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# Environmental Technology Verification Report

# Evaluation of Hydrometrics, Inc., High Efficiency Reverse Osmosis (HEROÔ) Industrial Wastewater Treatment System

**Prepared by**

CTC Concurrent Technologies Corporation

**Under a Cooperative Agreement with**

EPA **U.S. Environmental Protection Agency**



ETV ETV ETV

## NOTICE

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# Evaluation of Hydrometrics, Inc., High Efficiency Reverse Osmosis (HEROÔ) Industrial Wastewater Treatment System

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# FOREWORD

The Environmental Technology Verification (ETV) Program has been established by the EPA to evaluate the performance characteristics of innovative environmental technologies for any media and to report this objective information to the states, local governments, buyers, and users of environmental technology. EPA's Office of Research and Development (ORD) established a five-year pilot program to evaluate alternative operating parameters and to determine the overall feasibility of a technology verification program. ETV began in October 1995 and was evaluated through September 2000, at which time EPA prepared a report to Congress containing results of the pilot program and recommendations for its future operation.

EPA's ETV Program, through the National Risk Management Research Laboratory (NRMRL), has partnered with *CTC* under the Environmental Technology Verification Program Metal Finishing P2 Technologies (ETV-MF) Center. The ETV-MF Center, in association with EPA's Metal Finishing Strategic Goals Program, was initiated to identify promising and innovative metal finishing pollution prevention technologies through EPA-supported performance verifications. The following report describes the verification of the performance of the Hydrometrics, Inc., High Efficiency Reverse Osmosis (HERO™) Industrial Wastewater Treatment System.

## ACRONYM and ABBREVIATION LIST

| | |
|---|---|
| amp | Ampere(s) |
| C | Specific Conductivity |
| $^{o}$C | Degrees Celsius |
| cm | Centimeter |
| COC | Chain of Custody |
| *CTC* | Concurrent Technologies Corporation |
| CWA | Clean Water Act |
| DOE | U.S. Department of Energy |
| EFF | Effluent |
| EPA | U.S. Environmental Protection Agency |
| ETV-MF | Environmental Technology Verification Program for Metal Finishing P2 Technologies |
| FM&T | Federal Manufacturing & Technology |
| ft$^2$ | Square Feet |
| gal | Gallon(s) |
| gfd | Gallons of Permeate Produced per Square Foot of Membrane per Day |
| gpd | Gallons per Day |
| gpm | Gallons per Minute |
| HCl | Hydrochloric Acid |
| HERO™ | High Efficiency Reverse Osmosis |
| HP | Horsepower |
| hr(s) | Hour(s) |
| Hz | hertz |
| IC | Ion Chromatography |
| ICP-AES | Inductively Coupled Plasma – Atomic Emission Spectroscopy |
| IDL | Instrument Detection Limit |
| IN | Influent |
| IWPF | Industrial Wastewater Pre-Treatment Facility |
| KCP | Kansas City Plant |
| kWh | Kilowatt-Hour |
| L | Liter |
| lb | Pound |
| MBS | Metabisulfite |
| MDL | Method Detection Limit |
| mg | Milligram |
| mg/L | Milligram per Liter |
| min | Minute |
| mL | Milliliter |
| MP&M | Metal Products & Machinery |
| MRL | Method Reporting Limit |
| µg | Microgram |
| µS | Micro-siemens |
| NA | Not Applicable |
| NaOH | Sodium Hydroxide |

## ACRONYM and ABBREVIATION LIST (continued)

| | |
|---|---|
| ND | Not Detected |
| NRMRL | National Risk Management Research Laboratory |
| O&G | Oils and Grease |
| O&M | Operating and Maintenance |
| ORD | Office of Research & Development |
| P | Percent Recovery |
| POTW | Publicly Owned Treatment Works |
| PVD | Physical Vapor Deposition |
| QA/QC | Quality Assurance/Quality Control |
| QMP | Quality Management Plan |
| RO | Reverse Osmosis |
| RPD | Relative Percent Difference |
| SAC | Strong Acid Cation |
| SP- | Sampling Point |
| SR | Sample Result |
| SSR | Spiked Sample Result |
| TDS | Total Dissolved Solids |
| TOC | Total Organic Carbon |
| TSA | Technical System Audit |
| TSS | Total Suspended Solids |
| U.S. | United States |
| VOC | Volatile Organic Carbon |
| WAC | Weak Acid Cation |

**ACKNOWLEDGEMENTS**

This is to acknowledge Valerie Whitman of *CTC* for her help in preparing this document. *CTC* also acknowledges the support of all those who helped plan and implement the verification activities and prepare this report. In particular, a special thanks to Alva Daniels, EPA National Risk Management Research Laboratory (NRMRL) Assistant Director, and Lauren Drees, EPA Quality Assurance Manager. *CTC* also expresses sincere gratitude to Hydrometrics, Inc., the manufacturer of the High Efficiency Reverse Osmosis (HERO™) Industrial Wastewater Treatment System, for their participation in and support of this program, and their ongoing commitment to improve metal finishing operations. In particular, *CTC* thanks Steve Ackerlund and Mark Reinsel for their assistance. *CTC* also thanks Honeywell Federal Manufacturing & Technology's (FM&T's) Kansas City Plant (KCP) of Kansas City, Missouri, for the use of their facilities and materials, and the contributions of Mike Stites and Bob Hughes for their cooperation during this verification test.

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

Concurrent Technologies Corporation

# ETV VERIFICATION STATEMENT

| | |
|---|---|
| **TECHNOLOGY TYPE:** | **REVERSE OSMOSIS** |
| **APPLICATION:** | **INDUSTRIAL WASTEWATER TREATMENT** |
| **TECHNOLOGY NAME:** | **High Efficiency Reverse Osmosis (HEROô)** |
| **COMPANY:** | **Hydrometrics, Inc.** |
| **POC:** | **W. Steve Ackerlund** |
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The United States Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved, cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, and stakeholder groups consisting of buyers, vendor organizations, and states, with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The ETV Metal Finishing P2 Technologies (ETV-MF) Program, one of 12 technology focus areas under the ETV Program, is operated by Concurrent Technologies Corporation, in cooperation with EPA's National Risk Management Research Laboratory. The ETV-MF Program has evaluated the performance of a reverse osmosis (RO) technology for the treatment of industrial wastewater. This verification statement provides a summary of the test results for the Hydrometrics, Inc., High Efficiency Reverse Osmosis (HERO™) Industrial Wastewater Treatment System.

