STANFORD UNIVERSITY MEDICAL CENTER

WATER & WASTEWATER COPPER EVALUATION

Prepared for the
Palo Alto Regional
Water Quality Control Plant

December 1995

PREFACE

This report is an account of a study performed of water and wastewater systems at Stanford University Medical Center. The opinions expressed are those of the authors, and do not necessarily represent the position or policy of either Stanford University Medical Center or the Palo Alto Regional Water Quality Control Plant, the two entities that jointly sponsored the work. Further, the mention in this report of specific equipment or systems is not to be considered an endorsement of same by either Stanford University Medical Center or the Palo Alto Regional Water Quality Control Plant.

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1.0 SUMMARY

1.1 INTRODUCTION

This report presents the results of an evaluation of copper discharges to the sanitary sewer from Stanford University Medical Center (SUMC). Stanford University Medical Center is in general compliance with the requirements of its sewer discharge permit, and is participating in the present review as a volunteer study site.

The evaluation is one of a series of on-site reviews jointly-sponsored by the Palo Alto Regional Water Quality Control Plant (RWQCP) and individual sewer system dischargers in its service area. Copper, nickel, silver, zinc, and other pollutants are of concern to the RWQCP because of the effects of these metals on South San Francisco Bay and on the RWQCP's compliance with its Bay discharge standards.

The report begins with a description of the various hospital facilities at SUMC, summarizes previous water and wastewater studies completed for the site, and then describes work performed during the present effort. Laboratory test results, flow meter readings, and other data are presented in the Appendix.

1.2 SITE DESCRIPTION

Stanford University Medical Center occupies a 70-acre site adjacent to Sand Hill Road at the northern end of the Stanford campus. The Center comprises a number of interconnected facilities, four of which are the focus of the present study:

1. Core Hospital Building (referred to as the "Core");

2. Palo Alto and Stanford Pavilions (the "Pavilions"), located adjacent to the Core;

3. Diagnostic & Treatment Buildings (the "D&T" facility), including laboratories, clinics, and nursing care areas; and

4. Lucile Packard Children's Hospital ("Children's Hospital" or "LPCH").

1.3 STUDY FINDINGS

Site staff compiled a summary of water use in each of the four hospital areas for the period of late-1992 through mid-1994. This summary indicates that the average combined water use in these facilities is about 360,000 gallons per day.

During the same time period, copper concentrations measured in the site's sewer discharge points averaged 0.08 mg/l, while the highest observed level was 0.31 mg/l.

On a flow-weighted basis, the overall amount of copper in the sewer discharge from the studied SUMC facilities averages 0.17 lb/day. This waste copper is believed to be generated by four primary sources:

1. Water Supply - Copper present in the water supply furnished to the site contributes an estimated 0.014 lb/day, or about 8% of this total.

2. Pipe Corrosion - Another 0.123 lb/day, or 75% of the discharged copper load, comes from the site's numerous circulating hot water systems. Most of this copper is believed to be from simple corrosion of the pipe itself. Because of the several miles of piping involved, a relatively modest corrosion rate of 0.001 to 0.002 inches per year is sufficient to produce this amount of copper loading.

   About an eighth of the 0.123 lb/day copper load is contributed by sacrificial anodes used for disinfection in the circulating hot water system of Children's Hospital. This contribution is an estimate based upon vendor literature. The present study did not actually measure the copper waste load from anodes.

3. Kitchen Wastes - Based upon two kitchens serving 8,750 meals, food wastes are estimated to contribute 0.022 lb/day of copper, or 13% of the total.

4. Human Wastes - Most of the remaining 0.006 lb/day of copper discharged by SUMC is believed to come from human wastes, while the balance is from unidentified sources.

1.4 RECOMMENDATIONS

The project team makes four recommendations for managing pipe corrosion within the circulating hot water systems at SUMC:

1. Operations - Operate each recirculating hot water system so as to minimize corrosion. Operational conditions that minimize corrosion include keeping temperatures at or below 140°F, using flow rates at or below 3 feet per second, and keeping air out of the piping system. Routine maintenance of each system should include inspection of control and isolation valves, and closed loop flushing.

2. Monitoring - It is important to monitor corrosion at every opportunity. Therefore, site staff should take physical samples whenever pipe sections need to be replaced during routine maintenance. It would be well to focus this attention initially on

pipe in the locations where the highest copper concentrations have been discovered.

Next, have a qualified test laboratory cut these samples open and examine them for corrosion type and amount. Investigate corrosion reduction measures if these inspections show that the corrosion type and extent may be leading to an unacceptably high pipe failure frequency.

3. Corrosion Reduction - Reductions in corrosion rates and related discharges of copper in the site's wastewater may be possible. Alternative approaches include:

   - Lower chlorine dosage;
   - Periodic chlorine dosage;
   - Alternative disinfection methods;
   - Sacrificial anodes; and
   - Corrosion inhibitor.

4. Other Hospitals - Keep up to date on water system maintenance and disinfection practices at other local hospitals that face similar corrosion issues.

The other waste copper in the SUMC sewer discharge appears to be from human occupancy of the facility. The project team has no recommendations to make for reducing copper wastes from these sources.

2.0 SITE WATER AND SEWER SYSTEMS

2.1 SITE DESCRIPTION:

Stanford University Medical Center occupies a 70-acre site adjacent to Sand Hill Road at the northern end of the Stanford campus. As shown by Exhibit 1, the Center comprises a number of interconnected and separate buildings. The present study focuses upon four of these facilities:

1. Core Hospital Building (referred to as the "Core");

2. Palo Alto and Stanford Pavilions (the “Pavilions”), located adjacent to the Core;

3. Diagnostic & Treatment Buildings (the "D&T" facility), including laboratories, clinics, and nursing care areas; and

4. Lucile Packard Children’s Hospital (“Children’s Hospital” or “LPCH”).

The Core area of SUMC dates to 1968, while the other buildings have been built during the last seven to ten years. Clinics, laboratories, offices, and public service areas such as the cafeteria occupy the Core building. The Palo Alto and Stanford Pavilions, which were originally used for in-patient care and nursing, are now dedicated to offices, labs, and treatment clinics.

Both pavilion wings and the D&T facility have been built as part of Stanford’s on-going Hospital Modernization Project (the "HMP"). Children’s Hospital, connected to the north side of the D&T facility, is operated as a separate institution.

2.2 PRIOR STUDIES:

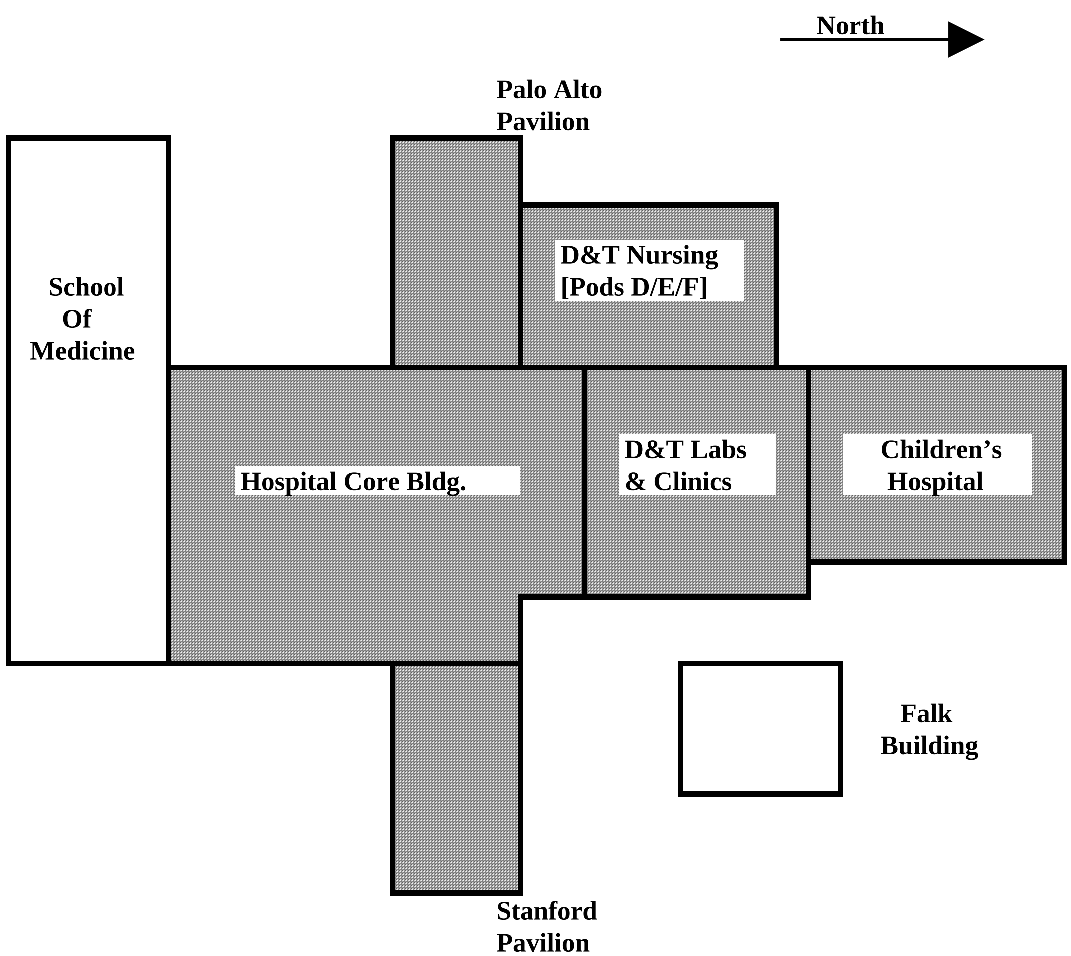
Two earlier utility studies examined water use in the D&T Building, and copper in the sanitary sewer discharges of both the Core and D&T Buildings. [References 1 & 2]

1. D&T Water Use Study - This study [Ref 1], conducted in early-1992 by Water Resources Engineering, determined that the D&T portion of the hospital was using about 400,000 cubic feet of water each month. About one-third of this total flow was used in film processors. Another quarter of the water was used in sterilizer equipment. The remainder was used by sinks, showers, toilets, and utilities in both laboratory and patient care areas. Results from this earlier study are used in the present effort.

