Health Consultation

ANALYSIS OF LUNG CANCER INCIDENCE NEAR
CHROMIUM-CONTAMINATED SITES IN NEW JERSEY
(a/k/a Hudson County Chromium Sites)
JERSEY CITY, HUDSON COUNTY, NEW JERSEY

SEPTEMBER 30, 2008

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

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HEALTH CONSULTATION

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(a/k/a Hudson County Chromium Sites)
JERSEY CITY, HUDSON COUNTY, NEW JERSEY

Prepared By:

New Jersey Department of Health and Senior Services
Public Health Services
Consumer and Environmental Health Services

and

New Jersey Department of Environmental Protection
Division of Science, Research and Technology

Under a Cooperative Agreement with the
U.S. Department of Health and Human Services
The Agency for Toxic Substances and Disease Registry

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Summary

In response to community requests, the New Jersey Department of Environmental Protection (NJDEP) and the New Jersey Department of Health and Senior Services (NJDHSS) evaluated the relationship between historic exposure to chromium from chromium ore processing residue (COPR) sites and the incidence of lung cancer in Jersey City (Hudson County), New Jersey over a 25 year period.

Hudson County was a major center for chromium ore processing and manufacturing. Nearly three million tons of COPR was produced, and much of was used as fill material in construction of residential and commercial sites in the 1950s and 1960s. More than 160 COPR disposal sites have been identified in Hudson County, 136 sites in Jersey City alone. COPR contained high concentrations of total chromium, with small and varying proportions being hexavalent chromium (Cr^{+6}), the most toxic form. Cr^{+6} is known to cause lung cancer in humans.

This investigation of lung cancer incidence included the population residing in Jersey City from 1979 through 2003. Annual population estimates were derived from U.S. Census Bureau data. The New Jersey State Cancer Registry in the NJDHSS was used to determine the number of lung cancer cases occurring in the Jersey City population. A total of 3,249 malignant incident lung cancer cases (2,040 males and 1,209 females) were included in this investigation. Lung cancer cases were aggregated by U.S. Census Bureau census block groups, based on the case's residence at the time of diagnosis.

The NJDEP, using historic information on the location of known COPR sites along with their contaminant levels, characterized census block groups as to their potential for residential Cr^{+6} exposure in Jersey City. The Appendix to this Health Consultation contains a detailed description of the chromium exposure categorization. For the epidemiological analysis, census block groups were aggregated into "exposure intensity groups" (none, low, or high) based on the proportion of the residential part of the block group within 300 feet of COPR site boundaries. Four alternative definitions were considered for the "high" exposure intensity group.

Data were analyzed two ways. The first approach compared the incidence of lung cancer in Jersey City for the populations classified within each exposure intensity group to cancer incidence for the entire state during the same 25-year time period. The second approach compared the lung cancer incidence in each exposure intensity group in Jersey City over the entire exposure period to the lung cancer incidence in the non-exposed group in Jersey City during the same period. The analyses showed similar results.

Compared to the state, lung cancer incidence in Jersey City was higher than expected in all exposure groups for males and lower than expected in all exposure groups for females.

In both analysis approaches, an increase in the rate of lung cancer incidence was found for populations living in closer proximity to historic COPR sites. Based on the internal Jersey City comparison, males in the high exposure group had a lung cancer incidence rate ranging from 7% to 17% higher than the no exposure group, depending on the definition of high exposure. Similarly, females in the high exposure group had a lung cancer incidence rate ranging up to 10% higher than the no exposure group.

Lung cancer is the second most common cancer diagnosed in both males and females, and is the leading cause of cancer mortality for both sexes in New Jersey and the country. Recent trends indicate that incidence and mortality rates have been declining nationwide for males, but continuing to rise for females. Tobacco smoking is considered the most important risk factor, accounting for more than 85% of all lung cancer deaths. Other known risk factors for lung cancer include indoor exposure to radon and environmental tobacco smoke, occupational exposure to cancer-causing agents in the workplace, and exposure to air pollution. Information on these potential risk factors was not available for analysis in this investigation.

Residential proximity to COPR sites at the time of cancer diagnosis was used as a crude surrogate for exposure potential. However, it is unlikely that all of the residents in the designated areas were exposed to hexavalent chromium from the COPR sites, and those living outside the designated exposed areas may have been exposed to chromium. In addition, no information was available on the residence histories of cases. The consequence of misclassifying true exposure in this investigation is to decrease the chances of seeing differences in incidence rates due to exposure.

Based on the internal comparison within Jersey City, an increased risk of lung cancer incidence was found for populations living in close proximity to historic COPR sites, although the increases were not statistically significant. The results suggest that living closer to COPR sites is a potential risk factor for the development of lung cancer, but these findings do not prove a cause-effect relationship. While the findings are consistent with evidence from occupational health studies, other potential risk factors that could not be accounted for in the analysis cannot be ruled out.

It is important to note that the historic potential exposures described in this investigation do not represent the current conditions in the city, since considerable remediation of the COPR sites has occurred. However, it is recommended that efforts to remediate COPR sites to limit human exposure to hexavalent chromium should continue.

Recent information from the National Toxicology Program indicates that ingestion of Cr^{+6} in drinking water increases the risk of oral and small intestine cancers in laboratory animals. A recent study of a Chinese population exposed to Cr^{+6} in drinking water provided evidence of an increased risk of stomach cancer. Therefore, the NJDHSS should consider evaluating additional cancer types in relation to proximity to COPR sites.

Purpose

Malignant lung cancer incidence was evaluated in relation to the historic locations of chromium ore processing residue (COPR) in Jersey City, Hudson County, New Jersey. COPR is known to contain hexavalent chromium, a lung carcinogen. Lung cancer incidence was analyzed for a 25-year period, 1979-2003. The potential for exposure to chromium from COPR was based on New Jersey Department of Environmental Protection (NJDEP) estimates of the percentage of a census block group's residential area that was located within 300 feet of one or more known COPR waste sites.

Background and Statement of Issues

From 1905 to 1976, Hudson County was a major center for chromium ore processing and manufacturing. Two of the three chromate production facilities in Hudson County were located in Jersey City. Nearly three million tons of COPR was produced by the three facilities and disposed of throughout the County, especially in Jersey City. The COPR was sold or given away for use as fill material and used extensively in construction of residential and commercial sites. In addition, COPR was used for backfilling demolition sites, road construction, building foundations, and disposal in wetlands (Burke et al. 1991).

More than 160 COPR disposal sites have been identified in Hudson County, 136 sites in Jersey City alone. Historically, concentrations of total chromium remaining in the disposed COPR ranged as high as 20,000 to 70,000 parts per million (ppm) (Burke et al 1991). At most COPR sites, hexavalent chromium (Cr^{+6}) represented a relatively small and variable proportion of the total chromium in the COPR. Much of the disposal of the COPR took place in the 1950s and 1960s and was deposited in many densely populated areas.

Cr^{+6} is known to be a human respiratory carcinogen with substantial epidemiologic evidence consistently reporting increased risk of lung cancer among exposed workers, including those engaged in chromate production (NTP 2005).

In the early 1990s, the New Jersey Department of Health and Senior Services (NJDHSS) conducted exposure screening among over 2,000 workers and residents of Jersey City (and nearby cities) who worked or lived near COPR sites. The investigation found evidence of low levels of exposure to chromium among some participants living or working near COPR sites (NJDOH 1994; Fagliano et al 1997).

Currently, final or interim remedial measures have been implemented at all of the COPR sites in Jersey City. Final remediation has been completed at 51 sites in Jersey City, resulting in "No Further Action" determinations from NJDEP. Of these, 41 sites were remediated by complete excavation and off-site disposal of COPR. The remaining 10 sites were remediated by on-site containment of COPR with institutional and engineering controls.

The NJDEP held three community meetings in Jersey City in late 2005 and early 2006. At the meetings, the community voiced concerns about remedial strategies and consequences of historic exposure to chromium on lung cancer incidence in Jersey City. NJDEP and NJDHSS worked together to conduct this study.

Methods

Population

This investigation of lung cancer incidence in relation to historic chromium exposure included the entire population residing in Jersey City, Hudson County, in the period 1979 through 2003. Population counts for each census block group were determined from 1980, 1990, and 2000 U.S. Census Bureau data (Geolytics 2003). Populations in each of these years were aggregated into U.S. Census Bureau census block group boundaries as of the year 2000. Annual population estimates were calculated by interpolation and extrapolation of the population reported for each of the three census reporting years for each census block group and then summed over the 25-year period to create person-time estimates.

Cancer Case Ascertainment

The New Jersey State Cancer Registry (NJSCR) was used to determine the number of lung cancer cases occurring in the Jersey City population in the period 1979 through 2003. The first full year of NJSCR data collection was 1979. The NJSCR is a population-based cancer incidence registry covering the entire state of New Jersey. By law, all cases of newly diagnosed cancer are reportable to the registry, except for certain carcinomas of the skin. In addition, the registry has reporting agreements with the states of New York, Pennsylvania, Delaware, Maryland, North Carolina, and Florida. Information on New Jersey residents who are diagnosed with cancer in those states is supplied to the NJSCR.

A "case" was defined as an individual who was diagnosed with a new primary malignant lung cancer during the investigation time period while residing in Jersey City. Registry cases identified only through search of death records or autopsy reports were excluded from this evaluation. Information on important cancer risk factors, such as genetics, personal behaviors (e.g., diet and smoking), or occupational history, is not available from the cancer registry.

Lung cancer cases were aggregated by U.S. Census Bureau census block groups, based on the case’s residence at the time of diagnosis. Block group location was determined for all Jersey City cases using the U.S. Census Bureau's on-line American Factfinder resource (U.S. Census Bureau 2006).

Chromium Exposure Categorization

The NJDEP, using historic information on the location of known COPR sites along with their contaminant levels, characterized the potential for residential Cr^{+6} exposure in Jersey City. The Appendix to this Health Consultation contains a detailed description of the NJDEP's chromium exposure categorization. A brief description is provided here.

First, each COPR site was classified into categories based on measured or estimated Cr^{+6} concentration. When site-specific data on Cr^{+6} were available, they were used directly to categorize the site. When only the total chromium contaminant level was known for a specific site, Cr^{+6} concentrations were estimated to be either 3% or 14% of the total chromium value. These percentages represent the average and upper end of the expected proportion of Cr^{+6} to total chromium based on existing data (ES&E 1989). (Note that only the analysis based on the estimate of 14% is presented in this report since the epidemiologic results were very similar.) Sites were characterized as falling into one of three categories: 1) measured or estimated Cr^{+6} concentration of 900 ppm or higher; 2) measured or estimated Cr^{+6} concentration less than 900 ppm; or 3) a known COPR site, but no available total or hexavalent chromium concentration.

A 300 foot buffer was then drawn around each of the COPR site property boundaries, and the proportion of the residential area in each census block group that fell within a 300 foot buffer of each of the Cr^{+6} concentration categories was calculated. The size of the buffer was chosen based on modeling of PM_{10} (particles with a mean diameter of 10 micrometers). The PM_{10} modeling showed that 300 feet was a reasonable buffering distance from site boundaries, representing a distance within which most particulate deposition would occur and ambient PM_{10} concentrations are substantially reduced.

For the epidemiological analysis, census block groups were aggregated into "exposure intensity groups" (none, low, or high) based on the proportion of the residential part of the block group within the 300 foot buffers around COPR sites. Census block groups were categorized as "none" if no residential part of the block group was intersected by a COPR site buffer. Four alternative definitions were considered for the "high" exposure intensity group based on varying proportions of the block group in buffered areas of COPR sites classified by the hexavalent chromium concentration categories. These four alternative high exposure intensity group definitions are:

1. any part of the residential area in a census block group fell within a Cr^{+6} buffer;

2. at least 10% of a residential area in the census block group was within a high ($\geq$900+ ppm) Cr^{+6} buffer, <u>or</u> at least 25% of a residential area was within any Cr^{+6} buffer;

3. at least 25% of a residential area in the census block group was within a high ($\geq$900+ ppm) Cr^{+6} buffer, <u>or</u> at least 50% of a residential area within any Cr^{+6} buffer;

4. at least 50% of a residential area in the census block group was within a high ($\geq$900+ ppm) Cr^{+6} buffer, <u>or</u> at least 75% of a residential area within any Cr^{+6} buffer.

These definitions, going from 1 to 4, are increasingly restrictive in the requirements for considering a census block group to have had historic potential for high Cr^{+6} exposure intensity. As the definitions become more restrictive, the number of census block groups that remain in the high exposure intensity category decreases.

Table 1 presents a detailed definition of each of the exposure intensity groups for the four alternate analysis methods along with the number of census block groups which fall into each group. The population area defined as having an exposure intensity of "none" is the same across all four alternate definitions.