## VERIFICATION TEST DESCRIPTION

The Hydrometrics, Inc., HERO™ system was tested, under actual production conditions, on combined industrial wastewater at Honeywell Federal Manufacturing & Technology's (FM&T's) Kansas City Plant (KCP) in Kansas City, Missouri. A mobile pilot-scale HERO™ system was installed at the KCP, after their conventional wastewater treatment system, in order to evaluate the system's ability to treat and recycle the KCP's combined, post-treated wastewater for reuse within the facility. While beyond the scope of this verification test, the equipment vendor claims the HERO™ system may also be used to treat dilute rinse waters directly (pre-treatment), and more concentrated wastes after appropriate conditioning (post-treatment).

Testing was conducted on two separate processes over a four-day period:

- A large portion (46 percent) of the combined KCP wastewater is dilute, non-production wastewater. The remaining 54 percent of the KCP's spent process water consists of non-metal-finishing industrial process wastewaters, and rinse waters from metal finishing. The HERO™ system was evaluated on its ability to separate chemical contaminants from the post-conventionally-treated wastewater and condition it for reuse within the facility.

- A very small amount of the KCP's wastewater, about 330 gallons per day (gpd), is cyanide-bearing rinse water from the KCP metal finishing shop's copper plating operations. Copper is a potential recyclable/salable metal. This verification test included a separate weak acid cation (WAC) ion exchange unit installed between the pre-conventional treatment cyanide rinse water storage tank and the first step of the cyanide oxidation process. This smaller-scale WAC unit used resin identical to the WAC unit within the HERO™ system where metals recovery normally takes place. Due to the KCP's conventional wastewater treatment system, this separate WAC unit was installed upstream in order to recover the copper. The verification on this WAC unit demonstrated the HERO™ system's ability to remove valuable metals for recovery, recycle and/or sale.

Historical operating and maintenance labor requirements, chemical usage, and waste generation data were collected to perform the cost analysis.

## TECHNOLOGY DESCRIPTION

The patented three-step HERO™ process combines "off-the-shelf" equipment to convert wastewater into reusable water. In the first step of the HERO™ process, ion exchange removes ions that form scale (water softening). Removing the hardness from the wastewater results in a concentrated brine waste. The second step is membrane degasification, which removes the buffering effect from carbon dioxide to lower caustic demands in the final step of the process. Carbon dioxide is the only byproduct of the second step, where the wastewater alkalinity is removed. The final step in the HERO™ process is RO. Addition of NaOH to the wastewater raises the pH to the proper operating level before entering the final stage of treatment. The high pH of the wastewater entering this stage eliminates fouling of the RO membrane. A concentrated brine waste is generated from this step as well.

## VERIFICATION OF PERFORMANCE

Daily grab samples were collected over a four-day period from the HERO™ influent, HERO™ effluent, HERO™ RO waste solution, copper recovery WAC unit influent, and copper recovery WAC unit effluent. Samples were analyzed to determine the contaminant levels before and after each process in order to calculate contaminant removal efficiency. Results from the HERO™ RO waste solution analysis were used for mass balance purposes, and to determine waste disposal restrictions and costs.

Average analytical results for key parameters are shown in **Table i.** Wastewater parameters of concern include heavy metals from metal finishing and other rinsing operations, hardness, alkalinity, specific conductivity, residual chlorine and cyanide from the conventional wastewater treatment system, sulfate, sulfides, nitrate, and total dissolved solids (TDS).

Various other parameters were monitored in order to determine external water quality standards compliance, such as local regulatory discharge as well as KCP recycled water quality standards.

| Parameter | HEROÔ Influent (mg/l) | HEROÔ Effluent (mg/L) | KCP Recycle Standard (mg/L) | HEROÔ RO Waste (mg/L) | Disposal Limits (mg/L) |
|---|---|---|---|---|---|
| **Aluminum** | <0.075 | <0.075 | <0.075 | 0.537 | - |
| **Arsenic** | <0.085 | <0.085 | <0.085 | <0.085 | 1.82 |
| **Barium** | 0.024 | <0.004 | <0.0185 | 0.045 | - |
| **Cadmium** | <0.005 | <0.005 | <0.005 | <0.005 | 0.05 |
| **Calcium** | 112.2 | 0.2 | <31.8 | 166.1 | - |
| **Chromium** | <0.007 | <0.007 | <0.007 | 0.537 | 1.268 |
| **Copper** | 0.011 | <0.01 | <0.01 | 0.029 | 1.547 |
| **Iron** | 0.011 | <0.04 | <0.0429 | 0.027 | - |
| **Lead** | <0.050 | <0.050 | <0.050 | <0.050 | 0.316 |
| **Magnesium** | 0.09 | <0.05 | <6.88 | 1.10 | - |
| **Manganese** | <0.007 | <0.007 | <0.007 | 0.0018 | - |
| **Mercury** | <0.0002 | <0.0002 | <0.002 | <0.0002 | 0.052 |
| **Molybdenum** | 0.252 | <0.02 | <0.02 | 4.502 | - |
| **Nickel** | 0.008 | <0.03 | <0.03 | 0.119 | 1.822 |
| **Silver** | <0.007 | <0.007 | <0.007 | 0.016 | 0.197 |
| **Sodium** | 56.2 | 11.5 | <31.6 | 440 | - |
| **Tin** | <0.250 | <0.250 | <0.250 | <0.250 | - |
| **Zinc** | <0.100 | <0.100 | <0.100 | <0.100 | 1.195 |
| **TDS** | 527 | 36 | <246 | 5,192 | - |
| **TSS** | <5.0 | <5.0 | <5.0 | 1.25 | - |
| **TOC** | <10.0 | <10.0 | <10.0 | 37.3 | - |
| **O&G** | <5.0 | <5.0 | <5.0 | <5.0 | 150 |
| **Chloride** | 18.8 | <1.0 | <17.8 | 277 | - |
| **Fluoride** [1] | 0.8 | 0.3 | <1.5 | 12.6 | - |
| **Nitrate as N** | 4.6 | 1.3 | <2.13 | 70.4 | - |
| **Sulfate** [1] | 145.7 | <1.0 | <93.9 | 2,302.5 | - |
| **Sulfide** | <0.500 | <0.500 | <0.500 | <0.500 | 102 |
| **Total Alkalinity** | 148.8 | 29.9 | <46 | 288.6 | - |
| **Total Cyanide** | 0.003 | <0.005 | <0.0212 | 0.074 | 0.86 |
| **Dissolved Silica** | 3.3 | <1.0 | <5.73 | 40.1 | - |
| **Total Residual $Cl_2$** | <0.02 | 0.01 | <2.14 | <0.02 | - |
| **Specific Conductivity** | 1,116 (µS/cm) | 142 (µS/cm) | <441 | 6,616 | - |

[1] This data is an estimate only, due to a wide range of accuracy used by the lab.
[2] Total Discharge Limits

**Table i. Summary of Key Analytical Data**

**Wastewater & Copper Recovery.** The recovery percentages for wastewater were consistently high. Using flowmeters installed on the HERO™ system influent and effluent, along with the system's operational schedule, accurate wastewater recoveries were calculated for each verification test day. The overall membrane flux was 17.7 gfd (gallons per foot per day), which is much higher than the industry standard of 11 gfd. These results indicate the HERO™ system is very efficient in recovering water for reuse within the facility. Copper recovery percentages from the separate WAC ion exchange unit were less pronounced, showing that the HERO™ system did a fair job of recovering copper for resale or reuse.