2. SUMC Copper Waste Study - A sewer discharge study [Ref 2], completed in 1993 by Kennedy/Jenks Consultants, evaluated both laboratory and clinic areas in an effort to find sources of waste copper sufficient to produce the concentrations observed in SUMC sanitary sewer discharges. In the end, this study concluded that water pipe corrosion was the most likely source of waste copper found. The present study is an extension of this earlier work.

There have not been any previous wastewater studies of Children's Hospital.

Exhibit 1
Stanford University Medical Center

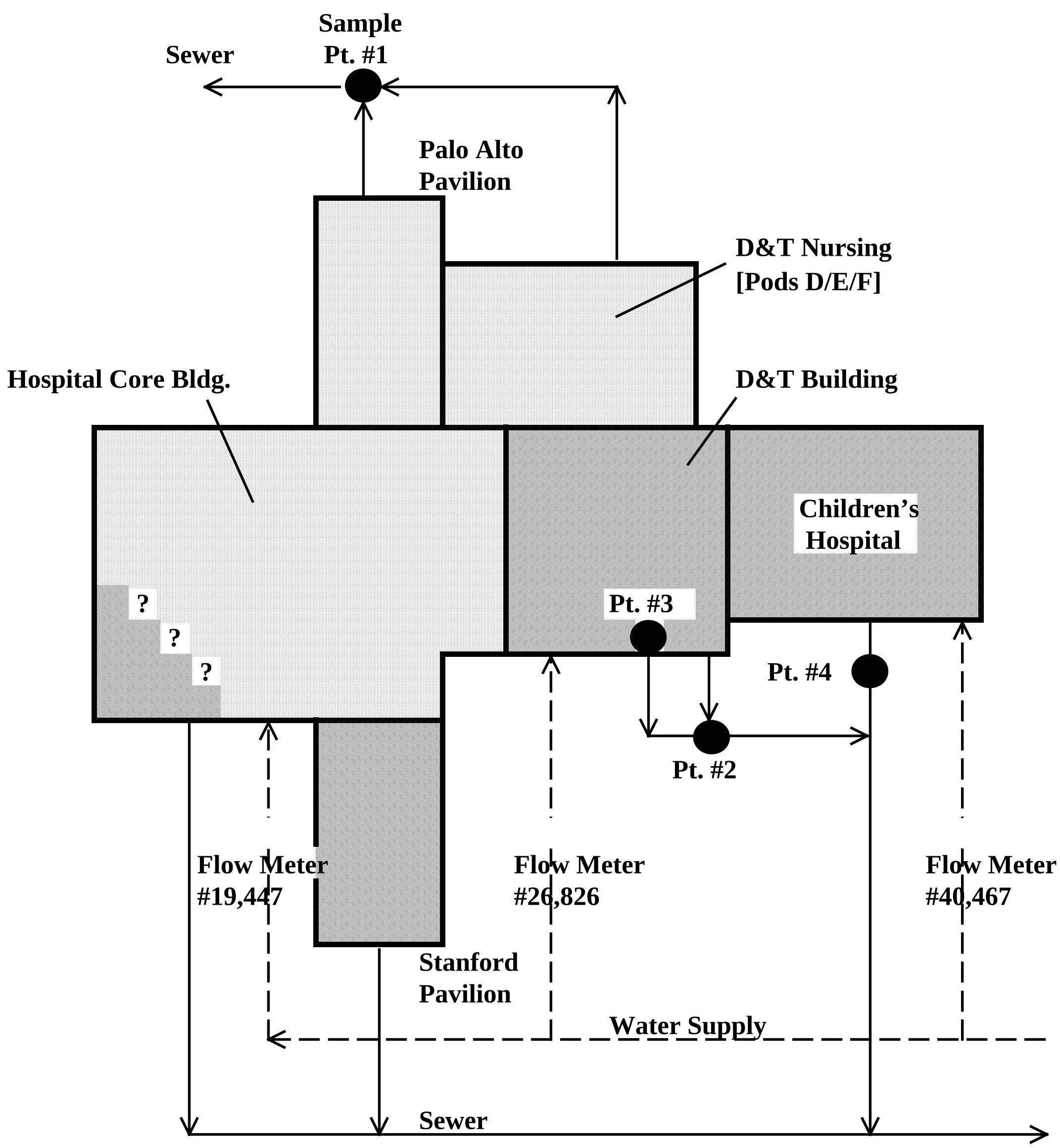


Note: The shaded buildings are the subject of the present study.

2.3 WATER & SEWER SYSTEMS:

Exhibit 2 is a simplified diagram of SUMC highlighting the site's water supply systems (dashed lines) and sanitary sewers (solid lines). These systems are summarized below.

Exhibit 2
SUMC Water & Sewer Lines



2.3.1 Water Supplies

The site receives its water primarily from the City of Palo Alto. Emergency back-up water sources include local wells and alternative connections to the Palo Alto distribution system. Analyses made during the present study indicate that during mid- to late-1994 the concentration of copper in the site's primary water supply was typically 0.005 mg/l or less. The back-up supplies were not tested.

Three primary water supply pipelines enter the Core, D&T, and LPCH buildings from the eastern edge of the SUMC complex. As shown by the dashed circles in Exhibit 2, above, each of these lines has its own flow meter:

- Meter #19447 - serving the Core area;
- Meter #26826 - for the D&T buildings; and
- Meter #40467 - for Children's Hospital.

After each meter, the water flows into a basement utility room where it is fed into various sub-systems. Generally, each of the facilities has its own water systems, while there is some sharing of sewer systems. The present effort included making an estimate of how much water from each supply ultimately flows into each sewer discharge point.

The Core, D&T, and LPCH areas each have their own cold and hot domestic water, and de-ionized water systems. These separate systems each supply sinks, showers, drinking fountains, and special fixtures (e.g., photo processing equipment) in the respective areas of the SUMC.

In addition, chilled and heated water loops operate as part of the building heating, ventilating, and air conditioning systems. These systems are essentially closed-loop, meaning that under normal operations there is only a small atmospheric condensate discharge to the site's sewers. Therefore, these systems are judged to contribute a negligible amount of copper waste to the sewer, and are not included in the present study.

Utility water is also supplied to the site's cooling towers. One of these towers (located in the Palo Alto Pavilion) discharges about 1 gallon of blowdown per day to the sanitary sewer via Point No. 1, and is therefore included in the present evaluation.

Fire and irrigation water lines and their associated meters are also completely separate from the domestic and utility water systems. These other water lines do not discharge to the SUMC sanitary sewer, and therefore are not included in the present study.

2.3.2 Domestic Water Systems

The two largest users of water in each hospital area are the cold and hot domestic water systems:

1. Cold Water Systems - Cold water undergoes supplementary disinfection with sodium hypochlorite in the basement utility area of each building, and is then supplied to points-of-use via copper piping that ranges in diameter from 2.5 inches down to 3/4-inch. The disinfection step produces a residual chlorine level of 2.0 mg/l.

   The cold water systems only operate upon demand, i.e., water flows in them only when a tap or other fixture is opened.

2. Hot Water Systems - Hot water is drawn from the cold water supply after disinfection, and is then passed through indirect steam heat exchangers. Steam for the mechanical rooms comes from Stanford's near-by utility plant.

   The hottest delivered water temperature is 120°F in most of the lab, clinic, and nursing care area systems, and 140°F in systems supporting kitchens. After heating, the hot water is supplied to these points of use via insulated copper piping that ranges in diameter from 2.5 inches down to 3/4 inch.

   LPCH uses Tarnpure™ sacrificial anode units to provide supplementary disinfection in both of its hot water systems. According to vendor literature furnished by Children's Hospital staff, these anodes release copper and silver into the hot water at levels of <0.9 mg/l and <0.05 mg/l, respectively [Ref 3].