Data Analysis

Two different approaches were utilized in the analysis of lung cancer and Cr^{+6} exposure in Jersey City. The first approach compared the incidence of lung cancer in Jersey City for the populations classified within each exposure intensity group combined across the entire period from 1979-2003 to the cancer incidence for the entire state during the same 25-year time period. This is referred to as the standardized incidence ratio (SIR) analysis. The second approach compared the lung cancer incidence in each exposure intensity group in Jersey City over the entire exposure period to the lung cancer incidence in the non-exposed group in Jersey City during the same period. This is referred to as the rate ratio analysis.

Standardized Incidence Ratio Analysis:

SIRs were used for the initial quantitative analysis of lung cancer incidence (Kelsey et al 1996; Breslow and Day 1987). The SIR is calculated by dividing the observed number of cases (determined from the NJSCR) by an expected number for the investigated population based on statewide data over the same time period, 1979 to 2003.

The expected number was derived by multiplying a comparison population's age-sex-specific cancer incidence rates by the investigation area's age-sex-specific population figures. The comparison rates used to derive the expected number of cases were the New Jersey average annual lung cancer incidence rates for 1979 to 2003. State rates were calculated using SEER*Stat software (Surveillance Research Program 2007). Each census block group's age-sex-specific populations were determined from the 1980, 1990, and 2000 U.S. Census data (Geolytics 2003). Each analysis used 14 age-specific population groups. Block group populations were aggregated by exposure group and person-time estimates were calculated by interpolation/extrapolation of the census data. Males and females were evaluated separately.

The observed and expected numbers are evaluated by interpreting the ratio of these numbers. If the observed number of cases equals the expected number of cases, the SIR will equal 1.0. An SIR less than 1.0 indicates that fewer cases are observed than expected. An SIR greater than 1.0 indicates that more cases than expected are observed.

Random fluctuations may account for some SIRs being higher or lower than 1.0. The statistical significance of deviations from SIR equal to 1.0 was evaluated using a 95% confidence interval (CI). The 95% CI was used to evaluate the probability that the SIR may be greater or less than 1.0 due to chance alone, and was based on the Poisson distribution (Breslow and Day 1987; Checkoway et al 1989). If the confidence interval includes 1.0, then the estimated SIR is not considered to be statistically significantly different than 1.0.

Rate Ratio Analysis:

Lung cancer incidence rate ratios (RRs) were computed for each exposure level. Epidemiologic analyses were conducted using Stata statistical software (Stata 2003). Rate ratio estimates were computed using the Poisson regression model (Clayton and Hills 1993). Confidence intervals (95%) and p-values were generated for the RR estimates. RRs were adjusted for age group and the percent of the population below the poverty level. Sex-specific analyses were conducted.

Results

Table 2 presents the number of block groups by the percentage of their residential area within 300 feet of a COPR site with Cr^{+6} levels: $\geq$900+ ppm; 1-899 ppm; and unknown Cr^{+6} exposure. Table 2 also compares the number of block groups that had at least some of their residential area within 300 feet of a COPR site to the number of block groups where none of the residential areas were within 300 feet of a COPR site. Of the 161 block groups, 57 (35.5%) had some residential area of the block group within 300 feet of a COPR site while 104 (64.6%) block groups had no residential area within 300 feet of a site. Figures 1 through 4 present maps of the block group exposure intensity classifications based on the four alternate exposure categorization methods.

Table 3 presents the 25-year person-time estimates by each exposure category. The total person-time for males was 2,786,286 years (1,794,840 person-years with no residential exposure (64%) and 991,446 person-years with some residential exposure (36%)). The total person-time for females was 2,992,075 years (1,916,083 person-years with no residential exposure (64%) and 1,075,992 person-years with some residential exposure (36%)).

A total of 3,311 malignant incident lung cancer cases (2,087 males and 1,224 females) were diagnosed in the Jersey City population over the 25-year investigation time period. Of the total cases, all but 62 (1.9%) had sufficient address information to assign to the appropriate block group. Table 4 presents the number of lung cancer cases by each exposure category. In the "no exposure" group there were 2,106 lung cancer cases (1,327 males and 779 females). In the "any exposure" group there were 1,143 lung cancer cases (713 male and 430 females).

Standardized Incidence Ratio Analysis:

Table 5 presents the SIR results for each of the exposure categories. In the no exposure group, lung cancer in males was statistically significantly elevated (SIR=1.07; 95% CI=1.01, 1.12), while in females lung cancer was statistically significantly low (SIR=0.86; 95% CI=0.80, 0.92) compared to average state rates. In the exposed groupings, two SIRs were statistically significantly elevated: males with any exposure using exposure grouping method 1 (SIR=1.10; 95% CI=1.02, 1.19) and males with high exposure in exposure grouping method 2 (SIR=1.14; 95% CI=1.02, 1.26). The highest SIR, though not statistically significant, was found for males with high exposure using the most restrictive exposure grouping method 4 (SIR=1.24; 95% CI=0.99, 1.52). None of the SIRs for females in the exposed groups were statistically significant.

A graphical presentation of the SIRs can be found in Figures 5 and 6. For males, a similar pattern of increasing SIRs with increasing exposure is evident, for all four alternate exposure definition methods. While all SIRs for females were below 1.0, the same increasing pattern seen for males is evident for all alternate exposure definition methods except the one with the most restrictive high exposure group.

Rate Ratio Analysis:

In the rate ratio analysis an internal (Jersey City) comparison of lung cancer is done by exposure group with the no exposure group considered the referent group. Table 6 presents the RR analysis results. Since the variable for the percent of the population below the poverty level did not change the RR results, it was not considered to be a confounder variable and only the results without this adjustment are presented. None of the RRs were found to be statistically significantly elevated. The highest RR was found for males with high exposure using the most restrictive exposure grouping method 4, (RR=1.17; 95% CI=0.94, 1.45). The highest RR for females with high exposure using exposure grouping 2 (RR=1.10; 95% CI=0.94, 1.28).

A graphical presentation of the RRs can be found in Figures 7 and 8. A similar pattern in the RRs is evident for both males and females as in the SIR graphical display. For males, as the higher exposed group became more restrictive, the risk of lung cancer increased to 17% more than the unexposed group. For females, with the exception of the most restrictive high exposed group, the risk of lung cancer increased with exposure to about 9 to 10% more than the unexposed group.

Discussion

Hexavalent chromium is a known human lung carcinogen (NTP 2005; ATSDR 2000, IARC 1990; USEPA 1998). Numerous epidemiological studies of workers exposed to inhaled chromium, including chromate workers, have clearly established an increased risk of lung cancer mortality (Langard 1990; Gibb et al, 2000; Luippold et al 2003). New Jersey chromate production workers were included in several studies. As an example, Rosenman and Stanbury (1996) found a 50% increased risk of lung cancer mortality in New Jersey chromate workers, rising to 94% increased risk for workers with more than 20 years of exposure.

It is less clear what impact non-occupational, and presumably, lower dose exposures might have on lung cancer rates. The purpose of this investigation was to evaluate lung cancer incidence in the Jersey City population relative to its residential proximity to areas known to be contaminated with chromium and Cr^{+6}.

In the current analysis, census block populations were aggregated by exposure intensity groups and evaluated using both an external and an internal comparison. The external comparison (SIR analysis) evaluated the exposure intensity groups relative to an expectation based on average state lung cancer rates over the 25-year investigation time period. The internal comparison (RR analysis) evaluated the exposure intensity groups relative to the "no exposure" group within Jersey City.

Compared to the state, lung cancer incidence was higher than expected in all exposure groups for males and lower than expected in all exposure groups for females. For males, as the definition of high exposure became more restrictive, a similar, but somewhat stronger, increase was evident in the SIR estimate with the most restrictive high exposure group displaying a 24% higher incidence than expected. While lung cancer in females was lower than expected, a similar pattern in the SIRs was seen for the three least restrictive high exposure group categories. While not statistically significant, the internal (rate ratio) comparison revealed similar patterns as the external (SIR) comparison. For males in the most restrictive high exposure group, there was a 17% increase in risk compared to the no exposed areas. The results for females were less remarkable than for males, with a maximum 10% increased risk which disappeared in the most restrictive high exposure category.

Lung cancer is the second most common cancer diagnosed in both males and females, and is the leading cause of cancer mortality for both sexes in New Jersey and the country (American Cancer Society 2007, NJDHSS 2005). Recent trends indicate that incidence and mortality rates have been declining nationwide for males, but are continuing to rise for females. While there are multiple risk factors for lung cancer, tobacco smoking is considered the most important risk factor, estimated to account for more than 85% of all lung cancer deaths (National Cancer Institute 1996; Schottenfeld and Fraumeni 1996).

Other known risk factors for lung cancer include indoor exposure to radon and environmental tobacco smoke, occupational exposure to asbestos and other cancer-causing agents in the workplace (including radioactive ores; chemicals such as arsenic, vinyl chloride, nickel, chromates, coal products, mustard gas, and chloromethyl ethers; fuels such as gasoline; and diesel exhaust), and exposure to air pollution (American Cancer Society 2007).

A limitation of cancer incidence investigations of this type is the inability to assess actual past exposure levels to individuals in the population. The ability to assess a cause-effect relationship is strengthened when the analysis includes data on actual personal exposure to the contamination and other relevant risk factors over time. That is, who was exposed and who was not exposed, and the magnitude and timing of the exposure that did occur.

Because personal exposure information does not exist, residential proximity to the contaminated areas was used as a surrogate measure for potential past environmental exposure. This was accomplished by aggregating and analyzing populations living in relatively small geographic areas (block groups) within 300 feet of a contaminated site. Although proximity to these areas may be a reasonable surrogate for past environmental potential exposures, it is also unlikely that all of the residents in the designated areas were exposed to hexavalent chromium from the COPR sites. Similarly, those living outside the designated exposed areas may have been exposed to chromium from COPR sites, for example if their workplace was near a site. This would result in misclassifying some of the population as exposed when they are not, and vice versa. The consequence of exposure misclassification would be to bias the results toward not finding an association even if such an association truly existed (Kelsey et al 1996).

Another interpretation problem is that lung cancer is a chronic disease that takes many years after exposure to reveal itself as a clinical disease. The information supplied by the cancer registry provides only an address at time of diagnosis for each case. No information is available on length of time an individual may have lived at the address before diagnosis. It is possible that some cases were new, short-term residents with little or no exposure to the contamination. Furthermore, former residents who moved out of the investigation area before diagnosis are not available for analysis. Population mobility cannot be accounted for in this analysis. Therefore, some cases would be incorrectly associated with a potential exposure while some cases that should have been associated with a potential exposure would have been missed.

The approach used for this descriptive lung cancer investigation was census-based. The population of Jersey City and the State of New Jersey were reviewed in order to calculate age standardized incidence ratios and rate ratios for the investigation area by Cr^{+6} exposure categories. This census approach (ecologic design) is a practical surveillance or screening method for lung cancer incidence. Although this approach is well suited for providing a picture of lung cancer incidence in the specific localities, cause-effect relationships are difficult to evaluate. Important information on potential risk factors (such as genetics, life style, environmental factors, occupation, etc.) that might explain the results were not available for analysis. As noted above, occupational exposures to chromates have been found to be a potential risk factor for lung cancer. Historically, Jersey City offered significant employment opportunities in the chromate production industry. However, this investigation had no information on occupational histories of the lung cancer cases. Consequently, occupational exposures to chromium could not be controlled for in the analysis.

Conclusions and Recommendations

Based on an internal comparison within Jersey City, an increased risk of lung cancer incidence was found for populations living in close proximity to historic COPR sites. The increase in risk was stronger in males. However, both males and females appear to demonstrate a consistent pattern of increased risk in areas with higher potential for historic exposure to chromium from COPR sites, although the increases were not statistically significant. The results suggest that living closer to COPR sites is a potential risk factor for the development of lung cancer. However, it is important to note that these findings do not prove a cause-effect relationship. While the findings are consistent with evidence from the published occupational health literature that exposure to Cr^{+6} increases the risk of lung cancer, other potential risk factors that could not be accounted for in the analysis cannot be ruled out.

Since a significant amount of remediation of the chromium slag has occurred, the historic potential exposures noted in this investigation do not represent the current conditions in the city. However, it is recommended that efforts to remediate COPR sites to limit human exposure to hexavalent chromium should continue.

Recent information from a draft National Toxicology Program (NTP) study report indicates that ingestion of Cr^{+6} in drinking water increases the risk of oral and small intestine cancers in rats and mice, respectively (NTP 2007). In addition, a re-analysis of cancer mortality in a Chinese population exposed to Cr^{+6} in drinking water provided evidence of an increased risk of stomach cancer (Beaumont 2008). Therefore, the NJDHSS should consider replicating this investigation's design of lung cancer and residential proximity to historic COPR sites for an evaluation of stomach, small intestine and oral cancer incidence in Jersey City.

