Santa Clara
Valley Urban
Runoff Pollution
Prevention Program

City of Sunnyvale
Industrial Stormwater Monitoring Pilot Project

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VOLUME I

Prepared by:

Jeff Soller – EOA, Inc.
Robert Gallo – City of Sunnyvale

With Contributions from:

Dave Grabiec – City of San Jose

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Executive Summary

The San Francisco Bay Regional Water Quality Control Board reissued the second 5-year NPDES permit to the 15 agencies who are co-permitees in the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) in August, 1995. One of the Provisions required the Program to develop a Metals Control Measures Plan (MCMP) to reduce the amount of copper and other metals of concern in stormwater discharged to the Bay.

The results of the MCMP were incorporated into the SCVURPPP Urban Runoff Management Plan (URMP) which was submitted to the Board in September 1997. One of the findings of the MCMP was that several types of industrial activities (metal finishers, electroplaters, and semiconductor manufacturers) may be responsible for a large percentage of the copper and nickel loading from industrial sources to South San Francisco Bay. The MCMP also noted that there were significant limitations in the methodology that was used to generate this finding. In particular, the MCMP cites concerns over the quality of the data submitted by industries to fulfill the monitoring requirements in the General stormwater permit.

Based on results of the metals source identification in the MCMP and consistent with the URMP, several of the co-permittees including the Cities of Sunnyvale, San Jose, and Palo Alto have taken action to investigate some of the limitations of the approach used during that study.
This report documents in detail the City of Sunnyvale's efforts in this regard and includes a coordinated follow-up plan based on the findings of the most recent Program-wide investigations.

As specified in Section 4C of the URMP (i.e. Industrial-1), the City of Sunnyvale developed a systematic pilot-scale program designed to verify if stormwater copper and/or nickel concentrations are significantly different at electroplating, metal finishing, and/or semiconductor manufacturing facilities than at other commercial/industrial sites. The pilot program, was conducted between November 1997 and May 1998.

The pilot program consisted of three facilities from each of the three targeted industrial categories as well as several commercial/industrial parking lots that served as control sites. Over 190 stormwater samples were collected and analyzed during the course of the investigation.

During each monitored storm event, each facility attempted to collect "first flush" and "second flush" samples. Samples followed strict sampling methodology and chain of custody protocol, were analyzed with low detection limits to minimize non-detect data to the fullest extent practical, and were subject to an intensive QA/QC program.

The results of the investigation indicate that there were not significant differences between the concentrations of copper or nickel at the control sites when compared to either semiconductor manufacturing or metal finishing facilities. Significant differences ($p<0.01$) were found for both copper and nickel when observed concentrations from electroplating facilities were compared to the control sites.

When average results from this investigation were compared to those reported in the MCMP, it was found that for all types of facilities, the observed mean copper concentrations were very similar given the variability inherent in the data. Mean nickel concentrations reported during this investigation were found to be lower than those reported in the MCMP by factors ranging from 2 to 5. Based on these results, it is suggested that the concerns raised regarding the MCMP data, particularly with respect to nickel may have been justified.

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Related Work - City of San Jose

The City of San Jose conducted a pilot program to evaluate the suitability of the MCMP data for assessing pollutant loading for the watershed, to assess the significance of industrial stormwater discharges relative to the MCMP, and to determine the extent to which industries have met the objectives of the General Permit and implemented SWPPPs.

Printed circuit board manufacturers in San Jose were surveyed to determine the extent to which SWPPPs were developed and implemented, and a pilot scale source monitoring program was implemented to evaluate the effectiveness of the currently employed BMPs at two printed circuit board manufacturers.

San Jose's investigation determined that the development of SWPPP and BMPs to control pollutants is not widely practiced and documented by industrial facilities in San Jose. Moreover, the source monitoring program identified industrial venting processes to rooftops as a likely significant contributor of copper and nickel to stormwater runoff from printed circuit board manufacturers.

Future Work

Based on the investigations described above, a coordinated follow up plan for the upcoming winter season is recommended. The recommended follow up includes expanded education and outreach to industrial dischargers, investigation of a larger study group of facilities to determine if the results reported in the initial phase of investigation are representative of the entire class of facilities in Santa Clara Valley, partership with industry to identify controllable in-house sources of pollutants, and evaluation of the need for new or improved BMPs once controllable sources have been identified.

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City of Sunnyvale
Industrial Stormwater Monitoring Pilot Project

Introduction and Background

The San Francisco Bay Regional Water Quality Control Board reissued the second 5-year NPDES permit to the 15 agencies who are co-permitees in the Santa Clara Valley Urban Runoff Pollution Prevention Program in August, 1995. One of the Provisions required the Program to develop a Metals Control Measures Plan to reduce the amount of copper and other metals of concern in stormwater discharged to the Bay.

The results of the MCMP[1] were incorporated into the SCVURPPP Urban Runoff Management Plan[2] (URMP) which was submitted to the Board in September 1997. The MCMP was a three part study that included the identification of metals of highest priority, the identification of sources for high priority metals within the watershed, the estimation of relative contributions to the Bay from these sources, and the identification and evaluation of existing and new control measures for their ability to control significant sources of high priority metals.

One of the findings of the MCMP was that several types of industrial activities may be responsible for a large percentage of the copper and nickel loading from industrial sources to South San Francisco Bay. The MCMP also noted that there were significant limitations in the methodology that was used to generate this finding. In particular, the MCMP cites concerns over the quality of the data submitted by industries to fulfill the monitoring requirements in the General stormwater permit (which was the data source used in the MCMP calculations).

Based on results of the metals source identification in the MCMP and consistent with the URMP, the co-permittees have taken action to investigate some of the limitations of the approach including those associated with data below detectable limits, developed and implemented a more rigorous method of calculating copper loading, and developed a pilot program designed to verify (or disprove) apparent elevated copper and nickel concentrations in runoff from electroplating, metal finishing, and semiconductor manufacturing facilities. As specified in Section 4C of the URMP, the City of Sunnyvale has developed a systematic pilot-scale program which is designed to verify if stormwater copper and/or nickel concentrations are significantly different at electroplating, metal finishing, and semiconductor manufacturing facilities than at other commercial and industrial sites. The pilot program, which is the subject of this report, was conducted between November 1997 and May 1998.

The pilot program consisted of three facilities from each of the three targeted industrial categories (9 facilities total) as well as several other commercial/industrial sites that served as a control group. During each monitored storm event, each facility attempted to collect two stormwater samples. The initial samples were to be taken within the first hour of the rain event and were labeled first flush samples. The second samples were taken after the second hour of the rain event and labeled second flush samples. The pilot program used sufficiently low detection limits to minimize and avoid non-detect data, and included a comprehensive QA/QC program.

The results were analyzed statistically to determine if significant differences existed between the observed concentrations of copper or nickel at the control facilities when compared to the observed concentrations of runoff from the participating facilities representing the targeted industries.

[1] Santa Clara Valley Metals Control Project, August, 1996.
[2] 1997 Urban Runoff Management Plan, SCUVURPPP, Sept., 1997.

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Experimental Design

The pilot program consisted of monitoring the stormwater quality of three facilities from each of the three targeted industrial categories as well as four other commercial/industrial sites which served as a control group. A summary of the notations used throughout this report to designate the facilities is presented in Table 1.

Table 1
Designation of Facilities Used in Pilot Study

Metal Finishing Facilities	Semiconductor Manufacturers	Electroplating Facilities	Commercial - Industrial Control Facilities
MF-1	EEC-1	EP-1	CIC-1
MF-2	EEC-2	EP-2	CIC-2
MF-3	EEC-3	EP-3	CIC-3
			CIC-4

The goal of the pilot program was to monitor stormwater quality from each facility during five storm events during the 1997/98 winter season. To qualify for the pilot program, storms had to occur at least three business days apart. This requirement was established to match Federal specifications for industrial stormwater sampling.

During each monitored storm event, each facility was to collect two stormwater samples, a "first flush" and a "second flush" sample. It was thought that the first flush sample may not be representative of equilibrium concentrations of stormwater runoff from these industrial facilities, and that there could be differences between samples collected immediately after a storm event began and those collected at some point later in the storm. Moreover, it was believed that if differences did exist, the samples collected later in the storm event would be more representative of the average stormwater quality from these facilities than the first flush samples.

First flush samples were to be taken within the first hour of the storm event, and second flush samples were to be taken at some point later during the storm after the first 120 minutes. Prior to the start of the pilot program, sampling locations were identified for each facility. Each grab sample collected is considered representative of the stormwater discharge for that facility.

Each sample was analyzed for total recoverable copper and nickel, pH, TOC, conductivity, suspended solids, and in some cases oil and grease. Constituents of primary concern during this pilot study were copper and nickel. The analytical detection limits used during the study for copper and nickel were 0.001 and 0.003 mg/L, respectively. These low analytical detection limits were employed so that non-detected observations could be avoided to the fullest extent practical.

All samples collected followed strict sampling protocols based on Standard Methods for the Examination of Water and Wastewater for sampling, preservation and analyses. All handling of samples from the pilot project facility to the City of Sunnyvale WPCP used proper chain of custody protocol. The Quality Assurance program implemented is described on page 23.

Based on the design described above, a total of 120 industrial stormwater samples were to be collected during the pilot program (3 facilities x 4 types of facilities x 5 storms x 2 samples per storm).

Sampling Methodology

Storm events were sampled by the grab or catch method and by flow measurement sampling using an automatic sampling instrument. Sample points, which were intended to be representative of stormwater

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runoff for the entire facility were identified through each facility's Stormwater Management Pollution Prevention Plan. Sample points at the commercial/industrial control sites were identified by the City of Sunnyvale's Pretreatment Program by identifying the final point of collection before discharge to the overall stormwater collection system. Samples at each participating facility were collected by representatives of that facility and the Sunnyvale Pretreatment Staff. Samples taken from the control sites were collected by Sunnyvale Pretreatment Program staff.

Sample containers met or exceeded analyte specifications established in the U.S. EPA "Specifications and Guidance for Contaminant-Free Sample Containers" for use in Superfund and other hazardous waste programs. Stormwater sampling occurred in the first 60 minutes for first flush samples and after the first 120 minutes for second flush samples. All samples were documented by chain of custody forms from the time of sampling until they were relinquished to the WPCP Lab. All samples were collected and preserved based on SM 1060: Collection and Preservation of Samples. Stormwater analysis method for nickel and copper was based on Standard Methods 3113 B. Electrothermal Atomic Absorption Spectrometric Method; c. Graphite furnace.