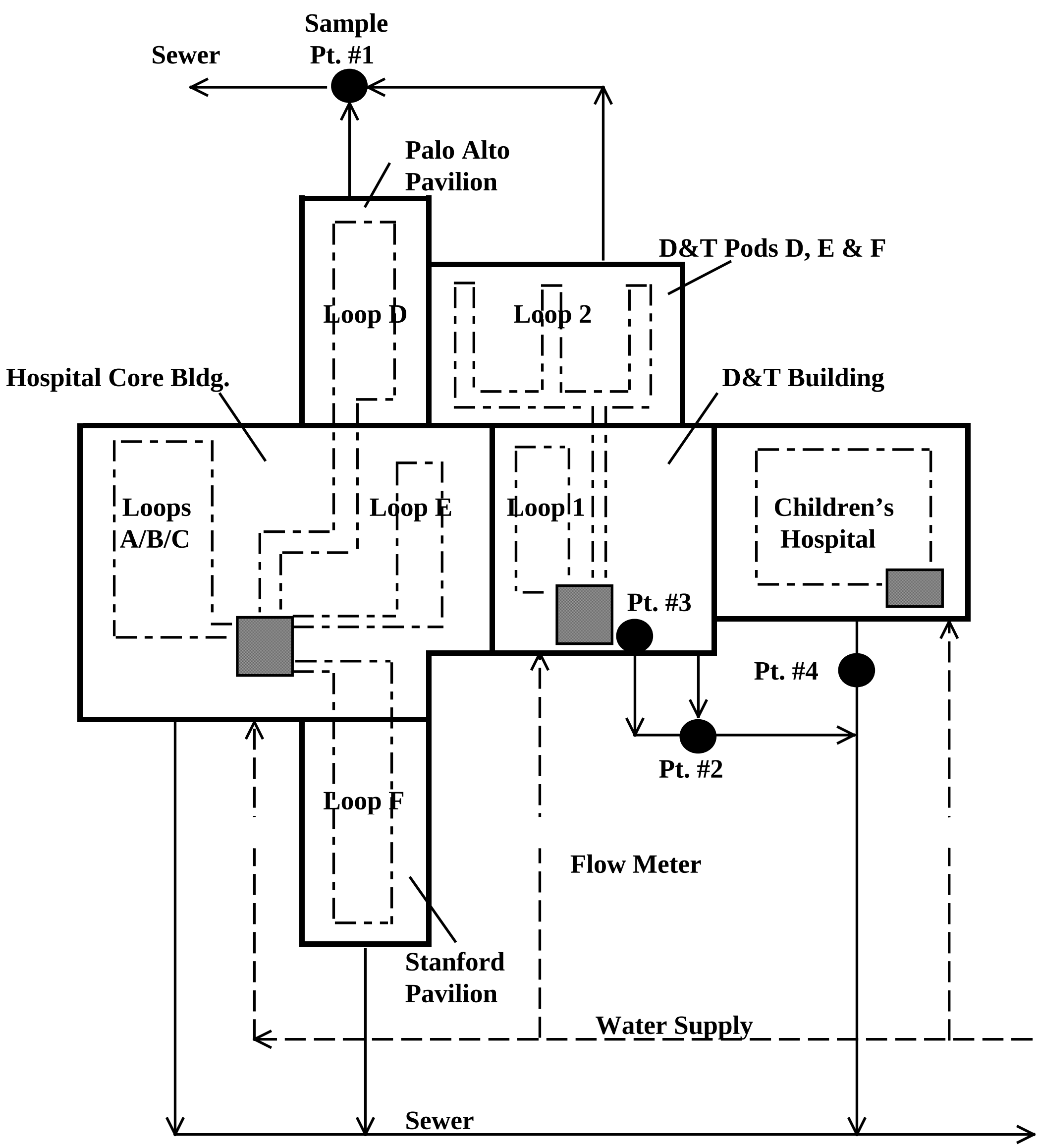
   Flows in each hot water system are recirculating, i.e., there is a continuous flow at all times regardless of whether or not there is a tap opened by a water user. According to the system designers [Ref. 6], the minimum continuous flow is sized to offset heat losses that occur through the pipe walls continuously during the day. At mid-day when water use is greatest, the return flow is a small fraction of the total flow. Late at night, the return flow can be as much as 100% of the flow. On average, return flows are from 10% to 20% of the total hot water consumed.

Having been identified in an earlier study [Ref 2] as a probable copper source, the recirculating hot water systems were examined in more detail during the present effort. Exhibit 3 identifies the eight recirculating systems located in the Core and D&T areas of the hospital. Two additional systems serve Children's Hospital.

Core Hospital - Hot water loops "A" through "F" originate from steam heaters in the Core Mechanical Room, and serve the older portions of the hospital. Loops "A" and "B" serve the ground and first floors, while Loop "C" serves upper floors at the south end of the Core. The other loops each serve all of the hospital floors in their respective areas.

D&T Facilities - Loops "1" and "2" originate in the D&T Mechanical Room, and serve a number of relatively newer diagnostic, treatment, and patient care areas in that building. Most of the hot water in D&T Loop "1" serves the first and second floor D&T laboratory areas. Hot water in Loop "2" flows to the multi-story Nursing Pods, and to upper floors of the D&T building.

Exhibit 3
Circulating Hot Water Systems



Children's Hospital - Loops "1" and "2" originate in the LPCH Boiler Room, and serve a number of diagnostic, treatment, and patient care areas in that building. The hot water in Loop "1" serves the laboratory, clinic, and nursing care areas, while the water in Loop "2" flows to the kitchen.

2.3.3 De-Ionized Water Systems

De-ionized water for laboratory and clinic use is made on-site in each of the three utility rooms. City water is fed through the following steps during this process:

- Softening;
- Reverse Osmosis;
- Ion Exchange; and
- Ultra-violet disinfection.

The reverse osmosis reject stream is sent to the sanitary sewer system, while the product stream passes through ion exchange columns for further purification. Resins in these columns are sent off-site for regeneration.

Plastic piping is used to convey the de-ionized water to each point of use. Water flows through these systems only upon demand, i.e., when a local tap is opened.

2.3.4 Utility Water Systems

Un-softened water is used in each hospital area for HVAC requirements. Except for cooling towers, these systems are generally closed-loop, and need relatively little make-up water. These HVAC systems were not reviewed as part of the present study. Additional utility water needs include pump seals, vacuum pump cooling, and maintenance room floor washing.

2.3.5 Sanitary Sewer Collection Systems

Domestic and kitchen wastewaters are collected through out the SUMC facility, and are conveyed to main sewer lines in plastic or cast iron collection piping. Vent pipes are typically cast iron. Copper piping is generally not used, except for sink traps that are sometimes chrome-plated brass. Most but not all of these collection systems are fully closed, preventing access for sampling.

Utility wastewaters are usually produced and released in the mechanical rooms, flowing either via copper piping or cast iron floor drains directly to local sumps, from which they are pumped to the nearest domestic wastewater collection line.

A very small amount of utility wastewater is produced by condensation occurring in compressed air systems, while a somewhat larger flow comes from pump seals, floor washing, and draining of water lines for maintenance. However, the total amount of utility wastewater from these sources is judged to be very small, i.e., less than 0.1% of the site's total discharge.

2.3.6 Sanitary Sewer Discharge Lines

Seven primary sewer lines leave the Core, D&T, and LPCH buildings. Each of these lines has manholes at changes in direction and where it is joined by other sewers.

Four of the manholes, indicated as darkened circles in Exhibits 2 and 3, above, are points where the RWQCP routinely obtains composite samples of the SUMC sewer discharges. Different parts of the hospital complex release wastewaters to each of these points.

1. Sewer Sample Point #1, located in a manhole west of the hospital, receives flows from most of the Core, and from the D&T nursing areas (which, because of their modular arrangement, are designated as "Nursing Pods"). This point is also designated RWQCP Sample Point 1.

2. Sample Point #2 (also RWQCP Point #2), in a manhole east of SUMC, receives sewer flows from the remainder of the D&T building, including some laboratory area wastes that first pass through Sample Point #3.

3. Sample Point #3 (also RWQCP Point #3), located inside the D&T basement utility room, receives laboratory and treatment area waste streams.

4. Sample Point #4 (also RWQCP Point #1), in a manhole east of SUMC, serves Children's Hospital.

The next section of this report discusses sampling and analysis work undertaken in the present study to quantify the amounts of copper wastes present in these various wastewater sources and discharge lines.

3. RESULTS OF THE PRESENT STUDY

3.1 DESCRIPTION OF STUDY

The present evaluation took place in stages from April 1994 through December 1995. Sampling and other field work took place from April - September 1994, followed by evaluation of the data and development of copper mass balances. The work was completed by a team of site environmental and facilities staff, RWQCP representatives, and the authors. Additional information was provided by the staff of engineering firms involved with the site, equipment suppliers, and other hospitals.

At the start of the present study it was suspected, but not known for certain, that corrosion of copper water pipes is the major cause of the higher than background levels of that metal observed in the site's sewer discharges. Prior work by Kennedy/Jenks [Ref. 2] and RWQCP staff [Ref. 4] had examined potential copper waste sources in most of SUMC's laboratories and clinics. However, none of these sources had proven sufficient to account for the copper concentrations observed in the site's wastewater discharges. Therefore, the previous studies concluded that water pipe corrosion should be evaluated next as the most likely source of waste copper.

With this guidance, the present study focused its initial sampling upon the site's water supply systems, and upon a few previously un-evaluated potential copper waste sources in other areas:

- Cold and hot water faucets in various laboratories and restrooms;
- Hot water return lines;
- Reverse osmosis system blowdown;
- Air compressor drains;
- Cooling tower biocide chemicals;
- Janitorial chemicals;
- X-Ray processor drains;
- Kitchen sanitary sewer traps; and
- Manholes in the sanitary sewer system.

The project team reviewed site utility drawings to identify initial sample point locations that would be representative of major water and sewer systems in the medical center. A total of 33 such points were selected in this process. Each point was numbered and tagged so that different team members could easily find where to take samples.

A total of about 125 liquid samples were obtained from water and sewer systems in the Core, D&T, and Children's Hospital. About half of these samples were taken from various hot water taps and hot water return loops through-out the buildings. The other grab samples were obtained in utility drains and local sewer traps.

Twenty daily composite samples were obtained during the project at Sewer Discharge Points No. 1 - No. 4, but not always on the same days as the water samples.

All of these 1-liter grab and composite samples were preserved with nitric acid, and were then shipped to the laboratory within 48 hours. Sequoia Analytical of Redwood City analyzed the samples with an atomic adsorption unit to determine total copper concentrations. These test results are listed in the Appendix.

Additional composite samples were taken and tested by the RWQCP during routine monitoring of near-by residential sewer trunk lines. These off-site residential wastewater data were used to establish a "background" for copper levels in a residential sanitary sewer system. Using residential samples taken concurrently with the study allowed the project team to determine that variations in study samples were not from water supply characteristics varying over time.

3.2 WATER USE DATA

In support of the present study, site staff compiled a summary of water use in each of the three hospital areas. These data are summarized in Exhibit 4, and are provided in more detail in the Appendix. For the period of late-1992 through mid-1994, the average water use in the three studied facilities totals about 360,000 gallons per day.