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Certification

This health consultation was prepared by the New Jersey Department of Health and Senior Services under a cooperative agreement with the Agency for Toxic Substances and Disease Registry. This health consultation is in accordance with approved methodology and procedures existing at the time it was initiated. The cooperative agreement partner performed an editorial review of this document.

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The Division of Health Assessment and Consultation (DHAC), ATSDR, has reviewed this health consultation and concurs with its findings.

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Tables

Table 1. Exposure Intensity Group Definitions and Number of Census Block Groups.

Exposure Grouping Method	Exposure Groups	Exposure Group Definitions	Number of BGs[1]
1	• None • Any	• 0% of the area of the Residential Block Group (RBGA)[2] within 300 ft of any site • >0% of RBGA within 300 ft of any site	• 104 • 57
2	• None • Low • High	• 0% of RBGA within 300 ft of any site • All other BGs • $\geq$10% of RBGA within 300 ft of site with $\geq$900 ppm[3] Cr^{+6} ***or*** $\geq$25% of RBGA within 300 ft of any site	• 104 • 28 • 29
3	• None • Low • High	• 0% of RBGA within 300 ft of any site • All other BGs • $\geq$25% of RBGA within 300 ft of site with $\geq$900 ppm Cr^{+6} ***or*** $\geq$50% of RBGA within 300 ft of any site	• 104 • 42 • 15
4	• None • Low • High	• 0% of RBGA within 300 ft of any site • All other BGs • $\geq$50% of RBGA within 300 ft of site with $\geq$900 ppm Cr^{+6} ***or*** $\geq$75% of RBGA within 300 ft of any site	• 104 • 50 • 7

Note: [1] BG = Block group (U.S. Census 2000 boundaries)
[2] RBGA = Residential block group area
[3] ppm = parts per million (or milligrams per kilogram)

Table 2. Block Groups (BG) by Cr^{+6} Exposure Potential using Cr^{+6} = 14% of Total Chromium Value.

Percent of Residential Area within 300 feet of a COPR Site with ≥ 900+ ppm Cr^{+6}	**Number of BGs**
0%	129
>0% to <10%	13
10% to <30%	9
30% to <50%	4
50+%	6
Total	161
Maximum Area	88.8%
Percent of Residential Area within 300 feet of a COPR Site with < 900 ppm Cr^{+6}	**Number BGs**
0%	118
>0% to <10%	23
10% to <30%	11
30% to <50%	5
50+%	4
Total	161
Maximum Area	77.6%
Percent of Residential Area within 300 feet of a COPR Site with Unknown Cr^{+6} Levels	**Number BGs**
0%	158
>0% to <10%	2
10% to <30%	1
Total	161
Maximum Area	24.6%
Residential Areas with 300 feet of any COPR site	**Number BGs**
None	104
Any	57

Table 3. Person-time (1979-2003) by Exposure Intensity Group.

High Exposure Definition	Exposure Group	Males	Females
1. Any residential area within 300 feet	None	1,794,840	1,916,083
	Any	991,446	1,075,992
2. 10%+ ≥900 ppm or 25%+ any	Low	549,111	589,994
	High	442,335	485,998
3. 25%+ ≥900 ppm or 50%+ any	Low	786,834	854,651
	High	204,612	221,341
4. 50%+ ≥900 ppm or 75%+ any	Low	894,723	966,222
	High	96,723	109,770

Table 4. Malignant Lung Cancer Incidence by Exposure Intensity Group (1979-2003).

High Exposure Definition	Exposure Group	Males	Females
1. Any residential area within 300 feet	**None**	1,327	779
	Any	713	430
2. 10%+ ≥900 ppm or 25%+ any	**Low**	358	211
	High	355	219
3. 25%+ ≥900 ppm or 50%+ any	**Low**	540	325
	High	173	105
4. 50%+ ≥900 ppm or 75%+ any	**Low**	625	383
	High	88	47

Note: 62 Jersey City cases could not be coded to a census block group.

Table 5. Standardized Incidence Ratios (SIR) for Malignant Lung Cancer in Jersey City by Sex and Exposure Group.

Exposure Group	Block Groups	Males Observed	Males Expected	Males SIR	Males 95% CI Lower	Males 95% CI Upper	Females Observed	Females Expected	Females SIR	Females 95% CI Lower	Females 95% CI Upper
No Exposure	104	1,327	1,245.8	1.07	1.01	1.12	779	910.3	0.86	0.80	0.92
Any Exposure	57	713	647.0	1.10	1.02	1.19	430	473.7	0.91	0.82	1.00
10%+ ≥900 ppm or 25%+ Any Exposure:											
Low	28	358	334.4	1.07	0.96	1.19	211	240.2	0.88	0.76	1.01
High	29	355	312.6	1.14	1.02	1.26	219	233.5	0.94	0.82	1.07
25%+ ≥900 ppm or 50%+ Any Exposure:											
Low	42	540	498.8	1.08	0.99	1.18	325	360.8	0.90	0.81	1.00
High	15	173	148.2	1.17	1.00	1.35	105	112.9	0.93	0.76	1.13
50%+ ≥900 ppm or 75%+ Any Exposure:											
Low	50	625	575.8	1.09	1.00	1.17	383	417.8	0.92	0.83	1.01
High	7	88	71.2	1.24	0.99	1.52	47	55.9	0.84	0.62	1.12

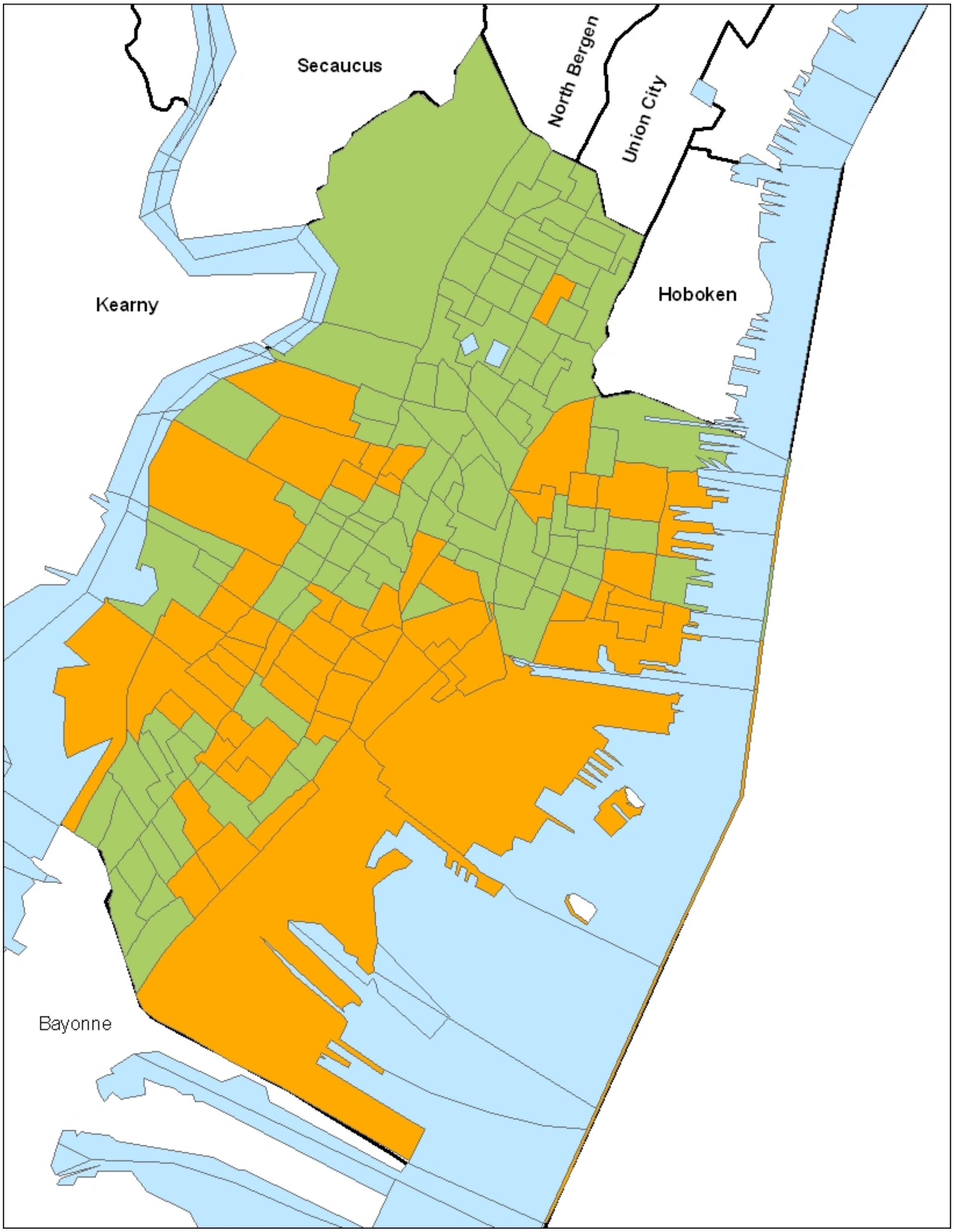
Note: SIR is statistically significantly: High Low

Table 6. Rate Ratios (RR) for Malignant Lung Cancer in Jersey City by Sex and Exposure Group.

Exposure Group	Block Groups	Males RR	95% CI Lower	Upper	p-value	Females RR	95% CI Lower	Upper	p-value
No Exposure	104	1.0	-	-	-	1.0	-	-	-
Any Exposure	57	1.03	0.94	1.13	0.47	1.06	0.94	1.19	0.36
10%+ ≥900 ppm or 25%+ Any Exposure:									
Low	28	1.00	0.89	1.12	1.00	1.02	0.78	1.19	0.82
High	29	1.07	0.95	1.20	0.25	1.10	0.94	1.28	0.22
25%+ ≥900 ppm or 50%+ Any Exposure:									
Low	42	1.01	0.92	1.12	0.79	1.05	0.92	1.19	0.50
High	15	1.10	0.94	1.29	0.23	1.09	0.89	1.34	0.39
50%+ ≥900 ppm or 75%+ Any Exposure:									
Low	50	1.02	0.93	1.12	0.72	1.07	0.94	1.20	0.31
High	7	1.17	0.94	1.45	0.16	0.99	0.74	1.33	0.95