Description of Participating Facilities

Participating facilities were divided into four categories: semiconductor manufacturing facilities, electroplating facilities, metal finishing facilities, and commercial / industrial control sites. The following is a brief description of each of the participating facilities.

Semiconductor Manufacturing Facilities:

EEC1 is a facility listed under 40 CFR 469 Electrical and Electronic Components, Subpart A-Semiconductor. EEC1 is a medium-sized semiconductor manufacturer occupying one building with a total floor area of 30,000 sq. ft. 23,000 sq. ft. of the area is used for manufacturing processes which generates approximately 95,000 gallons of wastewater per day. All generated wastewater is treated through a continuous four stage neutralization system before discharge to the sanitary sewer. The outside equipment pad which houses the treatment system, scrubber system, solvent oxidizing system and chiller units is covered. EEC1 has six storm drain inlets on site. Two of the storm drain inlets are located on the east side of the facility and receive only parking lot stormwater runoff. The other four storm drain inlets are located on the west side of the facility and receive stormwater runoff from the rear of the facility. The pilot program sample point was the second storm drain inlet on the west side of the facility. This monitoring location collects runoff from the roof, debris bin, construction activities, and hazardous waste loading and unloading areas.

EEC2 is listed under 40 CFR 469 Electrical, and Electronic Components, Subpart A-Semiconductor. EEC2 is a medium-sized semiconductor manufacturer occupying one building with a total floor area of 30,000 sq. ft. 23,000 sq. ft. of the area is used for manufacturing processes which generates approximately 30,000 gallons of wastewater per day. All generated wastewater is treated through a continuous four stage neutralization system before discharge to the sanitary sewer. The neutralization system resides under an easement or roof area, with the fume scrubbers, cooling towers and chiller units placed outside on the equipment pad area. EEC2 has five storm drain inlets on site. One storm drain inlet is located on the south side of the facility. Three storm drain inlets are located in the rear of the facility. The fifth storm drain inlet is located at the northeast corner of the parking area. The pilot program sample point was the storm drain inlet located at the northeast corner of the parking area. This monitoring location collects runoff from the roof of the facility, equipment pad area, debris bin and hazardous waste loading and unloading area.

EEC3 is listed under 40 CFR 469 Electrical and Electronic Components, Subpart A-Semiconductor. EEC3 is a large semiconductor manufacturer occupying four buildings with a total floor area of 150,000 sq. ft. with 100,000 sq. ft. dedicated for the manufacturing of semiconductors which generates approximately 275,000 gallons of wastewater per day. The four buildings are surrounded by an impervious surface with limited space for landscaping. All generated wastewater is treated through two separate continuous neutralization systems. One of the neutralization systems resides under an easement and the other is located in a double containment vault with no cover. The facility has storm drain inlet valve inserts that collect stormwater before manual discharge to the stormwater collection system.

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The area surrounding Building 936 and Building 943 has ten storm drain inlets. The sample point for this location is storm drain inlet A located on the north side of the building. This monitoring location collects runoff from the roof of the facility, debris bin and parking areas. The area surrounding Building 915 and the semiconductor manufacturing (SM) facility has 30 storm drain inlets. Building 915 has two sample locations listed as E and B. These monitoring locations collect runoff from the roof of the facility, equipment pad, debris bin and parking areas. The SM facility has two sample locations, C and D. Sample point C is located at the southeast side of the building with sample point D on the west side of the building. Monitoring location C collects impervious surface runoff from the east side and south side of the facility. Monitoring location D collects runoff from the roof of the facility, debris bin, loading dock and parking areas. Storm drain inlets have manual valve inserts that are closed during dry weather and opened for stormwater flow to the collection system.

Electroplating Facilities:

EP1 is listed under 40 CFR 413, Electroplating Point Source Category; subpart H-Printed Circuit Board Subcategory. EP1 is a medium sized printed circuit board manufacturer with a total floor area of 30,000 sq. ft. with 18,000 sq. ft. dedicated to the manufacturing of printed circuit boards that produces 42,970 gallons of wastewater per day. Pollutant generating processes are housed inside. All process wastewater is collected, chemically treated to precipitate heavy metals, passed through microfiltration membranes, and pH adjusted for discharge to the Sunnyvale Water Pollution Control Plant. Floor drains and secondary containment structures within the building are either fully separated from other materials or flow into the wastewater treatment system. All hazardous materials and wastes are stored in areas with sufficient secondary containment. In between the buildings and on the west side of the facility, a fenced storage yard houses bins of scrap metals, such as copper, scrap printed circuit boards, aluminum, router and drilling dust, and silver photographic film. These accumulated materials are designated for either recycling or to be reclaimed at offsite facilities. In addition, other recyclable materials stored in-yard include office paper and plastic.

EP1 has three storm drain inlets on the north side of the two buildings and a stormwater channel on the south side of the two buildings. The stormwater channel is shared with two other businesses that are just south of facility EP1. The businesses that contribute to the stormwater channel are an automotive repair shop and a solar panel installation and assembly facility, as well as EP1. The first sample point, A is the storm drain inlet located between Building #1 and Building #2 in the parking area. The second sample point, B is at the end of the stormwater channel before discharge to the street gutter. Monitoring point A collects stormwater runoff from the area between the two buildings, the roofs of the two buildings and the northwest parking area. Monitoring point A is downgradient of scrap metal storage, waste treatment activities, municipal garbage storage, and truck deliveries and pick-ups. Monitoring point B collects stormwater runoff from the roofs and the south side of the two buildings. A commercial building is located at the north side of the property. Automation electronic tests are performed in this commercial building.

EP2 is listed under 40 CFR 413, Electroplating Point Source Category; subpart F & H. EP2 is a small sized electroplating facility with a total floor area of 15,000 sq. ft. with 13,000 sq. ft. of the facility used for the plating process which generates 14,000 gallons of wastewater per day. The wastewater is treated through a Memtec system and a batch system for metals removal. The treatment system is located adjacent to the facility in a covered area surrounded by a two-foot berm. The two storm drain inlets are located on the southwest side of the building and the east side of the building. Both storm drain inlets were used for pilot program monitoring during the wet season. Monitoring location A is a storm drain inlet located on the southwest side of the building that collects runoff from the back parking area and roof runoff. Monitoring location B is a storm drain inlet located at the east side of the facility that collects runoff from the area around the batch treatment system, wastewater treatment system, parking area and the roof. There are multiple commercial buildings surrounding the location of EP2. These commercial buildings are not associated with a categorical process, but do have activities that involve machining of metal parts and office space.

EP3 is listed under 40 CFR 413, Electroplating Point Source Category, Subpart H-Printed Circuit Board Subcategory. EP3 is a medium sized printed circuit board manufacturer with a total floor area of 40,000 sq.

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ft. with 37,000 sq. ft. dedicated to the manufacturing of printed circuit boards which produces 32,000 gallons of wastewater per day. All process wastewater is collected and treated through a continuos metals removal and pH adjustment system. At the rear of the facility there are two hazardous materials loading and unloading areas, an uncovered treatment system with an 18 inch berm for secondary containment, caustic storage sheds, acid storage sheds, and recycle bins for silver film, copper, tin, lead, and aluminum. EP3 has two storm drain inlets on site. Monitoring point A is located on the south side of the process building and receives stormwater from buildings 1272 and 1274. This monitoring location collects runoff from the roofs of buildings 1272, the debris bin, the four printed circuit board recycle bins, acid storage sheds, sanding shed and drill/router dust shed, construction activities, and hazardous waste loading and unloading area. Monitoring point B is located on the north side of the process building and receives stormwater from buildings 1274 and 1276. This monitoring location collects runoff from the debris bin, the caustic storage shed, hazardous materials loading and unloading areas, the sludge hopper and sludge bag storage area.

Metal Finishing Facilities:

MF1 is listed under 40 CFR 433-Metal Finishing Point Source Category; Subpart A-Metal Finishing Subcategory. MF1 is a small-sized facility and is a manufacturer of printed circuit board processes with hot air leveling and soldermask applications. The building has a total floor area of 20,000 sq. ft. with 15,000 sq. ft. dedicated to soldermask applications, metals coating, and board washing which generates 12,000 gallons of wastewater per day. All process wastewater is collected and treated through a continuos metal bearing waste stream removal system and a non-bearing pH adjustment system which is located on the west side of the facility building. There are two storm drain inlets and three stormwater transfer pipes located on the site. The two storm drain inlets collect stormwater runoff from a small parking area and landscaping. The stormwater transfer pipes are located in the north parking area and discharge to the main collection system. The pilot program stormwater sample point for this location is the collection of stormwater runoff before entering the stormwater transfer pipes. This monitoring location collects stormwater runoff from the roof of the building, main parking area, hazardous materials loading area, and debris bin.

MF2 is listed under 40 CFR 433-Metal Finishing Point Source Category; Subpart A-Metal Finishing Subcategory. MF2 is a small-sized facility and is a manufacturer of high intensity light sources and power supplies. The building has a total floor area of 20,000 sq. ft. with 15,000 sq. ft. dedicated for the plating process, which generates 10,000 gallons of wastewater per day. All process wastewater is collected and treated through a continuos metals removal and pH adjustment system, which is located on the west side of the facility with adequate cover. MF2 has five storm drain inlets located on site. The two pilot program sample points for this facility are the final collection points before discharge to the stormwater collections system. Sample point A is located in the front parking lot at the southeast corner next to the landscaping. Sample point B is located in the rear of the facility (north side) adjacent to the loading dock area. Monitoring point A collects runoff from the roof of the building and the front parking area. Monitoring point B collects runoff from the backside area of the roof, debris bin, and loading dock area for hazardous materials.

MF3 is listed under 40 CFR 433-Metal Finishing Point Source Category; Subpart A-Metal Finishing Subcategory. MF3 is a large-sized facility with four buildings that perform metal finishing operations. Building #1 is solely dedicated to metal finishing operations and has a total floor area of 30,000 sq. ft. with 29,000 sq. ft dedicated to metal finishing operations which generates 12,000 gallons of wastewater per day. Building #2 has precious metals etch processes with a total floor area of 50,000 sq. ft with 5,000 sq. ft dedicated to metal finishing operations. Building #3 has a small tinning area that accounts for less than 100 sq. ft of the total floor area of 30,000 sq. ft. Building #4 has a small printed circuit board manufacturing area, which accounts for 5,000 sq. ft of a total floor area of 40,000 sq. ft. All non-metal bearing wastewater and aqueous cleaners are discharged to the retention ponds for pH adjustment. All metal bearing wastewater and caustic waste are containerized for off site treatment.