Exhibit 4
Average Daily Water Use

Meter #19447 - serving the Core area:	209,000 gpd
Meter #26826 - for the D&T buildings:	111,000 gpd
Meter #40467 - for Children's Hospital:	40,500 gpd
	360,500 gpd

Because branch line flowmeters are not installed in the hospital complex, flow data for individual water systems are unavailable. Also, because of pipe insulation and geometry, it was not feasible for the project team to measure flows with an external ultrasonic meter. Therefore, a count of fixtures on each water supply loop and an evaluation of hospital water use patterns were made to estimate local flows within the various areas.

Piping drawings, maintenance staff input, and conversations with site contractors proved sufficient to develop a count of fixtures, to identify *generally* which areas are served by each hot water loop, and to establish *generally* which parts of the buildings drain to each sewer connection point. These sources were able to account for many but not all changes in the water and sewer piping systems that have been made during the 25 years that the Core building has been in service.

Based upon the 1992 water use survey of the D&T buildings [Ref. 1] and upon the general literature [Ref. 5 & 6], the project team concludes that about one-third of the water supplied to patient care areas of SUMC is typically heated. Further, it is estimated that about one-fourth of the water used in the hospital laboratory and clinic areas is heated. These water use patterns guided development of the copper mass balances described below.

3.3 INITIAL SAMPLING RESULTS

Initially, the project team examined the site's copper discharge history, and compared it to copper levels found in local residential sewer mains. Inside the hospital complex, the team sampled circulating hot water systems, utility areas, and other potential copper waste sources not examined previously.

3.3.1 Copper in the Site's Sewer Discharges

Copper concentrations measured in the site's sewer discharge points are shown in Exhibits 5 and 6, with the latter being an expanded presentation of just the data taken during the mid-1994 study period.

The average concentrations for these monitoring points range from 0.04 to 0.20 mg/l, while the highest individual sample is 0.31 mg/l. The patterns visible in these data suggest:

- The copper concentration in the site's sewer discharge is routinely 0.10 mg/l or less (75% of the monitoring days).
- The copper released to the sewer on these "routine" days averages 0.048 mg/l, equivalent to 0.14 lb/day.
- On 25% of the days, the copper concentration is above this "routine" level.
- The copper released on these "high" days is 0.19 mg/l, equivalent to 0.58 lb/day.

3.3.2 Copper in Residential Sewer Discharges

The RWQCP routinely monitors its sewage collection system for metals and other wastewater parameters. This program includes sampling of Points No. 20 and 21, which are two manholes in residential areas. Copper levels observed at these two locations are shown in Exhibit 7 to represent a "background" for domestic sewage.

Exhibit 5
1992-94 Copper Concentrations in the SUMC Sewer Discharge

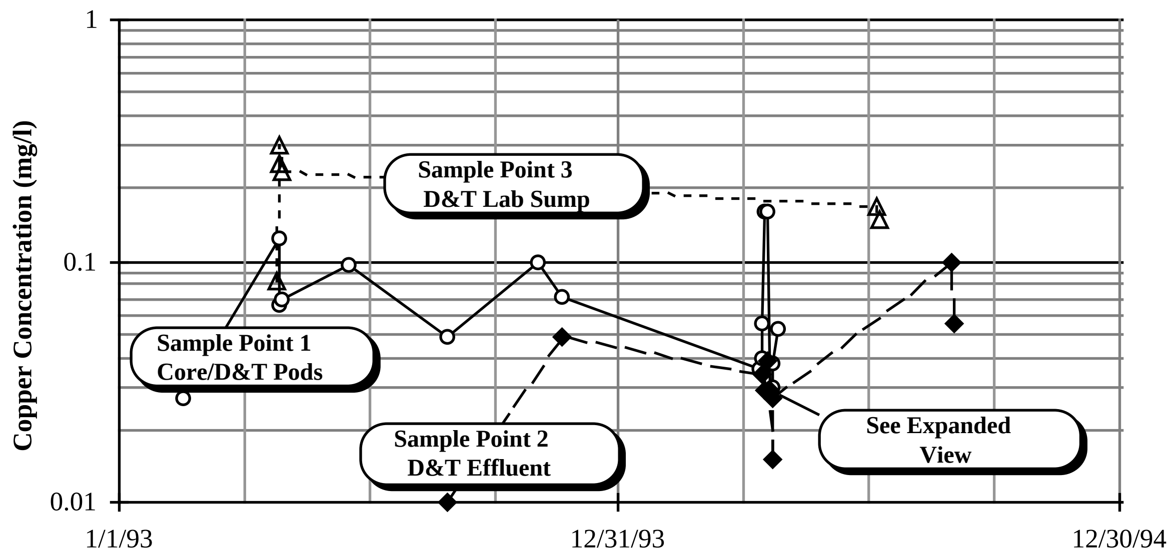


Exhibit 6
1994 Copper Concentrations in the SUMC Sewer Discharge

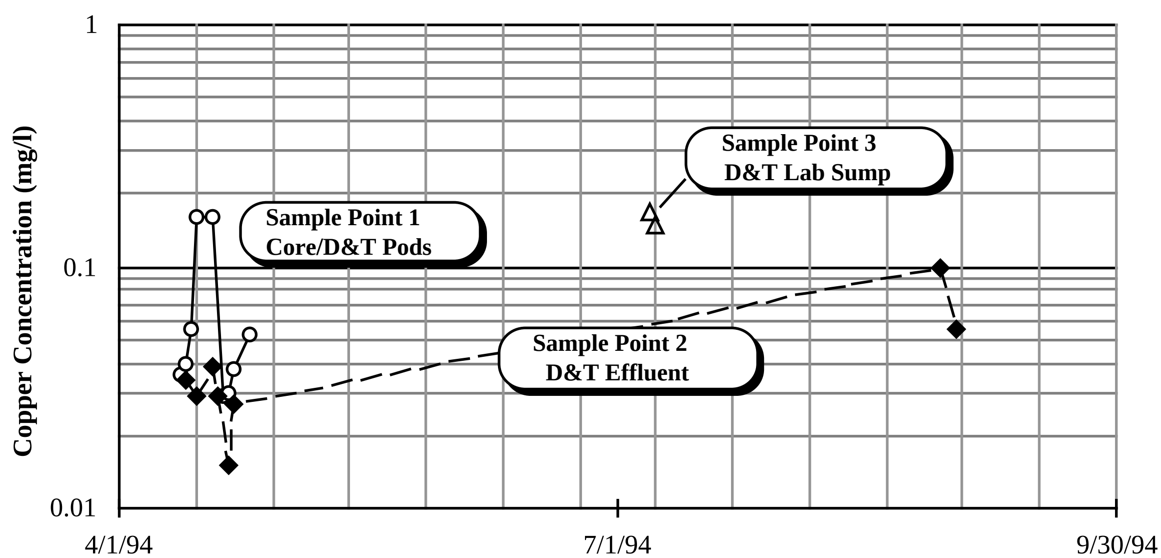
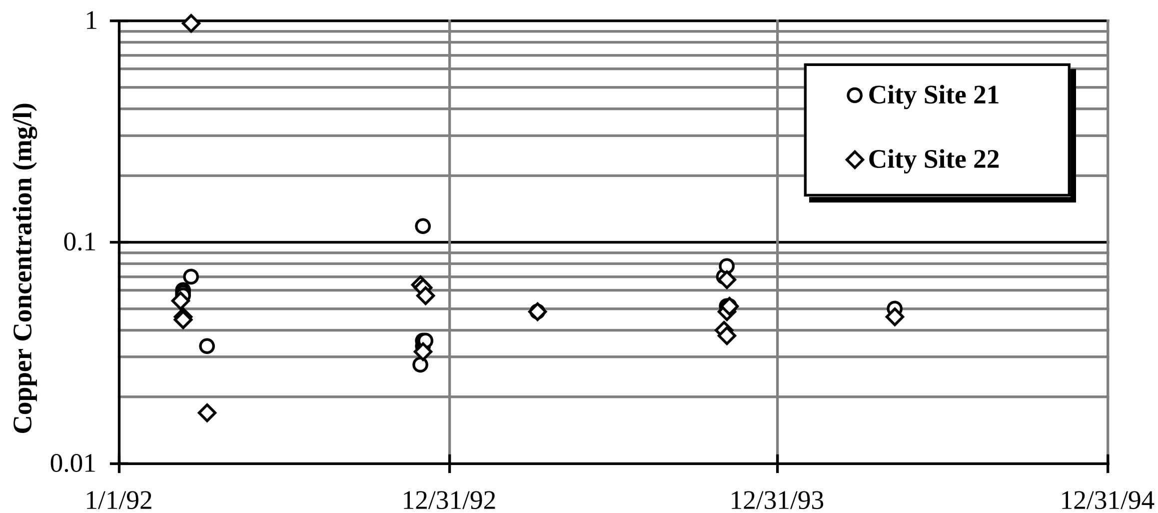


Exhibit 7
Copper Concentrations in Residential Sewer Systems



At first, comparing the SUMC and residential sewer data in Exhibits 5 through 7 suggests that the average copper concentration in both the residential sewer discharge and the sewer discharges from SUMC average 0.08 mg/l. However, this proves to only be a coincidence.

Upon closer examination, the SUMC discharge is seen to be sufficiently far above 0.08 mg/l sufficiently often to suggest the occurrence of events that release higher than normal amounts of copper. As discussed later in the report, these events are believed to be periodic flushing of circulating water system return lines.

3.3.3 Copper in SUMC Water and Wastewater Systems

The initial water and wastewater sampling in the Core and D&T facilities took place from April 11 through April 25, 1994. Because of the variety of locations involved, a daily checklist was used to guide the effort. Samples in Children's Hospital were taken later, in the next phase of work.

