in caulk samples from the San Francisco Bay Area buildings ranged over six orders of magnitude, from 1 to 220,300 ppm (Table 1). When considering only the samples containing greater than 50 ppm, the median concentration in the San Francisco Bay samples (9,580 ppm) was comparable to the medians in the Boston and Toronto surveys (7,990 and approximately 7,500 ppm, respectively), and the concentration distribution was comparable to that observed in the Switzerland survey (>20-550,000 ppm; median not provided). Further, the percent of samples greater than 10,000 ppm in the present study (20%) was similar to those in Boston (9%), Toronto (10%), and Switzerland (20%). These results suggest that use patterns of PCBs in caulk in the San Francisco Bay Area were similar to those in Boston, Toronto, and Switzerland. The maximum concentration detected in Bay Area caulk samples was lower than the highest concentration detected in the Switzerland survey (550,000 ppm), but higher than

Table 1. PCB concentrations in caulk from San Francisco Bay Area buildings.

Building Construction Year	Building Construction Type*	Caulk Location on Building	PCB concentration (ppm)
1950s	PC2	Between concrete	220,000
1950s	PC2	Between concrete	198,000
1950s	PC2	Between metal window frame and concrete	146,000
1960s	W2	Between glass and window frame	12,500
1950s	PC2	Between concrete	11,500
1950s	PC2	Around metal window frame	7,630
1950s	PC2	Between glass and metal window frame	3,600
1960s	C2	Between window glass and window frame	89
1980s	RM	Unknown	87
1970s	W2	Between wood and wood	60
1960s	C2	Between window glass and window frame	48
1950s	W1	Between glass and metal window frame	15
Unknown	Unknown	Around window frame	15
1970s	W2	Between glass and window frame	11
1970s	W2	Between window frame and wood	10
1970s	W2	Around doorframe	8
1950s	W1	Around doorframe	6
1950s	W1	Around doorframe	5
1950s	W1	Between glass and window frame	3
1950s	W1	Between metal window frame and concrete	2
1960s	PC1	Between concrete	2
1950s	W1	Between wood window frame and wood	1
1950s	W1	Between wood and concrete	0
1950s	W1	Between wood and wood	0
1960s	RM	Between glass and window frame	0

*Construction codes: PC1=Precast/tilt-up concrete shear-wall; PC2=Pre-cast concrete frame; C2=Concrete shear-wall; W1=Light wood-frame residential and commercial smaller than or equal to 5,000 square feet; W2=Light wood-frame larger than 5,000 square feet; RM=Reinforced masonry

Table 2. Summary of results from this study and previous surveys of PCBs in caulk in buildings.

	San Francisco Bay Area[a]	Greater Boston Area[b]	Toronto[c]	Switzerland[d]
Sample size (n)	25	24	95	1348
Building Use Types	Mixed	Institutional	Commercial, industrial, residential, infrastructure	Institutional
Construction Types	Concrete, wood, masonry, unknown	Concrete, masonry	Concrete, brick, other	Concrete
PCB detection frequency	88%	54%	14% (27% not including residential)	48%
PCB detection frequency for samples >50 ppm	40%	33%	14% (27% not including residential)	42%
Range of PCB concentrations detected in caulk samples (ppm)	1-220,000	70-36,000	570-82,000	>20-550,000
Method detection limits (ppm)	≥25	0.5	50	20

[a]This study; [b]Herrick et al. 2004; [c]Robson et al. 2010; [d]Kohler et al. 2005

the maximum concentrations detected in the Boston and Toronto surveys (36,200 and 82,000 ppm, respectively).

As stated above, a high proportion (48%) of the San Francisco Bay Area caulk samples had PCB concentrations that ranged between detection limits and 50 ppm. When all the samples in the present study were considered, the median PCB concentration was 32 ppm. It has been hypothesized that when used as plasticizers in caulk, PCBs were added in concentrations that were at least 10,000 ppm (1%) to maintain the elasticity of the material (Kohler et al. 2005). Kohler et al. (2005) suggested that samples containing less than 10,000 ppm may be due to the use of PCB contaminated equipment during the application of caulk in the building construction process (e.g., when alternative, non-PCB plasticizers such as chlorinated paraffins were used on the same equipment instead) or because of secondary contamination by migration of PCBs from adjacent construction materials (originating from caulk containing PCB replaced previously). Though the sample size was limited, the detectable PCB concentrations in caulk in the present study appear to generally support this hypothesis, since concentrations were either less than 90 ppm or greater than 3,600 ppm. However, building owners/consultants/contractors that provided the caulk samples for the present study stated that it was not likely that the caulk had been replaced since building construction, suggesting that the low PCB concentrations may have been the result of construction equipment contamination. It was not possible to determine the age of the caulk samples, and thus the likelihood of having been relatively recently replaced, based on physical appearance.

The congener profiles for the San Francisco Bay Area caulk samples suggest that Aroclor 1254 was the primary PCB commercial mixture used. This is supported by the predominance of PCBs 87, 95, 99, 101, 110, and 118 in the samples (Frame et al. 1996). This observation is consistent with the previous surveys in Boston, Toronto, and Switzerland, which primarily detected the presence of Aroclor 1254 with some use of Aroclor 1260 (Herrick et al. 2004, Robson et al. 2010, Kohler et al. 2005). PCB 11, a congener not present in Aroclor mixtures (Frame et al. 1996) but commonly detected in wastewater effluent and environmental samples, was not detected in any caulk samples (method detection limits 1000 ppb).

PCBs were detected in samples that were collected from buildings constructed in the target age range (1950-1980), supporting previous observations of the use of PCBs in caulk in buildings constructed during this time period (Table 3). PCBs were also detected in one sample collected from a building reportedly constructed in the 1980s, past the year in which the sale and production of PCBs was banned. This latter observation conflicts with the Toronto survey, which did not detect PCBs in caulk from buildings constructed after 1980 (Robson et al. 2010). The Bay Area caulk samples containing more than 1% PCB were all collected from buildings constructed in the 1950s and 1960s (Table 3), with the samples collected from structures constructed in the 1950s containing the highest PCB concentrations (Table 1). In the Toronto and Switzerland surveys, most caulk samples containing more than 1% PCB were collected from buildings constructed in the 1960s (Robson et al. 2010, Kohler et al. 2005). However, the present study is not directly comparable to these studies conducted in other locations due to differences in the total number of samples analyzed, the number of samples analyzed from structures constructed in each decade, and the analytical methods used. Samples of caulk located between concrete blocks and around window frames on concrete buildings contained the highest PCB concentrations in the present study (>3,600 ppm) (Table 1). One exception was a sample located between concrete blocks from a concrete building constructed in the 1960s which contained only 2 ppm PCBs. Wood frame buildings generally contained low PCB concentrations in caulk (≤ 60 ppm), with the exception of one sample located around a window frame that contained 12,500 ppm PCBs. These data are in agreement with results from the previous caulk surveys conducted in Boston, Toronto, and Switzerland, which primarily focused on buildings with concrete and masonry construction and observed generally comparable concentrations (Table 2). In the blind

Table 3. Temporal distribution of PCB concentrations in caulk samples from San Francisco Bay Area buildings.

Construction Year	# samples	# <MDL	# >MDL-50 ppm	# 50-10,000 ppm	# >10,000 ppm	% >50 ppm
1950s	14	2	6	2	4	43
1960s	5	1	2	1	1	40
1970s	4	0	3	1	0	25
1980s	1	0	0	1	0	100
Unknown	1	0	1	0	0	0
Total #	25	3 (12%)	12 (48%)	5 (20%)	5 (20%)	

sampling procedure used in the present study, information on building use (e.g., industrial, commercial, institutional) was not collected so no comparisons in this regard could be made with previous studies.

2.3.2 Use of Portable XRF to Predict the Presence of PCBs

The preliminary XRF validation study conducted in 2009 (Section 2.1) indicated that false positives were possible when using XRF to identify caulk samples containing PCBs. That is, Cl was detected by XRF but GC-MS analysis indicated that PCBs were below detection limits. These observations were hypothesized to be the result of the presence of chlorinated compounds other than PCBs in the samples.

In the present study there were only three samples in which PCBs were not detected by GC-MS, therefore the ability to assess false positives was limited. Further, the results were not consistent among these samples: one sample indicated a false positive, one sample did not, and the other sample could not be analyzed by XRF because there was not enough sample material left over from the GC-MS analysis. False negatives (i.e., when Cl was not detected by XRF but the GC-MS analysis indicated the presence of PCBs) were also observed at low concentrations, which were likely due to the higher detection limits of the portable XRF analyzer.

The preliminary XRF validation study conducted in 2009 also indicated that XRF may be a useful screening tool for PCBs in caulk because it detected Cl when PCBs were present at percent levels and did not detect Cl when PCB concentrations were less than ~0.1%. The results from this study were generally in agreement with the previous results (Figure 1; Appendix Table 1). When PCBs were present at concentrations greater than 3,600 ppm (0.36%), portable XRF always detected Cl, but there was no consistent relationship between the XRF-estimated Cl concentration and the GC-MS measured PCB (or Cl) concentration (Figure 1). When PCBs were present at concentrations less than 100 ppm