Stormwater monitoring is performed at the last storm drain inlet before discharge to the main collection system. This monitoring location collects stormwater runoff from parking area, roof drains and outside storage areas surrounding the process buildings. Some runoff may reach the sample point within a half four after deposition but some areas further off stream usually require hours to reach the sample location. During heavier storm events this site has localized ponding as the below-street pipes fill and water is restricted at the inlets where it ponds in parking lots or flows down slope along street gutters to the next open curb inlet. On

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pervious areas the peak rainfall causes the flow over grassy or exposed soils to open ditches or eventual curb inlets. Given the delayed passage from initial runoff from the more remote surfaces to the sampling point, second flush samples may included some first flush runoff. In a related way, first flush samples may be composed of runoff from the prior storm as well as that from the current storm event.

Control Commercial and Industrial Facilities:

The four control sites for the Stormwater Monitoring Pilot Project were chosen based on the following characteristics: a commercial business park with no categorical process facilities occupying a suite in the complex, a sufficiently large area to produce sufficient coverage of a control sample location, and a sample point that is representative of the total flow of stormwater on that site. Control locations CIC-1, CIC-2 and CIC-3 are business parks with processes ranging from light industrial machine shops to restaurants. These three locations have been occupied with tenants for more that five years. CIC-4 houses a building that has been vacant for the past year and a half. The monitoring locations for the control sites collected stormwater runoff from the total area of the business parks, which include impervious parking surfaces, debris bins, and cardboard recycle bins.

Data Summary

A summary of the storms sampled during the course of the pilot program is presented in Table 2. A brief description of each storm event included in this pilot study, a list of samples collected during each storm event, and a summary of parameters analyzed from each sample is provided in Appendix A. Raw data for all data collected during the course of this study in the form of laboratory data sheets are presented in Volume II: The City of Sunnyvale Industrial Stormwater Monitoring Pilot Project (under separate cover and available upon request). A summary of rainfall data collected during the course of the study is also presented in Volume II.

Inspection of Table 2 reveals the following:

- There were a total of 19 storms monitored as part of the pilot program from November 6, 1997 through May 27, 1998.
- The total number of stormwater samples collected from the participating facilities and control sites exceeds the number of samples specified in the experimental design;
- Each of the participating facilities collected at least nine samples;
- First and second flush samples were not collected for all monitored storm events at all participating facilities; and
- Approximately 60% of the samples collected during the pilot study were first flush samples.

Review of the data collected during the course of the study will reveal that, in fact over 190 individual stormwater samples were collected during the pilot study. The original intention of the pilot program was for each facility to submit one sample (for each storm/flush combination) which could be considered representative of the stormwater quality for the facility. However, representatives from several of the participating facilities were uncertain about where that representative sampling point for the facility would be. A number of facilities therefore collected and submitted stormwater samples for numerous locations within the facility for some or all of the events sampled.

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Table 2
Summary of Data Collected for Pilot Study

		Electroplating Facilities			Metal Finishing Facilities			Semiconductor Manufacturers			Control Facilities			
Date	Sample Type	EP-1	EP-2	EP-3	MF-1	MF-2	MF-3	EEC-1	EEC-2	EEC-3	CIC-1	CIC-2	CIC-3	CIC-4
11/6/97	1st flush			X	X	X				X	X		X	
	2nd flush													
11/10/97	1st flush	X		X	X	X	X			X				
	2nd flush					X								
12/4/97	1st flush			X	X									
	2nd flush													
12/5/97	1st flush										X			
	2nd flush										X			
12/14/97	1st flush										X	X		
	2nd flush										X	X		
1/2/98	1st flush			X	X									
	2nd flush													
1/9/98	1st flush	X	X	X	X	X		X	X		X	X	X	X
	2nd flush	X	X	X	X								X	
1/14/98	1st flush													
	2nd flush		X											
1/29/98	1st flush									X				
	2nd flush		X			X	X	X						
2/12/98	1st flush						X							
	2nd flush						X							
3/5/98	1st flush	X	X			X	X	X	X	X	X	X		X
	2nd flush		X				X	X	X	X	X	X		X
3/12/98	1st flush		X	X	X		X	X	X	X				
	2nd flush						X							
3/13/98	1st flush			X										
	2nd flush													
3/16/98	1st flush						X							
	2nd flush						X							
3/23/98	1st flush	X					X	X	X					
	2nd flush	X					X							
3/31/98	1st flush													
	2nd flush	X	X	X	X	X		X	X	X	X	X		X
5/4/98	1st flush	X	X	X	X	X		X	X		X	X		X
	2nd flush													
5/11/98	1st flush	X	X					X	X	X	X	X		X
	2nd flush	X												
5/27/98	1st flush					X	X			X				
	2nd flush					X	X	X	X	X	X	X		X
	Total #	10	10	10	9	10	14	10	9	10	12	9	3	7

Data Analysis

Summaries of the copper and nickel analyses reported at metal finishing facilities, electroplating facilities, semiconductor manufacturing facilities, and at control sites are presented in Tables 3, 4, 5, and 6, respectively. Summary statistics for the data presented in Tables 3-6 are given in Appendix B. Facilities that submitted samples for more than one location have multiple entries in the “Site” column in these tables. Observations which were reported to be below detectable limits are recorded at the corresponding detection limit and are noted with an “ND” entry in the corresponding column.

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Table 3
Summary of Copper and Nickel Concentrations Observed at Metal Finishing Facilities
Concentration units are mg/L

Sample #	Facility	Site	Date	Time	Sample Type	Copper Conc.	Copper ND	Nickel Conc.	Nickel ND
10874	MF-1	A	11/6/97	4:00 PM	1st	0.371		0.058	
10902	MF-1	A	11/10/97	7:30 AM	1st	0.240		0.012	
SW003	MF-1	A	12/4/97	11:55 PM	1st	0.057		0.012	
SW012	MF-1	A	1/2/98	5:30 AM	1st	0.024		0.003	ND
SW017	MF-1	A	1/9/98	4:30 PM	1st	0.077		0.047	
SW025	MF-1	A	1/9/98	6:02 PM	2nd	0.040		0.006	
SW089	MF-1	A	3/12/98	3:00 PM	2nd	0.136		0.015	
SW104	MF-1	A	3/31/98	10:30 AM	2nd	0.090		0.016	
SW132	MF-1	A	5/4/98	5:00 PM	1st	0.025		0.005	
10870	MF-2	A	11/6/97	4:00 PM	1st	0.163		0.102	
10871	MF-2	B	11/6/97	4:15 PM	1st	0.179		0.113	
10885	MF-2	A	11/10/97	6:15 AM	1st	0.030		0.163	
10886	MF-2	B	11/10/97	6:25 AM	1st	0.024		0.023	
10894	MF-2	A	11/10/97	1:15 PM	2nd	0.037		0.036	
10895	MF-2	B	11/10/97	1:25 PM	2nd	0.077		0.096	
SW032	MF-2	A	1/9/98	3:50 PM	1st	0.061		0.023	
SW033	MF-2	B	1/9/98	4:00 PM	1st	0.028		0.007	
SW037	MF-2	A	1/29/98	8:40 AM	2nd	0.111		0.208	
SW038	MF-2	B	1/29/98	8:50 AM	2nd	0.008		0.007	
SW063	MF-2	A	3/5/98	11:05 AM	1st	0.049		0.013	
SW064	MF-2	B	3/5/98	10:55 AM	1st	0.235		0.105	
SW105	MF-2	A	3/31/98	9:10 AM	2nd	0.001	ND	0.004	
SW106	MF-2	B	3/31/98	9:20 AM	2nd	0.074		0.056	
SW120	MF-2	A	5/4/98	4:15 PM	1st	0.012		0.014	
SW121	MF-2	B	5/4/98	4:17 PM	1st	0.033		0.018	
SW148	MF-2	B	5/27/98	6:15 AM	1st	0.326		0.233	
SW149	MF-2	A	5/27/98	6:25 AM	1st	0.085		0.027	
SW150	MF-2	B	5/27/98	8:15 AM	2nd	0.035		0.031	
SW151	MF-2	A	5/27/98	8:25 AM	2nd	0.026		0.009	
10884	MF-3	A	11/10/97	8:55 AM	1st	0.037		0.006	
SW044	MF-3	A	1/29/98	9:00 AM	2nd	0.007		0.003	ND
SW045	MF-3	A	2/12/98	7:45 AM	1st	0.005		0.003	ND
SW046	MF-3	A	2/12/98	10:00 AM	2nd	0.004		0.003	ND
SW051	MF-3	A	3/5/98	11:00 AM	1st	0.001		0.003	ND
SW052	MF-3	A	3/5/98	1:20 PM	2nd	0.011		0.004	
SW077	MF-3	A	3/12/98	3:10 PM	1st	0.001	ND	0.012	
SW078	MF-3	A	3/12/98	4:15 PM	2nd	0.003		0.003	ND
SW092	MF-3	A	3/16/98	7:30 AM	1st	0.001	ND	0.003	ND
SW093	MF-3	A	3/16/98	9:15 AM	2nd	0.002		0.003	
SW094	MF-3	A	3/23/98	3:15 PM	1st	0.002		0.003	ND
SW095	MF-3	A	3/23/98	4:15 PM	2nd	0.002		0.003	ND
SW157	MF-3	A	5/27/98	8:25 AM	1st	0.007		0.003	ND

Inspection of Tables 3 through 6, reveals that there are a number of variables associated with each sample, and that the interpretation of the data may not be a straightforward process. To illustrate this point, note that for each sample taken, there is an associated type of facility (MF, EP, EEC, or CIC), facility code (i.e. MF1, MF2, etc.), sample type (1^{st} or 2^{nd} flush), and potentially multiple sites within a facility. The purpose of this data analysis section is to explore the observed results for important factors and/or trends and to facilitate the interpretation of the results.