Initial sample results showed that the X-Ray processor drain, kitchen grease trap, and various mechanical room sample points had relatively low copper concentrations, generally on the order of 0.1 mg/l or less. The only copper concentrations above 0.1 mg/l were found in the two circulating hot water loops that were sampled, with the highest levels occurring in the "return" portion of each loop. Cooling tower and janitorial chemicals proved to either have no copper in them, or to be used in such small quantities that any copper present would not be noticeable in the sewer discharge.

At this point the team computed approximate mass balances for copper in the Core and D&T water and wastewater systems. These initial calculations indicated that on a daily basis the copper concentrations found in the site's hot water loops are probably large enough to account for the levels of this metal found in the sanitary sewer discharges during the same time period.

However, in preparing the initial mass balance the project team assumed that each of the site's hot water loops contributes the same amount of copper. The next step was to improve upon this approximation by determining individual copper levels in each hot water loop.

3.4 ADDITIONAL SAMPLING RESULTS

To obtain the needed additional data, the project team identified sample points in each of ten separate hot water loops serving the Core, D&T, and Children's Hospital buildings. Intermittent samples were obtained at these points during July, August, and September of 1994.

Next, the project team updated the earlier copper mass balances and added a new one for Children's Hospital. The revised calculations, presented in Exhibits 7, 8, and 9, confirm that copper concentrations found in the hot water loops are sufficiently large to account for the levels measured in each of the site's three primary sanitary sewer discharge lines.

The "closures" of these mass balances are estimated to be ±30%, meaning that the sum of copper waste loads in the hot water systems adds up to a total that is within 30% of the amount measured in the related sewer discharge.

This level of closure is reasonable considering both the number and timing of samples and flowrate measurements that were obtained during the present study. Further, the results are sufficient for the present calculations, but would need to be supplemented to reveal daily or other fluctuations of copper concentrations within the hot water systems.

3.5 DISCUSSION OF RESULTS

The average copper concentrations in the eight Core and D&T area hot water loops ranged from 0.08 to 0.27 mg/l. Individual samples in these loops ranged from a low of 0.06 mg/l to a high of 6.4 mg/l. Copper concentrations in the Children's Hospital water systems ranged from 0.13 to 4.5 mg/l, and averaged 0.22 mg/l. During the same time period, copper levels in the three sewer discharge points ranged from 0.03 to 0.16 mg/l.

- Sewer Discharge Point #1 (Core Area and D&T Nursing Pods) - As shown by Exhibit 8, the average amount of copper observed in this discharge is 0.13 lb/day.

  - An estimated 0.01 lb/day is present in the water supply.

  - A further 0.10 lb/day of this total is believed to come from corrosion in the six circulating hot water systems that discharge to Point #1.

  - Using data from a study of metals in residential wastewaters [Ref. 11], the project team estimates that 0.006 lb/day of waste copper comes from human wastes.

  - On the same basis, the remaining 0.02 lb/day of copper is estimated to be present in dishwashing wastewaters and food wastes arising from the 8,000 meals served each day to patients, staff, and visitors.

- Sewer Discharge Points #2 & #3 (D&T Laboratories and Clinic Areas) - The observed copper waste load in this discharge averages 0.007 lb/day.

  - As shown by Exhibit 9, most of this copper comes from the D&T lab area circulating hot water system.

  - The balance is present in the water supply (0.001 lb/day), or is contributed by human wastes (0.001 lb/day).

- Sewer Discharge Point #4 (Children's Hospital) - As shown by Exhibit 10, the computed level of copper from the hospital's two circulating hot water systems is 0.025 lb/day.

  - About 75% of this total is from corrosion, while 25% is believed to be from the TarnPure™ disinfection system. Measurements of anode weight changes in this electrolytic disinfection unit could be used in the future to confirm how much of the copper is from this process.

  - An additional 0.007 lb/day of copper is estimated to come from the water supply and from human and kitchen wastes.

- Stanford Pavilion - The sewer discharge from this area was not monitored during the present study, and is therefore not included in the above mass balances. The mass balance for the Core Area (Exhibit 9) assumes that 20% of the water supplied through Meter No. 19,447 is used in this wing.

Exhibit 8
Copper Mass Balance - Discharge Point #1
Hospital Core, Palo Alto Pavilion, and D&T Nursing Pods

	Flow gal/day	Copper Conc. mg/l	Mass lb/day
Present In Water Supply			
80% of Meter #19,447	167,200	0.005	0.007
80% of Meter #26,826	88,800	0.005	0.004
Added By Human Wastes			
24hr. Patients & Care Staff (est. 600)	[1,300 µg/person/day - Ref. 11]		0.002
Visitors & Day Staff (est. 7,400)	[25% of 1,300 µg/person/day]		0.004
Added By Corrosion in Circulating Hot Water System			
Six Recirculating Loops			0.096
Added By Food Wastes			
8,000 meals/day	[0.000003 lb/meal - Ref. 11]		0.020
Added By Cooling Tower Conc.			
Palo Alto Pavilion	1 [See Ref. 9 - Site #50]		0.000003
Calculated Sewer Discharge:	**256,001**	**0.062**	**0.133**
Observed Sewer Discharge [Point #1 - 9 Samples]	**256,000**	**0.067**	**0.143**
		Mass Balance Closure:	93%

Note: Totals are 3 decimal places to show arithmetic, not to imply accuracy of results.

Exhibit 9
Copper Mass Balance - Discharge Points #2 and #3
D&T Laboratories and Clinics

	Flow gal/day	Copper Conc. mg/l	Mass lb/day
Present In Water Supply			
0% of Meter #19,447	0	0.005	0.000
20% of Meter #26,826	22,200	0.005	0.001
Added By Human Uses	[See Ref. 11 & 12]		
Visitors & Day Staff (est. 2000)	[25% of 1,300 µg/person/day]		0.001
Added By Corrosion in Circulating Hot Water System			
D&T Loop 1 [4 Samples]			0.007
Calculated Sewer Discharge:	**22,200**	**0.048**	**0.009**
Observed Sewer Discharge [Point #2 - 9 Samples]	**22,200**	**0.037**	**0.007**
		Mass Balance Closure:	130%

Note: Totals are 3 decimal places to show arithmetic, not to imply accuracy of results.

Exhibit 10
Copper Mass Balance - Discharge Point #4
Packard Children's Hospital

	Flow gal/day	Copper Conc. mg/l	Mass lb/day
Present In Water Supply			
Estimated Flowrate (RWQCP Data]	40,450	0.005	0.002
Subtotal:			
Added By Human Uses			
24hr. Patients & Care Staff (est. 100)	[1,300 µg/person/day - Ref. 11, 12]		0.0006
Visitors & Day Staff (est. 500)	[350 µg/person/day - Ref. 11, 12]		0.0004
Added By Food Wastes			
750 meals/day	[0.000003 lb/meal - Ref. 11]		0.002
Added By Disinfection and Corrosion in Circulating Hot Water System			
Loops 1 & 2 [17 samples] [Est. hot water flow = 33% of total]			0.020
Calculated Sewer Discharge:	**40,450**	**0.074**	**0.025**
Observed Sewer Discharge: [Children's Hosp. Sample Point] [10 Samples After 7/93]	**40,450**	**0.074**	**0.025**
		Mass Balance Closure:	100%

Note: Totals are 3 decimal places to show arithmetic, not to imply accuracy of results.

3.6 CONCLUSIONS

3.6.1 Core and D&T Buildings

The present study indicates that pipe corrosion in the Core and D&T circulating hot water systems contributes most of the 0.14 lb/day copper load measured in the two sanitary sewer discharges from this part of the hospital complex. All other potential sources that have been tested show relatively low copper concentrations, and are judged to be insufficient by themselves to account for the effluent copper loads observed.

There are approximately 3 miles of copper water pipe in the hot water loops serving the Core and D&T areas. Copper pipe corrosion at a relatively modest uniform rate of only 0.001 to 0.002 inch per year would be sufficient to produce the combined copper load of 0.01 lb/day shown in Exhibits 7 and 8, above.

However, the waste copper load from some of the hot water loops appears to be higher than from others. This circumstance could be due either to artifacts in the sampling program, or to actual differences in conditions within the various water supply loops.

- Sampling artifacts, such as the time of day that samples were obtained, individual sampling techniques of project team members, periodic flushing of lines, or other maintenance factors could incorrectly suggest a more rapid corrosion rate in some areas than is actually occurring.

- On the other hand, the highest copper concentrations were found in the return legs of hot water Loops “D” and “E” (see Exhibit 3). These particular loops are used less today than when they were originally placed in service. In fact, it is believed by site facilities staff that some segments of these loops may actually be closed off and not flowing at all. Without dilution from make-up water, the copper concentration in these loops would naturally rise to some equilibrium level.

- Alternatively, there could be localized corrosion or pipe erosion occurring in these particular loops that is significantly faster than an equivalent overall average rate.

Additional observations would be necessary to resolve these uncertainties.

3.6.2 Children’s Hospital

The level of copper in Children’s Hospital two circulating hot water systems averages 0.22 mg/l, and the load discharged to the sanitary sewer is estimated to be 0.025 lb/day.

According to the equipment supplier, the disinfection system used by the site adds copper to the hot water at a level of 0.05 mg/l [Ref. 3]. Therefore, it is estimated that about 0.005

lb/day of copper in the hot water systems comes from the disinfection system anodes, while the remaining 0.015 lb/day is from corrosion.

However, the present study did not actually evaluate how much of the 0.02 lb/day of copper in the site's sewer discharge is from corrosion compared to the amount that is contributed by the site's sacrificial Ag/Cu anode disinfection system. Measurements of anode weight loss in the electrolytic disinfection unit could be used in the future to determine how much of the copper this process contributes.