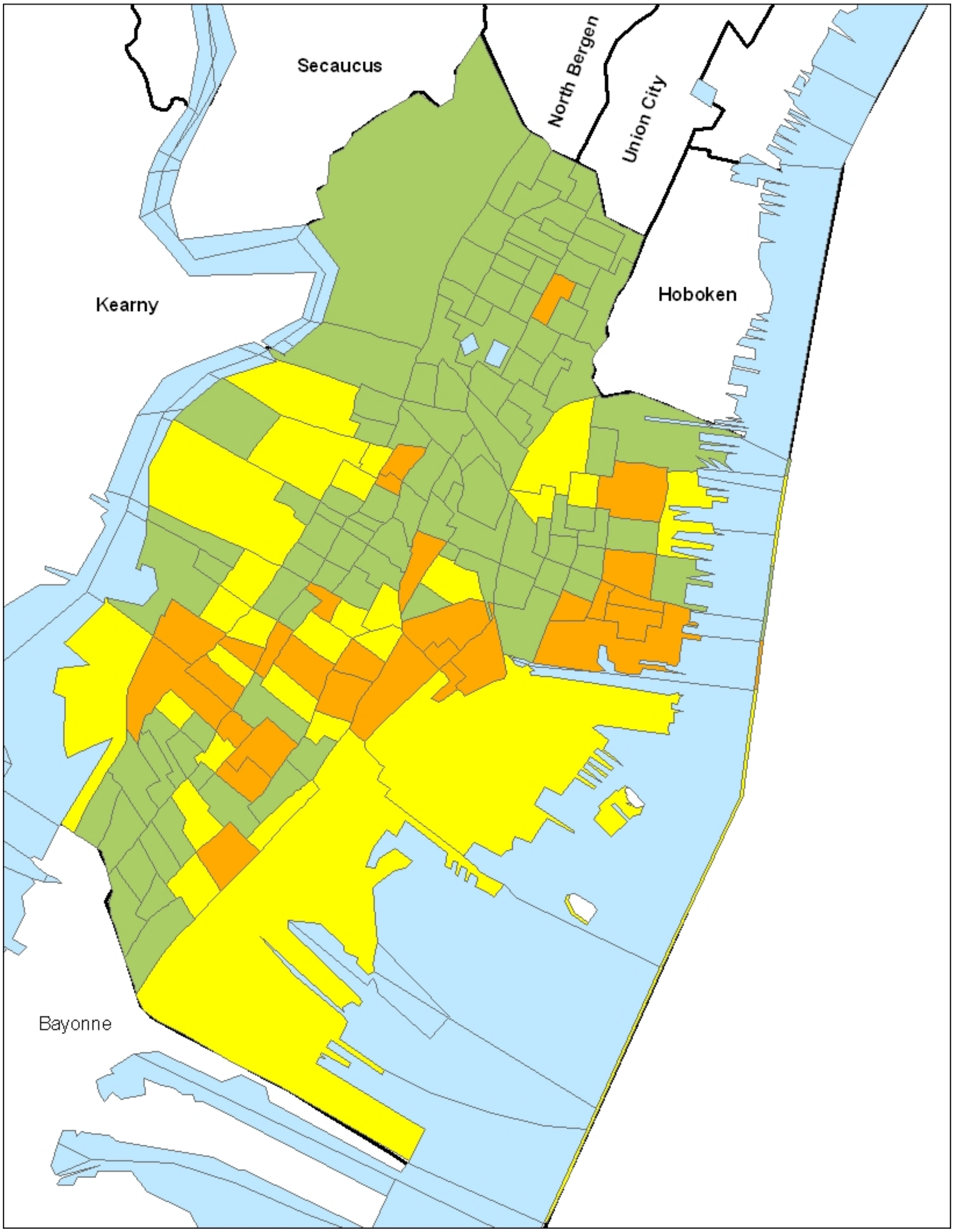
Figures

Figure 1. Jersey City Cr^{+6} Exposure by Block Group: Any Exposure



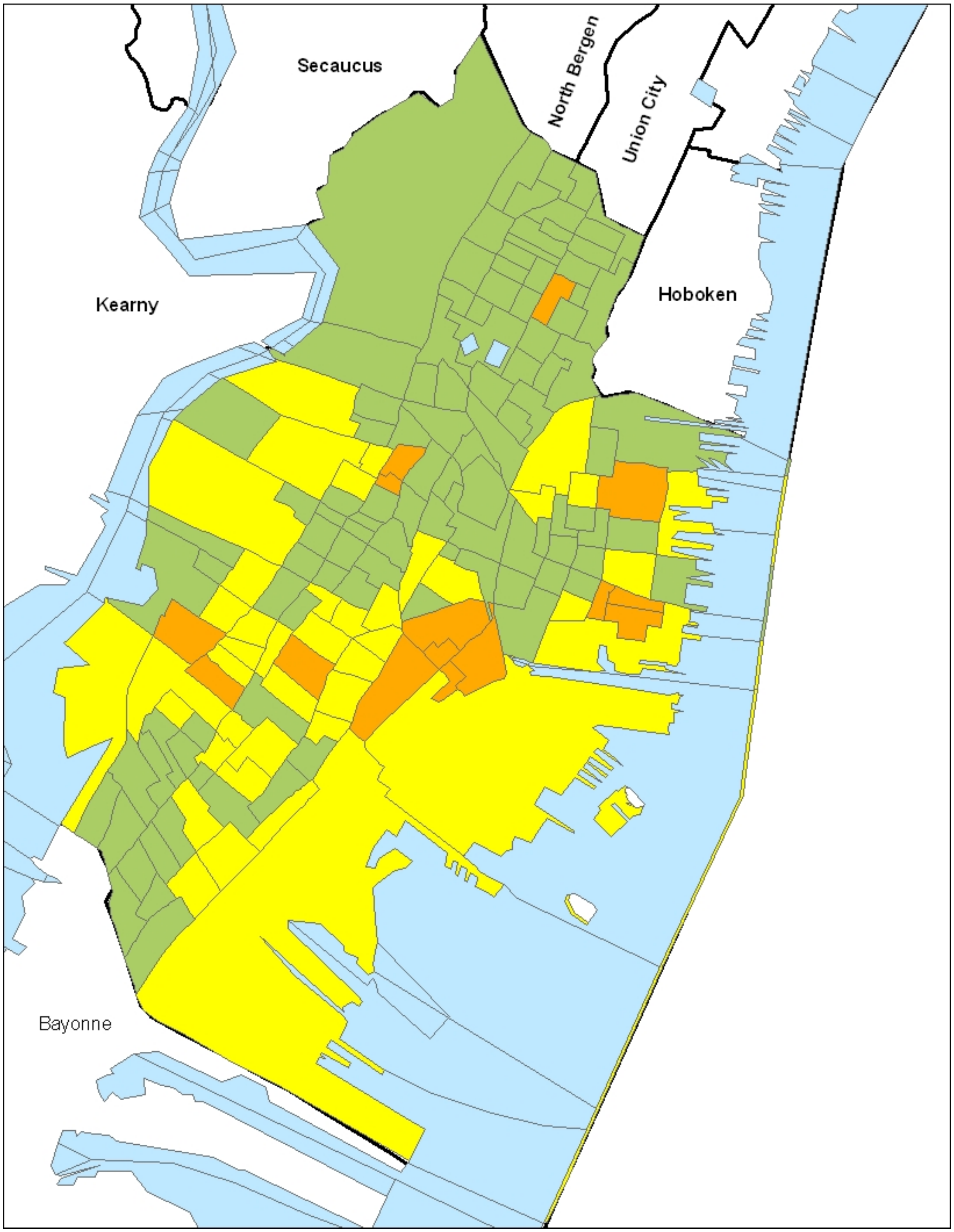
Exposure Category: **Green = None**
Orange=Any Exposure

Figure 2. Jersey City Cr^{+6} Exposure by Block Group



Exposure Category: **Green = None** **High=10%>900ppm or 25%+Any**
Yellow=Low/Medium
Orange=High

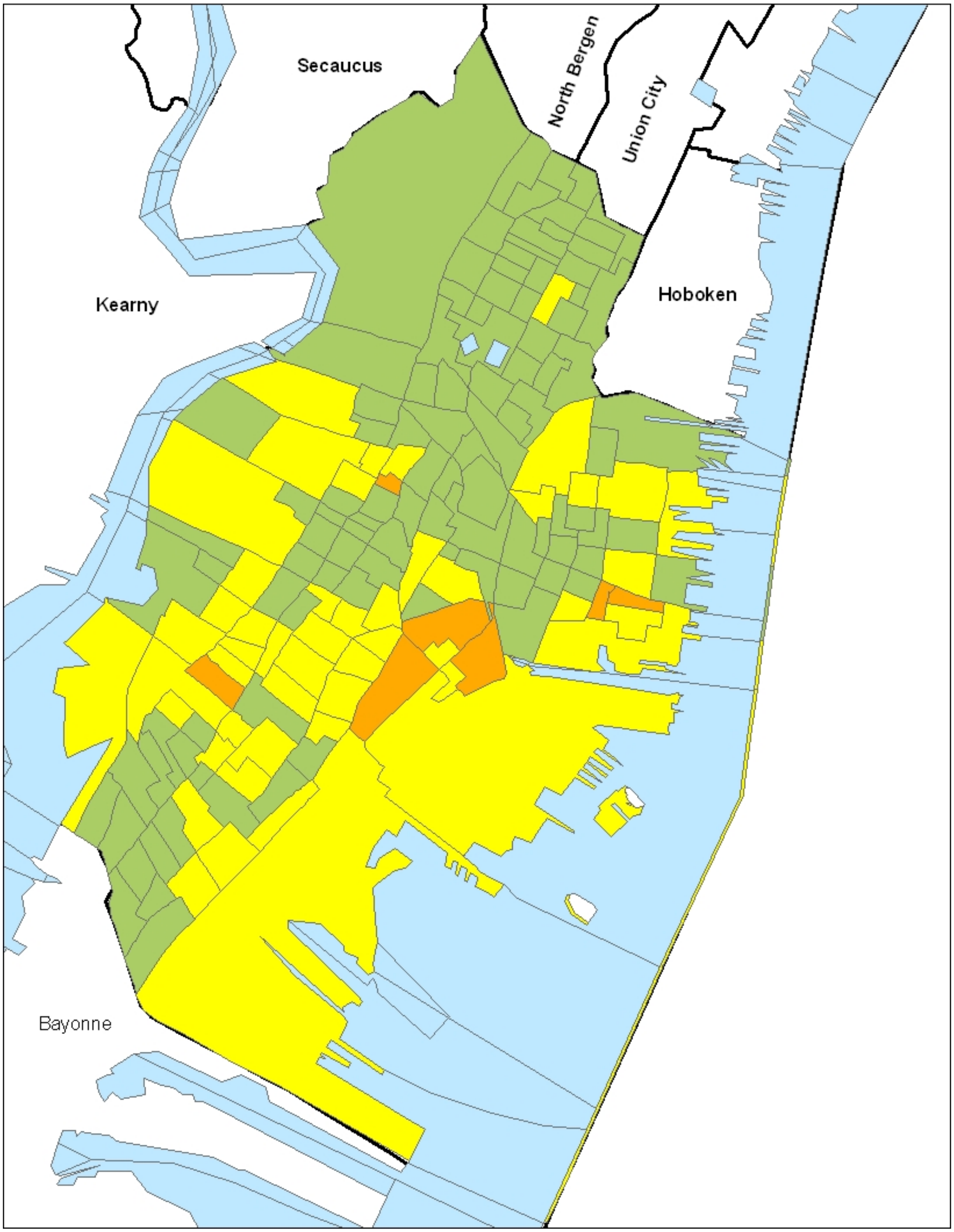
Figure 3. Jersey City Cr^{+6} Exposure by Block Group



Exposure Category: **Green = None**
Yellow=Low/Medium
Orange=High

High=25%>900ppm or 50%+Any

Figure 4. Jersey City Cr^{+6} Exposure by Block Group



Exposure Category:	**Green = None**	**High=50%>900ppm or 75%+Any**
	Yellow=Low/Medium	
	Orange=High	

Figure 5. Standardized incidence Ratios for Lung Cancer in Jersey City Males by Cr^{+6} Exposure Category

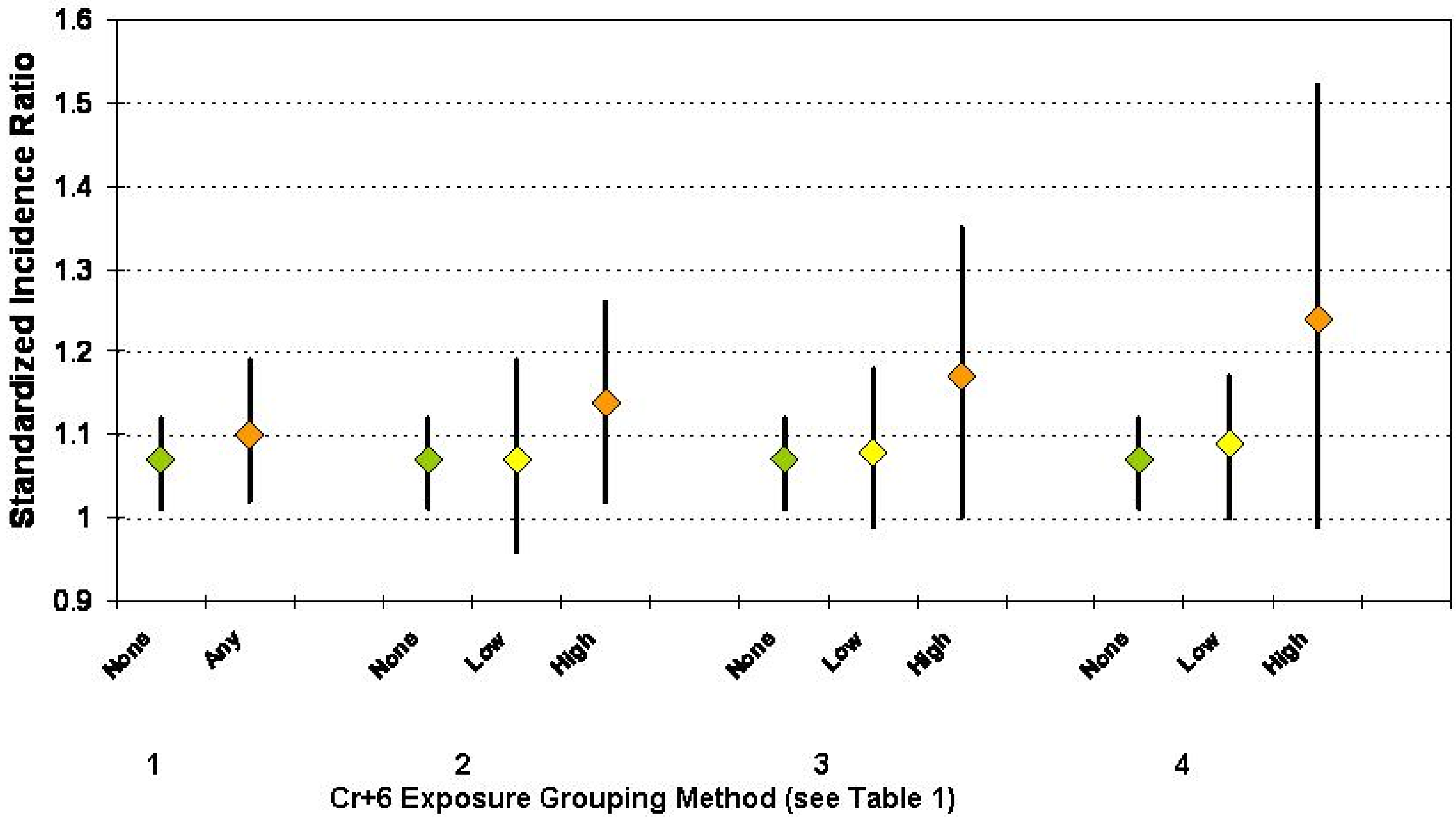


Figure 6. Standardized incidence Ratios for Lung Cancer in Jersey City Females by Cr^{+6} Exposure Category