The relatively low concentration of copper in the influent could have had an effect on the copper recovery efficiency. Passing the water through the WAC unit multiple times may increase the copper recovery percentage significantly. Wastewater and copper recovery are summarized in **Table ii.**

| | Average | Min | Max | Standard Deviation |
|---|---|---|---|---|
| **Wastewater Recovery %** | 94.3 | 92.20 | 96.7 | 1.8 |
| **Copper Recovery %** | 40.6 | 25.6 | 51.3 | 11.2 |

**Table ii. Summary of Wastewater & Copper Recovery**

**Contaminant Removal.** Since this pilot test treated wastewater that had already gone through the KCP's traditional wastewater treatment process, the HERO™ influent already met local regulatory discharge limits for the sanitary sewer. The HERO™ influent did not meet the quality standards for in-facility reuse. The wastewater had excess levels of calcium, sodium, TDS, total alkalinity, and nitrate (as N). Throughout the four days of sampling, analysis showed that the daily average contaminant levels of the HERO™ effluent were low enough to meet KCP's recycled water standard. The HERO™ RO waste solution met the current local sanitary sewer discharge limits. Contaminant removal is summarized in **Table iii.**

| | Average | Min | Max | Standard Deviation |
|---|---|---|---|---|
| **Calcium % Removal** | 99.8 | 99.8 | 99.9 | 0.05 |
| **Sodium % Removal** | 79.7 | 69.7 | 89.8 | 9.13 |
| **Nitrate (as N) % Removal** | 68.0 | 63.5 | 77.9 | 6.65 |
| **Total Alkalinity % Removal** | 81.6 | 70.2 | 90.5 | 8.66 |
| **TDS % Removal** | 93.8 | 90.6 | 96.5 | 2.45 |

**Table iii. Summary of Contaminant Removal**

**Energy Use.** Energy requirements for operating the HERO™ pilot unit at the KCP included electricity for the five liquid feed pumps. Electricity is also used for system instrumentation, compressed air and reagent feed pumps; however, the energy requirements for these are less significant and were not evaluated during this project. Electricity for the pilot trailer lighting and air conditioning was also not included in the HERO™ system energy use calculations. Electricity use was determined to be 36.7 kWh/10,000 gallons (gal) of treated wastewater.

**Waste Generation.** A waste generation analysis was performed using operational data collected during the verification test period, and historical records from the KCP and Hydrometrics. Waste generation data normalized to the amount of wastewater processed over the verification test period showed an RO waste generation rate of about one gal for every 12.6 gal of wastewater treated. Implementation of the HERO™ system reconditioned the wastewater for potential reuse within the KCP, thus eliminating the discharge of this wastewater to the sanitary sewer. However, some of this waste reduction is offset by the RO waste solution and WAC ion exchange regeneration waste generated by the HERO™ system.

Since the WAC ion exchange system was not regenerated during the verification test period, a theoretical extrapolation had to be considered.

Chemical mass balance calculations determined a WAC regeneration waste solution creation rate of approximately one gal for every 128.5 gal of KCP wastewater processed. Analytical characterization of this waste stream was not possible, but historical records of the HERO's™ WAC regeneration waste solution for similar wastewaters indicate that a standard dischargeable water-softener-like regeneration solution would be generated. Hydrometrics provided an estimate of approximately one gal of combined pretreatment waste for every 41.3 gal of wastewater processed. The combined waste stream is a brine solution with a high hardness count, and is generally suitable for direct discharge to the sanitary sewer. The cumulative waste generation rate from the HERO™ system is approximately one gal for every 8.93 gal of wastewater processed, an overall waste reduction of 89 percent.

**Operating and Maintenance Labor.** Hydrometrics personnel operated the HERO™ pilot system during verification testing. The HERO™ system requires an operator during startup and shutdown. During operation, the system is self-regulating; however, for testing purposes, a Hydrometrics operator was on-site at all times during the HERO™ system operation. The operational tasks performed by the Hydrometrics operator during the verification test period included: daily inspections of the unit, recording of system parameters, filter change-outs, minor adjustments, and chemical additions. Considerable labor was expended when the membrane degassifier and SAC unit failed to operate initially, however, these were start-up equipment issues, and not counted as general operating and maintenance labor activities. The down-time of these components had no significant effects on water quality, chemical or electrical demand. Estimates by Hydrometrics and validation of operational tasks indicate that for a full-scale 86,400 gpd HERO™ system, approximately seven hours of operating and maintenance (O&M) labor each week would be required.

Cost Analysis. A cost analysis of the HERO™ system was performed using current operating costs and historical records from the KCP normalized to a cost/savings per gal of treated water. An estimated capital cost (2001) of a HERO™ system able to process the KCP average of 86,000 gpd of industrial wastewater is $270,000 (includes $216,000 for the system and $54,000 for installation costs). Based on the reduction of sewer discharge and cost avoidance realized from recycling the wastewater for reuse, the annual cost savings associated with the unit is approximately $60,065. The projected payback period would be approximately 4.5 years.

## SUMMARY

The test results show that the HERO™ system provides an environmental benefit by conditioning the KCP's industrial wastewater for reuse within the facility, thereby reducing the amount of fresh make-up water required each day. The HERO™ system achieved a very high recovery of the treated water (94%), and a high membrane flux rate (1.6 times higher than the conventional norm). There was no indication of membrane fouling during the verification test period. Copper recovery operations performed marginally, but further adjustments and processing could yield significantly better results. The relatively low concentration of copper in the KCP wastewater may have been a poor matrix to test the effectiveness of the HERO™ system's metals recovery ability. The major economic benefit associated with this technology is in reduced waste disposal costs and raw water purchase costs associated with the recycling of the wastewater within the facility. When the labor and electrical costs associated with operating the HERO™ system are factored in, the payback period is approximately 4.5 years. The equipment vendor also claims that other benefits at some installations may include: reduced wastewater in support of zero liquid discharge, reduced clarifier or other pre-treatment needs, and improved operations associated with reuse of low-hardness, high-quality water. As with any technology selection, the end user must select appropriate wastewater treatment equipment and chemistry for a process that can meet their associated environmental restrictions, productivity, and water quality requirements.