3.7 RECOMMENDATIONS

Corrosion rates in the Core, D&T, and Children's Hospital hot water systems appear to be relatively low. However, this corrosion is probably higher than it would otherwise be because the site adds chlorine to the cold make-up water to a residual level of 2.0 mg/l. This addition decreases the pH and makes the water more corrosive, particularly in the circulating hot water system [Ref. 1].

In addition, it is possible that the pipe corrosion is locally more rapid than the overall average rate suggested by the amount of copper in the site's wastewater. Therefore, four recommendations are made to SUMC staff:

1. Recirculating Hot Water System Operations - Operate these systems so as to minimize corrosion:

   - Operating Temperatures: Assure that the system temperature is at or below 140°F, as higher temperatures significantly increase corrosion rates. This important factor is discussed in the City of Palo Alto report: Copper Corrosion Reductions Associated with ... Hot Water Circulating Systems [Ref. 9].

   - Flow Rates: Similarly, assure that all flows in the systems are at or below 3 feet per second. This recommendation is also mentioned in Reference 9.

   - Control Valves: Routinely inspect the control valves throughout each circulating hot water system to assure that they are all operating correctly.

   - Isolation Valves: Assure that all isolation valves are open.

   - Closed-Loop Flushing: Also, periodically open the pump control valves to increase the flow rate and thereby flush (but do not drain) each of the hot water return lines.

   - Air: Keep air out of the piping systems as much as possible.

2. Monitor Corrosion Rates - Quantify copper pipe corrosion by taking physical samples whenever pipe sections need to be replaced during routine maintenance. Have a qualified test laboratory cut the samples open and examine them. Investigate corrosion reduction measures if these inspections show that the corrosion type and extent may be leading to an unacceptably high pipe failure frequency.

   Focus this attention initially on pipes in the locations where the highest copper concentrations have been discovered. Routine observation of this sort should be continued in all the piping systems as the hospital ages.

3. Corrosion Reduction - Reductions in corrosion rates and related discharges of copper in the site's wastewater may be possible. Alternative approaches include:

   - Lower chlorine dosage - Reduce the residual level below the 2.0 mg/l currently used as a set point.

   - Periodic chlorine dosage - Add disinfectant on a time schedule or for a fixed time after reaching a lower residual concentration control point, rather than adding chlorine continuously as is done today. The time schedule addition approach is reportedly used successfully at Moffitt Hospital in San Francisco (UCSF) [Ref. 7].

   - Alternative disinfection methods - Monitor the literature on hospital water supply disinfection, and evaluate alternatives to the current disinfection systems that may reduce corrosion and copper discharges.

   - Sacrificial anodes - Provide magnesium anodes as part of a complete, electrically-driven corrosion protection system.

   - Corrosion inhibitor - Add a chemical such as sodium bicarbonate that will increase the pH of the water to offset the acidifying effect of having added chlorine.

4. Contact Other Hospitals - Keep up to date on water system maintenance and disinfection practices at other local hospitals that face similar corrosion issues.

The other waste copper in the SUMC sewer discharge appears to be from human occupancy of the facility. The project team has no recommendations to make for reducing copper wastes from these sources.

APPENDIX A - REFERENCES

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3. Water Components Company, Tarn-Pure™ USA Hospital Water Disinfection, no date.

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5. Tchobanoglous, G., and E. Schroeder, Water Quality, Addison Wesley, Reading, MA, 1987.

6. Fielding, K., of Mechanical Planning, Inc., personal communication with the authors, 12/95.

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10. Larry Walker Associates, Residential Metals Study - Human Waste Data, Central Contra Costa Sanitary District, 5/94.

11. Larry Walker Associates, Residential Metals Study - Food Waste Data, Central Contra Costa Sanitary District, 5/94.

12. Montgomery Watson Americas, Local Limits Development - Headworks Loading Allocation Evaluation, Palo Alto RWQCP, 1/94.

13. Kennedy/Jenks Consultants, Copper Corrosion Reductions Associated with the Design and Construction Practices of Piping Systems, Heating Systems, Cooling Systems, and Hot Water Circulating Systems, Cities of Palo Alto and San José, 6/95.

APPENDIX B - WATER USE DATA

The following meter data represent monthly water use in two of the three supply lines furnishing City water to the SUMC buildings that were studied here. Data for the third line, supplying City water to Children's hospital, were obtained in summary form.

	Meter #19,477 [Medical Center]				Meter # 26,826 [HMP / D&T]			
Month	**CCF/mo.**	**kgal/mo.**	**Days**	**kgal/day**	**CCF/mo.**	**kgal/mo.**	**Days**	**kgal/day**
Sep-91	8,672	6,488	•••	•••	4,438	3,320	29	114.5
Oct-91	7,910	5,917	•••	•••	2,501	1,871	31	60.4
Nov-91	7,500	5,611	•••	•••	4,227	3,162	31	102.0
Dec-91	7,000	5,237	•••	•••	3,973	2,972	31	95.9
Jan-92	7,018	5,250	•••	•••	4,118	3,081	30	102.7
Feb-92	7,884	5,898	•••	•••	4,371	3,270	30	109.0
Mar-92	8,059	6,029	•••	•••	4,207	3,147	30	104.9
Apr-92	8,058	6,028	•••	•••	4,278	3,200	•••	•••
May-92	8,818	6,597	•••	•••	4,096	3,064	•••	•••
Jun-92	7,723	5,778	•••	•••	3,705	2,772	•••	•••
Jul-92	8,336	6,236	•••	•••	4,094	3,063	•••	•••
Aug-92	8,034	6,010	•••	•••	4,053	3,032	•••	•••
Sep-92	8,538	6,387	•••	•••	4,055	3,034	•••	•••
Oct-92	8,157	6,102	•••	•••	3,736	2,795	•••	•••
Nov-92	7,696	5,757	•••	•••	3,949	2,954	•••	•••
Dec-92	7,913	5,920	32	185.0	4,375	3,273	33	99.2
Jan-93	7,180	5,371	28	191.8	3,956	2,959	28	105.7
Feb-93	9,045	6,767	35	193.3	4,636	3,468	33	105.1
Mar-93	7,532	5,635	28	201.2	3,733	2,793	30	93.1
Apr-93	8,186	6,124	30	204.1	4,938	3,694	30	123.1
May-93	8,098	6,058	27	224.4	4,038	3,021	27	111.9
Jun-93	7,732	5,784	32	180.8	4,784	3,579	32	111.8
Jul-93	8,607	6,439	30	214.6	4,831	3,614	30	120.5
Aug-93	8,554	6,399	30	213.3	4,685	3,505	30	116.8
Sep-93	9,678	7,240	34	212.9	4,931	3,689	34	108.5
Oct-93	8,817	6,596	30	219.9	4,413	3,301	30	110.0
Nov-93	8,001	5,986	32	187.0	4,000	2,992	29	103.2
Dec-93	9,590	7,174	30	239.1	5,372	4,019	33	121.8
Jan-94	9,110	6,815	27	252.4	4,216	3,154	27	116.8
Feb-94	9,782	7,318	32	228.7	4,770	3,568	32	111.5
Mar-94	8,852	6,622	30	220.7	4,447	3,327	30	110.9
Apr-94	10,211	7,639	30	254.6	4,934	3,691	30	123.0
			Average: 30	Average: 213			Average: 30	Average: 108
			Total: 457 Days	Total: 95,626 kgal			Total: 458 Days	Total: 50,630 kgal
				Daily: 209				**Daily: 111**

APPENDIX C - COPPER CONCENTRATION DATA

The following sample data show the range of copper concentrations measured in samples from various water and wastewater systems during the hospital study.

Sample Location	Sample Number	Date	Copper Conc. [mg/l]	Remarks
X-Ray North (D&T)	*61-07*	4/12/94	0.005	1/2 of D.L. (= 0.01 mg/l)
[cold water]	*61-26*	4/14/94	0.005	
	61-45	4/18/94	0.005	
	61-68	4/22/94	0.005	
Core Mechanical Room	*61-05*	4/11/94	0.005	Recirc. Hot Water - Point of Use
• Hot Recirc. Water (Out)	*61-23*	4/14/94	0.023	
(Mens' Room - #H0140)	*61-42*	4/18/94	0.019	
	61-64	4/22/94	0.005	
Core Mechanical Room	*61-06*	4/11/94	1.500	Composite of Several Loops
• Hot Recirc. Water (Return)	*61-24*	4/14/94	0.062	[In later field work these lines
	61-40	4/18/94	0.870	were sampled separately]
	61-62	4/22/94	0.190	
Recirc. Hot Water - Loop A				
Core: HW Loop A: Return	*61-74*	8/23/94	1.800	Ground & 1st Floors, Areas 3 - 6
Core: HW Loop A: Room H1130n	*61-85*	8/23/94	0.083	[Mostly utilities and treatment labs]
Core: HW Loop A: Return	*61-95*	9/1/94	0.037	
Core: HW Loop A: Room H1130n	*61-114*	9/1/94	0.200	
Recirc. Hot Water - Loop B				
Core: HW Loop B: Return	*61-75*	8/23/94	0.530	1st Floor, Areas 3 - 6
Core: HW Loop B: Room H1132c	*61-84*	8/23/94	0.200	[Treatment labs & lobby area]
Core: HW Loop B: Return	*61-96*	9/1/94	0.043	
Core: HW Loop B: Room H1132c	*61-113*	9/1/94	0.290	