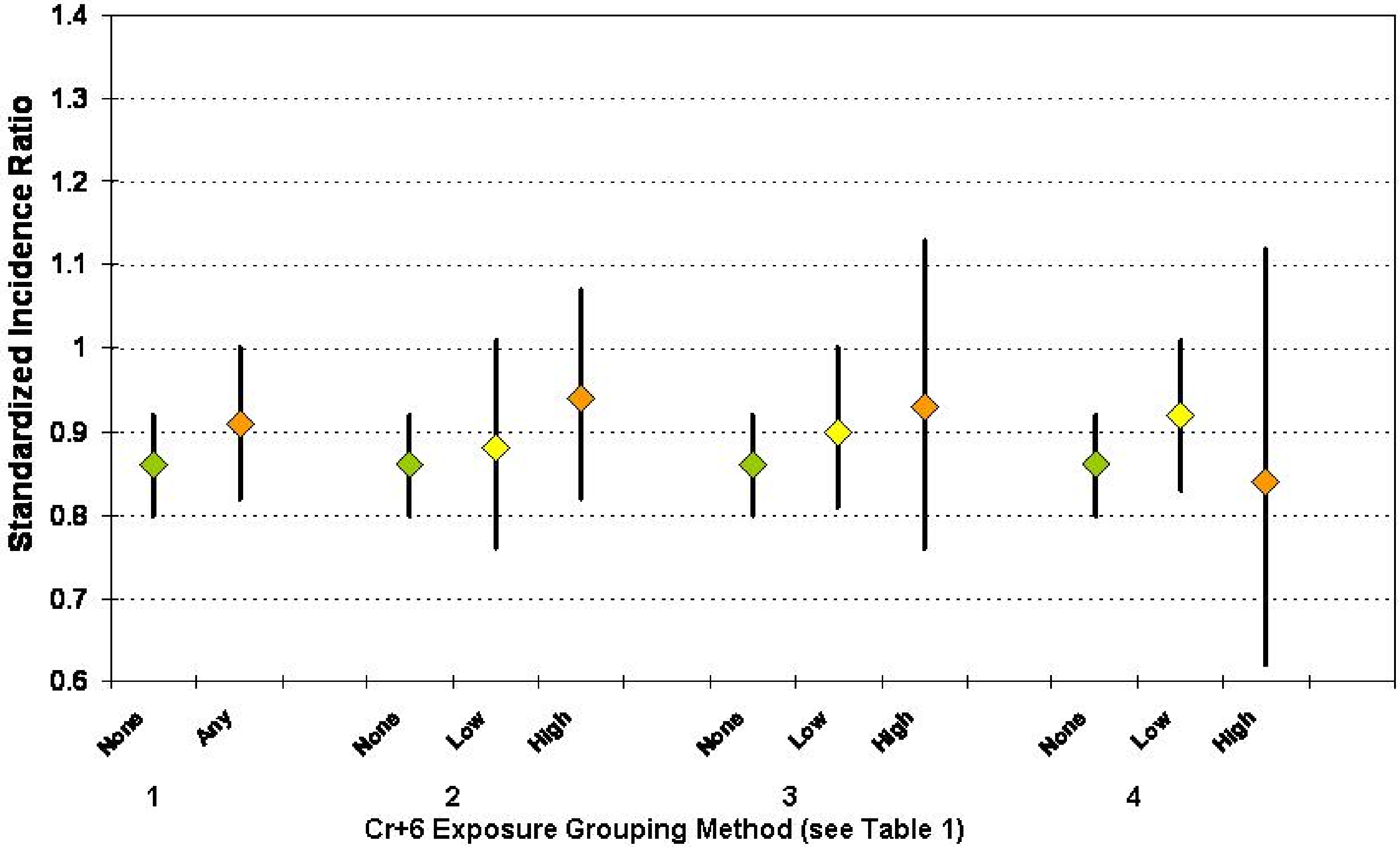


Figure 7. Rate Ratios for Lung Cancer in Jersey City Males by Cr^{+6} Exposure Category

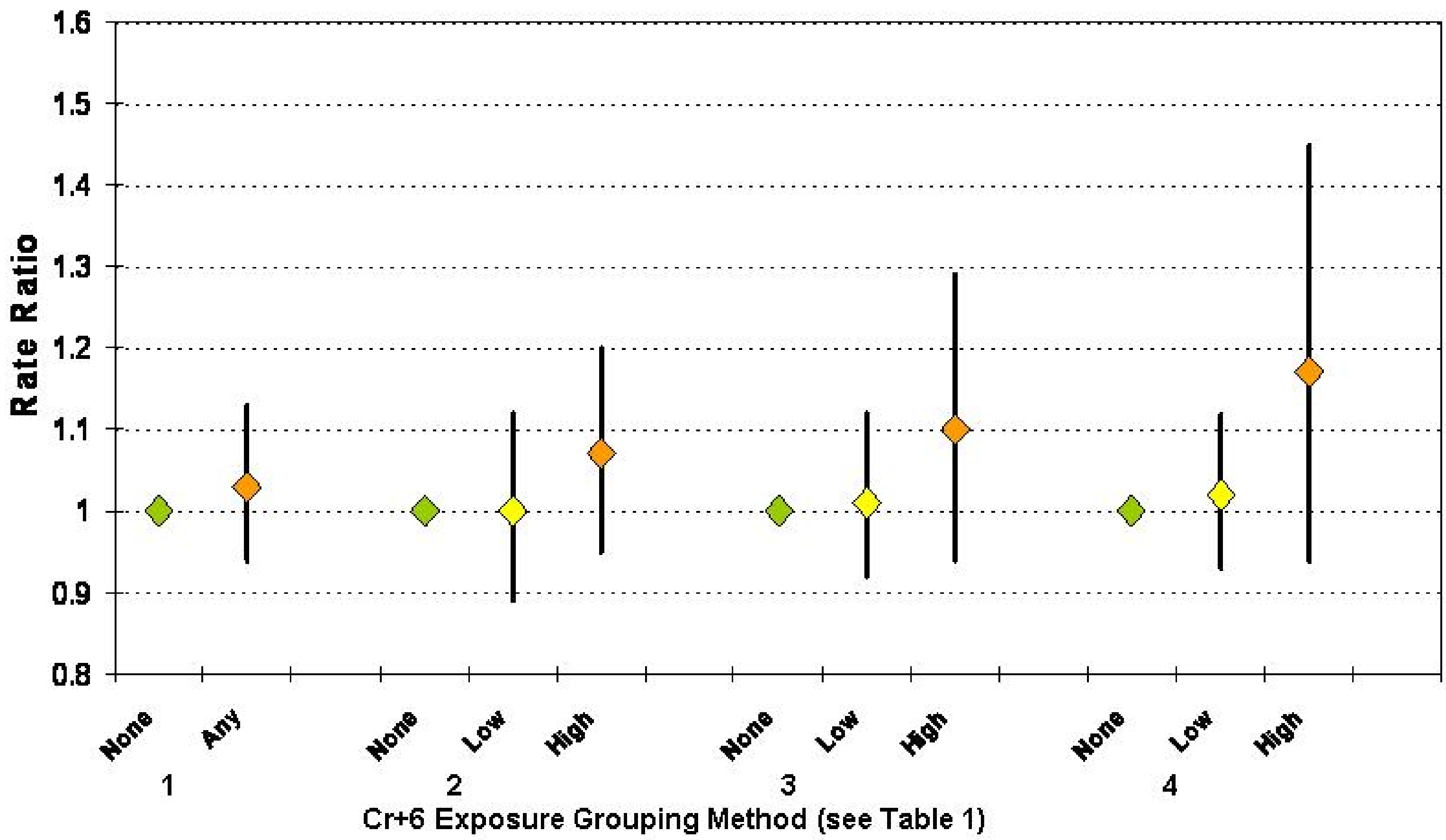
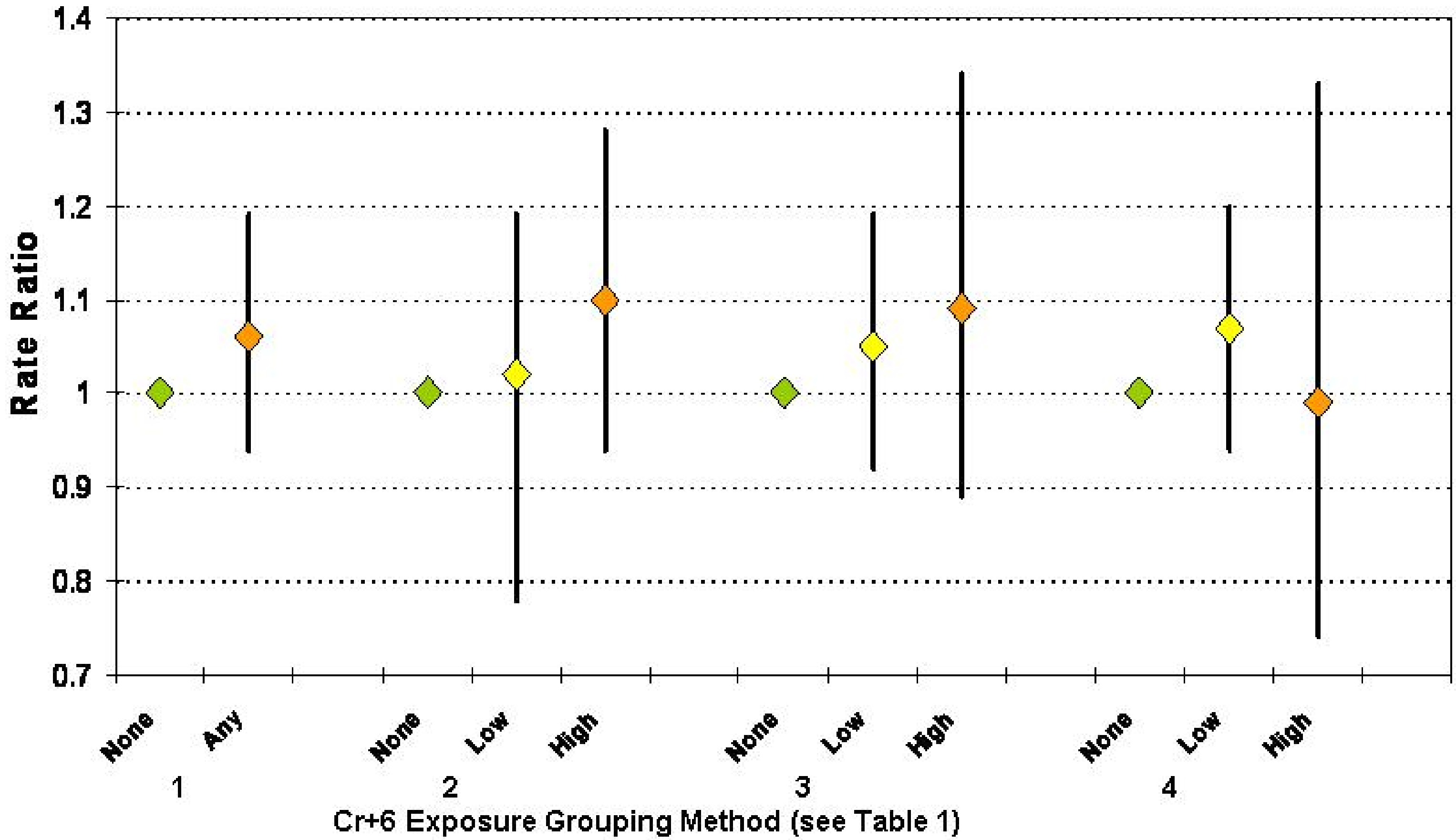


Figure 8. Rate Ratios for Lung Cancer in Jersey City Females by Cr^{+6} Exposure Category



Appendix to Health Consultation

Characterization of Chromium Exposure Potential for US Census Block Groups, Prepared by the New Jersey Department of Environmental Protection

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Characterization of Chromium Exposure Potential for US Census Block Groups, Prepared by the New Jersey Department of Environmental Protection

Overview

The New Jersey Department of Environmental Protection (NJDEP) used historic measurements from chromium ore processing residue (COPR) sites, air dispersion modeling, and geographic information system (GIS) analysis methods to estimate the residential population's potential exposure to past chromium contamination in Jersey City. The result of the analysis is the percentage of residential land use potentially exposed to three concentration categories of chromium, for each U.S. Census block group in Jersey City.