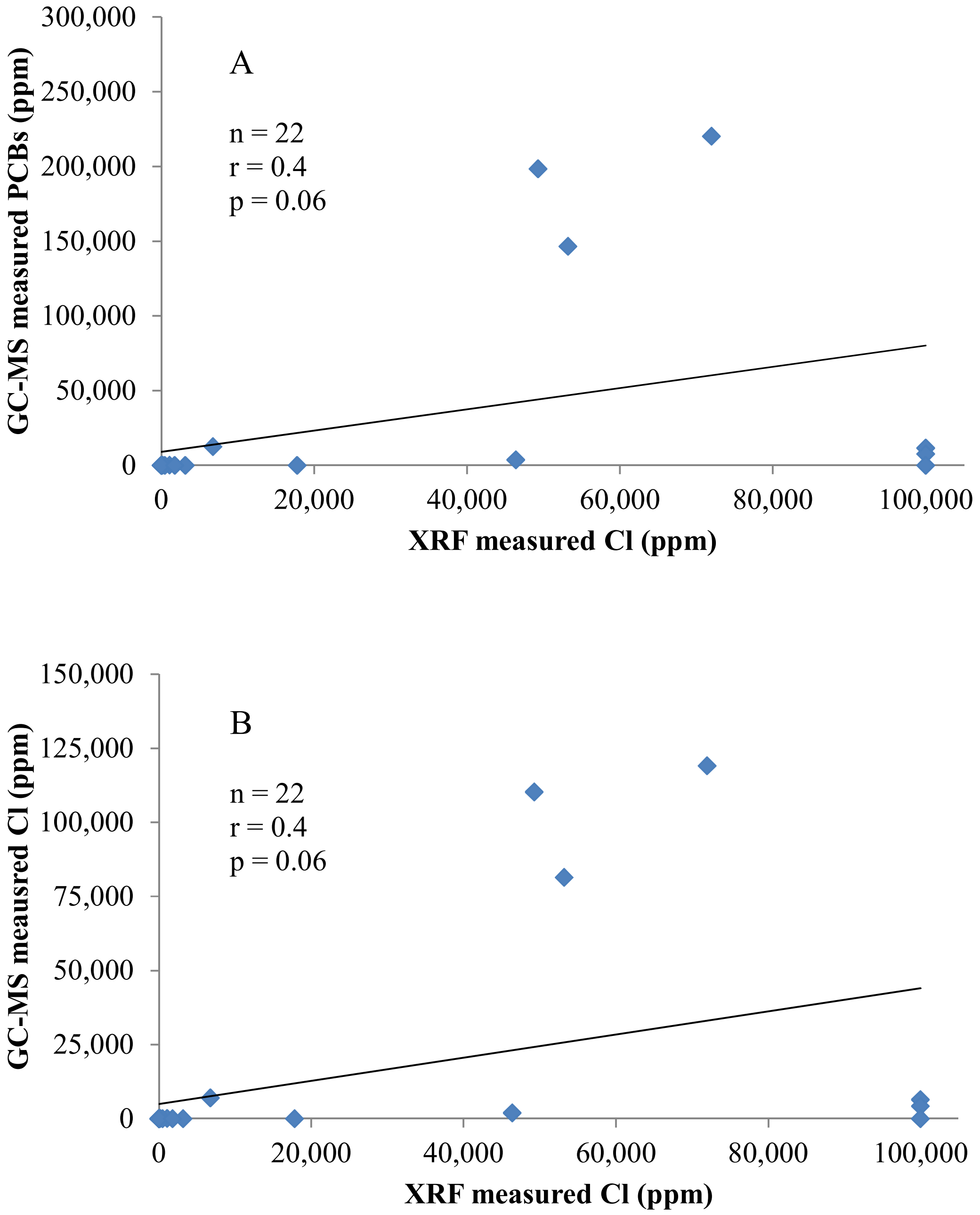

Figure 1. Comparison of XRF measured chlorine (Cl) concentrations to GC-MS measured PCB concentrations (A) and GC-MS measured Cl concentrations (B). The figures do not include samples where XRF and GC-MS concentrations were both below detection limits.

(0.01%), portable XRF detected Cl about half the time, also with no clear relationship between the XRF-estimated Cl concentration and the GC-MS measured PCB (or Cl) concentration. When XRF did not detect Cl (detection limit average 459 ppm), PCBs were present at concentrations less than 100 ppm in the caulk.

Results from this study and the preliminary investigation completed previously indicate that portable XRF analysis may only be useful for identifying caulk that does not contain high concentrations of PCBs (≥1%) (see Section 2.1). However, users are cautioned that estimates of Cl by portable XRF should not be used to estimate the PCB Cl content of these materials because of the lack of a predictable relationship between XRF measured Cl and GC-MS measured PCB (or PCB Cl), in addition to the potential for false positives.

2.3.3 Considerations

Representativeness of Samples

Results from this field assessment demonstrated that PCBs were present in caulk in Bay Area buildings constructed in the 1950s, 1960s, 1970s, and 1980s, and that these concentrations were generally comparable to concentrations in caulk used in buildings from this era in other locations. However, the small sample size (n=25 analysed samples from ten structures) leaves considerable uncertainty regarding the prevalence of PCB-containing caulk in Bay Area buildings and the range of PCB concentrations that may be present.

GC-MS Method Detection Limits

The method detection limits (MDLs) in the present study for individual PCB congeners ranged from 60-284,000 ppb (0.06-280 ppm) and were most often about 10,000 times higher than the MDLs listed in the project QAPP (0.6 to 7 ppb) (SFEI 2011). The MDLs in the QAPP were provided by the analytical laboratory and were based on a nominal 10 g sample size (undiluted samples). Only 0.1 g of each sample was extracted because the concentrations expected were high and because the matrix is mostly soluble in the extraction solvents, making it impossible to concentrate a sample greater than 1 g to 1 ml of extract. Some samples were further diluted to prevent severe contamination of the analytical equipment and achieve concentrations within the instrument calibration range. These steps accounted for the substantial difference between the nominal and actual MDLs. Despite the impact on MDLs, concentrations as low as 0.7 ppm were detected in the samples and only three samples contained PCB concentrations below the actual detection limits. Adjustments to the nominal MDLs to account for the smaller sample size and dilution indicate that the samples reported as non-detects in the present study likely contained less than 25 ppm PCBs.

Results from this study indicate that the analytical methods used were suitable for determining PCB concentrations in caulk samples that were equal to or above the regulatory threshold of 50 ppm, the concentration at which a material is considered PCB bulk product waste. Use of a high resolution GC-MS method would have provided detection limits lower than 25 ppm, however, these methods are typically three to five times more expensive than the low resolution method used in the present study. We conclude that the analytical methods applied were appropriate for the purposes of the PCBs in Caulk project and the defined study objectives.

Heterogeneity of PCBs within Caulk Samples

Analysis of duplicate samples in the present study indicates that a single measurement of a caulk sample may not represent the average concentration of PCBs present in the material. The two samples analyzed in duplicate had relative percent differences (RPDs) for each of the congeners ranging from 2.2 and 144% of the initial analysis. Because the target performance criterion was a RPD of ≤ 50%, initially there were concerns regarding the reliability of the analytical method used and therefore the quality of the data. However, the performance criterion of RPDs ≤ 50% was only applicable to PCB concentrations that were 10 times greater than the MDL. The two samples selected for duplicate analysis ultimately contained low PCB concentrations, and only two congeners out of the 86 analyzed had concentrations that were sufficiently high to evaluate the precision. Previous studies have reported that PCBs are not likely to be homogeneous in the caulk used throughout a particular building (Robson et al. 2010; Jansson et al. 2000), thus it was possible that the poor precision was the result of inherent variability in concentrations within the small caulk samples used in the duplicate analysis. To investigate whether the poor precision observed was a result of the analytical method used or the variability of PCB concentrations within a sample, all caulk samples were re-analyzed. In the follow-up analysis, good precision (average RPDs < 50%) was obtained between the original results and the results obtained from the re-analyses. The smaller variability seen in the repeat analyses using all samples suggests that the primary cause of poor precision was the low concentrations in the random samples previously chosen for repeat analysis. Heterogeneity within each sample also does not appear to be a major factor, as variability would be similarly high in higher concentration samples if that were the case.

In future analysis of caulk samples, it is possible that precision on randomly selected samples could be improved by modifying the sample extraction and analytical methods. Evaluation of analytical precision on samples containing higher PCB concentrations and dilution of the sample extracts prior to cleanup and analysis improves precision, but those samples cannot be identified a priori, and would require repeated analyses of all samples as was done here, pre-screening for concentration range followed by dilution and re-analysis within calibration range, or dilution of all samples followed by undiluted analysis of lower concentration samples. Obtaining a homogeneous sample of the caulk matrix might be improved by grinding up a larger portion of sample to homogenize before extracting and analyzing a small subsample.

3.0 PCB STOCK IN CAULK IN THE SAN FRANCISCO BAY STUDY AREA BUILDINGS

3.1 Approach

Because PCBs have been used in a wide variety of applications in urban areas, an understanding of the current reservoir in caulk in buildings is a necessary first step in determining the importance of these materials as a potential source of PCBs to the environment. In the present study, the PCB mass estimate in caulk was specifically used to estimate the amount of PCBs released to stormwater runoff during renovation and demolition of these buildings, and to compare this amount to other, previously characterized sources of PCBs to stormwater in the Bay Area (Section 4). It is anticipated that results from this evaluation will inform decisions regarding potential management of caulk in buildings.

The dataset needed to most accurately develop this estimate should ideally include an actual inventory of building types in the study area. However, building inventory databases for the Bay Area were not available for use in this project. A geographic information system (GIS)-based approach was therefore used to estimate the number, area, and volume of currently standing buildings in the study area that were built during the era of PCB use in caulk. The GIS approach was based on historical imagery and modern land use, and involved characterization of buildings in randomly selected samples within the area of interest, which was then scaled up to estimate total building counts and areas within the study area. Information regarding the mass of caulk and the PCB concentrations in caulk in various building types also was ideal for use to develop the estimate; however, this information was not available. Therefore, various assumptions, including the frequency of anticipated PCB detection in buildings, were applied to the GIS-estimated total building counts and areas to calculate an estimate of the total PCB mass in caulk in the study area buildings (detail provided in Section 3.2.2).

3.2 Methods

3.2.1 GIS Evaluation

The GIS evaluation replied upon the datasets listed below.

- USGS Urban Extent 1954 and 1974 (sfurb1954, sfurb1974) **--** These datasets were developed by the United States Geological Survey (USGS) and the

Association of Bay Area Governments (ABAG) to perform an analysis of human-induced land transformations in the San Francisco Bay / Sacramento area (1994).

- ABAG 2005 land use data -- This dataset was developed by ABAG to provide a high-resolution land use layer that incorporates detailed county-specific data for the San Francisco Bay Area.
- Aerial imagery -- Georectified NHAP July 1982 tiffs, NAIP 2010 geotiffs -- These images were developed by the National High Altitude Program (NHAP) and National Agricultural Imagery Program (NAIP). The timeframe of NHAP is 1980-87, while NAIP is 2003-present. NHAP imagery is at scales of 1:80,000 (black and white) and 1:58,000 (color). NAIP is at 1 m resolution with about 6 meters ground accuracy.

The urban area containing buildings constructed during the target era of PCB use in caulk (1950-1980) was isolated using historical and modern aerial imagery and land use data. All urban land use polygons from sfurb1954 were selected and erased from sfurb1974 (Figure 2). All resulting land use polygons were then deleted except commercial, industrial, infrastructure, and mixed commercial/industrial. This historical land use dataset is hereafter referred to as the Area Of Interest (AOI). Residential land use area was intentionally excluded because it is currently understood that PCBs were not commonly added to caulk in residential structures.