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## 1.0 INTRODUCTION

The High Efficiency Reverse Osmosis (HERO™) unit is a three-stage reverse osmosis (RO) wastewater treatment system for wastewater recycling and metals recovery. The verification test evaluated the ability of the HERO™ unit to purify wastewater from chemical rinses, spent baths, non-contact cooling, boiler blow-down, and laboratory sinks for potential reuse within a manufacturing facility. Additionally, the HERO™ system was tested for the recovery of copper from cyanide-bearing rinsewater from copper plating operations. It was tested by *CTC* under the U.S. Environmental Protection Agency (EPA) Environmental Technology Verification Program for Metal Finishing P2 Technologies (ETV-MF). The purpose of this report is to present the results of the verification test.

The HERO™ system was tested to evaluate and characterize the operation of the RO wastewater treatment system through measurement of various process parameters. Testing was conducted at Honeywell Federal Manufacturing & Technology's (FM&T's) Kansas City Plant (KCP), in Kansas City, Missouri. The KCP is owned by the U.S. Department of Energy (DOE), and is operated by Honeywell FM&T. The KCP manufactures a wide range of electronic, mechanical, and engineered material components for national defense systems.

## 2.0 DESCRIPTION OF THREE-STAGE WASTEWATER TREATMENT SYSTEM

### 2.1 Three-Stage Wastewater Treatment Equipment

The HERO™ wastewater treatment system utilizes a three-stage process: weak acid cation (WAC) ion exchange, membrane degasification, and high-pH RO. WAC ion exchange is used to remove hardness associated with alkalinity. Additionally, cations (such as copper, barium, iron, manganese, zinc and sodium) may also be removed. Treated water is slightly acidic. The bicarbonate alkalinity in the water is converted to carbon dioxide. Additional acid may be added to convert the remaining alkalinity to carbon dioxide. After degasification in the next step, the total dissolved solids (TDS) are reduced. The WAC is regenerated periodically using sulfuric or hydrochloric acid. The concentrated waste brine solution is mixed with the RO reject stream for disposal. Alternatively, the brine solution could be recirculated to a clarifier, if one is used as pretreatment to the HERO™ system, for further precipitation of any remaining contaminants.

After WAC ion exchange treatment, the water is passed through a counter-current air stripper (membrane degasifier) to remove the carbon dioxide created in the WAC ion exchange process. This step removes the buffering capacity of the water, thereby minimizing caustic addition in the next step.

In the high-pH RO step, a small amount of caustic is used to increase the pH prior to treatment. Operating at high pH has several important advantages:

- Fats and oils are emulsified. These materials are kept in solution and rejected rather than plating out on the membrane surface.

- Silt fouling is eliminated. Membranes used in normal RO systems become fouled with silt, biological growth, and organic matter. When this occurs, the membranes are cleaned with softened water at pH 10. HERO™ systems operate continuously with softened feed water at pH 10. Silt and organic matter are continuously cleaned from the membrane surface and biological growth is eliminated.

- Silica solubility is increased. Increased silica solubility at high pH prevents silica scaling on the membrane. Silica can often be a limiting factor controlling the recovery limit of an RO system.

- Weak organic acids are neutralized. Low concentrations of these acids can foul membranes unless they are ionized. Once neutralized at high pH, the membranes reject these ions.

The technology utilizes proven and available "off-the-shelf" equipment components. The equipment is compact (about 8' x 20' depending on flow and application), skid-mounted, and modular for simple expansion. Electrical service of 480 volt, 50 amperes (amp), 3-phase, 60 hertz (Hz) is required. Automated operations result in low operating and maintenance costs. The unit usually operates in a continuous mode, although it also has the capability to operate in a batch mode. Existing RO systems can be easily retrofitted to operate in the HERO™ configuration.

## 2.2 Test Site Installation

Hydrometrics, Inc., selected the Honeywell FM&T's KCP in Kansas City, Missouri, as the test site for the verification testing of the HERO™ system. Honeywell FM&T, a prime contractor for the DOE, manages and operates the approximately one million square foot KCP. Honeywell and its divisions produce many high-tech products for consumer and government use. Virtually every form of air transportation depends on at least one of Honeywell's systems, including every manned space flight since the beginning of the U.S. space program.

The KCP manufactures electronic, mechanical, and engineered material components for national defense systems. Within the engineered material components operations they have capabilities for applying and evaluating low and zero volatile organic carbon (VOC) paints, dry film lubricants, and powder coatings. Plasma, electrophoresis, and chemical surface pretreatments are also available. Electroplated coating applications include copper, tin, tin-lead, zinc, cadmium, nickel, electroless nickel, hard and soft gold, rhodium, and black and brown oxides. They electroform copper, nickel, and gold. On difficult-to-plate substrates, a combination of vacuum deposition and electroplating is used to achieve adherent coatings.

The microelectronics manufacturing division of the facility consists of 19,000 square feet ($ft^2$) of clean rooms, 1,800 $ft^2$ of laser rooms, and 26,000 $ft^2$ of manufacturing and support area.

Capabilities include Thin Film Networks, Thick Film Networks, and Low Temperature Co-fired Ceramic Networks. Several film materials including titanium, palladium, palladium-gold, platinum-gold, gold, silver, copper, and chromium are applied to a variety of substrate materials using processes such as electroplating, sputtering, and plasma vapor deposition (PVD).

These plating, coating, and other metal processing operations generate wastewaters that are combined with other non-process industrial wastewaters and treated in a conventional on-site wastewater treatment system, and then discharged to a Publicly Owned Treatment Works (POTW). The HERO™ system was installed after the conventional system to process the wastewater so it can be reused at the KCP.

Since industrial wastewater quality is inherently site-specific, wastewater treatment systems are generally designed for specific applications. For example, feed water with elevated hardness, total hardness in excess of total alkalinity, high total suspended solids (TSS), or high oil and grease (O&G) may require additional pretreatment prior to the HERO™ system. This pretreatment may include filters, strong acid cation (SAC) ion exchange, or clarifiers. For reasons like this, HERO™ systems are designed to address the specific wastewater quality characteristics of the host facility. Water conditions at the KCP required the use of a multimedia prefilter and a SAC ion exchange unit. A diagram of the HERO™ system, as it was installed at the KCP, is shown in **Figure 1**.

For the verification test, the KCP had a mobile unit installed following their conventional wastewater treatment system. The mobile unit only treated a small portion of the daily KCP wastewater effluent for demonstration purposes. Pictures of a mobile HERO™ system like the one installed at the KCP for the verification test are provided for reference in **Figure 2**.