COPR Sites in Jersey City

The NJDEP Site Remediation Program (SRP) is responsible for all COPR sites in the state. SRP maintains a comprehensive site list and has assigned a site identification number to each. The list includes sites that are actively being investigated or remediated, as well as sites that have been capped, excavated, remediated, closed, or redeveloped. A total of 136 COPR sites on the list are located in Jersey City.

GIS Mapping of COPR Sites

Initial information on all COPR sites was obtained from an NJDEP SRP database in Excel. These records contained information on each site, including owner name, tax parcel lot and block and SRP site ID number. GIS point locations were available from SRP for 84 of the 136 sites. These point locations were based on submissions from the individual responsible party. Some of the GIS point locations were at the "front door" of a site, while others were at the center of the facility (i.e., centroids).

For the purpose of this investigation, site boundaries rather than point locations were needed. The air dispersion model, discussed below, calculates maximum contaminant migration distance from the site perimeter. Because of the inadequacy of the existing GIS information, the site property boundaries of all 136 COPR sites were mapped. COPR site mapping was conducted using historic or current descriptive records from SRP for each COPR site, together with four standardized GIS reference layers:

1) tax parcel data created and maintained by the Jersey City GIS office, with an accuracy of 1:6,000; and
2) three sets of high resolution, low altitude, orthorectified, digital aerial photography (taken in 1986, 1995, and 2001). These 3 sets of digital imagery were created specifically to

function as formal cartographic base layers for the purpose of GIS mapping. The orthophotography varies in accuracy from 1:24,000 to 1:2,400.

All four of the reference layers are valid mapping bases, meeting NJDEP's digital mapping standards and cartographic requirements, as well as the National Mapping Accuracy Standards reference base map requirements. These photographs and their metadata may be viewed at the NJDEP website, **www.state.nj.us/dep/gis/**. Maps developed using these base maps, and proper methods, meet National Map Accuracy Standards for professional cartographic products.

Municipal tax block and lot parcels from the current Jersey City tax parcel mapping, or the historic Jersey City parcel mapping, were matched to the NJDEP registered block and lot parcels from the SRP files. These parcels were then extracted from the 42,721 tax parcels in the municipal GIS record. Aerial photography was used to confirm that the indicated tax parcels matched the written description of each site by NJDEP staff. Many of the older sites, especially those closed many years ago, have been redeveloped. This necessitated using aerial photography from the appropriate time period to match to the written description. Site boundaries were then mapped using the combination of tax parcels and photography.

As a final check, the street addresses for each COPR site were available in the NJDEP SRP records. Each site's street address was located in the GIS using both the U.S. Census Tiger road files and the TeleAtlas street files. The address-based point locations were then cross-checked against tax lot and block locations for consistency. One hundred and twenty seven (93.4%) of the 136 COPR sites had consistency between the many independent data sources, and were mapped with high confidence at a 1:12,000 scale.

For eight of the nine sites with less confident mapping, the issue involved a question of the full extent of the original site. In these cases, the entire local area was selected to avoid eliminating any possible area with chromium contamination.

For the single remaining site, it was not possible to identify the original parcel. The street name in the file no longer existed in Jersey City. Occasionally, in old data files one finds records where the local "common name" for a site was used. Unfortunately, in this case there is no accompanying lot and block data. Examination of the aerial photography surrounding those Jersey City streets that have undergone name changes did not reveal any potential sites. With no reliable location information available this site (SRP site ID number 189) was excluded from the analysis.

Air Dispersion Modeling

With the COPR sites adequately mapped, the next step was to estimate the effective zone of influence of COPR particulates from a site. For this purpose, the U.S. EPA's ISCST3 Model (version 02035), a Gaussian plume model, was used to estimate both deposition and ambient concentration of PM_{10} (i.e., particles with a diameter of 10 microns or less), as a function of site size and distance from the site. The model was run under several different assumptions -- no deposition, dry deposition, and wet deposition -- and for several site sizes. The modeling was performed using meteorological data from Newark International Airport. Model results from the quarter and half acre runs assuming both dry and wet deposition concentrations were predicted to be the same as the dry deposition results. Consequently, only dry deposition was evaluated for the remainder of the site sizes.

The concentration in the air of particulates from a ground-level source will decrease with distance from the source, because particulates deposit out of the air and because of dilution. In theory, particulate dispersion can occur over an infinite distance from a source. In practice, however, most site specific deposition will occur in the near-field relative to the site, and the ambient PM_{10} contribution from a site will become independent of site size as distance from the site increases.

The distance from the site boundary within which substantial particulate deposition can be assumed was determined by comparing the output for the dry deposition and no deposition models. The specification of the near-field for the majority of particulate deposition was based on identifying the distance from a site at which predicted ambient PM_{10} concentrations for the deposition model decreased below the predicted ambient concentration for the no deposition model. This distance, determined by models for sites of different sizes from 0.25 to 3 acres, was about 70 to 100 feet beyond the site boundary. For example, Table A1 shows that for a 1 acre site the crossover point (yellow highlight) occurs at approximately 53 - 32 = 21 meters, or about 70 feet from the site boundary , while for the 2 acre site the crossover point occurs at approximately 76 – 45 = 31 meters, or about 100 feet from the boundary.

Table A1. Modeled PM_{10} concentrations for 1 acre and 2 acre sites from dry deposition and no deposition models.

Site Size (Distance from Center to Site Boundary)	Model Type	PM Concentration at X Feet (Meters) from Center														
		50 (15)	75 (23)	100 (30)	125 (38)	150 (46)	175 (53)	200 (61)	250 (76)	300 (91)	350 (107)	400 (122)	450 (137)	500 (152)	600 (183)	700 (213)
1 acre (32 meters)	Dry deposition	--	--	--	1275	464	229	149	81.1	52	36.6	27.2	21.1	16.8	11.5	8.3
	No deposition	--	--	--	927	380	243	198	120	82.4	60.9	47	37.5	30.7	21.7	16.2
2 acre (45 meters)	Dry deposition	--	--	--	--	793	717	351	102	57.5	38.1	27.8	21.3	16.9	11.4	8.3
	No deposition	--	--	--	--	609	499	316	138	86.7	61.6	47.1	37.3	30.4	21.5	16.1

In addition, the distance necessary to reduce the PM_{10} air concentrations by approximately 98% of the PM_{10} level at the site boundary was estimated for sites of varying sizes. Table A2 presents the modeled PM_{10} air concentrations at increasing distances for selected site sizes. Boundary distances needed for a 98% reduction in PM_{10} air concentrations (yellow highlight) were approximately 225 feet for a 0.5 acre site (91 - 22 meters), 300 feet for a 1 acre site (122 – 32 meters), and 350 feet for a 2 acre site (152 – 45 meters).

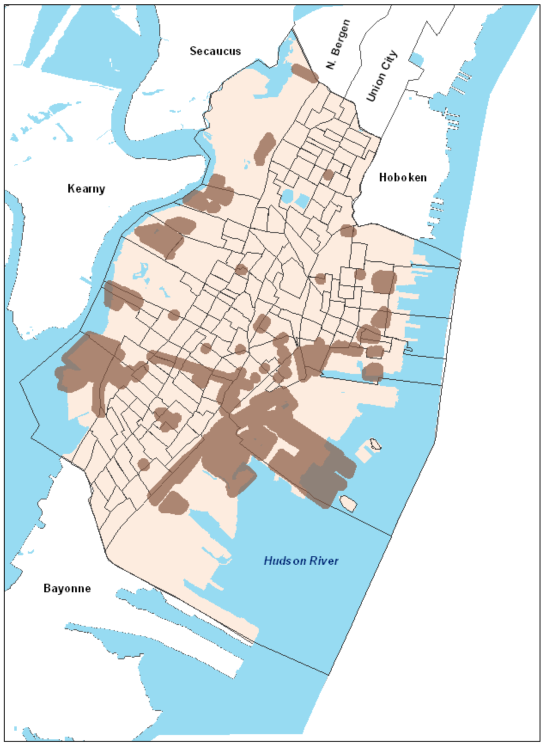
Consequently, a value of 300 feet was chosen as a reasonable buffer distance from site boundaries, which represents a distance within which most particulate deposition would occur and ambient PM_{10} concentrations are substantially reduced. This distance is thus intended as a reasonable estimate of the zone of influence of a site for exposure to airborne particulates from that site. This distance is not intended to express the limit of the distance that wind can carry particulates from a site.

Table A2. Modeled PM_{10} concentrations at increasing distances from the centers of 0.5, 1, and 2 acre sites.

Site Size (Distance from Center to Site Boundary)	PM Concentration at X Feet (Meters) from Center														
	50 (15)	75 (23)	100 (30)	125 (38)	150 (46)	175 (53)	200 (61)	250 (76)	300 (91)	350 (107)	400 (122)	450 (137)	500 (152)	600 (183)	700 (213)
0.5 acre (22 meters)	--	2621	1389	466	271	182	130	77.1	51.1	36.5	27.2	21.1	16.8	11.5	8.4
1 acre (32 meters)	--	--	--	1275	464	229	149	81.1	52	36.6	27.2	21.1	16.8	11.5	8.3
2 acre (45 meters)	--	--	--	--	793	717	351	102	57.5	38.1	27.8	21.3	16.9	11.4	8.3

Using the GIS, a 300-foot buffer was extended beyond the parcel boundary to account for dispersion of site material. Figure A1 displays the COPR sites and their 300 foot buffer zone.

Figure A1. COPR Site Boundaries Extended by a 300 Foot Buffer



Hexavalent Chromium Concentrations at COPR Sites

A hexavalent chromium (Cr^{+6}) concentration was assigned to each COPR site and its buffer zone. Where possible, this was done based on historical measurement of Cr^{+6} concentration collected by the NJDEP. The highest Cr^{+6} soil measurement available in a site's data record was used to characterize the entire site. Of the 135 COPR sites in Jersey City (after exclusion of site 189), 23 sites (16.9%) had Cr^{+6} data available. Of the remaining 112 sites, 94 sites (69.1% of the total) had historic measurements of total chromium concentrations available, and 18 sites (13.2% of the total) had no chromium measurements of any kind. Where possible, these sites were assigned an estimate for the Cr^{+6} value, as described below. Table A3 lists each of the Jersey City COPR sites, indicates which type of information was used, and the final value determined for chromium concentration.

To characterize the 94 sites with only total chromium data, NJDEP evaluated the ES&E database containing information on 42 sites (ES&E, 1989). Of the sites in the ES&E database, 28 sites had both Cr^{+6} and total chromium measurements that could be used to estimate the ratio of Cr^{+6} to total chromium in the COPR material. For these 28 sites, the Cr^{+6} and total chromium measurements were moderately correlated (r=0.37) with an overall mean ratio of 0.03 (standard deviation=0.04). However, it was found that this ratio was dependent on the Cr^{+6} concentration such that as the Cr^{+6} concentration increased, it tended to make up a larger proportion of the total chromium. The 95th percentile of the Cr^{+6} to the total chromium ratio was 0.12. The largest ratio value was 0.18. However, this value was a statistical outlier of the overall relationship between the ratio and Cr^{+6} concentration. The next largest ratio, 0.14, was consistent with this relationship. Therefore, a ratio of 0.14 was selected to represent the upper end of the range of the proportion of Cr^{+6} of total chromium.

To address the potential variability of the ratio of Cr^{+6} to total chromium in COPR material, the Cr^{+6} estimates for the 94 sites with only total chromium measurements were initially calculated using both the 3% mean estimate and the 14% upper percentile estimate of the percentage of total chromium that was Cr^{+6}.

Of the 18 sites with no historical chromium data of any kind, six sites are adjacent to sites with values, and were operationally linked to the adjacent site in the historical site case files. These six sites were assigned the same value as that measured at the adjacent site. Table A3 identifies these sites in the *Source* column as having no data, and notes the site identification number in which data was used.

The remaining 12 "no data" sites are not able to be assigned a chromium value. Ten of the 12 sites were more than 300 feet from any residential area and only impacted non-residential areas. Therefore, these ten "no data" sites would not have influenced the outcome of the analysis regardless of their true Cr^{+6} value, since their buffered areas do not intersect any residential areas.