To create the modern land use dataset, a clip of ABAG 2005 was taken that matches the extent of the AOI, and only the features in the general categories commercial, industrial, infrastructure, and mixed commercial/industrial were selected. All roads, lots, yards, and rails (land use 141x, 142 only) were removed, thereby keeping all transportation and utility-related buildings. This combination of land use classes is hereafter referred to as PCB land use (PCBLU).

Under the assumption that present-day PCBLU features can be a reasonable proxy for matching features within historical land use data, the AOI was intersected with the edited ABAG 2005 to isolate the areas where they overlap. This product is referred to as AOI-int. The resulting detailed land use was binned into the general land use classes used in the 1974 land use dataset (commercial, industrial, infrastructure, mixed). This layer represents the assumed total area of PCBLU features containing buildings constructed during the target era of PCB use in caulk (1950-1880) that still stand today.

As time constraints did not allow for a thorough digitization of all building footprints in the San Francisco Bay study area, a random sampling method was used to limit the amounts of photo interpretation and digitizing needed, and the results were then scaled up to estimate total extent. A grid was created of 0.25 square mile square cells within the MRP extent. From this grid, all cells that did not intersect with the AOI were removed. To further refine the selection to include only cells that had a sufficient sampling of AOI, cells with less than 5% AOI area were also removed. Random number generators were then used to select a proportional number of cells from each MRP county stormwater program area (San Mateo County, Santa Clara County, Alameda County, Contra Costa County, Vallejo City, and Fairfield-Suisun Cities). In a sample set of 100 cells, the number of cells in each MRP county to be sampled was determined proportionally by weighting by the total PCBLU feature area of each county, minimum one per county: San Mateo=8, Santa Clara=37, Alameda=30, Contra Costa=23, Vallejo=1, Fairfield=1.

To develop a building area dataset for the random sample grids, the footprints of all PCBLU buildings in the grid subset that are present in both 1982 NHAP imagery and 2009 NAIP imagery were digitized based solely on the geometry of features in the NAIP imagery. The number of buildings per polygon was also assigned. This building footprint polygon layer was used to calculate area statistics by land use type, and these were scaled up to estimate building footprint area totals per MRP county by dividing the total randomly sampled area by the percentage of AOI captured by the random grids (Appendix Table 2). As an example of this procedure, maps developed for parts of San Mateo and Santa Clara counties showing the random grid cells are shown in Figures 3 and 4.

The extrapolated total number of buildings and total building footprint area were derived by dividing the total buildings counts and footprint areas within sample grids per county by the percent of AOI sampled per county (Appendix Table 2). This assumes that the area of AOI sampled is representative of the full extent of currently standing PCBLU buildings. To quantify the uncertainty in these numbers, the standard deviation was calculated for building counts and extrapolated in the same manner (for county / land use combinations with greater than one sample cell).

To estimate the average number of building stories per general land use class, the building footprints were broken into categories based on both land use and MRP county. From a total of 50 samples, area-weighted random samples were selected from each unique MRP county/land use combination (e.g. San Mateo / industrial). A minimum of one sample was given to combinations with low total counts to ensure full representation. Each of the 50 building footprint polygons was then exported to KML for viewing in Google Earth Street View, and the number of visible stories per building was recorded. If buildings were not visible in Google Earth Street View due to recent demolition, etc., another random footprint within the same category was substituted (n=2). The building story estimate was calculated by averaging all sampled building stories. This estimate was not derived for each separate land use class, as story estimates were determined for land use classes and the differences among them were determined to be insignificant (Kruskal-Wallis chi-square = 1.2, df=3, p-value=0.8). The average number of stories in buildings in the AOI was 1.46.

A quality assurance check of the extrapolated building footprint area estimates was conducted by calculating the results as a percent of total ABAG 2005 land use area of the same general land uses (Appendix Table 3). ABAG 2005 land use is certainly an overestimate of actual building footprints, but this step was simply to check that the digitized footprint area was less than the land use area. The extrapolated area estimates ranged from 0.05% (mixed land use for Alameda) to 7.74% (mixed land use for Santa Clara) of the total ABAG 2005 land use area of the same general land uses, and the average was 1.8%.

Key considerations for the GIS-based exercise are listed below.

- The only available historical urban datasets close to the time period of interest were from 1954 and 1974, therefore buildings constructed both before and after this time period that may have contained caulk with PCBs were not accounted for in this estimate. Similarly, as the closest year to 1980 that provided complete aerial photo coverage of the study area was 1982, buildings demolished from 1980 – 1982 were also unable to be considered, and those constructed during these two years may have been digitized and added to the dataset.

- An estimate for the amount of PCB in pre-1954 buildings that were renovated during the time period of interest, and therefore may include PCB-containing caulk, was not included. Information was not available to develop this estimate. The possible implication of this omission is that the PCB stock estimate for the study area presented in this report is an underestimate because older buildings renovated between 1950 and 1980 (during the era of PCB use) were not included.

- Historical urban extents for 1954 and 1974 were taken from datasets jointly produced by USGS and ABAG (Kirtland et al. 1994) and do not precisely align spatially with modern imagery. These data were used unedited for the random sampling. After sampling was completed, it was decided to shift all features in these layers ~200 m in order to collect more accurate statistics for the results and to visualize them better for use as ancillary data during digitization. This spatial shift was deemed negligible and the originally sampled sites persisted.

- The historical urban extent for 1954 has three land use classes ("urban", "urban open space", and "non-urban"), while 1974 has nine ("water", "residential", "commercial", "industrial", "infrastructure", "mixed com/ind", "mixed res/com", "open space", "undefined"). As the urban extent used as a proxy for 1950-1980 was created by erasing all 1954 "urban" from 1974, then deleting all land uses but "com", "ind", "inf", "mix com/ind" (PCBLU), this assumes that any residential urban areas from 1954 were not converted to any of the AOI land uses in 1974.

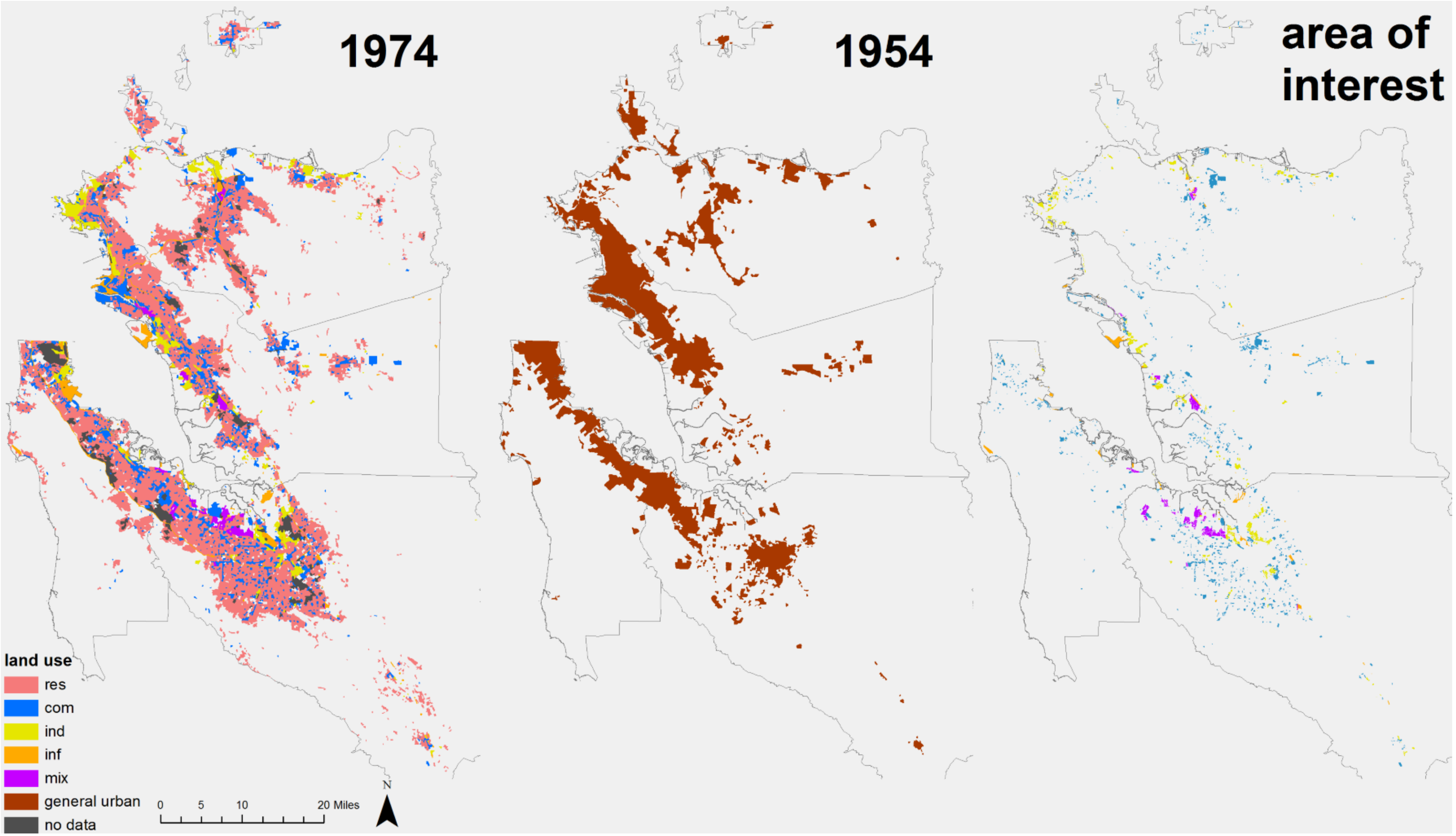

Figure 2. Historical Land Use Maps Used to Create the Study Area of Interest (AOI). Note that the area of interest excludes residential land use because it is currently understood that PCBs were not commonly added to caulk in residential structures.