Copper was recovered from the plating shop cyanide rinse water waste stream by employing a separate WAC ion exchange unit supplied by Hydrometrics, Inc. This smaller, separate unit removed copper that was complexed with cyanide. Normally, metals recovery with the HERO™ process is achieved in the WAC ion exchange unit that is integral to the three-step treatment process. However, since cyanide oxidation results in copper precipitation, copper removal is more efficient prior to KCP's traditional cyanide oxidation process. A full-scale separate WAC ion exchange unit would have been regenerated with sulfuric acid; however, due to the relatively short duration of the verification test, regeneration was not necessary or feasible. The quantity of recovered copper is calculated by mass balance.

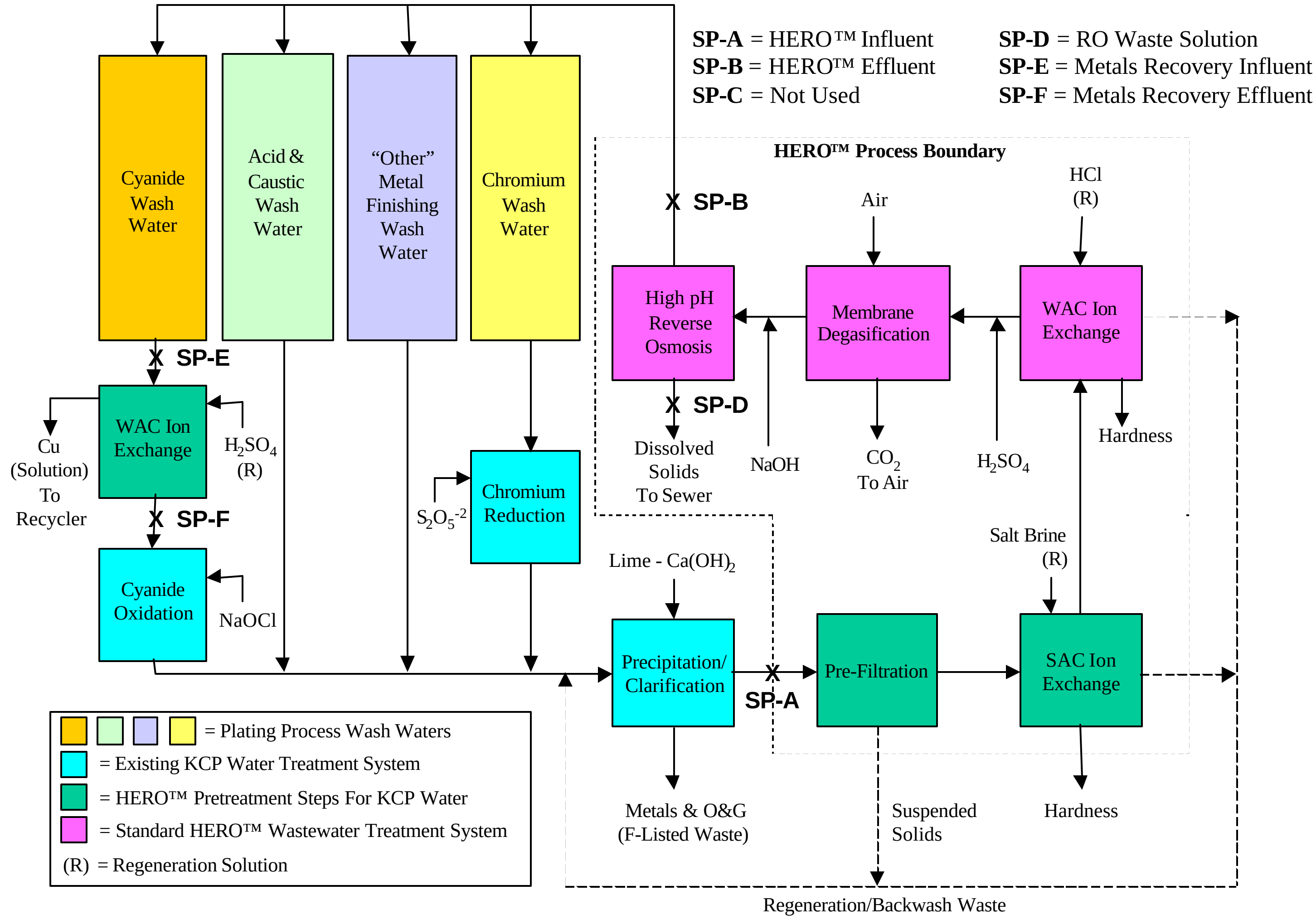


**Figure 1. HEROô Wastewater Treatment System at Honeywell FM&T's KCP**

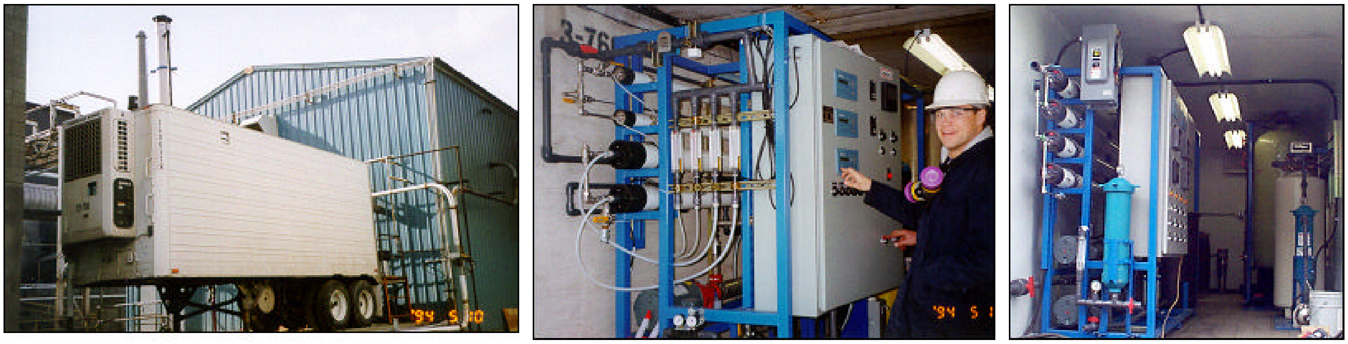

**Figure 2. HEROÔ System Pilot Trailer**

## 2.3 Operating Flow

Wastewater flow at the KCP Industrial Wastewater Pre-Treatment Facility (IWPF) follows a conventional multi-step process. Cyanide-bearing rinsewaters are collected in two 10,657-gallon (gal) storage tanks. Chromium-bearing rinsewaters are collected in two 22,520-gal storage tanks. Acid/caustic rinsewaters are collected in two 74,642-gal storage tanks, and non-process industrial wastewater is collected in two 214,207-gal storage tanks. Each pair of storage tanks can be operated in a "collection" or "feed" mode, isolated from each other, and circulation pumps within each storage tank continually keep the wastewater well mixed. Wastewater is drawn from each isolated, well mixed feed tank for conventional treatment, while the collection tank is open, and accepting wastewater from the manufacturing facility. Collection and feed tanks typically reverse roles each night, after plant shutdown, as the feed tank's wastewater becomes depleted.