The remaining two sites were assigned a "no data" classification with unknown impact. The buffered areas of these two sites intersect three census block groups: 38001, 38002, and 45002. One should note that much of the buffer zones of the "no data" sites are overlapped by the buffer zone from other sites with data. Where overlap occurs, the air dispersion buffer with a known value overwrites the "no data" buffer.

Table A3. List of the COPR sites and data used to classify each site.

Site ID	Source: SRP unless noted	Sampling Result (ppm)	Cr*3% (ppm)	Cr*14% (ppm)
1		5,900	177	826
2		8,400	252	1,176
3		6,200	186	868
4	no data	no residential impact		
5		5,800	174	812
6		19,000	570	2,660
7		360	11	50
8		4,300	129	602
10		4,700	141	658
11		10,000	300	1,400
12		8,800	264	1,232
13		11,000	330	1,540
14		6,400	192	896
15		6,600	198	924
16		7,900	237	1,106
17		18,000	540	2,520
18		13,000	390	1,820
19		9,940	298	1,392
20		8,100	243	1,134
22		43,700	1,311	6,118
23		2,900	87	406
24		4,400	132	616
25		37	1	5
26		55	2	8
27		90	3	13
28		270	8	38
29		620	19	87
30		22	1	3
31		23	1	3
32		7,710	231	1,079
33		64	2	9
34		51	2	7
35		46	1	6
36		38	1	5
37		8,900	267	1,246
38		13,000	390	1,820
39		19,800	594	2,772

Site ID	Source: SRP unless noted	Sampling Result (ppm)	Cr*3% (ppm)	Cr*14% (ppm)
63		3,150	95	441
65		910	27	127
66		7,320	220	1,025
67		5,510	165	771
68		19,500	585	2,730
69		4,240	127	594
70		2,613	78	366
71	Cr^{+6}/ES&E	8,500	8,500	8,500
73	Cr^{+6}/ES&E	15,000	15,000	15,000
74		472	14	66
75	no data/Site 36	38	1	5
76		705	21	99
77	no data/Site 76	705	21	99
79	Cr^{+6}	12,840	12,840	12,840
80		12,200	366	1,708
81		12,100	363	1,694
82		14,492	435	2,029
83		230	7	32
84		377	11	53
85		4,910	147	687
86		1,397	42	196
87	Cr^{+6}/ES&E	15,000	15,000	15,000
88	Cr^{+6}/ES&E	15,000	15,000	15,000
89		2,044	61	286
90	Cr^{+6}/ES&E	25,000	25,000	25,000
91	no data/Site 204	15	15	15
92	no data/Site185	20	20	20
93	no data	no residential impact		
94		280	8	39
95	no data	no residential impact		
96		26,200	786	3,668
97		39	1	5
98		39	1	5
99		35	1	5
100		4,990	150	699
101		5,423	163	759
102		13,800	414	1,932
107		5,468	164	766
108		18,240	547	2,554
112		23,500	705	3,290
114		63,040	1,891	8,826

Site ID	Source: SRP unless noted	Sampling Result (ppm)	Cr*3% (ppm)	Cr*14% (ppm)
115		35,000	1,050	4,900
117		25,900	777	3,626
118		63	2	9
119		16,000	480	2,240
120	no data/Site 115	35,000	1,050	4,900
121		730	22	102
123		3,520	106	493
124	Cr^{+6}/ES&E	15,000	15,000	15,000
125	Cr^{+6}/ES&E	15,000	15,000	15,000
127		2,223	67	311
128		1,927	58	270
129		184	6	26
130		16,560	497	2,318
132		6,101	183	854
133		17,510	525	2,451
134	Cr^{+6}/ES&E	15,000	15,000	15,000
135		3,145	94	440
137	no data	no residential impact		
140	Cr^{+6}/ES&E	15,000	15,000	15,000
142		2,277	68	319
143		1,214	36	170
151		17,720	532	2,481
153	no data	no residential impact		
154	Cr^{+6}	13,000	13,000	13,000
155	Cr^{+6}	10,000	10,000	10,000
156		10,340	310	1,448
157	no data	no residential impact		
159		445	13	62
160		2,000	60	280
161		303	9	42
163	Cr^{+6}/ES&E	15,000	15,000	15,000
165		9,560	287	1,338
172		20,100	603	2,814
173		31,000	930	4,340
175		12,000	360	1,680
178		100	3	14
180	no data	no residential impact		
183	no data/Site 200	38	38	38
184	Cr^{+6}	25,000	25,000	25,000
185	Cr^{+6}	20	20	20
186	no data	unknown impact		

Site ID	Source: SRP unless noted	Sampling Result (ppm)	Cr*3% (ppm)	Cr*14% (ppm)
187	Cr^{+6}	726	726	726
188	no data	unknown impact		
189	no parcel found	Excluded	Excluded	Excluded
194		25,000	750	3,500
196		28,000	840	3,920
197		11,000	330	1,540
198	Cr^{+6}	51	51	51
199	Cr^{+6}	11,900	11,900	11,900
200	Cr^{+6}	38	38	38
202	Cr^{+6}	23	23	23
203	Cr^{+6}	17	17	17
204	Cr^{+6}	15	15	15
205	Cr^{+6}	111	111	111
206	no data	no residential impact		
207		27,683	830	3,876
208	no data	no residential impact		
211	no data	no residential impact		

Determination of Cr^{+6} Concentration Categories

The NJDEP then classified each COPR site into one of three hexavalent chromium concentration "categories" based on the measured or estimated Cr^{+6} value, in parts per million (ppm). The three categories include:

1) Cr^{+6} concentration of $\geq$ 900 ppm;
2) Cr^{+6} concentration of < 900 ppm; or
3) a known COPR site, but no available total or hexavalent chromium value.

The purpose of this categorization was to differentiate those COPR sites with higher Cr^{+6} concentration from the other known sites, assuming that those sites with higher Cr^{+6} concentrations would have posed a greater potential for exposure. There is no one value that uniquely differentiates high concentration sites from all other sites. However, a cutoff value of 900 ppm Cr^{+6} was chosen. This is approximately the median Cr^{+6} value under the assumption that Cr^{+6} constitutes 3% of total chromium in COPR, and approximately the 30th percentile value under the assumption that Cr^{+6} constitutes 14% of total chromium.

Figure A2 shows the chromium site buffers, shaded according to chromium concentration category, based on a 3% ratio of Cr^{+6} to total chromium. Figure A3 shows the chromium site buffers shaded according to chromium concentration category, based on a 14% ratio of Cr^{+6} to total chromium. In every instance that an air dispersion buffer from one site overlaps with the buffer from another site, the highest value "overwrites" the lower value.

Figure A2. COPR Site Characterized by Highest Cr^{+6} Concentration using 3% Total Chromium

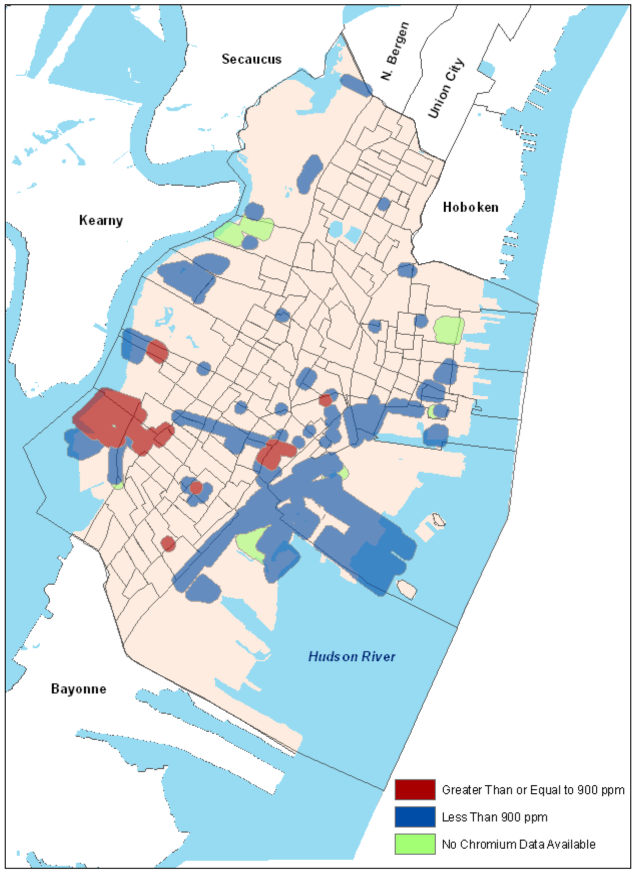
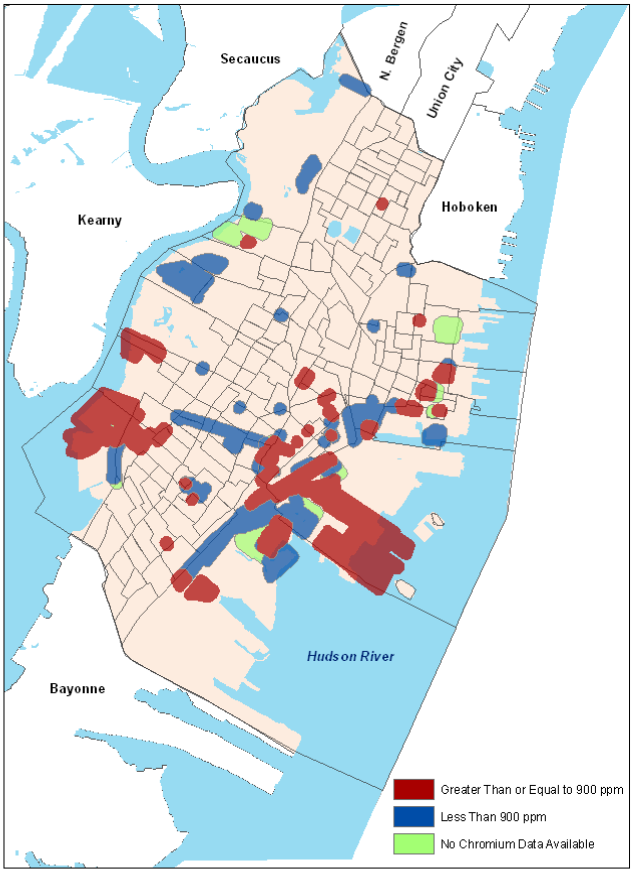


Figure A3. COPR Site Characterized by Highest Cr^{+6} Concentration using 14% Total Chromium



Determining the Relationship between Residential Areas and Chromium Exposure

High quality land use data in a GIS format was available for Jersey City for the years 1986, 1995, and 2002. This mapping was created from the low altitude aerial orthophotography. The metadata information for this data is available at **www.state.nj.us/dep/gis/**. Residential land use was extracted from the 1986 and 1995 layers. Residential areas developed from non-residential areas after 1995 were not included in the study. This is because we were characterizing historic residential land use in order to account for at least a ten year latency period for lung cancer. Therefore, more recent residential development of previously non-residential areas, and resultant exposures, if any, would not have been expected to have led to the onset of lung cancer during the study time period. Residential land use is shown in Figure A4.

GIS tools were then used to find the intersection of residential areas and the spatial extent of the 300-foot chromium site buffers. The results of this analysis are displayed in Figure A5. Figure A6 shows a detailed view of the spatial relationship between residential areas and air dispersion buffer zones.