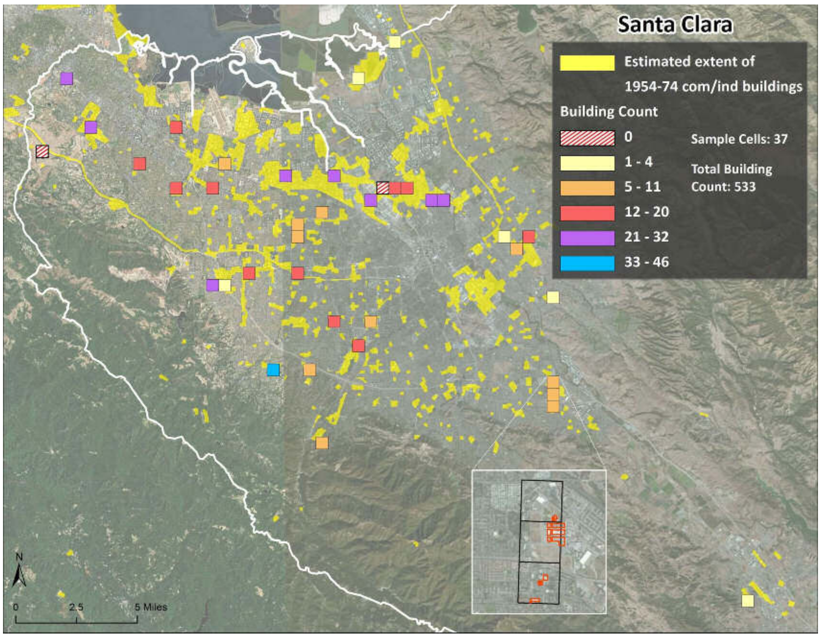

Figure 3. A portion of the map developed for Santa Clara County, showing the estimated area of commercial, industrial buildings built between 1950 and 1980. The random grid cells are also shown, which were used to estimate the number of buildings within the area.

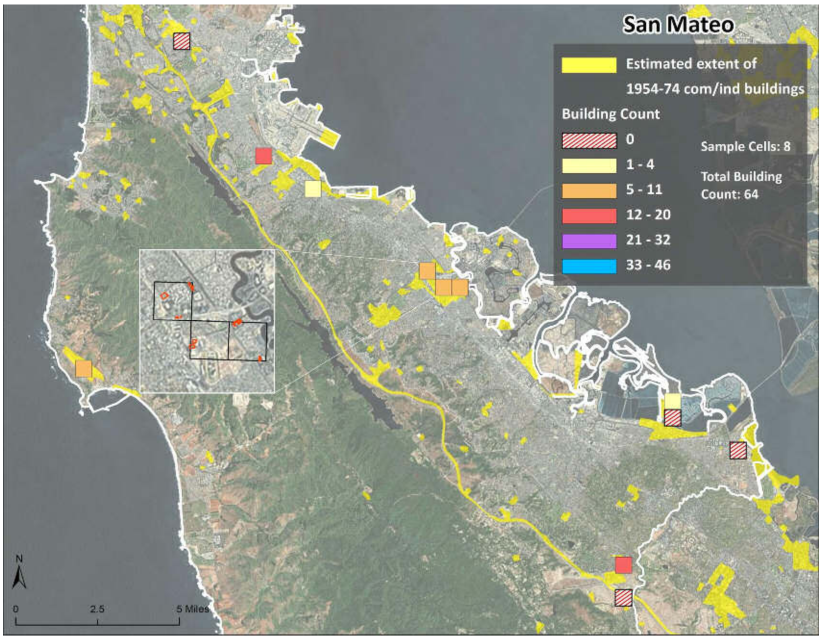

Figure 4. A portion of the map developed for San Mateo County, showing the estimated area of commercial, industrial buildings built between 1950 and 1980. The random grid cells are also shown, which were used to estimate the number of buildings within the area.

- The area extrapolation made by scaling up the randomly sampled building footprints was made by interpreting this area as a proportion of the total AOI intersect with ABAG 2005 per municipality. The building count extrapolation was made in the same way. These statistics assume that the sampled areas represent the municipality well enough to make this extrapolation.

3.2.2 PCB Mass Calculations

Estimates for the PCB mass in caulk in the San Francisco Bay study area buildings were calculated by applying a number of factors (i.e., assumptions) to the estimates developed in Section 3.2.1 for total building footprint area and the number of currently standing buildings built during the era of PCB use in caulk (Table 4). A range of estimates (low, medium, and high) was developed based on the variation in the detection frequency and concentrations of PCBs in caulk observed in the present study and those reported in published building surveys conducted in Boston, Toronto, and Switzerland (Herrick et al. 2004, Robson et al. 2010, Kohler et al. 2005). A brief description of the calculations is listed below. The complete calculations linked to the list of factors used are provided in the Excel spreadsheet titled 'PCB Building Mass Estimates' which accompanies this report (available upon request and co-located with this report on SFEI website).

The estimate for the total number of buildings with PCB-containing caulk within the AOI was calculated by multiplying the estimate for the total number of buildings in the AOI (developed in Section 3.2.1) by the PCB detection frequency. The values used for the PCB detection frequency in caulk were based on the detection frequencies in the present study and the previous surveys in Boston, Toronto, and Switzerland. For the purposes of this estimate, the PCB detection frequency considered only the samples that were collected from commercial (including institutional), industrial, and infrastructure type buildings built between approximately 1950 and 1980 and that contained caulk with PCB concentrations ≥ 50 ppm. Because PCB concentrations for each of the samples in the Switzerland study were not available, samples containing >20 ppm, the detection limit in the study, were also included. The values used for this estimate were 22%, 36%, and 46% for the low, medium, and high estimates, respectively – corresponding to the minimum, median, and maximum percent of buildings with PCBs in caulk above 50 ppm that were found in all the above-referenced studies.

The volume of buildings with PCB-containing caulk within the AOI was calculated by multiplying the total number of buildings with PCB-containing caulk within the AOI by the average building footprint area and the average building height within the AOI. The average building footprint area was calculated by dividing the extrapolated total building area within the AOI by the extrapolated number of buildings in the AOI. The average building height within the AOI was calculated by multiplying the average number of stories in buildings within the AOI (1.46, developed in Section 3.2.1) by 10.3 feet, which was the average building story height in a recent building study conducted for a county in the state of Washington (Serdar et al. 2011).

Table 4. Factors used to estimate the PCB mass in caulk in San Francisco Bay study area buildings

Factor		Source
Height of one building story (ft)	10.3	Serdar et al. 2011; not standardized
Average # of stories in study area buildings	1.46	This study, Section 3.2.1
Mass caulk per volume building (g/m^3)	55	Robson et al. 2010; estimate from building contractor in Toronto
% of buildings with PCB > 50 ppm in caulk (i.e., detection frequency)		Based on detection frequencies in this study, Boston (Herrick et al. 2004), Toronto (Robson et al. 2010), and Switzerland (Kohler et al. 2005).
Low	22	
Medium	36	
High	46	
PCB concentration in caulk (ppm)		25th, 50th, and 75th percentiles of the concentration distribution of this study, Boston (Herrick et al. 2004), and Toronto (Robson et al. 2010). Only samples with PCB > 50 ppm collected from buildings built between 1950-1980 were considered.
Low	950	
Medium	7,990	
High	27,300	

The total PCB mass in caulk in buildings within the AOI was calculated by multiplying the volume of buildings with PCB-containing caulk by the density of caulk in buildings and the caulk PCB concentration (described below). The density of caulk in the buildings was assumed to be 55g caulk/m^3 building, the estimate received by a contractor in Toronto in support of the PCB-containing caulk survey recently conducted for the city (Robson et al. 2011; Miriam Diamond, personal communication). Because this estimate is based on building volume, the estimate for total PCB mass in caulk in buildings in the study area described in this report applies to both interior and exterior caulk. The intent of the PCBs in Caulk project was to focus on exterior caulk only, however, this volume-based estimate was used because it was thought to be the most reliable estimate available to describe the amount of caulk typically used in buildings. An estimate for the relative percent of caulk located on building exterior vs. building interior was not available, and thus it was not possible to distinguish the mass on only building exteriors.

The range of PCB concentrations in caulk used in the estimate of total PCB mass in cauk in buildings was based on the distribution of individual sample concentrations in the present study and the Toronto and Boston surveys. Only samples containing ≥ 50 ppm PCBs were considered to avoid bias due to differences in detection limits among studies and because this concentration is the concentration at which caulk falls under U.S. EPA PCBs regulations. Similar to the estimates of PCB detection frequency mentioned above, only samples collected from buildings constructed between 1950 and 1980 were included. Concentrations of 950, 7,990, and 27,300 ppm (0.095%, 0.8%, and 2.73%) were used for the low, medium, and high estimates of PCB concentrations in a structure's caulk, respectively, corresponding to the 25th, 50th, and 75th percentile concentrations of the cumulative frequency distribution of the three studies (the present study; Greater Boston Area, Herrick et al. 2004; Toronto, Robson et al. 2010). Data from the Switzerland survey (Kohler et al. 2005) were not included because the individual sample concentrations were not provided in the report. However, in addition to having a comparable detection frequency (42% $\geq$ 50 ppm PCBs), the distribution of PCB concentrations in the caulk samples in the Switzerland survey was comparable to this study and those in Boston and Toronto, suggesting the PCB concentrations used are representative of the surveys conducted thus far.

A key consideration is that this evaluation was limited to an aggregate estimate for counties under the jurisdiction of the MRP. As a result, buildings in Marin, Sonoma, and Napa Counties (except for the cities of Fairfield, Suisun, and Vallejo), and the County and City of San Francisco were not included in the PCB mass estimate. The presence of PCBs in caulk in buildings in the Bay Area (Section 2) suggests a high likelihood that PCBs were also used in San Francisco, in particular. This estimate therefore is not comprehensive for the entire San Francisco Bay Area, and may not reflect actual relative inventory among municipalities or counties.

3.3 Results and Discussion

3.3.1 Number of Currently Standing Buildings Built During Era of High PCB Use in Caulk

The GIS evaluation estimated nearly 6,300 currently standing buildings in the San Francisco Bay study area that were built during the era of PCB use in caulk (Table 5). Almost half (48%) of these buildings were located in Santa Clara county, followed by 26% in Alameda, 19% in Contra Costa, and 6% in San Mateo counties. The municipalities of Fairfield and Vallejo each contained less than one percent of the total buildings identified. It is interesting to note that the pattern of standing buildings does not follow the population demographics at the sub-regional scale (e.g. for 1980, Santa Clara: 34%, Alameda: 29%, Contra Costa: 17%, San Mateo: 15%, and Fairfield/Suisun/Vallejo: 4%). However, the density of buildings with potential PCBs in caulk in Santa Clara, Alameda, Contra Costa, and Fairfield was similar (~2 buildings/mi^2), and these were higher than the density of such structures in San Mateo and Vallejo (1 and 0.2 buildings/mi^2, respectively). Of these areas, population increased the most in Santa Clara County as a whole from 1950-1980 (446%), followed by San Mateo (249%), Contra Costa (220%), and Alameda (149%) (US Census Bureau). In some city areas, population increased much more than this. For example, San Jose increased 661% and Fairfield/Suisun City/Vallejo increased 497%. The majority of buildings identified as built during this time period were commercial (67%), followed by industrial (30%), infrastructure (2%), and mixed use (1%). Thus the methods used in this study were sensitive to the unique land use patterns of each county or city area helping to highlight the need for care when making aggregate assumptions across broad urban landscapes. Estimates of the footprint areas of these buildings are provided in Appendix Table 2.