### 2.3.1 KCP Conventional Wastewater Treatment

#### 2.3.1.1 Cyanide Oxidation

Copper/cyanide-bearing rinse waters are formed when drag-out or drippage from cyanide plating baths contaminate rinse baths during normal copper plating operations. The wastewater goes through a normal cyanide oxidation process using sodium hypochlorite. This is necessary to prevent health and safety issues associated with the release of cyanide gas later in the treatment system.

#### 2.3.1.2 Chromium Reduction

Another conventional step of the KCP wastewater treatment process is the reduction of chromium in the chromium plating rinse waters. The chromium plating rinse waters are treated with metabisulfite (MBS) in order to reduce chromium in the hexavalent state to the more stable and less toxic trivalent chromium state. The effluent from this step moves directly to the next conventional step, precipitation/clarification.

#### 2.3.1.3 Lime Precipitation & Clarification

Spent rinse water from the cyanide oxidation, chromium reduction, acid and caustic rinse water, and other non-process industrial wastewater are then commingled in 3,750-gal flash mix tanks, where they are treated with a sodium hydroxide/lime slurry and mechanically mixed. They are pumped at a rate of approximately 170 gal per minute (gpm) into the conventional wastewater clarifier. Approximately 80,000 gal of combined wastewater per day are treated in this conventional lime precipitation/ clarification unit during the single 10-hour operating shift. This system removes metals and O&G, and provides a consistent water quality feed to the sand filter and final pH adjustment/monitoring before discharge to the sanitary sewer. The concentrated reject from the clarifier is pressed, dried, and sent for disposal as an F006 waste.

### 2.3.2 HEROÔ Pretreatment

#### 2.3.2.1 Prefiltration

In addition to the normal three-stage HERO™ process, the post-clarified feed water will be pretreated prior to going through the HERO™ process. The first step of HERO™ pretreatment will be to pass the water through a multimedia prefilter to remove residual suspended solids. Removing these solids will keep the RO membranes from becoming damaged.

#### 2.3.2.2 SAC Ion Exchange

Water from the multimedia prefilter will then go through a SAC ion exchange process. This is necessary due to the high hardness-to-alkalinity ratio of the wastewater at this point. (SAC ion exchange treatment is not normally required for full-scale treatment if pre-softened water is used. The equipment vendor claims that a full-scale system could support 95 percent recycle of the water. A standard water softener could be used to treat the 5 percent make-up water stream, and eliminate hardness from the process water circuit.) SAC ion exchange treated water is then sent to the first step in the standard HERO™ process, the WAC ion exchange unit.

### 2.3.3 HEROÔ System

#### 2.3.3.1 WAC Ion Exchange Treatment

Wastewater from the pretreatment process is pumped into the HERO™ system at a flow rate of approximately 18 gpm. Wastewater from the SAC ion exchange flows into the WAC ion exchange step of the HERO™ process to remove all remaining hardness. Because the WAC resin is in acid form, this step also lowers the pH of the water to approximately 4.5, and converts carbonate and bicarbonate to carbon dioxide. When required (approximately every 20–30 days of operation), this unit is regenerated using a dilute solution of hydrochloric acid.

#### 2.3.3.2 Membrane Degasification

From the WAC ion exchange outlet, the wastewater goes through degasification to remove carbon dioxide. This step removes the buffering capacity of the water, minimizing pH adjustment costs. Acid addition prior to the degasifiers may be necessary to lower the pH to below 4.5 for complete carbon dioxide conversion.

#### 2.3.3.3 pH Adjustment and Reverse Osmosis (RO)

The final step in the HERO™ system is adjustment to pH 10 and RO treatment. Operating the RO at high pH avoids bio-fouling and silica scaling, and enhances silt rejection. Treated wastewater is returned to the rinse water make-up system at a flow of approximately 17 gpm. Under current regulatory discharge limits, the RO reject can be discharged to the sanitary sewer.

The diagram in **Figure 3** illustrates the reactions that typically take place within the HERO™ system.

## 3.0 METHODS AND PROCEDURES

### 3.1 Test Objectives

The following are statements of specific project objectives (see **Table 1** for summary):

- Evaluate, document, and verify the performance of the separate HERO™ wastewater WAC ion exchange treatment technology for the recovery of copper that builds up in the process rinse water during the cyanide-containing finishing operations. Characterize the recovered copper for salability options.
- Evaluate, document, and verify the HERO™ wastewater treatment technology's removal efficiency for TDS, O&G (as HEM), Ag, Al, As, Ba, Ca, Cd, Cl, CN, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Na, Ni, Pb, Sn, Zn, total residual chlorine, sulfate, nitrate, sulfides, chloride, fluoride, dissolved silica, total alkalinity, TOC, and TSS that accumulate in process rinse waters during finishing operations and other industrial wastewater generating operations.
- Quantify the energy required to operate the system. Primary energy users include the electrical service to the automated system, instrument readouts, and the liquid feed pumps. This information will be used to estimate operating costs for the HERO™ wastewater treatment system.
- Quantify environmental benefit by determining the reduction in wastewater disposal quantities versus HERO™ waste sludge quantities/characteristics.