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Table 4
Summary of Copper and Nickel Concentrations Observed
at Electroplating Facilities
Concentration units are mg/L

Sample #	Facility	Site	Date	Time	Sample Type	Copper Conc.	Copper ND	Nickel Conc.	Nickel ND
10904	EP-1	A	11/10/97	8:15 AM	1st	0.718		0.028	
10905	EP-1	B	11/10/97	9:45 AM	2nd	0.172		0.015	
SW026	EP-1	A	1/9/98	4:45 PM	2nd	0.528		0.016	
SW027	EP-1	B	1/9/98	5:00 PM	2nd	0.022		0.002	
SW028	EP-1	A	1/9/98	3:45 PM	1st	1.523		0.044	
SW029	EP-1	B	1/9/98	3:50 PM	1st	0.054		0.012	
SW065	EP-1	A	3/5/98	1:15 PM	2nd	0.650		0.014	
SW066	EP-1	B	3/5/98	1:25 PM	2nd	0.041		0.003	ND
SW096	EP-1	B	3/23/98	3:30 PM	1st	0.115		0.023	
SW097	EP-1	A	3/23/98	3:40 PM	1st	2.343		0.288	
SW098	EP-1	B	3/23/98	4:40 PM	2nd	0.088		0.006	
SW099	EP-1	A	3/23/98	3:40 PM	2nd	1.170		0.065	
SW118	EP-1	B	3/31/98	9:15 AM	2nd	0.010		0.003	ND
SW119	EP-1	A	3/31/98	9:00 AM	2nd	0.340		0.007	
SW128	EP-1	A	5/4/98	4:20 PM	1st	0.696		0.019	
SW129	EP-1	B	5/4/98	4:30 PM	1st	0.025		0.006	
SW133	EP-1	A	5/11/98	1:30 AM	1st	1.498		0.062	
SW134	EP-1	B	5/11/98	1:45 PM	1st	0.081		0.015	
SW135	EP-1	A	5/11/98	3:00 PM	2nd	0.950		0.029	
SW136	EP-1	B	5/11/98	3:15 PM	2nd	0.262		0.044	
SW013	EP-2	A	1/9/98	4:10 PM	1st	0.137		0.013	
SW021	EP-2	A	1/9/98	5:36 PM	2nd	0.030		0.004	
SW034	EP-2	A	1/14/98	11:00 AM	2nd	0.346		0.088	
SW035	EP-2	A	1/29/98	9:05 AM	2nd	0.084		0.019	
SW047	EP-2	A	3/5/98	11:50 AM	1st	0.163		0.017	
SW048	EP-2	B	3/5/98	12:00 PM	1st	0.103		0.004	
SW059	EP-2	A	3/5/98	2:50 PM	2nd	0.184		0.022	
SW060	EP-2	B	3/5/98	3:05 PM	2nd	0.232		0.012	
SW086	EP-2	A	3/12/98	3:00 PM	1st	0.150		0.021	
SW109	EP-2	A	3/31/98	8:40 AM	2nd	0.434		0.094	
SW124	EP-2	A	5/4/98	4:55 PM	1st	0.032		0.016	
SW140	EP-2	A	5/11/98	1:30 PM	1st	0.325		0.079	
10875	EP-3	A	11/6/97	4:00 PM	1st	1.149		0.152	
10876	EP-3	B	11/6/97	4:00 PM	1st	13.24 [1]		0.944 [1]	
10901	EP-3	B	11/10/97	7:30 AM	1st	1.368		0.272	
10903	EP-3	A	11/10/97	7:30 AM	1st	2.451		0.129	
SW001	EP-3	A	12/4/97	11:50 AM	1st	0.451		0.660	
SW002	EP-3	B	12/4/97	11:45 PM	1st	0.289		0.038	
SW010	EP-3	A	1/2/98	5:00 AM	1st	0.152		0.003	ND
SW011	EP-3	B	1/2/98	5:15 AM	1st	0.210		0.047	
SW015	EP-3	A	1/9/98	4:25 PM	1st	0.268		0.011	
SW016	EP-3	B	1/9/98	4:27 PM	1st	0.572		0.127	
SW023	EP-3	A	1/9/98	5:53 PM	2nd	0.608		0.038	
SW024	EP-3	B	1/9/98	5:56 PM	2nd	0.217		0.096	
SW087	EP-3	A	3/12/98	2:15 PM	1st	0.966		0.105	
SW088	EP-3	B	3/12/98	2:20 PM	1st	0.098		0.029	
SW090	EP-3	A	3/13/98	5:10 AM	2nd	0.132		0.014	
SW091	EP-3	B	3/13/98	5:00 AM	2nd	0.232		0.068	
SW102	EP-3	A	3/31/98	10:15 AM	2nd	0.178		0.015	
SW103	EP-3	B	3/31/98	10:00 AM	2nd	0.437		0.064	
SW130	EP-3	A	5/4/98	5:00 PM	1st	0.060		0.006	
SW131	EP-3	B	5/4/98	5:00 PM	1st	0.302		0.138	

1. Outlier not used in data analysis

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Table 5
Summary of Copper and Nickel Concentrations Observed
at Semiconductor Manufacturing Facilities

					Sample	Copper		Nickel	
Sample #	Facility	Site	Date	Time	Type	mg/L	ND	mg/L	ND
10872	EEC-3	B	11/6/97	4:30 PM	1st	0.064		0.010	
10873	EEC-3	A	11/6/97	4:10 PM	1st	0.027		0.012	
10896	EEC-3	A	11/10/97	2:05 PM	2nd	0.042		0.008	
10897	EEC-3	E	11/10/97	1:29 PM	2nd	0.022		0.013	
10898	EEC-3	B	11/10/97	2:00 PM	2nd	0.011		0.007	
10899	EEC-3	C	11/10/97	1:20 PM	2nd	0.005		0.003	ND
10900	EEC-3	D	11/10/97	1:36 PM	2nd	0.014		0.003	ND
SW039	EEC-3	C	1/29/98	8:58 AM	1st	0.013		0.009	
SW040	EEC-3	D	1/29/98	9:06 AM	1st	0.008		0.004	
SW041	EEC-3	A	1/29/98	9:06 AM	1st	0.012			
SW042	EEC-3	E	1/29/98	9:06 AM	1st	0.024		0.003	ND
SW043	EEC-3	B	1/29/98	9:06 AM	1st	0.146		0.031	
SW067	EEC-3	A	3/5/98	11:41 AM	1st	0.011		0.009	
SW068	EEC-3	A	3/5/98	1:33 PM	2nd	0.017		0.005	
SW069	EEC-3	D	3/5/98	11:18 AM	1st	0.010		0.003	ND
SW070	EEC-3	D	3/5/98	1:41 PM	2nd	0.025		0.004	
SW071	EEC-3	E	3/5/98	11:31 AM	1st	0.056		0.009	
SW072	EEC-3	E	3/5/98	1:55 PM	2nd	0.009		0.003	
SW073	EEC-3	C	3/5/98	11:08 AM	1st	0.004		0.004	
SW074	EEC-3	C	3/5/98	1:50 PM	2nd	0.002		0.011	
SW075	EEC-3	B	3/5/98	11:37 AM	1st	0.164		0.036	
SW076	EEC-3	B	3/5/98	2:00 PM	2nd	0.177		0.036	
SW079	EEC-3	A	3/12/98	3:08 PM	1st	0.006		0.003	ND
SW080	EEC-3	E	3/12/98	3:05 PM	1st	0.044		0.005	
SW081	EEC-3	B	3/12/98	3:06 PM	1st	0.182		0.050	
SW082	EEC-3	C	3/12/98	2:43 PM	1st	0.022		0.020	
SW083	EEC-3	D	3/12/98	2:53 PM	1st	0.009		0.003	
SW113	EEC-3	C	3/31/98	9:30 AM	2nd	0.004		0.004	
SW114	EEC-3	D	3/31/98	9:46 AM	2nd	0.006		0.011	
SW115	EEC-3	E	3/31/98	9:56 AM	2nd	0.004		0.008	
SW116	EEC-3	B	3/31/98	10:02 AM	2nd				
SW117	EEC-3	A	3/31/98	10:10 AM	2nd	0.003		0.003	
SW141	EEC-3	E	5/11/98	1:20 PM	1st	0.721		0.068	
SW142	EEC-3	B	5/11/98	1:35 PM	1st	0.232		0.052	
SW143	EEC-3	A	5/11/98	1:45 PM	1st	0.033		0.031	
SW144	EEC-3	C	5/11/98	1:10 PM	1st	0.028		0.036	
SW145	EEC-3	D	5/11/98	1:15 PM	1st	0.018		0.010	
SW159	EEC-3	A	5/27/98	8:00 AM	1st	1.509		0.492	
SW160	EEC-3	E	5/27/98	7:45 AM	1st	0.099		0.018	
SW161	EEC-3	B	5/27/98	7:50 AM	1st	0.069		0.031	
SW162	EEC-3	C	5/27/98	7:30 AM	1st	0.024		0.021	
SW163	EEC-3	D	5/27/98	7:38 AM	1st	0.005		0.003	ND
SW164	EEC-3	A	5/27/98	10:10 AM	2nd	0.256		0.204	
SW165	EEC-3	B	5/27/98	9:58 AM	2nd	0.028		0.008	
SW166	EEC-3	B	5/27/98	9:50 AM	2nd	0.051		0.016	
SW167	EEC-3	C	5/27/98	9:56 AM	2nd	0.037		0.038	
SW168	EEC-3	D	5/27/98	9:53 AM	2nd	0.001	ND	0.003	ND
SW031	EEC-1		1/9/98	4:20 PM	1st	0.023		0.003	
SW036	EEC-1		1/29/98	9:10 AM	2nd	0.014		0.003	ND
SW049	EEC-1		3/5/98	12:10 PM	1st	0.035		0.005	
SW061	EEC-1		3/5/98	3:15 PM	2nd	0.032		0.007	
SW085	EEC-1		3/12/98	2:45 PM	1st	0.068		0.025	
SW101	EEC-1		3/23/98	3:18 PM	1st	0.078		0.022	
SW107	EEC-1		3/31/98	8:30 AM	2nd	0.024		0.015	
SW123	EEC-1		5/4/98	4:45 PM	1st	0.057		0.008	
SW147	EEC-1		5/11/98	1:25 PM	1st	0.042		0.010	
SW156	EEC-1		5/27/98	9:30 AM	2nd	0.278		0.055	
SW030	EEC-2		1/9/98	4:20 PM	1st	0.012		0.004	
SW050	EEC-2		3/5/98	11:55 AM	1st	0.014		0.004	
SW062	EEC-2		3/5/98	3:05 PM	2nd	0.012		0.005	
SW084	EEC-2		3/12/98	3:20 PM	1st	0.016		0.006	
SW100	EEC-2		3/23/98	3:05 PM	1st	0.038		0.017	
SW108	EEC-2		3/31/98	8:46 AM	2nd	0.001	ND	0.009	
SW122	EEC-2		5/4/98	4:25 PM	1st	0.046		0.049	
SW146	EEC-2		5/11/98	1:10 PM	1st	0.027		0.012	
SW155	EEC-2		5/27/98	9:20 AM	2nd	0.019		0.009	