Table 5. Estimated number of currently standing buildings in the study area built during the era of PCB use in caulk[1]

Land Use	Alameda	Contra Costa	Fairfield	San Mateo	Santa Clara	Vallejo	Total Land Use
Commercial	988±40	942±49	50	288±27	1,932±44	5	4,204
Industrial	630±34	193±11	0	17	1,017±39	0	1,858
Infrastructure	27	58±34	5	29	17	0	136
Mixed	4	0	0	35±52	51±15	0	90
Total # of buildings	1,649±37	1,193±42	55	369±29	3,017±42	5	6,288
Total area of municipality (mi^2)	743	743	30	453	1,297	33	
# Buildings per mi^2	2.2	1.6	1.8	0.8	2.3	0.2	

[1] Additional significant digits were maintained for the purpose of propagating calculations but do not represent the degree of certainty.

3.3.2 Estimated PCB Mass in Caulk in Currently Standing Buildings

The medium (i.e., mid-range) estimate of the PCB mass in caulk in buildings in the San Francisco Bay study area (Counties of Alameda, Contra Costa, Santa Clara, San Mateo, and the cities of Fairfield, Suisun City, and Vallejo) was 10,500 kg (Table 6). This mass equated to an average of 4.7 kg PCB per building (calculated by dividing the total PCB mass in caulk in the study area buildings by the estimated total number of buildings with PCB-containing caulk in the study area).

This total PCB mass in buildings is very similar to the estimate of 13,000 kg made recently for PCBs in building caulk in the city of Toronto (Robson et al. 2010), which had a population comparable to the Bay Area in 1980. Although the evidence presented above suggested that population does not appear to be a perfect correlate at the sub-regional scale, it may be a reasonable proxy at the scale of a whole conurbation since city infrastructure allows commuting from place of residence to place of work. The 1980 population of the counties of Alameda, Contra Costa, Santa Clara, San Mateo, and the cities of Fairfield, Suisun City, and Vallejo was 3.8 million, and the population of the Toronto Census Metropolitan Area in 1980 was 3.0 million. These estimates of PCB mass in caulk for the San Francisco Bay study area and Toronto are lower than the estimate made recently for the Puget Sound Area (59,300 kg, range 39,500 –

79,200 kg), which included the entire Puget Sound watershed (Tanya Roberts, personal communication; draft report in prep). These estimates are all lower than the estimate of the PCB stock in caulk in Switzerland, which ranged from 50,000-150,000 kg (Kohler et al. 2005). Given the challenges with the derivation of any estimates, it is perhaps encouraging that the Bay Area estimates are so similar to those of Toronto. It is not possible to determine at this time if the estimates from the other regions are similar without knowing something about the demographics or commercial and industrial histories of each area.

Table 6. Estimates of PCB mass in caulk in the San Francisco Bay study area buildings

	PCB mass in caulk in study area buildings (kg)	Average PCB mass in caulk per building (kg)
Low estimate	767	0.6
Medium estimate	10,500	4.7
High estimate	46,000	16

It should be emphasized that this estimate of PCBs in caulk in the study area buildings is not an estimate of what would enter stormwater (stormwater estimates are discussed in Section 4). These estimates are therefore best compared to other estimates of standing mass from other PCB uses and sources. McKee et al. (2006) collated much of what was known at that time about PCB mass in the Bay Area (Table 7). In comparison to other potential sources, the standing mass of PCBs in caulk in buildings is estimated to be substantial, especially considering the estimates from McKee et al. (2006) were for the entire nine-county Bay Area (i.e. excluding the City and County of San Francisco with a combined sewer system), not just the MRP jurisdictions. For comparison, about 200,000 kg of PCBs are estimated to be currently in use in transformers and large capacitors in the nine-county Bay Area (excluding City and County of San Francisco), about 1,300 kg of PCBs is passed into landfills each year from shredding vehicles and white goods, and an unknown but perhaps large amount is still contained in small capacitors found in light ballasts mostly in old commercial and industrial buildings.

3.4 Uncertainty

Factors potentially adding uncertainty to the PCB mass estimate are described below. Table 8 summarizes each of these elements of uncertainty and indicates whether the uncertainty element is likely to bias the estimate high or low, the likelihood of improving or increasing confidence in the estimate (high or low), and the ease of conducting these efforts or acquiring additional data to address this element in the short-term.

Table 7. Comparison of PCB mass in caulk to estimates of PCB mass in other sources and current uses (McKee et al., 2006).

	PCBs in caulk in buildings[1] (kg)	Transformers or large capacitors still in-use[2] (kg)	Small capacitors (fluorescent light ballasts) still in use	Shredder waste (kg/y)[3]
Low estimate	767	-	?	140
Medium estimate	10,500	197,000	?	1,300
High estimate	46,000	-	?	2,440

[1] The present study. [2]USEPA voluntary database. Note that all the entries in this database happen to be within the focus study area of this current report (Counties of Alameda, Contra Costa, Santa Clara, San Mateo, and the cities of Fairfield, Suisun City, and Vallejo). [3]For the nine county Bay Area excluding City and County of San Francisco.

- The ABAG 2005 land use layer is imperfect, as features are sometimes mislabeled, leading to possible misinterpretations of the data. A spatial join was performed on the building footprints with ABAG 2005 land use. All building footprints that did not intersect with PCBLU features were inspected on an individual basis and re-labeled only if they were mostly within AOI features. These relabeled features were incorporated into the final building footprint dataset and all others were deleted.

- There are no data to validate the caulk mass per building volume (55g /m^3) assumption. It is assumed that this includes both interior and exterior caulk. Improved data could be collected via a local survey and would have a very large impact on both the magnitude and confidence level of the resulting estimates.

- This evaluation was limited to buildings in the commercial, industrial, infrastructure, and mixed commercial/industrial land use categories. By design, residential buildings were not included in the PCB mass estimate. In the Toronto survey, PCBs were detected in only one of 13 single-detached residential buildings (houses) analyzed and were not detected in any large, non-institutional residential buildings (apartments, condominiums) (Robson et al. 2010). Information on the use of PCBs in caulk in residential buildings in the US in not available, thus it is not known to what extent PCBs were used in residential buildings in the Bay Area. If used, the PCB mass calculated in this report would be an underestimate.

- Due to the limited number of random grid cells that could be used to develop the extrapolated building count estimate for the study area, this may be a highly uncertain estimate.

Table 8. Elements of uncertainty in the PCB mass estimate[1].

Element	Likely to bias estimate high or low?	Likelihood of improvement	Ease of efforts to address in short-term
Imperfect ABAG 2005 land use layer	Unknown bias	High likelihood of an updated version	Easy; improvement for this application unknown
No data available to validate the caulk mass per building volume assumption (55g /m^3)	Unknown bias	High	Moderately easy with local survey
Limited information on the use of PCBs in caulk in residential buildings	Low	High	Moderately easy with residential building survey
No data to validate total building counts in study area	Unknown bias	High	Moderate with an increased number of random grid cells included in GIS analysis
PCB mass in buildings containing <50 ppm in caulk	Low	Moderate	Difficult; more sensitive lab method may be needed

[1] The table indicates whether the uncertainty element is likely to bias the estimate high or low, the likelihood of improving or increasing confidence in the estimate (high, medium, or low), and the ease of conducting these efforts or acquiring additional data to address this element in the short-term (high, medium, or low).

- This evaluation was generally limited to caulk containing at least 50 ppm PCB to avoid bias due to differences in detection limits among studies and because this concentration is the concentration at which caulk falls under U.S. EPA PCBs regulations. The percent of caulk samples containing detectable PCB concentrations less than 50 ppm was 6, 21, and 48% in the Switzerland, Boston, and present studies, respectively. The PCB mass calculated for this report likely captures the vast majority of PCB in caulk in the San Francisco Bay study area, but because it does not include caulk containing less than 50 ppm, it is an underestimate of the total PCB in the study area.

4.0 ESTIMATION OF PCB LOADING TO STORMWATER DURING BUILDING RENOVATION AND DEMOLITION

4.1 Approach

An estimate of the PCB mass released during the renovation and demolition of buildings with PCB-containing caulk was developed to determine their possible importance as a source of contamination to stormwater in the study area. A field study quantifying PCB losses during a demolition or renovation effort would be the ideal dataset to perform these estimates; however, this type of study was not within the scope of this project. Instead the estimate was developed using a conceptual understanding of potential losses to stormwater via the physical processes associated with demolitions and renovations in a spreadsheet evaluation. The estimate considered releases due to currently used renovation and demolition practices only (i.e., prior to implementation of BMPs for specifically managing PCBs in caulk). The estimate did not include releases from intact building caulk (e.g., PCB losses via volatilization, erosion of in-use caulk, or leaching via precipitation) or residues left on the ground or exposed to environmental transport process post-demolition or renovation.

4.2 Methods

A range of PCB mass release estimates (low, medium, and high) was calculated by applying a number of factors to the estimated number of annual building demolitions and renovations in the San Francisco Bay study area (Table 9). Note, consistent with the rest of the report, the ‘San Francisco Bay study area’ corresponds to the area covered by the current Phase I municipal regional stormwater permit (MRP): Alameda, Contra Costa, Santa Clara, and San Mateo Counties, and the cities of Fairfield, Suisun, and Vallejo. The Counties of San Francisco, Marin, Sonoma, Napa, and most of Solano are excluded from this area. A brief description of the calculations is listed below. The complete calculations linked to the list of factors used are provided in the Excel spreadsheet titled ‘Demo_Reno_Release_Estimates’ that accompanies this report and is co-located on the SFEI website.