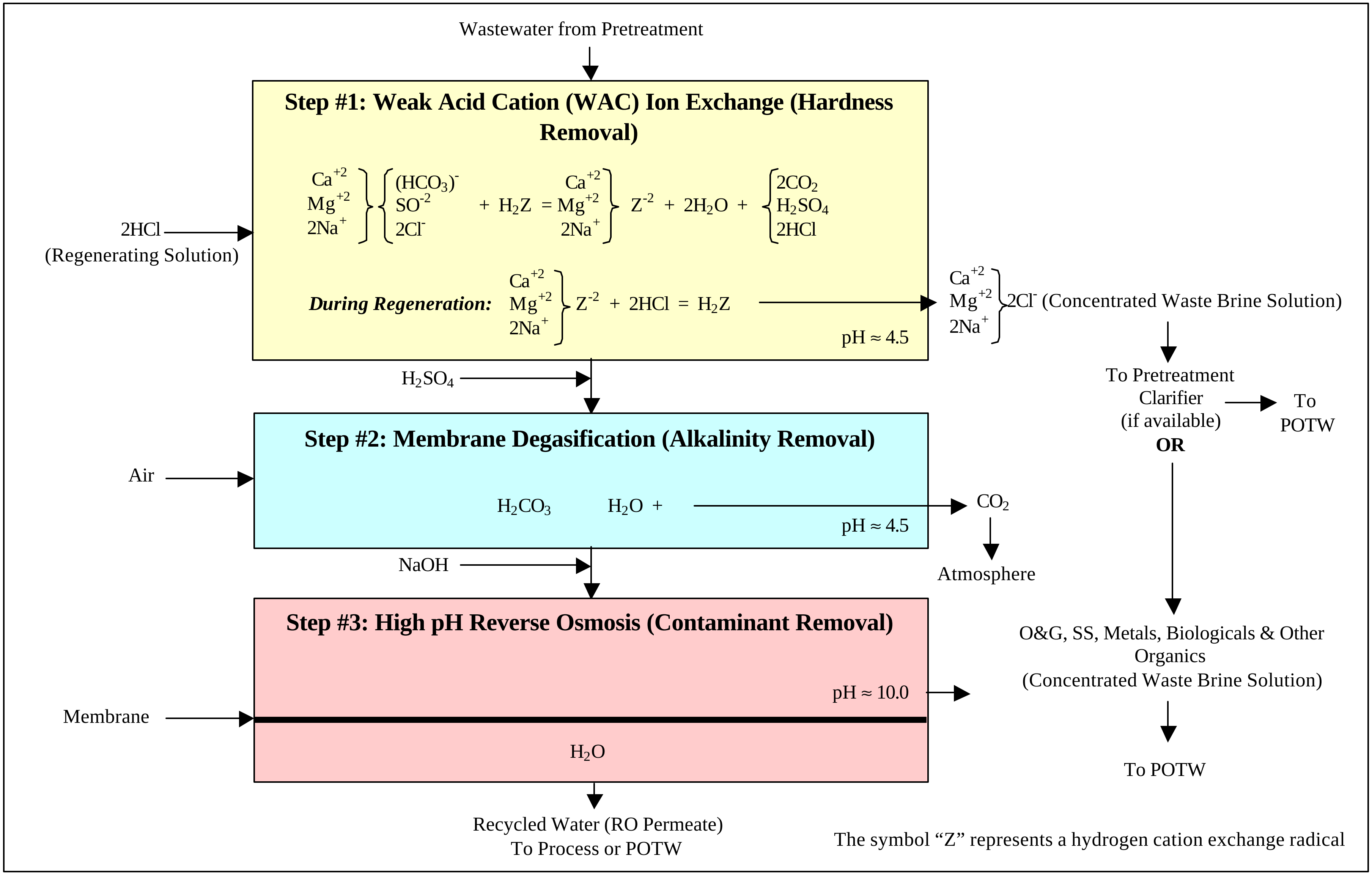


**Figure 3. HEROÔ System Chemical Reactions**

| Test | Test Objectives | Test Measurement |
|---|---|---|
| 1. HERO™ System Wastewater Recovery | Prepare a material balance for wastewater constituents. | • Chemical characteristics of influent.<br>• Chemical characteristics of effluent.<br>• Volume and chemical characteristics of the RO waste solution.<br>• Quantity of treatment chemicals used during testing. |
| | Evaluate the ability of the HERO™ system to process wastewater and separate chemical contaminants from water. | • Chemical characteristics of influent.<br>• Chemical characteristics of effluent. |
| | Determine the wastewater recovery rate of the system, normalized based on production throughput of wastewater. | • Volume of water recovered.<br>• Production throughput of wastewater. |
| | Determine the labor requirements needed to operate and maintain the HERO™ system. | • O&M labor requirements during test period. |
| | Determine the quantity of energy consumed by the HERO™ system during operation. | • Quantity of energy used by pumps and motors. |
| | Determine the cost of operating the wastewater recycle system for the specific conditions encountered during the testing. | • Costs of O&M labor, materials, and energy required during test period.<br>• Quantity and price of treatment chemicals used during testing. |
| | Quantify/identify the environmental benefit. | • Review of historical waste disposal records and compare to verification test practices. |
| 2. WAC Ion Exchange Unit Copper Recovery | Prepare a material balance for copper recovered from the cyanide-bearing wastewaster. | • Chemical characteristics (Cu) of influent.<br>• Chemical characteristics (Cu) of effluent.<br>• Volume and chemical characteristics of copper removed from the wastewater.<br>• Quantity of treatment chemicals used to recover the copper. |
| | Evaluate the ability of the WAC ion exchange unit to process wastewater and separate copper contaminants from water. | • Chemical characteristics (Cu) of influent.<br>• Chemical characteristics (Cu) of effluent. |
| | Determine the copper recovery rate of the system, normalized based on production throughput of wastewater. | • Volume of copper recovered.<br>• Production throughput of wastewater. |
| | Determine the labor requirements needed to operate and maintain the WAC ion exchange unit. | • O&M labor requirements during test period. |
| | Determine the cost of operating the WAC ion exchange unit for the specific conditions encountered during the testing. | • Costs of O&M labor and materials required during the test period.<br>• Quantity and price of chemicals used during copper recovery. |
| | Quantify/identify the environmental benefit. | • Review of historical waste disposal records and comparison to verification test practices. |

**Table 1. Test Objectives and Related Test Measurements Conducted During the Verification of the Hydrometrics HEROÔ System**

## 3.2 Test Procedure

### 3.2.1 System Set-Up

Prior to testing, the trailer-mounted HERO™ system was parked on a concrete pad adjacent to the building housing the existing lime precipitation clarifier wastewater treatment system. A blind sump surrounded the concrete pad, as this was a designated chemical loading/unloading area, complete with secondary containment. The separate copper recovery ion exchange unit was installed within the KCP wastewater treatment plant, inside the secondary containment sump area in the chemical transfer/storage bay. Treated water from KCP's conventional wastewater treatment plant was piped to the main HERO™ system, while the copper recovery ion exchange unit treated isolated cyanide-bearing rinse water from a continuously mixed 55-gal drum at a rate of approximately 16 milliliters per minute (mL/min). The HERO™ system polished wastewater at a rate of approximately 18 gpm, the target operating rate established by Hydrometrics for this test. Sampling proceeded once the unit was in operation and stabilized.

### 3.2.2 Testing

The HERO™ system and separate copper recovery WAC ion exchange unit were tested in accordance with the verification test plan [Ref. 1]. Testing for each operation was conducted during four consecutive days of wastewater processing.