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Table 6
Summary of Copper and Nickel Concentrations Observed at Control Commercial / Industrial Sites
Concentration units are mg/L

					Sample	Copper		Nickel	
Sample #	Facility	Site	Date	Time	Type	Conc.	ND	Conc.	ND
10869	CIC-3		11/6/97	4:50 PM	1st	0.122		0.015	
SW014	CIC-3		1/9/98	4:25 PM	1st	0.008		0.004	
SW022	CIC-3		1/9/98	5:44 PM	2nd	0.007		0.012	
SW018	CIC-4		1/9/98	3:55 PM	1st	0.078		0.015	
SW053	CIC-4		3/5/98	10:55 AM	1st	0.050		0.017	
SW056	CIC-4		3/5/98	2:20 PM	2nd	0.032		0.003	ND
SW112	CIC-4		3/31/98	9:13 AM	2nd	0.003		0.004	
SW126	CIC-4		5/4/98	4:30 PM	1st	0.298		0.036	
SW137	CIC-4		5/11/98	1:35 PM	1st	0.065		0.017	
SW154	CIC-4		5/27/98	9:50 AM	2nd	0.030		0.028	
SW008	CIC-2		12/14/97	1:25 AM	1st	0.028		0.042	
SW009	CIC-2		12/14/97	4:25 AM	2nd	0.006		0.004	
SW020	CIC-2		1/9/98	4:20 PM	1st	0.159		0.185	
SW055	CIC-2		3/5/98	11:25 AM	1st	0.025		0.008	
SW058	CIC-2		3/5/98	2:40 PM	2nd	0.002		0.003	ND
SW111	CIC-2		3/31/98	9:00 AM	2nd	0.002		0.003	ND
SW127	CIC-2		5/4/98	4:45 PM	1st	0.084		0.073	
SW139	CIC-2		5/11/98	1:20 PM	1st	0.051		0.067	
SW152	CIC-2		5/27/98	9:10 AM	2nd	0.111		0.037	
10883	CIC-1		11/6/97	4:00 PM	1st	0.062		0.032	
SW004	CIC-1		12/5/97	1:00 AM	1st	0.027		0.003	ND
SW005	CIC-1		12/5/97	2:00 AM	2nd	0.011		0.003	ND
SW006	CIC-1		12/14/97	1:55 AM	1st	0.013		0.003	ND
SW007	CIC-1		12/14/97	4:55 AM	2nd	0.003		0.003	ND
SW019	CIC-1		1/9/98	4:05 PM	1st	0.012		0.004	
SW054	CIC-1		3/5/98	11:05 AM	1st	0.007		0.011	
SW057	CIC-1		3/5/98	2:30 PM	2nd	0.010		0.003	ND
SW110	CIC-1		3/31/98	9:25 AM	2nd	0.002		0.003	ND
SW125	CIC-1		5/4/98	4:15 PM	1st	0.121		0.039	
SW138	CIC-1		5/11/98	1:40 PM	1st	0.029		0.016	
SW153	CIC-1		5/27/98	9:40 AM	2nd	0.043		0.009	

Graphical data summaries presenting the results summarized in Tables 3 - 6 are given in Figures 1- 10. Figures 1 through 10 are box and whisker plots presenting observed copper and nickel concentrations at each of the facilities. The upper and lower edges of the boxes presented in these figures represent the 25th and 75th percentiles of the observed data. The horizontal line inside each box represents the median of the observed data, and the vertical lines above and below the boxes represent the largest and smallest observed values that are not statistical outliers. Extreme values and outliers are represented as asterices and circles, respectively.

Figures 1 and 2 present observed concentrations of copper at the control sites. In Figure 1, all of the collected data from the different sites are grouped together, and the two boxes represent first and second flush results. In Figure 2, data have been separated into individual sites and also present first and second flush results.

Figure 1

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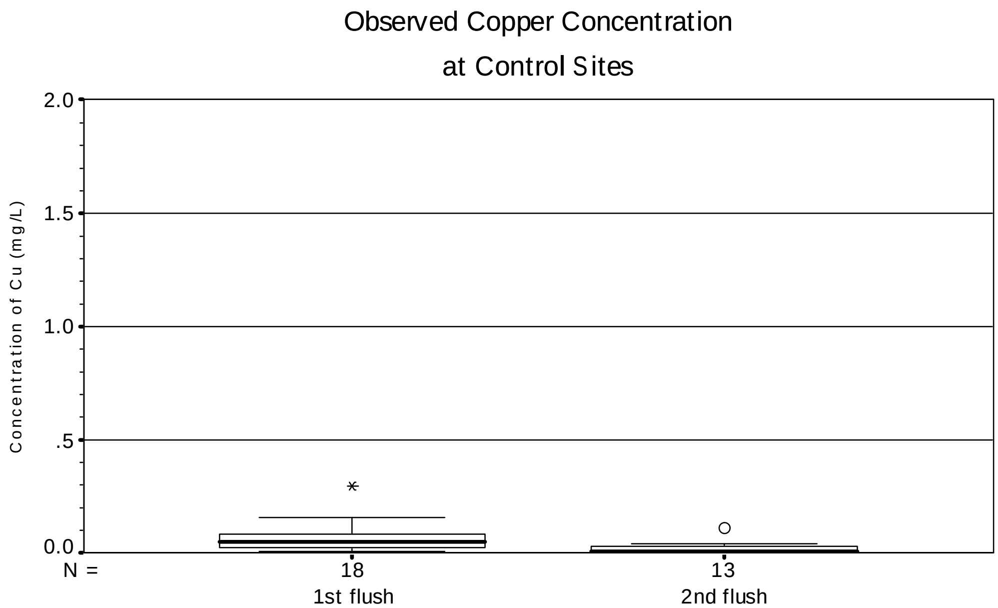
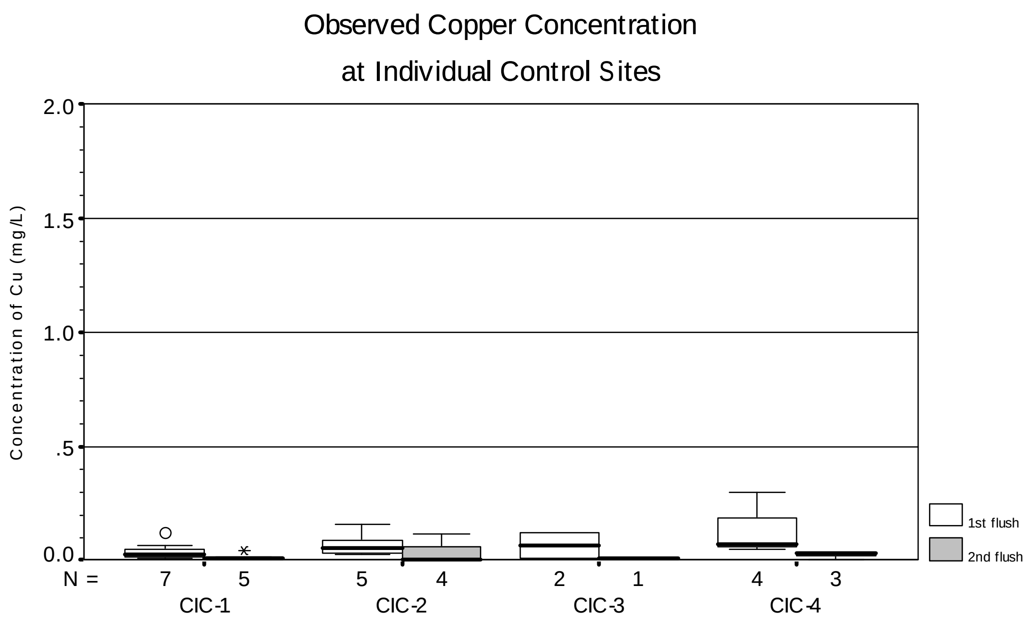


Figure 2



Several observations may be made from inspection of Figures 1 and 2:

- Median values for first and second flush samples are very similar in magnitude for all sites;
- Observed concentrations of copper are similar for all sites; and
- Slightly more variability was present in first flush samples than second flush samples.

Similarly, Figures 3 and 4 present observed nickel concentrations at the commercial / industrial control sites. Figure 3 presents the results for the grouped data, and Figure 4 presents data for individual control sites. In each case, results from first and second flush observations may be compared. Inspection of Figures 3 and 4 reveals that similar observations may be noted for observed nickel results as those noted above for copper.

Figure 3

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Observed Nickel Concentration

at Control Sites

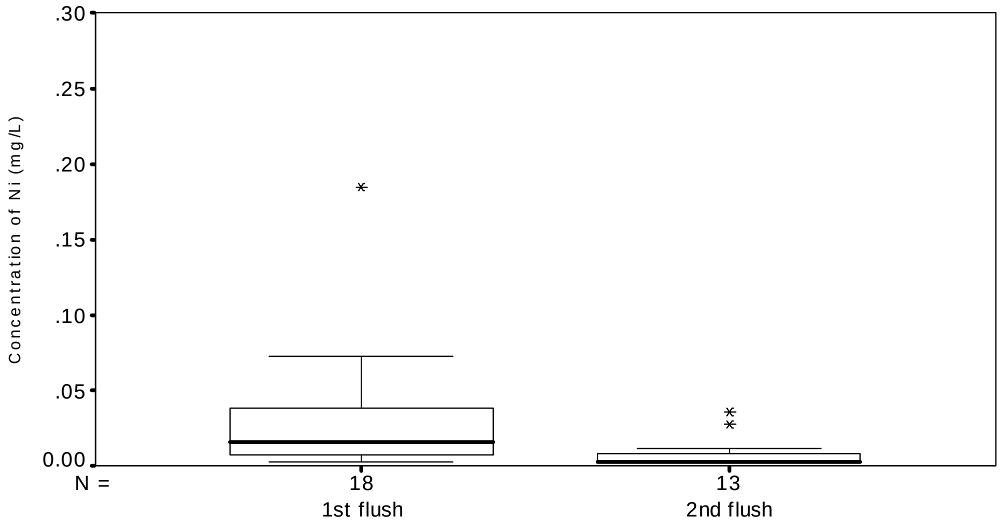
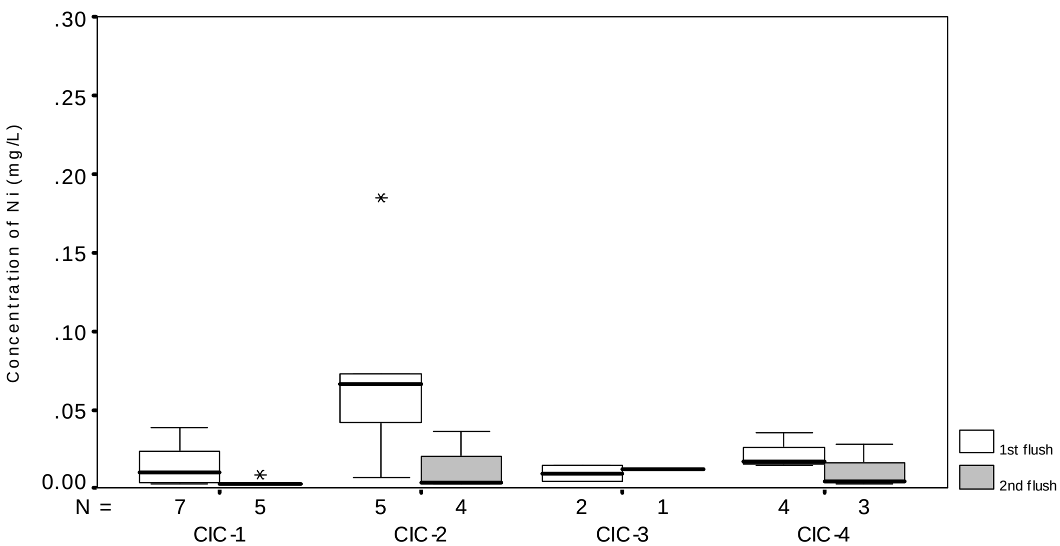