The number of demolitions and renovations of commercial and industrial buildings in the study area was obtained from the Bay Area Air Quality Management District (BAAQMD) “J” numbers. BAAQMD regulations require that a "J Number" be applied for and obtained prior to applying for a building permit for demolition of an existing structure or renovations removing greater than 100 square feet of asbestos material within the San Francisco Bay air basin. BAAQMD J numbers are categorized by land use (e.g., commercial, residential) and the address for each J number is provided in the BAAQMD records. The total number of permits (i.e., J numbers) issued from April 2010 to Mar 2011 was used as the basis for the estimates (Table 9). For the number of commercial/industrial demolitions, the total J numbers were used for the medium estimate (521) and the medium estimate plus 10% and the medium estimate minus 10% were used for the low (469) and high (573) estimates, respectively (i.e., assumes 10% variation in permitted demolitions per year). For the number of commercial/industrial renovations, the

Table 9. Factors used to estimate PCB mass released from caulk during renovation and demolition of San Francisco Bay study area building

Factor		**Source**
# comm./ind demos per year		
Low	469	Medium estimate, less 10%
Medium	521	BAAQMD J numbers (April 2010-March 2011)
High	573	Medium estimate, plus 10%
# comm./ind renovations per year		
Low	518	BAAQMD J numbers (April 2010-March 2011) (permitted)
Medium	648	Assumes 20% unpermitted
High	1036	Assumes 50% unpermitted
% of demos/renos to non-residential buildings built b/w 1950 and 1980		See Section 4.2 of this report
Low	23	Assumes all buildings demolished randomly regardless of age
Medium	46	Assumes 10% of new stock also subject to demo/reno
High	52	Assumes only buildings built prior to 1974 are demo/reno
% of buildings with PCB > 50 ppm in caulk		
Low	22	Based on detection frequencies in this study, Boston (Herrick et al. 2004), Toronto (Robson et al. 2010), and Switzerland (Kohler et al. 2005).
Medium	36	
High	46	
Average PCB per building (kg)		This study (Section 3)
Low	0.6	
Medium	4.7	
High	16	
% of PCB in building caulk released per building		See Section 4.2 of this report
Low	0.0027	
Medium	0.0043	
High	0.0099	

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[1] The low estimate for renovations was based on the number of known asbestos renovations. This was scaled up to include the number of non-asbestos renovations, which is unknown.

total J numbers were used as the low estimate (518). For the medium estimate (648), it was assumed that 80% of all commercial/industrial renovations are permitted. For the high estimate (1036), it was assumed that 50% of all commercial/industrial renovations are permitted. The total number of unpermitted building renovations in the Bay Area is unknown.

The number of commercial, industrial demolitions and renovations in the study area was multiplied by estimates of the percent of these buildings built during the era of high PCB use in caulk (i.e., 1950-1980) (description below), the percent that contain PCBs in caulk >50 ppm (Section 3), the average PCB mass in the study area buildings (Section 3), and the PCB mass released to the environment (description below), to estimate the total PCB mass released by the demolition and renovation of these buildings per year.

The percent of demolished and renovated buildings per year that were built during the era of high PCB use in caulk was estimated using a GIS evaluation. Commercial/industrial land use area (or areas of urban extent) was compared among years using available land use maps (1954, 1974, and 2005) and used as a proxy for the number of buildings that are commercial/industrial in each time period. Estimates of 23, 46, and 52% of current commercial/industrial area being from the period of interest were used for the low, medium, and high estimates, respectively. Additional details are provided in the Excel spreadsheet titled ‘Demo_Reno_Release_Estimates’ that accompanies this report.

A key element of the evaluation was estimating PCB losses via activities associated with the renovation and demolition of buildings. A study conducted to investigate PCB emissions during the replacement of PCB-containing caulk in a concrete house built in 1971 in Stockholm, Sweden is the only study known to have quantified losses somewhat related to renovation and demolition activities (Jansson et al. 2000, Astebro et al. 2000). Though not directly applicable because of the decontamination procedures used, results from the Jansson et al. (2000) study were used as a proxy in the present study to estimate PCB losses to the environment during building renovation and demolition. In the Jansson et al. (2000) study, the caulk was removed from the building and decontamination procedures specifically designed to remove residual PCB were used (grinding and power-washing the concrete or masonry substrate formerly in contact with the caulk). (Note PCBs in caulk are known to “migrate” into the base material (e.g., mortar). Currently, areas surrounding PCB-containing caulk are not decontaminated by grinding, sanding, or power washing. In the future, this practice may be used more frequently as building owners become aware of potential liabilities and/or PCB regulations are amended). The authors estimated the PCB mass lost to air, soil, and water (used in power-washing) during the caulk replacement procedure and developed a mass budget of PCB emissions. Emissions to air were quantified by analyzing the PCB concentration in the gas and particles that were captured in a vacuum attachment connected to the cement/mortar grinding tools. Emissions of PCBs to soil were quantified by analyzing soil near the building before and after the operation. Emissions of PCBs to the power-washing water were quantified by sampling the water dripping from the building during the procedure. Samples of the building caulk were also collected and analyzed for PCB content.

The values used for the low and high estimates of PCB mass released to the environment in the present study were based on the average PCB mass lost to air only, and the average mass loss to air plus the mass lost to soil, respectively, in the Jansson et al. (2000) study (0.0014 and 0.005% of the total PCB mass in caulk in the building, respectively). The value used for the medium estimate was calculated using the average mass lost to air plus the proportional mass lost to air and water multiplied by the mass lost to the soil (0.0022%), since the authors suggested some PCB lost to air and water ultimately settled in the soil. For the present study these values were multiplied by two to account for the additional amount of caulk surface area exposed to the environment during removal and subsequent grinding during the demolition and renovation processes (i.e., to account for PCB emissions during the physical process of removing the caulk from the building plus emissions that may occur while the caulk remains on-site during the construction process, following removal from the building but prior to transport to a waste facility). The low, medium, and high estimates used in the report were 0.0027, 0.0043, and 0.0099%, respectively -- all values represent the percent of the total PCB mass in building caulk lost to the environment. It was assumed that all PCBs released to the environment enters stormwater. The PCB mass lost to water in the Jansson et al. (2000) study was approximately ten times higher than the amount released to air, but was not included in the release estimate for this report because power-washing of known PCB-containing substrates is not currently standard practice in building demolition or renovation.

Additional key considerations for the release estimates are listed below.

- Only PCB releases that may occur during the actual demolition and renovation processes were considered (i.e., potential losses due to caulk scraps/rubble dispersed on-site or off-site following the building demolition/renovation were not considered). This is further discussed in Section 4.4.
- It was assumed that interior and exterior caulk on a building are equally vulnerable to loss during demolition activities.
- It was assumed that all building renovations are performed on exterior building caulk.
- It was assumed that all building renovations involve mobilization of caulk.

4.3 Results and Discussion

4.3.1 PCB Mass Released to Stormwater

The medium estimate of PCB mass released from caulk to stormwater during building demolition and renovation activities was 0.04 kg/yr (Table 10). Approximately 50% of the total PCB mass released was estimated to occur during renovations, and 50% during demolitions. This medium estimate for the total PCB mass released to stormwater is ten times lower than the

Table 10. Estimated annual PCB mass released from caulk to stormwater during building demolition and renovation activities in the San Francisco Bay study area (kg/yr)

	PCB mass from demolitions	PCB mass from renovations	Total PCB mass
Low estimate	0.0004	0.0004	0.0008
Medium estimate	0.02	0.02	0.04
High estimate	0.22	0.39	0.6

estimate of 0.4 kg/year calculated previously for the San Francisco Bay Area (the low and high estimates provided by Mangarella et al. 2010 were 0.4 and 4 kg/yr, respectively). The difference between estimates is mainly due to the ten times higher estimate of PCB loss on a per building basis in Mangarella et al. (2010) (0.002-0.02 kg per building) compared to the present study (medium estimate, 0.0002 kg per building).

4.3.2 Comparison to Releases from Other PCB Sources

The release estimate was compared to previously characterized sources of PCBs to stormwater in the Bay Area (McKee et al., 2006) to determine the relative importance of caulk as a potential source of contamination. The comparison is not perfect; the current estimate for caulk presented here covers only 73% of the population of the Bay Area as compared to the previous estimates that were for 87% of the Bay Area (i.e. excluding the City and County of San Francisco with a combined sewer system). McKee et al. (2006) used a series of thought experiments based on literature review of anything relevant that could be found at the time related to the PCB mass balance and mobilization to stormwater in urban environments. At the time, the estimates of PCB loss from caulk to stormwater were based on the work of Larry Walker Associates (2006). Although the caulk estimate by Larry Walker Associates (2006) seemed too large compared to other PCB releases to stormwater estimated by McKee et al. (2006), no other literature could be found to provide an alternative estimate. The original estimates from McKee et al. (2006) compared the caulk estimate (Larry Walker Associates 2006 high estimate: 4.1 kg) to other stormwater source estimates (Figure 5). The new estimate provided here for caulk, when compared to other sources to stormwater, is much smaller (0.3%) (Figure 5) but as discussed above and more below, all elements of our estimate are biased low.

Comparison of the loss rates of PCBs from caulk during building demolitions and renovations to those in other uses suggests these estimates appear reasonable. Based on the literature review of McKee et al. (2006), approximately 0.002% of the standing mass of PCBs still in use in the Bay Area is likely lost to stormwater each year. The estimate for PCBs in caulk entering stormwater during demolition and renovations each year presented in the present study is equivalent to 0.0005% of the estimated PCB standing mass in existing buildings in the study area; that is a