Figure A4. Residential Land Use in Jersey City through 1996

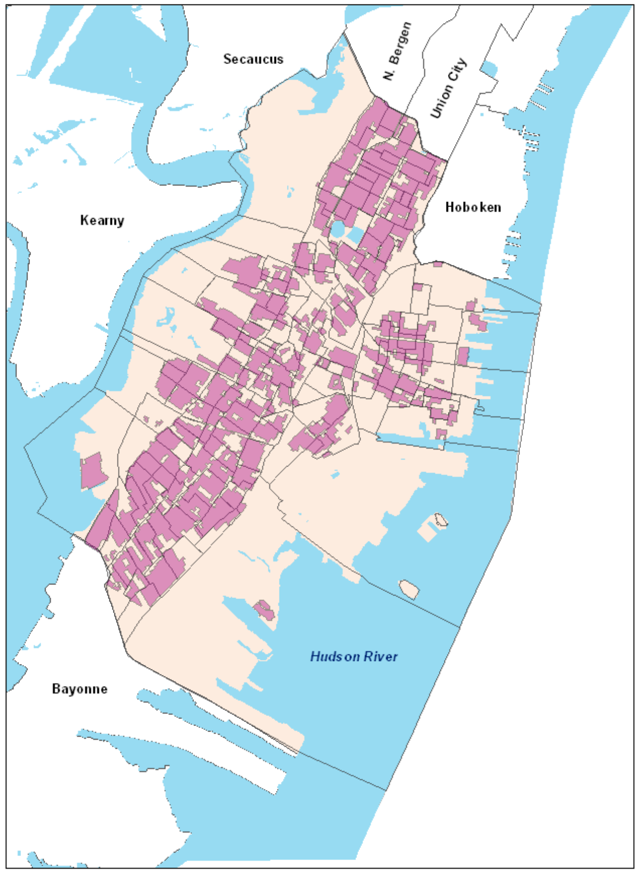


Figure A5. Residential Land Use in Relation to COPR Site Buffers

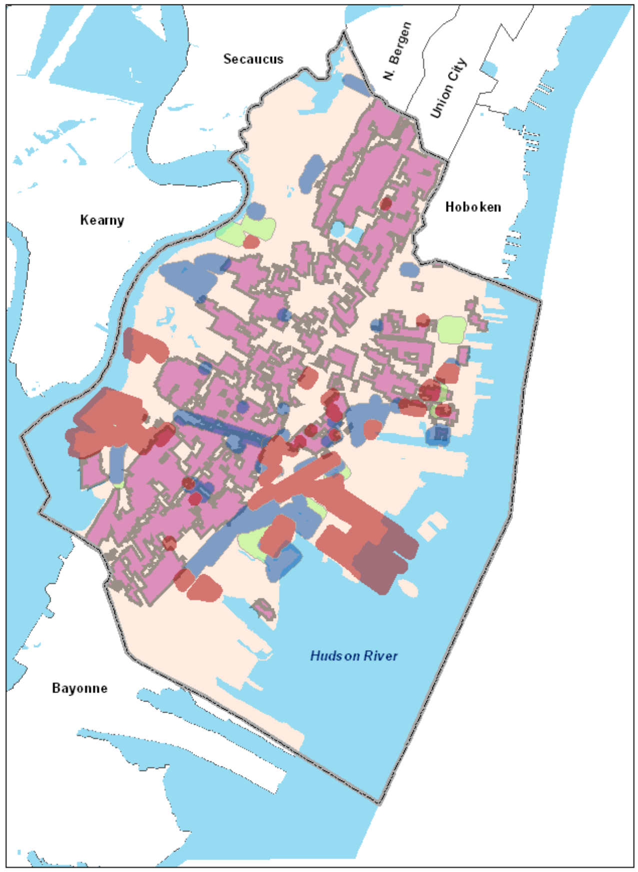
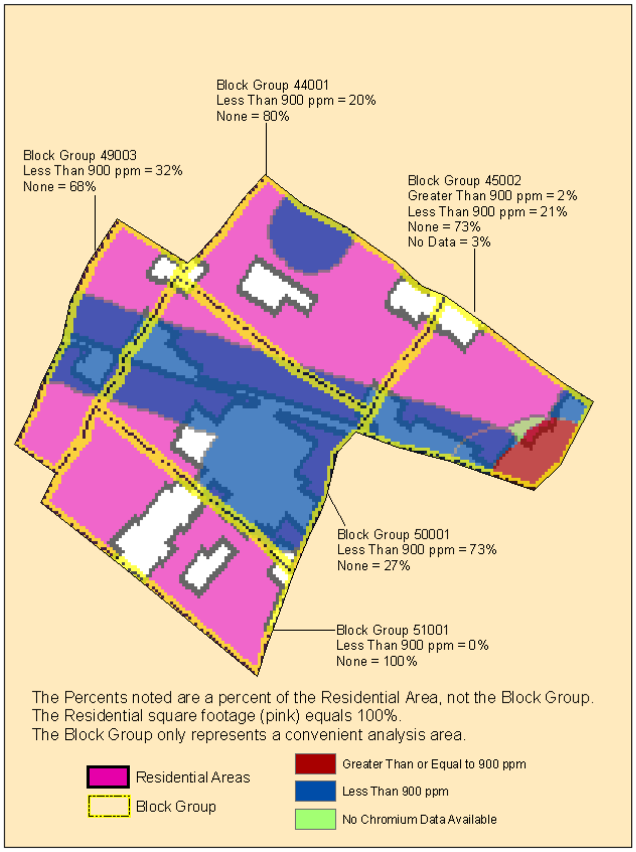


Figure A6. Close up of Buffers (blue, red, and green) Overlain on Residential Areas (pink)

Census Block Group Evaluation

The epidemiologic methods require that the exposure information be structured in a manner that enables it to relate to the Jersey City population data from the U.S. Census Bureau. Consequently, the exposure information was mapped to the U.S. Census Bureau's block group areas. Thus, the final step was to intersect chromium exposure buffers, with the residential area of the 161 census block groups in Jersey City. Figure A7 shows a map of this analysis.

Figure A7. Percent of Buffers (blue, red, and green) for Residential Areas (pink) by Census Block Groups



Residential square footage was determined for each census block group. Each of the 161 block groups were then assigned that residential square footage as 100 percent. Subsequently, the square footage for each category of chromium exposure ($\geq$ 900 ppm, 1-899 ppm, None, or Unknown) was determined for each of the block groups. The square footage for each chromium category was compared to the total residential square footage and a corresponding percentage was calculated. This was performed for all of the block groups.

This process was performed twice. The first iteration was performed assuming the hexavalent chromium to total chromium ratio was 3%. The calculations were performed again, assuming the hexavalent chromium ratio was 14%. Residential areas that were overlapped by more than one site buffer were always assigned the value of the highest hexavalent chromium category occurring. Table A4 provides a listing of each of the census block groups for Jersey City and the proportions of the block group potentially exposed to Cr^{+6}, measured or estimated using both the 3% and 14% assumptions.

Table A4. Proportion of census block group residential areas within 300-foot buffered areas around COPR site boundaries, by hexavalent chromium concentration category, using 3% and 14% assumptions.

Census Block Group	Cr^{+6} Assuming 3% of Total Chromium				Cr^{+6} Assuming 14% of Total Chromium			
	None	< 900 ppm	≥ 900 ppm	Unknown	None	< 900 ppm	≥ 900 ppm	Unknown
340170001001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170001002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170001003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170002001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170002002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170002003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170003001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170003002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170003003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170004001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170004002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170005001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170005002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170005003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170006001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170006002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170006003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170006004	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170007001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170007002	0.678	0.322	0.000	0.000	0.678	0.000	0.322	0.000
340170007003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170008001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170008002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170009019	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170009021	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170009022	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170009023	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170010001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170010002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170011001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170011002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170011003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170012011	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170012021	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170013001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170013002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170014001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170014002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170015001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170015002	0.955	0.045	0.000	0.000	0.955	0.045	0.000	0.000
340170016011	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000

Census Block Group	Cr^{+6} Assuming 3% of Total Chromium None	< 900 ppm	≥ 900 ppm	Unknown	Cr^{+6} Assuming 14% of Total Chromium None	< 900 ppm	≥ 900 ppm	Unknown
340170016021	0.742	0.258	0.000	0.000	0.742	0.000	0.258	0.000
340170016022	0.983	0.017	0.000	0.000	0.983	0.017	0.000	0.000
340170017001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170017002	0.926	0.074	0.000	0.000	0.926	0.074	0.000	0.000
340170018001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170018002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170019001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170020001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170020002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170020003	0.497	0.503	0.000	0.000	0.497	0.503	0.000	0.000
340170021001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170021002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170021003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170022002	0.803	0.197	0.000	0.000	0.803	0.197	0.000	0.000
340170022003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170023001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170023002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170024001	0.999	0.001	0.000	0.000	0.999	0.000	0.001	0.000
340170024002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170025001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170025002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170026001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170026002	0.769	0.231	0.000	0.000	0.769	0.000	0.231	0.000
340170026003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170027001	0.973	0.027	0.000	0.000	0.973	0.027	0.000	0.000
340170027002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170027003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170028001	0.997	0.003	0.000	0.000	0.997	0.003	0.000	0.000
340170028002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170028003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170028004	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170028005	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170029001	0.969	0.031	0.000	0.000	0.969	0.031	0.000	0.000
340170029002	0.224	0.776	0.000	0.000	0.224	0.776	0.000	0.000
340170029003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170030001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170030002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170031001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170031002	0.894	0.106	0.000	0.000	0.894	0.000	0.106	0.000
340170032001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170032002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170033001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170033002	0.973	0.027	0.000	0.000	0.973	0.000	0.027	0.000
340170033003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170033004	0.373	0.532	0.095	0.000	0.373	0.071	0.556	0.000
340170034001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170034002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000

Census Block Group	Cr+6 Assuming 3% of Total Chromium None	< 900 ppm	≥ 900 ppm	Unknown	Cr+6 Assuming 14% of Total Chromium None	< 900 ppm	≥ 900 ppm	Unknown
340170035001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170036001	0.615	0.385	0.000	0.000	0.615	0.143	0.242	0.000
340170036002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170037001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170037002	0.286	0.714	0.000	0.000	0.296	0.000	0.704	0.000
340170038001	0.112	0.888	0.000	0.000	0.112	0.000	0.888	0.000
340170038002	0.256	0.499	0.000	0.246	0.256	0.000	0.499	0.246
340170039001	0.582	0.401	0.000	0.017	0.582	0.335	0.066	0.017
340170040001	0.898	0.102	0.000	0.000	0.898	0.102	0.000	0.000
340170040002	0.893	0.107	0.000	0.000	0.893	0.107	0.000	0.000
340170040003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170040004	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170041011	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170041012	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170041013	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170041014	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170041021	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170041022	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170042001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170042002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170042003	0.705	0.295	0.000	0.000	0.705	0.295	0.000	0.000
340170043001	0.976	0.024	0.000	0.000	0.976	0.024	0.000	0.000
340170043002	0.987	0.013	0.000	0.000	0.987	0.013	0.000	0.000
340170044001	0.794	0.206	0.000	0.000	0.794	0.206	0.000	0.000
340170045001	0.933	0.067	0.000	0.000	0.933	0.067	0.000	0.000
340170045002	0.734	0.233	0.002	0.031	0.734	0.215	0.020	0.031
340170045003	0.643	0.295	0.062	0.000	0.643	0.295	0.062	0.000
340170046001	0.611	0.389	0.000	0.000	0.611	0.036	0.353	0.000
340170046002	0.441	0.432	0.127	0.000	0.441	0.000	0.559	0.000
340170047001	0.119	0.881	0.000	0.000	0.119	0.337	0.544	0.000
340170047002	0.363	0.637	0.000	0.000	0.363	0.610	0.027	0.000
340170047009	0.874	0.126	0.000	0.000	0.874	0.031	0.094	0.000
340170048001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170048002	0.998	0.002	0.000	0.000	0.998	0.002	0.000	0.000
340170048003	0.517	0.119	0.363	0.000	0.517	0.119	0.363	0.000
340170049001	0.753	0.247	0.000	0.000	0.753	0.247	0.000	0.000
340170049002	0.625	0.375	0.000	0.000	0.625	0.375	0.000	0.000
340170049003	0.676	0.324	0.000	0.000	0.676	0.324	0.000	0.000
340170049004	0.961	0.020	0.019	0.000	0.961	0.020	0.019	0.000
340170050001	0.274	0.726	0.000	0.000	0.274	0.726	0.000	0.000
340170051001	0.995	0.005	0.000	0.000	0.995	0.005	0.000	0.000
340170052001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170052002	0.456	0.000	0.544	0.000	0.456	0.000	0.544	0.000
340170053001	0.994	0.006	0.000	0.000	0.994	0.006	0.000	0.000
340170053002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170054001	0.980	0.020	0.000	0.000	0.980	0.000	0.020	0.000
340170054002	0.844	0.000	0.156	0.000	0.844	0.000	0.156	0.000

Census Block Group	Cr^{+6} Assuming 3% of Total Chromium				Cr^{+6} Assuming 14% of Total Chromium			
	None	< 900 ppm	≥ 900 ppm	Unknown	None	< 900 ppm	≥ 900 ppm	Unknown
340170054003	0.802	0.198	0.000	0.000	0.802	0.024	0.174	0.000
340170055001	0.548	0.291	0.162	0.000	0.549	0.350	0.102	0.000
340170056001	0.962	0.038	0.000	0.000	0.962	0.004	0.034	0.000
340170056002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170056003	0.937	0.000	0.063	0.000	0.937	0.000	0.063	0.000
340170058011	0.758	0.242	0.001	0.000	0.758	0.020	0.222	0.000
340170058012	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170058013	0.849	0.151	0.000	0.000	0.849	0.151	0.000	0.000
340170058021	0.920	0.080	0.000	0.000	0.920	0.080	0.000	0.000
340170059001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170059002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170059003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170059004	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170059005	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170060001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170060002	0.946	0.000	0.054	0.000	0.946	0.000	0.054	0.000
340170061001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170061002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170061003	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170061004	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170061005	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170062001	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170062002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170063001	0.854	0.109	0.037	0.000	0.854	0.008	0.138	0.000
340170063002	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
340170063003	0.980	0.020	0.000	0.000	0.980	0.000	0.020	0.000