Figure 4

Observed Nickel Concentration

at Individual Control Sites



Figures 5 and 6 present observed results for electroplating facilities for copper and nickel, respectively. Comparison of the results from the electroplating facilities and the control sites reveals that elevated levels of both copper and nickel were reported in some of the electroplating facility observations. It can also be noted that significant levels of variability were present for both copper and nickel observations reported by electroplating facilities.

Figure 5

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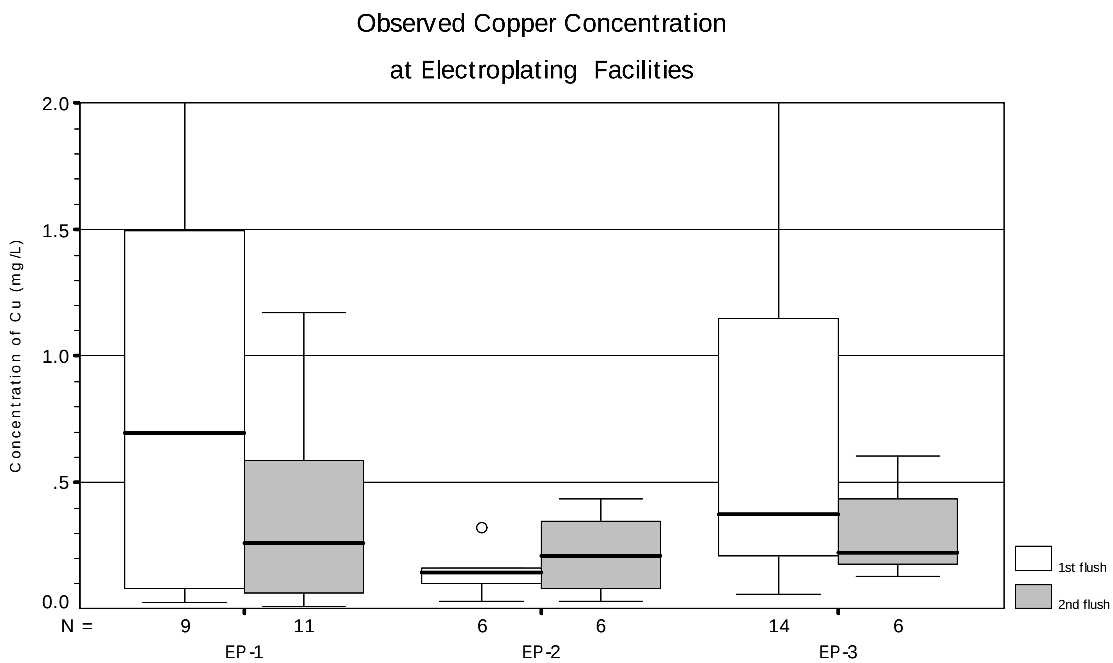
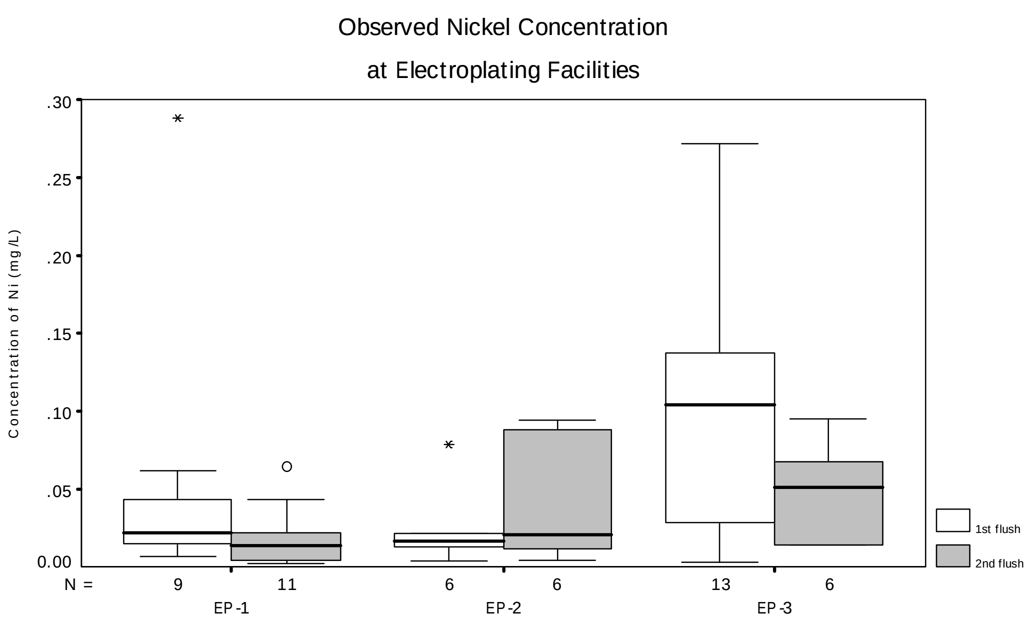


Figure 6



Figures 7 and 8 present results observed from metal finishing facilities for copper and nickel, respectively. Inspection of Figures 7 and 8 will reveal that copper and nickel concentrations appeared to be lower at facility MF-3 than either of the other participating metal finishing facilities.

Figure 7

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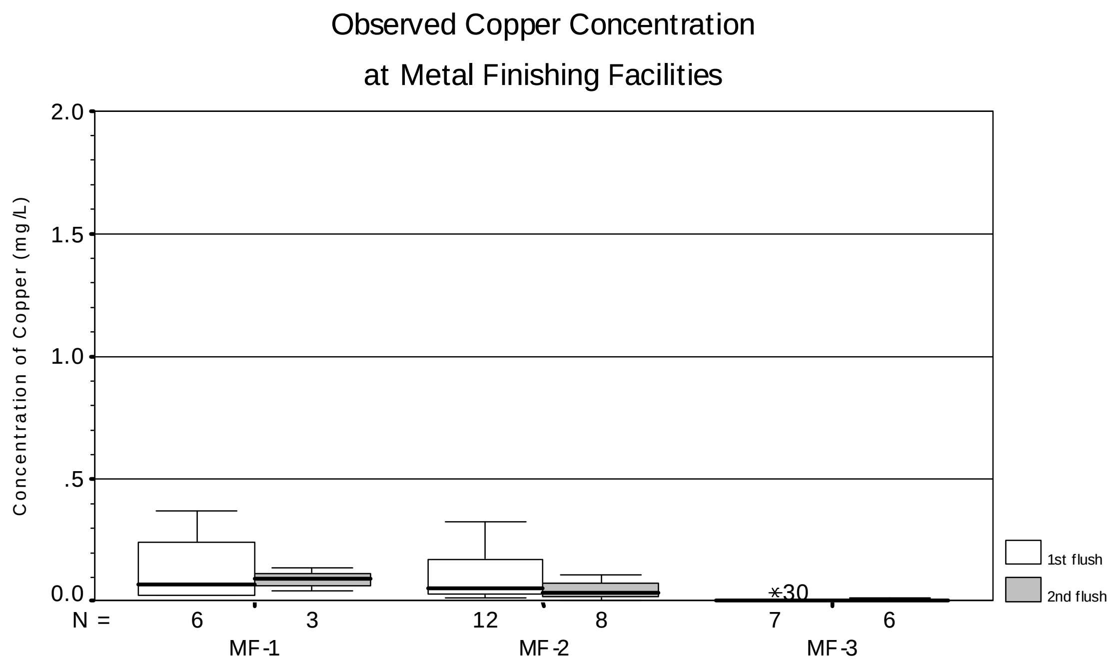
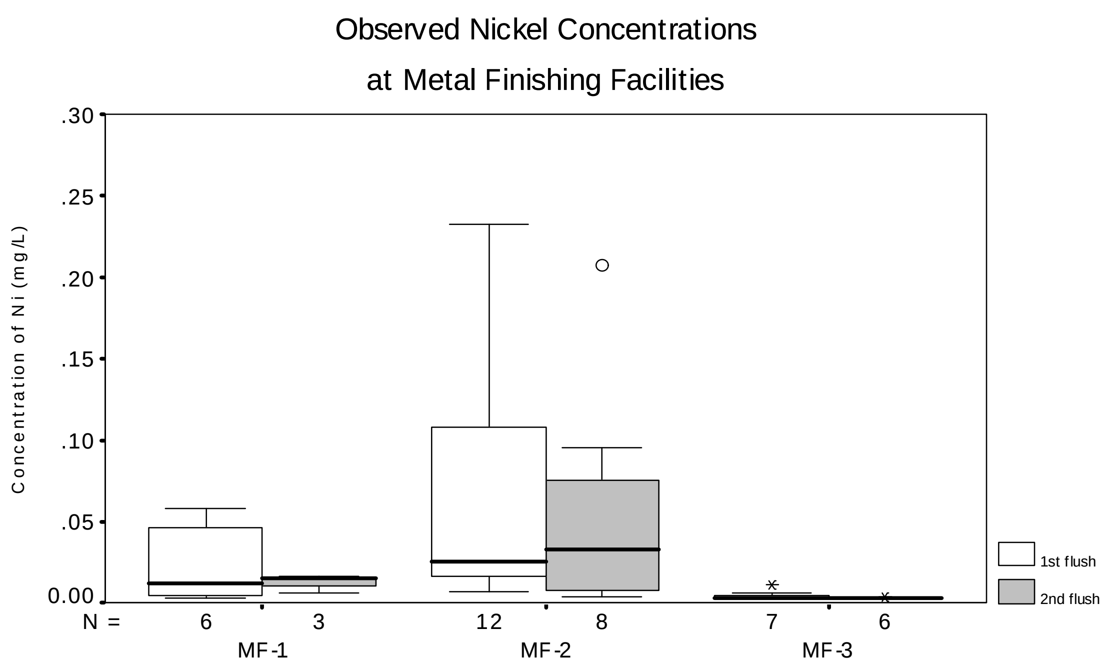


Figure 8



Comparison of Figures 7 and 8, with those presented previously indicates that in general, observed copper concentrations appear to be slightly lower at metal finishing and control facilities than at electroplating facilities. Further, median observed nickel concentrations at control sites, metal finishing, and electroplating facilities appear to be very similar with the possible exception of first flush samples from EP-3. The primary difference among the data presented thus far appears to be the increased variability observed at metal finishing and electroplating facilities when compared to the control sites.