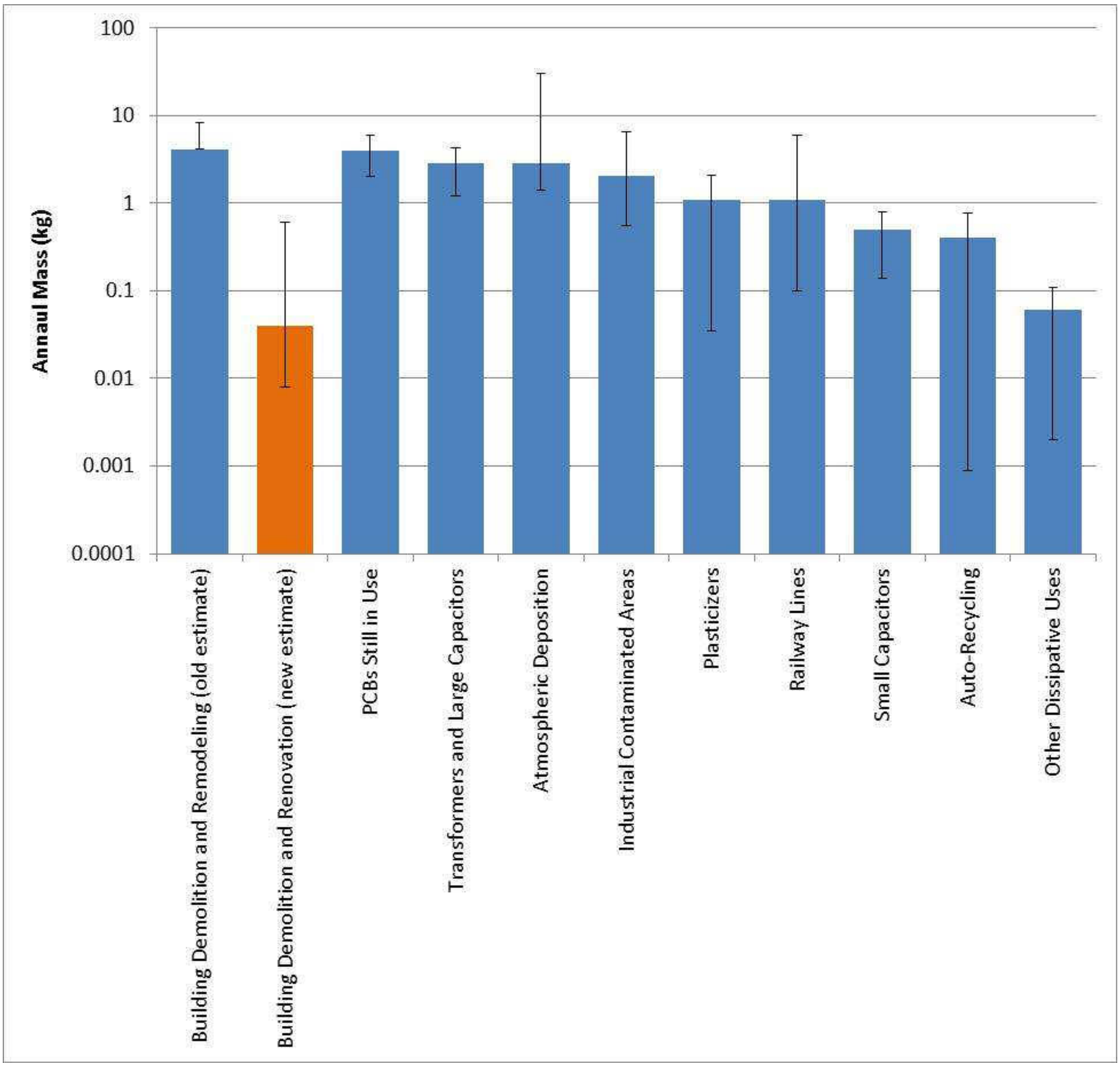

Figure 5. Estimates of PCB mass from various sources entering stormwater in the Bay Area urban environment. "Old" refers to the estimates from McKee et al. (2006) for the entire Bay Area; "New" refers to the estimates of supply from caulk from the present study. Note the size of the error bars in all of the estimates and the fact that bias is often very hard to determine. At this time only the PCB in caulk number has been re-evaluated but work is ongoing by BASMAA agencies to locate and abate contaminated areas and improve loading estimates.

release factor for caulk that is about four times less than the release estimate for oil leaking out of transformers and large capacitors still in use (Note, we have learned since that this estimate might be bias high since many large capacitors were housed inside buildings). Regardless, it seems reasonable that the emission factor for outdoor liquid applications such as use in dielectric fluids and hydraulic fluids and lubricants (in which indoor and outdoor uses comprise 75% of total US commercial sales; Erickson and Kaley II, 2011) should be greater than the release from a solid matrix, some of which is still intact during building demolition and renovations.

4.4 Uncertainty

Because of the limited amount of data available, the PCB release estimates were based on a number of assumptions and simplifications. Primary sources of uncertainty in the PCB mass estimate are listed below. Table 11 summarizes these elements of uncertainty and indicates whether the uncertainty element is likely to bias the estimate high or low, the likelihood of improving or increasing confidence in the estimate (high or low), and the ease of conducting these efforts or acquiring additional data to address this element in the short-term.

First, the total number of unpermitted building renovations in the Bay Area is unknown. The renovation estimates used in the report were based only on the number of permits for asbestos removal renovations provided by the Bay Area Air Quality Management District BAAQMD J number records (April 2010 – March 2011) and estimates provided by a local contractor for the percentage of all commercial/industrial renovations that are permitted (80%).

Second, and most importantly, there are no data to validate the PCB mass in caulk released to the environment during building renovations and demolitions. As noted previously, the PCB release estimates generated for this report were based on a study conducted to investigate PCB emissions during the replacement of PCB-containing caulk in a concrete house in Sweden (Jansson et al. 2000, Astebro et al. 2000). In that study the caulk was removed from the building and decontamination procedures specifically designed to remove residual PCB were used (grinding and power-washing the concrete or masonry substrate formerly in contact with the caulk). The Jansson et al. 2000 study was useful for estimating emissions from PCBs that have penetrated building materials and emissions of PCBs from caulk during the processes that occur during actual demolition and renovation activities (i.e., losses to air and surrounding soil). However, this estimate does not account for what may be the largest demolition and renovation PCBs source—caulk scraps remaining at a demolition/renovation site. Available information suggests that caulk may commonly be dispersed on site or off site and is not fully collected following building demolition and renovation activities (USEPA 2009b; http://www.pcbinschools.org).

Caulk on construction sites is very unlikely to be separated out and fully contained for off-site disposal in a location not subject to stormwater runoff for the following reasons:

- Because waste caulk lacks financial value, there is little incentive to collect it, and it is often not easy to collect, sometimes brittle enough to break into small fragments and dust, so it is not always removed from work sites.

- Since it is often difficult to separate caulk from surrounding building materials, unidentified PCBs-containing caulk is likely to be managed in conjunction with the management of other building materials (e.g., concrete or bricks that are re-used). When the presence of PCBs is unknown, a construction crew has no reason to carefully separate visible caulk from other building debris. This could cause PCBs-containing caulk to remain on site or to be transported to a processing or re-use site, where it could subsequently be released into urban runoff.

During demolition, remodeling, building material processing for re-use, or building material re-use at another site, PCBs-containing caulk may be dispersed onto impervious surfaces and onto soils. Once dispersed, the caulk could be subject to physical and environmental processes that could further degrade the caulk into smaller particles that are more readily washed away.

Because PCB losses from caulk scraps that may be left behind at a demolition/renovation site were not included, the estimate in this report is an underestimate. However, because of the lack of data to quantify these potential losses (reporting of residual scrap material is generally anecdotal and only qualitative), it is not possible to determine the magnitude of the low bias but it could be as large at several kilograms on average, a portion of which could find its way to stormwater. These significant information gaps, together with the small data set for concentrations of caulk in Bay Area buildings used in the present study (n=25 samples from ten structures: see section 2), leave considerable uncertainty in the release estimate made in this report for building demolition and renovation activities. Since all the elements of uncertainty in our calculations are bias low (Table 11), the comparison to mass released from other sources remains questionable also.

Table 11. Elements of uncertainty in the PCB mass release to stormwater estimate[1].

Element	Likely to bias estimate high or low?	Likelihood of improvement	Ease of efforts to address in short-term
Number of unpermitted building renovations in the Bay Area	Low	Low	Difficult without improved enforcement
PCB mass in caulk released to the environment during building renovations and demolitions	Low	Moderate	Difficult - measurable but expensive
Residual PCB in caulk on site after renovations and demolitions	Low	Low	Difficult – data anecdotal unless routinely collected

[1] The table indicates whether the uncertainty element is likely to bias the estimate high or low, the likelihood of improving or increasing confidence in the estimate (high, medium, or low), and the ease of conducting these efforts or acquiring additional data to address this element in the short-term (high, medium, or low).

4.5 Incorporation of New Information to Refine Estimates

Excel spreadsheets developed for this project (‘PCB Building Mass Estimates’ and ‘Demo_Reno_Release_Estimates’, which accompany this report) may be used to easily incorporate new information to refine the estimates produced in this report.

5.0 EFFECTIVENESS OF BMPS FOR DEMOLITION AND RENOVATION OF PCB-CONTAINING CAULK

A key outcome of the PCBs in Caulk project was the development of Bay Area-specific best management practices (BMPs) and a model implementation process (MIP) to prevent the release of PCBs from caulk to urban runoff during renovation, maintenance, and demolition of structures. Switzerland and Sweden have active programs for managing PCB-containing building materials, including caulk (references in Kohler et al. 2005, Jansson et al. 2000). In the US, the USEPA released guidance on precautionary measures and BMPs to follow when conducting a repair or renovation in older buildings where PCB-containing caulk may be present (USEPA 2010a). This guidance is communicated via a website containing ‘Suggested Tools and Methods for Caulk Removal’ (USEPA 2010b). A summary of the existing BMPs related to managing wastes and hazardous materials during building demolition and remodeling, which includes BMPs recommended by the USEPA for PCB-containing caulk, was developed for another element of this project (Geosyntec 2010). Though a variety of BMPs are available for consideration during a building demolition or renovation, little information is available regarding the relative effectiveness of these BMPs for preventing release of PCBs to the environment.

A study conducted in Sweden estimated that more than 99% of the PCB content in caulk was captured following the use of remedial actions specifically aimed at preventing PCB release from caulk to the environment (Sundahl et al. 1999). The study was conducted on a concrete block building and the remedial actions included cutting and grinding away the caulk material, as well as a few millimeters of the concrete surrounding the caulk. The actions included a variety of tools, which were connected to a high capacity vacuum cleaner to capture the dust produced during the removal process.

A similar result was obtained in the previously mentioned study in Stockholm, Sweden, which investigated PCB emissions during the replacement of PCB-containing caulk in a concrete house (Jansson et al. 2000, Astebro et al. 2000). The authors estimated that more than 99% of the PCBs in caulk were captured simply via the removal of the caulk from the building. The use of vacuum attachments connected to tools used for grinding the concrete formerly in contact with the caulk and power-washing the concrete to capture residual PCBs accounted for the removal of less than 1% of the total PCB in caulk in the building. The authors estimated that among the BMPs used, most PCBs were lost to the water (as a result of power washing), which accounted for 0.03% of the total PCB mass in the building caulk. In addition, it was determined that most PCB losses to air were in the gas phase as a result of the use of high temperature tools or heat generated during the act of grinding or other removal mechanisms.