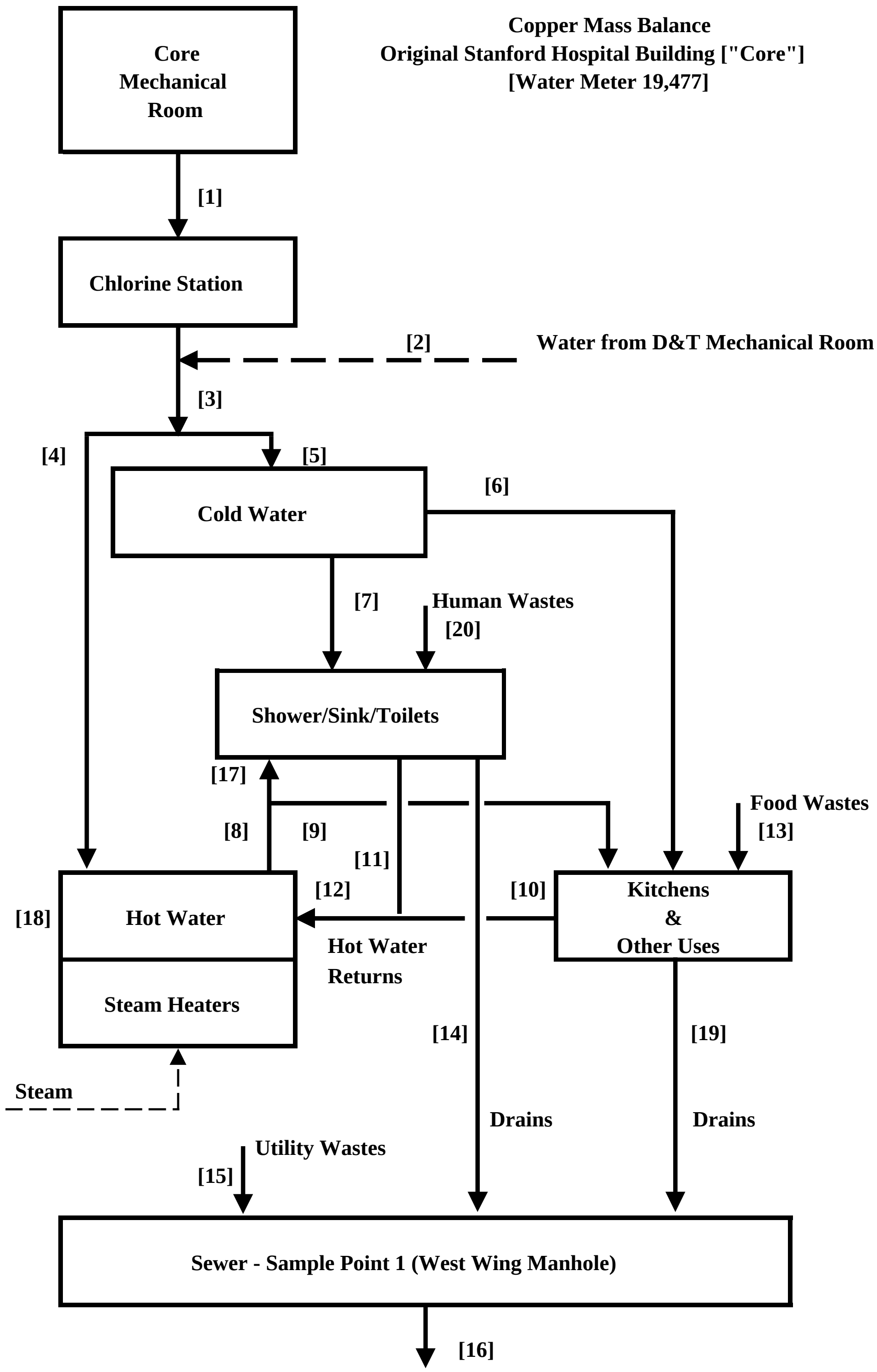
Sample Location	Sample Number	Date	Copper Conc. [mg/l]	Remarks
Recirc. Hot Water - Loop C				
Core: HW Loop C: Room B351	*61-09*	4/11/94	0.044	2nd & 3rd Floors, Areas 3-6
Core: HW Loop C: Room B351	*61-28*	4/14/94	0.032	[Labs, Surgery, & Other Care]
Core: HW Loop C: Room B351	*61-43*	4/18/94	0.054	
Core: HW Loop C: Room B351	*61-65*	4/22/94	0.049	
Core: HW Loop C: Return	*61-76*	8/23/94	0.210	
Core: HW Loop C: Room B351	*61-83*	8/23/94	0.094	
Core: HW Loop C: Return	*61-97*	9/1/94	0.038	
Core: HW Loop C: Room B351	*61-104*	9/1/94	0.083	
Recirc. Hot Water - Loop D				
Core: HW Loop D: Return	*61-77*	8/23/94	0.290	Palo Alto Pavilion - All Floors
Core: HW Loop D: Room HC311	*61-81*	8/23/94	0.070	[Labs, Offices, & Wards]
Core: HW Loop D: Return	*61-98*	9/1/94	0.190	
Core: HW Loop D: Room HC311	*61-103*	9/1/94	0.140	
Recirc. Hot Water - Loop E				
Core: HW Loop E: Return	*61-25*	4/14/94	6.400	All Floors, Areas 1 - 2
Core: HW Loop E: Return	*61-41*	4/18/94	0.510	[Labs & Offices]
Core: HW Loop E: Return	*61-63*	4/22/94	0.290	
Core: HW Loop E: Return	*61-78*	8/23/94	0.170	
Core: HW Loop E: Return	*61-99*	9/1/94	0.100	
Recirc. Hot Water - Loop F				
Core: HW Loop F: Return	*61-79*	8/23/94	0.180	Stanford Pavilion - All Floors
Core: HW Loop F: Room G328	*61-80*	8/23/94	0.031	[Labs & Offices - formerly wards]
Core: HW Loop F: Return	*61-100*	9/1/94	0.640	
Core: HW Loop F: Room G328	*61-101*	9/1/94	0.054	

Sample Location	Sample Number	Date	Copper Conc. [mg/l]	Remarks
D&T Recirculating Hot Water Loop 1				Lab & Treatment Areas - All Floors
Clinical Lab - 1st Floor	*61-89*	8/23/94	0.110	
D&T Loop 1 Return	*61-87*	8/23/94	22.000	instantaneous flow
D&T Loop 1 Return	*61-88*	8/23/94	0.130	established flow
Clinical Lab - 1st Floor	*61-110*	9/1/94	0.180	
D&T Loop 1 Return	*61-112*	9/1/94	0.150	established flow
D&T Recirculating Hot Water Loop 2				Patient Wards - All Floors
• Hot Water Return	*61-22*	4/14/94	0.280	
D&T Loop 2 Return [Pt. 11e]	*61-86*	8/23/94	0.082	
D&T Loop 2 • D&T 3rd Floor	*61-91*	8/23/94	0.040	
D&T Loop 2 • D Pod	*61-93*	8/23/94	0.064	Pods = Patient Wards
D&T Loop 2 • E Pod	*61-92*	8/23/94	0.042	
D&T Loop 2 • F Pod	*61-90*	8/23/94	0.028	
D&T Loop 2 Return [Pt. 11e]	*61-111*	9/1/94	0.073	
D&T Loop 2 • D&T 3rd Floor	*61-108*	9/1/94	0.071	
D&T Loop 2 • D Pod	*61-105*	9/1/94	0.110	
D&T Loop 2 • E Pod	*61-107*	9/1/94	0.070	
D&T Loop 2 • F Pod	*61-109*	9/1/94	0.056	
Average, Loops A-E, and 2			0.353	Discharge Point 1
Average, Loop 1			0.143	Discharge Point 3