Figures 9 and 10 present results observed from semiconductor manufacturing facilities for copper and nickel, respectively.

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Figure 9

Observed Copper Concentration

at Semiconductor Manufacturing Facilities

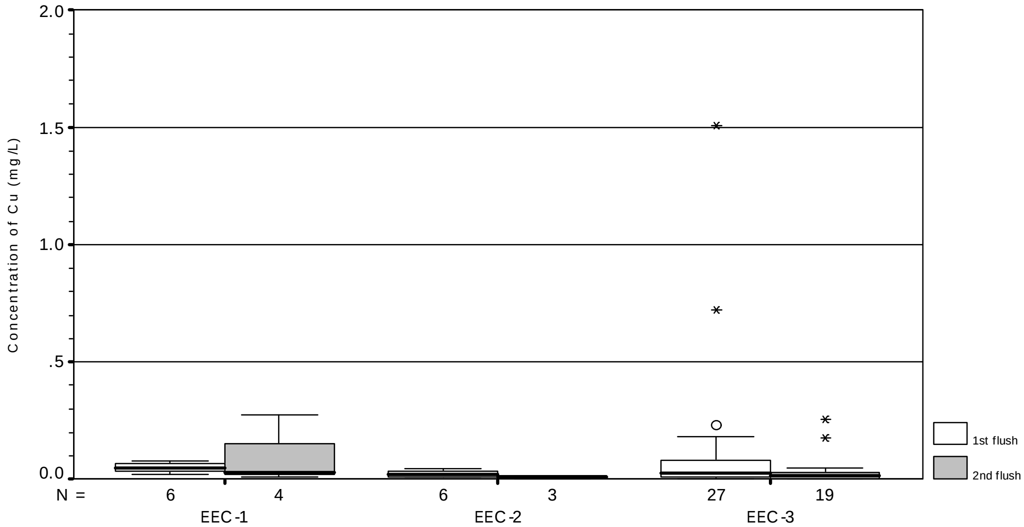
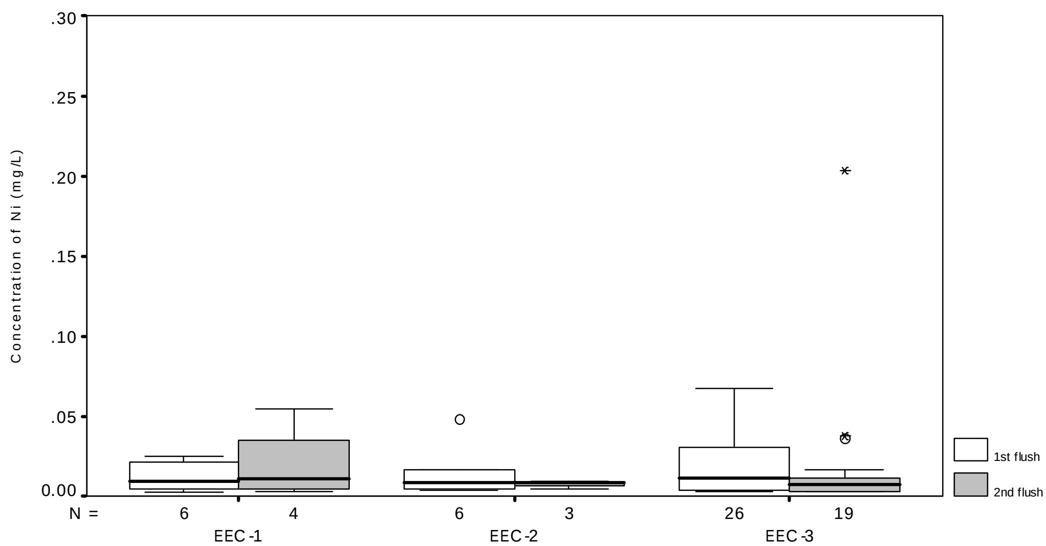


Figure 10

Observed Nickel Concentrations

at Semiconductor Manufacturing Facilities



Inspection of Figures 9 and 10 reveals that the observed results from all of the semiconductor manufacturing facilities are very similar, with low observed concentrations of both copper and nickel. Moreover, comparison of the observed copper and nickel results from the semiconductor manufacturing facilities and the control commercial and industrial sites (Figures 2, 4, 9, and 10) reveals that the results for these two classes of facilities are very comparable.

A final review of the data presented above shows that the principal difference between first and second flush samples is the increased variability found in the first flush samples. Close inspection demonstrates that the median of the first and second flush observations for most of the facilities are very comparable for both copper and nickel. From this observation it may be concluded that, in general, differences between first and second flush samples would be very difficult to discern due to the variability inherent in the data.

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The fact that several of the facilities sampled and reported results from multiple sites within their facility is an issue which has not yet been addressed. Given that the representatives from the facilities were not able to identify a single "representative" site within the facility, it is suggested that any of the sampling sites could have been chosen over the others for use in the pilot project. Further, it is suggested that averaging or weighting of these samples could bias the findings of this study. It is therefore suggested that the most unbiased manner of data analysis is to treat all data collected at each of the facilities equivalently (i.e. assume that all samples are independent and equally representative of the stormwater quality from the facility).

Based on the data, findings, and arguments presented above, graphical summaries showing a comparison of the observed copper and nickel concentrations between metal finishing, electroplating, and semiconductor manufacturing facilities and the commercial / industrial control sites, are presented below in Figures 11 and 12. Boxes shown in Figures 11 and 12 represent all of the observations collected for each of the types of facilities, including first and second flush samples and observations collected at multiple sites within a given facility.

To determine whether there were significant differences in observed copper and/or nickel concentrations between the commercial / industrial control facilities and facilities from the targeted industries, a series of statistical tests were conducted. T-tests are commonly used to compare two data sets to determine whether the two population means are equal. However, before performing statistical tests it is important to ensure that the underlying assumptions are appropriate. T-tests require that the samples are random observations selected from approximately normally distributed populations with equal variances. It can be shown that the data presented above do not meet these criteria.

Nonparametric tests require limited distributional assumptions about the data, but are not as powerful as the t-test (i.e. t-test will detect true differences between two populations more often than nonparametric tests). The Mann-Whitney test (aka Wilcoxin test) does not require assumptions about the shape of the underlying distribution. This test is based on the rank of the data to be tested rather than the actual observed values. If the two distributions are equal, values from one group should not consistently precede values in the other.

Figure 11

Comparison of Observed Copper Results

for All Participating Facilities

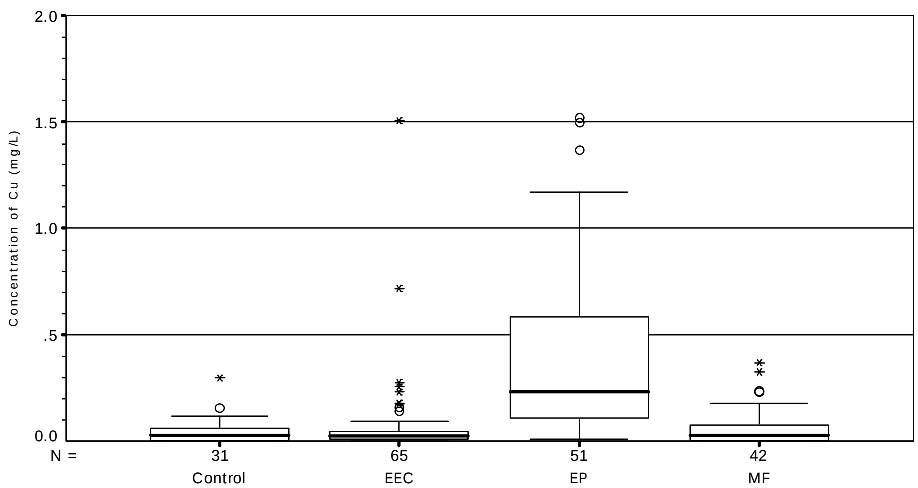

Figure 12

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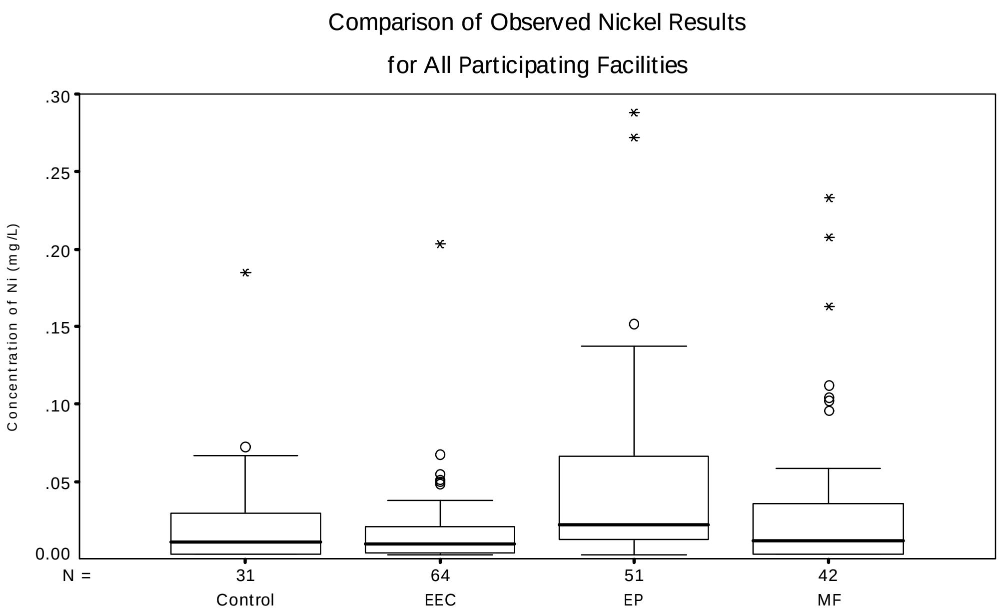

Results from the Mann-Whitney tests are presented in Table 7 along with relevant summary statistics describing the data sets used to conduct the tests. Inspection of Table 7 reveals that the observed differences between semiconductor manufacturing facilities and metal finishing facilities in comparison to the control group are not statistically significant. If the control group and semiconductor manufacturing facilities population means were equal, the probability of observing differences as least as large as those observed during this study correspond to 0.95 and 0.93 for copper and nickel, respectively. Since these values are greater than the threshold value (0.01 or 0.05), the hypothesis that the population means are equal cannot be rejected.