At least two studies examining mitigation measures for PCB-containing caulk are ongoing, and these primarily address minimizing impacts to human health (i.e. interior exposure) rather than preventing releases to stormwater. The first study was initiated in 2009 and is being conducted by the USEPA Office of Research & Development (USEPA 2010c). The study's objectives are to (i) support the development of risk reducing strategies and decision-making tools by evaluating the mitigation measures that reduce or eliminate available PCBs on building surfaces and, consequently, in indoor air and dust, and (ii) support exposure/risk assessment for PCBs in schools by characterizing PCB sources to better understand the transport and distribution of PCBs in buildings. The study tasks include an investigation of PCB encapsulation methods and a review of mitigation methods for PCBs in buildings. A related study investigating sources and exposure of PCBs in school buildings is also ongoing (USEPA 2010d). Final reports for both studies were expected in March 2011 but had not been completed before completion of this report.

A second study involving PCB caulk in school buildings was initiated in 2010 and is being conducted by the City of New York (TRC Engineers, Inc 2010). This purpose of this study is to evaluate the possible presence of PCB-containing caulk and the most effective methods for remediation, with the ultimate goal of developing a city-wide approach to assessing and managing PCBs in caulk in schools. The 'Pilot Remedial Investigation and Feasibility Study' will investigate five different remedies and includes the collection of pre- and post-remedial remedy samples for PCB analysis. This study also includes evaluation of current BMPs used in the schools.

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Summary

6.1.1 PCBs in Caulk Samples

This limited investigation revealed the presence of PCBs in 88% of the caulk samples collected from Bay Area buildings, with 40% exceeding 50 ppm, the concentration at which caulk falls under U.S. EPA PCBs regulations (Section 2). Detectable PCB concentrations ranged over six orders of magnitude, from 1 to 220,000 ppm (22%). These data suggest that PCBs are prevalent in currently standing Bay Area buildings, and are consistent with previous studies that have identified the highest concentrations of PCBs in concrete and masonry buildings built between 1950 and 1980. Portable XRF was not a good predictor of the PCB content in caulk and the results were consistent with previous work indicating that XRF may only be useful for identifying caulk that do not contain high concentrations of PCBs (≥10,000 ppm).

6.1.2 PCB Stock in Caulk in the San Francisco Bay Study Area Buildings

The evaluation resulted in a medium (i.e., mid-range) estimate of 10,500 kg (low and high estimates of 767 and 46,000 kg, respectively) of PCB in caulk in buildings in the geographical study area (i.e. MRP extent, not including the City and County of San Francisco, Marin County, Sonoma County, Napa County, or most of Solano County). This estimate equated to an average of 4.7 kg PCB per building (low and high estimates of 0.6 and 16 kg, respectively). Future work may examine the potential contribution to stormwater of PCBs in many other uncontained uses in interior building materials, such as floor and ceiling tiles, insulation, waxes, paints, varnishes, lacquers, mastics, etc.

6.1.3 PCB Loading to Stormwater from Building Renovation and Demolition

The medium estimate of PCB mass released per year from caulk to stormwater during building demolition and renovation activities in the San Francisco Bay study area was 0.04 kg (low and high estimates of 0.0008 and 0.6 kg, respectively). Approximately 50% of the total PCB mass released occurs during renovations, and 50% during demolitions. Significant information gaps, together with the small caulk sample size used in the present study, leave considerable uncertainty in this release estimate.

Because PCB losses from caulk scraps that may be left behind at a demolition/renovation site were not included, the estimate in this report is likely an underestimate. However, because of the lack of data to quantify these potential losses (reporting of residual scrap material is generally anecdotal and only qualitative), it is not possible to determine the magnitude of the low bias. These significant information gaps, together with the small sample size of concentrations in Bay Area caulks used in the present study (n=25 samples from ten structures), leave considerable uncertainty in the release estimate made in this report for building demolition and renovation activities. Since all the elements of uncertainty in our calculations are biased low, the comparison to mass released from other sources remains questionable also.

6.2 Recommendations

6.2.1 PCB Mass in Caulk in Study Area Buildings

The following actions could be taken to increase the accuracy and refine the estimate of the PCB stock in caulk in the San Francisco Bay study area buildings.

- Validate the estimates for the number of buildings that were constructed during the era of PCB use in building caulk. Due to the limited number of random grid cells that could be used to develop the extrapolated building count estimate for the study area, this may be a highly uncertain estimate. Detailed building information may be available in municipal records or databases. Alternatively, with a larger budget, it would have been possible to reduce uncertainty with either a larger number of random samples or a different sampling approach that accounted for the nature of new commercial and institutional development during the time frame of interest, which was not geographically random.

- Validate estimates for the prevalence of PCBs in these buildings, including their prevalence in different building types (e.g. residential, commercial/industrial) and locations (e.g. between concrete blocks, around windows). Also, validate estimates for the PCB concentration distribution. This information may be obtained from a study that includes the systematic collection of caulk samples from a larger number of buildings in the Bay Area and targets specific building types and caulk locations on the buildings.
- Validate the estimate for the average mass caulk per volume of building. The estimate used in this report (55 g caulk/m^3 of building) was obtained from the caulk survey conducted in Toronto (Robson et al. 2010). This estimate may be refined using information obtained from local building contractors.

6.2.2 PCB Loading to Stormwater from Building Renovation and Demolition

The following actions could be taken to refine the estimate of PCB loading to stormwater from caulk during building renovation and demolition.

- Validate estimates of the annual number of demolitions and renovations in the Bay Area by building type and building construction year. This information may be obtained by consulting several local building contractors.
- Validate estimates for the amount of PCBs released from caulk during renovation and demolition. This information may be obtained by performing pilot studies of actual building demolitions and renovations in which PCB losses to air and soil are quantified. Sample collections could be conducted to evaluate BMP effectiveness to provide the opportunity for lessons learned before BMPs are finalized. The design of a monitoring scheme is beyond the scope of this report and will likely be site specific but previous and ongoing studies provide a useful starting framework.
- Conduct a study to develop an estimate for the amount of PCB released from caulk scraps that may be left behind at a demolition/renovation site. To develop a scientifically credible estimate, it would be necessary to address the following types of questions about management of caulk from demolition and remodeling of older buildings[1]:
    - What fraction of caulk typically remains at demolition and renovation sites?
    - What is the typical particle size distribution of caulk that remains on site (i.e., is it small enough to wash away in runoff)?

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[1] This list of questions was developed in consultation with Kelly Moran, TDC Environmental.

- Of caulk remaining on sites, what fraction is typically exposed to urban runoff?
- What fraction of caulk typically remains with building debris?
- What fraction of caulk-containing building debris is ground up for reuse?
- Of caulk removed with materials for reuse, what fraction is typically exposed to urban runoff?
- What fraction of PCBs in runoff are removed by typical construction and post-construction stormwater treatment “best management practices” (BMPs) that are required by Water Board permits?
- Over what time frame could post-project PCBs runoff exceed pre-construction levels? (Time frame is necessary to estimate the total PCBs loss due to the demolition or construction activity).

This type of information does not appear to be readily available. Since awareness of PCBs in caulk will change caulk management practices, this information may be relatively difficult to obtain.

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8.0 APPENDIX

Appendix Table 1. Comparison of GC-MS measured PCB and Chlorine Concentrations to XRF-measured Chlorine (Cl) Concentration in the San Francisco Bay Area Caulk Samples

Building Construction Year	Building Construction Type*	Caulk Location on Building	GC-MS PCB (ppm)	GC-MS Cl (ppm)	XRF Cl (ppm)
1950s	PC2	Between concrete	220,000	119,046	72,000
1950s	PC2	Between concrete	198,000	110,245	49,300
1950s	PC2	Between metal window frame and	146,000	81,446	53,200
1960s	W2	Between glass and window frame	12,500	7,031	6,770
1950s	PC2	Between concrete	11,500	6,419	100,000
1950s	PC2	Around metal window frame	7,630	4,216	100,000
1950s	PC2	Between glass and metal window frame	3,600	1,989	46,400
1960s	C2	Between window glass and window	89	48	171
1980s	RM	Unknown	87	49	<694
1970s	W2	Between wood and wood	60	34	1,103
1960s	C2	Between window glass and window	48	26	143
1950s	W1	Between glass and metal window frame	15	8	461
Unknown	Unknown	Around window frame	15	8	<645
1970s	W2	Between glass and window frame	11	6	100,000
1970s	W2	Between window frame and wood	10	5	<3,072
1970s	W2	Around doorframe	8	4	3,180
1950s	W1	Around doorframe	6	3	<787
1950s	W1	Around doorframe	5	3	<65
1950s	W1	Between glass and window frame	3	2	<350
1950s	W1	Between metal window frame and	2	1	17,800
1960s	PC1	Between concrete	2	1	<891
1950s	W1	Between wood window frame and wood	1	0.4	<231
1950s	W1	Between wood and concrete	0	0	<816
1950s	W1	Between wood and wood	0	0	1,777
1960s	RM	Between glass and window frame	0	0	NA

*Construction codes: PC1= Precast/tilt-up concrete shear-wall; PC2=Pre-cast concrete frame; C2=Concrete shear-wall; W1=Light wood-frame residential and commercial smaller than or equal to 5,000 square feet; W2=Light wood-frame larger than 5,000 square feet; RM=Reinforced masonry

Appendix Table 2. Extrapolated Building Footprint Area (Acres) of Currently Standing, Commercial and Industrial Buildings Built During the Era of PCB Use in Caulk in the San Francisco Bay Study Area[1]

Land Use	Alameda	Contra Costa	Fairfield	San Mateo	Santa Clara	Vallejo	Total Land Use
Commercial	575	461	10	118	979	3	2,146
Industrial	437	138	0	11	777	0	1,363
Infrastructure	31	28	3	4	12	0	78
Mixed	1	0	0	11	38	0	49
Total	1,044	627	13	145	1,805	3	3,637

[1] Additional significant digits were maintained for the purpose of propagating calculations but do not represent the degree of certainty.

Appendix Table 3. Extrapolated Building Footprint Area for Each MRP County (the data in Appendix Table 2) as a Percent of Total ABAG 2005 Land Use Blocks of the Same General Land Uses

	Alameda	Contra Costa	Fairfield	San Mateo	Santa Clara	Vallejo
Commercial	2.4	1.9	0.7	1.0	3.2	0.2
Industrial	2.9	1.1	-	0.4	5.7	-
Infrastructure	0.4	0.9	-	0.1	0.6	-
Mixed	0.1	-	-	0.7	7.7	-