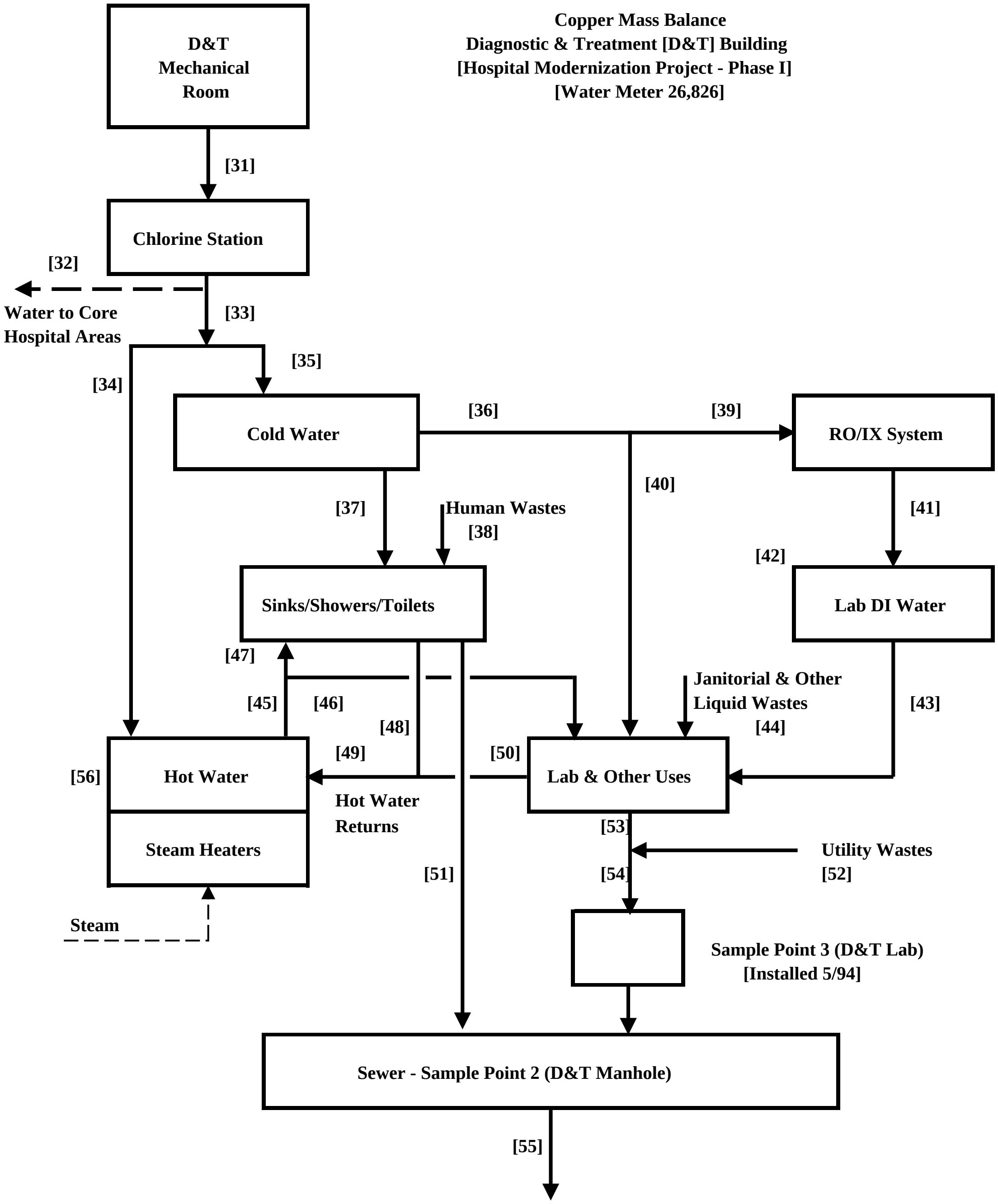
Children's Hospital

Sample Location	Sample Number	Date	Copper Conc. [mg/l]	Remarks
Hot Water Loop 1	*61-401*	7/6/94	0.230	Before TarnPure System [120F]
[Hospital, 120F]	*61-409*	7/7/94	0.150	Before TarnPure System [120F]
	61-418	8/23/94	0.085	Before TarnPure System [120F]
	61-424	9/1/94	0.160	Before TarnPure System [120F]
	61-404	7/6/94	0.380	[Ground Floor]
	61-412	7/7/94	0.600	[Ground Floor]
	61-420	8/23/94	4.500	[Ground Floor]
	61-426	9/1/94	0.510	[Ground Floor]
	61-405	7/6/94	0.160	[Ground Floor]
	61-413	7/7/94	0.160	[Ground Floor]
	61-406	7/6/94	0.180	[1st Floor]
	61-414	7/7/94	0.210	[1st Floor]
	61-407	7/6/94	0.150	[2nd Floor]
	61-415	7/7/94	0.130	[2nd Floor]
	61-408	7/6/94	0.150	[3rd Floor]
	61-416	7/7/94	0.150	[3rd Floor]
Average:			0.227	
Hot Water Loop 2	*61-402*	7/6/94	0.190	Before TarnPure System (140F)
[Kitchen, 140F]	*61-410*	7/7/94	0.180	Before TarnPure System (140F)
Cold Water Hose Bib	*61-403*	7/6/94	0.310	[Cold Water Hose Bib]
	61-403	7/7/94	0.280	[Cold Water Hose Bib]
Building D - Source Water (Outdoor Faucet)	*61-209*	5/9/94	ND	D.L. = 0.01 mg/l
	61-223	5/11/94	ND	
Building D Recirc. Hot Water - Room 27A	*61-203*	5/9/94	0.120	
	61-226	5/11/94	0.150	
Building R - Source Water (Sink Faucet)	*61-212*	5/9/94	0.012	Room 147
	61-233	5/11/94	0.045	
Building R Recirc. Hot Water - Room 137	*61-213*	5/9/94	0.020	
	61-234	5/11/94	0.048	

APPENDIX D - COPPER MASS BALANCES



Line #	Description	Basis			Flow [gpd]	[Cu] [mg/l]	Mass [lb/d]
1	Core Water Supply	# sqft/people/fixtures			167,200	0.005	0.0070
2	D&T Water Supply	# sqft/people/fixtures			88,800	0.005	0.0037
3	• Water Supply	•			256,000	0.005	0.0107
4	• Hot Make-up	33%			84,980	0.005	0.0035
5	• Cold Make-up	67%			171,020	0.005	0.0071
3	• Water Supply				256,000	0.005	0.0107
4	• Hot Make-up				84,980	0.005	0.0035
12	• Return Hot				5,915	0.258	0.0127
8	• Recirc. Hot				90,895	0.131	0.0995
9	Kitchen Recirc. Hot	33%			29,995	0.131	0.0328
17	Fixtures Recirc. Hot	67%			60,899	0.131	0.0667
18	Corrosion				•••	•••	0.0960
8	• Recirc. Hot				90,895	0.258	0.1955
10	Kitchen Return Hot	15%			4,207	0.258	0.0090
11	Fixtures Return Hot	3%			1,708	0.258	0.0037
12	• Return Hot				5,915	0.258	0.0127
6	Kitchen Cold	20%			34,204	0.005	0.0014
7	Fixtures Cold	80%			136,816	0.005	0.0057
5	• Cold Make-up				171,020	0.005	0.0071
9	Kitchen Recirc. Hot				29,995	0.131	0.0328
10	Kitchen Return Hot				-4,207	0.131	-0.0046
6	Kitchen Cold	lb/meal/d	meals/d		34,204	0.005	0.0014
13	Food Waste	0.000003	8,000		•••	•••	0.0201
19	Kitchen Drains	[See Ref. 11]			59,993	0.010	0.0497
17	Fixtures Recirc. Hot				60,899	0.131	0.0667
11	Fixtures Return Hot				-1,708	0.131	-0.0019
7	Fixtures Cold	µg/pers/d	people	type	136,816	0.005	0.0057
20	Human Waste	1,300	600	24hr			0.0017
20	Human Waste	325	6,000	day only			0.0043
14	Fixture Drains	[See Ref. 10]			196,007	0.047	0.0765
15	Utilities	[See Ref. 9 - Site 50]			1	0.300	0.000003
16	Sewer Discharge	•			**256,000**	**0.059**	**0.1263**


Copper Mass Balance
Diagnostic & Treatment [D&T] Building
[Hospital Modernization Project - Phase I]
[Water Meter 26,826]
D&T
Mechanical
Room
[31]
Chlorine Station
[32]
Water to Core
Hospital Areas
[33]
[34]
[35]
Cold Water
[36]
[39]
RO/IX System
[37]
Human Wastes
[38]
[40]
[41]
[42]
Sinks/Showers/Toilets
Lab DI Water
[47]
Janitorial & Other
Liquid Wastes
[44]
[45]
[46]
[48]
[43]
[49]
[50]
[56]
Hot Water
Lab & Other Uses
Steam Heaters
Hot Water
Returns
[53]
Utility Wastes
[52]
[51]
[54]
Steam
Sample Point 3 (D&T Lab)
[Installed 5/94]
Sewer - Sample Point 2 (D&T Manhole)
[55]

Line #	Description	Basis			Flow [gpd]	[Cu] [mg/l]	Mass [lb/d]
31	D&T Water Supply	# sqft/people/fixtures			111,000	0.005	0.00463
32	<To Core Areas>	# sqft/people/fixtures			-88,800	0.005	-0.00370
33	• Water Supply	•			22,200	0.005	0.00093
34	• Hot Make-up	25.00%			5,550	0.005	0.00023
35	• Cold Make-up	75.00%			16,650	0.005	0.00069
33	• Water Supply				22,200	0.005	0.00093
34	• Hot Make-up				5,550	0.005	0.0002
49	• Return Hot				555	0.280	0.0013
45	• Recirc. Hot				6,105	0.142	0.0072
47	Fixtures Recirc. Hot	75%			4,579	0.142	0.0054
46	Lab Recirc Hot	25%			1,526	0.142	0.0018
	Corrosion				•••	•••	0.0070
45	• Recirc. Hot				6,105	0.280	0.0142
48	Fixtures Return Hot	10%			416	0.280	0.0010
50	Lab Return Hot	10%			139	0.280	0.0003
49	• Return Hot				555	0.280	0.0013
39	DI System Feed	12.5%			2,081	0.005	0.00009
40	Lab Cold	12.5%			2,081	0.005	0.00009
37	Fixtures Cold	75%			12,488	0.005	0.00052
35	• Cold Make-up				16,650	0.005	0.00069
39	DI System Feed	Flow & Conc. Ratios			2,081	0.005	0.00009
•••	DI Blowdown	50%	10		-1,041	0.010	-0.00008
41	Lab DI				1,041	0.001	0.00000
42	Added by Lab Operations				0		0.00000
43	Lab DI Wastewater				1,041	0.001	0.00000
46	Lab Recirc. Hot				1,526	0.142	0.00181
40	Lab Cold				2,081	0.005	0.00009
44	Janitorial				0	•••	0.00000
50	Lab Return Hot				-139	0.142	-0.00016
43	Lab DI Wastewater				1,041	0.001	0.00000
53	Lab Drains				4,509	0.046	0.00173
47	Fixtures Recirc. Hot				4,579	0.142	0.00542
48	Fixtures Return Hot			Time	-416	0.142	-0.00049
37	Fixtures Cold	µg/pers/d	people	on site	12,488	0.005	0.00052
38	Human Waste	1,300	0	24hr	•••	•••	0.0000
38	Human Waste	325	2,000	day only	•••	•••	0.0014
51	Fixture Drains	[See Ref. 10]			16,650	0.050	0.00688
52	Utilities		Condensate [est.]		•••	•••	0.00025
•••	DI Blowdown				1,041	0.010	0.00008
53	Lab Drains				4,509	0.046	0.00173
54	Sample Point 3				5,550	0.045	0.00207
55	Sewer Discharge (Point 2)	•			**22,200**	0.048	**0.00895**