Similarly, results for metal finishing facilities demonstrate that the probability of observing differences as least as large as those observed during this study correspond to 0.85 and 0.54 for copper and nickel, respectively. Again, the hypothesis of equal means cannot be rejected.

Results from electroplating facilities for both copper and nickel demonstrate statistically significant results at p=0.01. These results indicate that the probability is less than p=0.01 that the population means of the control group and the electroplating group are the same.

Table 7
Comparison of Observed Data Between Targeted Industries and Control Facilities
Concentration units in mg/L

Type of		Copper		Different			Nickel		Different	
Facility	# Samples	Mean	Std Dev	Than Control [1]	p value [2]	# Samples	Mean	Std Dev	Than Control [1]	p value [2]
Control	31	0.048	0.062	NA	NA	31	0.023	0.035	NA	NA
Semi Conductor Manufacturing	65	0.078	0.208	N	0.95	64	0.025	0.065	N	0.93
Electroplating	51	0.464	0.559	Y	0.00	51	0.061	0.105	Y	0.003
Metal Finishing	42	0.065	0.089	N	0.85	42	0.036	0.056	N	0.54

1. Significantly different than the Control group at 99% confidence level
2. Probability that a difference at least as large as that observed would occur if the population means were equal

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As stated previously, a comprehensive quality assurance (QA) program[3] was carried out during the course of this pilot study. The purpose of the QA program was to ensure that the accuracy of the observed results could be stated with a high level of confidence. Quality control and quality assessment procedures were contained as components of the QA program. All samples were collected as described previously, forwarded to the City of Sunnyvale WPCP laboratory using proper chain of custody protocol, and analyzed by the City of Sunnyvale WPCP Laboratory which is state certified. All standard City of Sunnyvale WPCP laboratory QA/QC protocols[4] were followed.

Additionally, a quality assessment of the reported data was performed using 14 split samples which were analyzed by external laboratories. These split samples were analyzed to corroborate the accuracy and precision of the results reported by the City of Sunnyvale WPCP laboratory. Results from those split samples may be found in Appendix C. The data found in Appendix C and the corresponding data which was presented previously in Tables 3-6, indicate that the results reported by the City of Sunnyvale WPCP laboratory are acceptable both in terms of reliability and reproducibility.

Discussion of Results

The results presented previously indicate that the observed concentrations for both copper and nickel from electroplating facilities were higher than those observed at the commercial / industrial control facilities during this pilot study. Differences were not statistically significant between concentrations of these constituents at the control facilities and either semiconductor manufacturing facilities or metal finishing facilities.

It should be noted that the primary difference between facilities classified as electroplating facilities and those classified as metal finishing facilities is the age of the facility, not necessarily the type of industrial process practiced. In general, electroplating facilities are those that have been in operation since before July, 1983, while metal finishing facilities may be similar in nature and product, but started operating in August, 1983 or more recently. A printed circuit board manufacturer, for example could be classified as either an electroplating facility or as a metal finishing facility depending on when the manufacturing operation started.

The observed copper concentrations for electroplating facilities produced varied results from the three participating facilities. In general, it appears that observed copper concentrations were somewhat lower at EP2 than at the other participating facilities. A likely explanation for this observation is that the EP2 manufacturing processes involve plating of chrome, zinc, and aluminum oxidation, rather than copper. EP1 and EP3 both have manufacturing processes that use copper sheets for printed circuit boards.

The observed nickel concentrations for electroplating facilities also produced varied results from the three participating facilities. The results are somewhat more difficult to generalize, however it appears that observed nickel concentrations at EP3 were slightly higher than at the other facilities. EP3 and EP1 both have nickel plating baths as a fundamental portion of their manufacturing processes. Given the presence of these nickel plating baths, air deposition or other transport mechanisms may account for some of the nickel observed in the stormwater.

Observed copper concentrations reported from metal finishing facilities during the course of this pilot study were very comparable to those observed at the commercial / industrial control facilities. The observed nickel concentrations for metal finishing facilities varied considerably for the three participating facilities. The observed results at MF3 are lower in nickel concentration than the other facilities, and it appears that the concentrations observed at MF2 are higher than the other facilities. MF3 has multiple plating lines with a number of scrubber systems that appear to minimize air particulate dispersion. MF2 has a nickel plating line that may account for slightly increased nickel concentrations in the stormwater due to particle air deposition to the parking area. MF1 is a new facility that began operation in June of 1997. The main process for MF1 is cleaning and micro-etching of printed circuit boards. This facility does not utilize process-plating baths.

[3] Standard Methods for the Examination of Water and Wastewater, 19th Ed., 1995, Section 1020, pp.1-4:1-8.
[4] City of Sunnyvale, “WPCP Laboratory Quality Assurance Program Document”, July, 1996.

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Both copper and nickel concentrations reported from semiconductor manufacturing facilities during the course of this pilot study were very comparable to those observed from the commercial / industrial control facilities. Several factors may account for the low levels of copper and nickel concentrations reported from these facilities. All three facilities have enclosed industrial and wastewater pretreatment process systems that minimize stormwater contamination before entering the stormwater system. Further, none of these facilities use copper in their processes, most likely restricting copper contamination to motor vehicle traffic. Some semiconductor manufacturing facilities utilize a nickel sputtering technique the atomizes nickel ions, which are then plated onto a silicon substrate. This process does not produce off gassing of nickel ions and would not result in contaminated process venting. All solvent gases are burned through a catalytic oxidizer and toxic gases are sent through scrubbing units that discharge wastewater to the treatment system. The toxic gases used for this process are generally phosphine, arsine, silane, and dichlorosilane.

Related Work - City of San Jose

The City of San Jose conducted a pilot program to evaluate the suitability of the MCMP data for assessing pollutant loading for the watershed, to assess the significance of industrial stormwater discharges relative to the MCMP, and to determine the extent to which industries have met the objectives of the General Permit and implemented SWPPPs. A detailed discussion of that work can be found under separate cover[5]. Following is a brief summary of those efforts.

Printed circuit board manufacturers in San Jose were surveyed to determine the extent to which SWPPPs were developed and implemented, and a pilot scale source monitoring program was implemented to evaluate the effectiveness of the currently employed BMPs at two printed circuit board manufacturers.

San Jose's investigation determined that the development of SWPPP and BMPs to control pollutants is not widely practiced and documented by industrial facilities in San Jose. Moreover, the source monitoring program identified industrial venting processes to rooftops as a likely significant contributor of copper and nickel to stormwater runoff from printed circuit board manufacturers.

Recommendations and Conclusions

When average results from this investigation are compared to those reported in the MCMP, it is found that for all types of facilities, the observed mean copper concentrations were very similar given the variability inherent in the data. Further, average background residential copper concentrations reported in the MCMP are nearly identical to the average concentration of copper for the commercial/industrial control facilities investigated during the pilot study.

Nickel results from the pilot study do not match those reported in the MCMP nearly as well, however. Mean nickel concentrations observed during this investigation were found to be lower than those reported in the MCMP for all classes of facilities by factors ranging from approximately 2 to 5. Moreover, average residential background concentrations of nickel in the MCMP are reported to be approximately twice as high as the results from the pilot study commercial/industrial control sites. Based on these results, it is suggested that the concerns raised regarding the MCMP data, particularly with respect to nickel may be justified. It is likely that the lower concentrations observed during this pilot study as compared to the MCMP data are due to the fact that lower detection limits were used, thus yielding a more accurate estimate of the concentration of nickel in the industrial runoff.

A significant finding of this pilot study is that the observed results for different facilities within a "facility class" (i.e. metal finishers, electroplaters, or semiconductor manufacturers) varied considerably. This finding should be considered carefully, if the results of this study are to be generalized or extrapolated to make inferences about metal finishers, electroplaters, or semiconductor manufacturers throughout Santa Clara County. The results of this pilot study do demonstrate that the observed concentrations of copper and nickel were higher at the participating electroplating facilities than at the control facilities. However, it needs to be

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[5] City of San Jose, Industrial Stormwater Monitoring Pilot Program, 1998.

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emphasized that this result does not imply that all electroplating facilities in the County would yield similar results. Similarly, it should not be concluded that all metal finishing facilities in the County have stormwater concentrations of copper and nickel similar to all commercial sites. The results of this investigation, may however be used as a screening tool for the identification and characterization of facilities that may contribute significant copper and nickel loadings to the Bay through stormwater runoff.

Based on the investigations described above, a coordinated follow up plan for the upcoming winter season is recommended. It is recommended that the Cities of Sunnyvale and San Jose work together to develop a follow-up plan to the investigations described above. Further, it is recommended that the follow-up plan take advantage of the results obtained in each of the studies conducted during the 1997/98 winter season. Components of the investigation may include:

- Expanded education and outreach to industrial dischargers;
- Investigation of a larger sample of electroplaters (and related facilities) to determine if the results reported in the initial phase of investigation are representative of the entire class of facilities in Santa Clara Valley;
- Collaboration with industry to identify controllable in-house sources of pollutants; and
- Evaluation of the need for new or improved BMPs once controllable sources have been identified.

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