The main HERO™ system was tested on the KCP's post-conventionally-treated wastewater. A large portion (46 percent) of the combined KCP wastewater is dilute, non-production wastewater. This non-production wastewater consists of non-contact cooling water, boiler blow-down water, laboratory sink water, etc. The remaining 54 percent of the KCP's spent process water consists of non-metal-finishing industrial process wastewaters, and rinse waters from metal finishing.

A very small amount of KCP's wastewater, about 330 gal per day (gpd), is cyanide-bearing rinse water from the KCP metal finishing shop's copper plating operations. Copper is a potential recyclable/salable metal, and this verification test included a separate WAC ion exchange unit that treated rinse water from the cyanide rinse water storage tank before it was sent to the first step of the cyanide oxidation process. This WAC unit used resin identical to the WAC unit within the HERO™ system where metals recovery would normally take place, but on a smaller scale. Due to the KCP's conventional wastewater treatment system, a separate WAC unit had to be installed upstream of that system in order to recover the copper. Because of the small amount of cyanide-bearing rinse water generated at the KCP, copper recovery was not economically feasible. The verification on this WAC unit was to demonstrate the HERO™ system's ability to remove valuable metals for recovery, recycle and/or sale.

As in most field tests, mechanical and equipment problems arose during the verification test. Most of these problems were minor and had no effect whatsoever on the data collected during the test. However, two problems occurred that may have had a small effect on operating procedures and chemical usage. First, the membrane degasifier unit was not operational during the verification test period. The purpose of the membrane degasifier is to remove the carbon dioxide from the wastewater that was generated during the WAC ion exchange stage. This lowers the buffering capacity of the wastewater, in turn minimizing the pH adjustment costs required for the next stage, RO. The result of the membrane degasifier not operating during the test was an 18 percent increase in sodium hydroxide usage to bring the wastewater up to a pH of 10 prior to going into the RO stage. Since this 18 percent increase over the first two days was equivalent to less than a gallon of sodium hydroxide, the chemical cost increase was very small. There was no effect to water quality or electricity demand.

The other equipment problem was related to the SAC ion exchange unit used in the pretreatment of the wastewater before it entered the main HERO™ system. This unit was not in operation at the start of the verification test, and was not repaired and back online until the end of the second day of testing. Wastewater bypassed the SAC unit and went directly from the multimedia prefilters into the WAC ion exchange stage of the HERO™ system. The effect of the SAC ion exchange unit not operating was an increase in hardness in the RO feed and reject. The HERO™ system was able to handle this increase in hardness, and removed it during the WAC ion exchange and RO stages. There was no increase in chemical usage due to the SAC ion exchange unit being offline for the first two days of testing. There was no increase in electrical demand, and no effect on HERO™ system effluent water quality. Only the RO waste solution showed an increase in hardness, and since hardness is not a regulatory discharge parameter, it did not affect the disposition or cost requirements of the RO waste solution.

## 3.3 Quality Assurance/Quality Control

### 3.3.1 Data Entry

Sampling events, process measurements, and all other data were recorded by the ETV-MF Project Manager on pre-designed forms provided in the verification test plan [Ref. 1].

### 3.3.2 Sample Collection and Handling

Prior to the verification test, sampling ports were identified within the HERO™ trailer for wastewater influent, effluent, and RO waste solution. Sampling ports for cyanide-bearing rinse water influent and effluent were also identified on either side of the separate copper recovery WAC ion exchange unit in the KCP chemical storage bay. Where necessary, polyethylene tubes were connected to the sampling ports and directed into appropriate aqueous sample containers.

Appropriately sized grab samples were taken directly from the sampling port after the sampling lines were purged. During sampling, the sample containers were kept cool by placing them in a cooler containing ice.

All aqueous grab samples were collected in the appropriate sample containers at approximately 24-hour intervals over a four-day period. At the end of each sampling period, the containers were labeled, bagged, packed in ice, and immediately delivered to the analytical laboratory by the ETV-MF Project Manager. All shipments were secured with strapping tape and security seals, and accompanied by a chain of custody (COC) form.

A field blank sample was also collected during the last day of the verification test. The field blank consisted of deionized water purchased from a nearby grocery store. This sample was collected, stored, transported, and analyzed in an identical fashion to those samples collected during the verification test period.

A historical sample of the KCP's tap water was taken from the IWPF laboratory sink faucet several months earlier by the ETV-MF Project Manager on an earlier test site visit. This sample was collected, stored, transported, and analyzed in an identical fashion to those samples collected during the verification test period. The analytical results were used as the recycled water quality standard for the wastewater treated by the HERO™ system during the verification test.

### 3.3.3 Calculation of Data Quality Indicators

Data reduction, validation, and reporting were conducted according to the verification test plan [Ref. 1] and the ETV-MF Quality Management Plan (QMP) [Ref. 2]. Calculations of data quality indicators are discussed in this section.

#### 3.3.3.1 Precision

Precision is a measure of the agreement or repeatability of a set of replicate results obtained from duplicate analyses made in the laboratory under identical conditions. To satisfy the precision objectives, the replicate analyses must agree with the defined deviation limits, which are expressed as a percentage and are shown in **Table 2**. The Relative Percent Difference (RPD) is calculated as follows:

$$RPD = \left\{ \frac{|X_1 - X_2|}{\frac{(X_1 + X_2)}{2}} \right\} x100\,\%$$

where:

$X_1$ = larger of the two observed values
$X_2$ = smaller of the two observed values

The analytical laboratories performed a total of 131 precision evaluations on aqueous samples. All but three of the results were within the precision limits identified in the verification test plan [Ref. 1]. These results consisted of two dissolved silica samples and a cyanide sample. Excluding these three results from the data set had no effect on the reported conclusions. The results of the precision calculations are summarized in **Appendix A**.

### 3.3.3.2 Accuracy

Accuracy is a measure of the agreement between an experimental determination and the true value of the parameter being measured. Analyses with spiked samples were performed to determine percent recoveries as a means of checking method accuracy. The accuracy required for this project is shown in **Table 2**. The percent recovery (P), expressed as a percentage, is calculated as follows:

$$P = \left[\frac{(SSR - SR)}{SA}\right] x\ 100\%$$

where:

SSR = Spiked sample result
SR = Sample result (native)
SA = the concentration added to the spiked sample

Quality Assurance (QA) objectives are satisfied for accuracy if the average recovery is within selected goals. The analytical laboratories performed 104 accuracy evaluations on aqueous samples. All but three results were within the limits identified in the verification test plan [Ref. 1]. These results consisted of a nitrate (as N), a calcium, and a cyanide sample. Excluding these three results from the data set had no effect on the reported conclusions. The results of the accuracy calculations are summarized in **Appendix B.**

### 3.3.3.3 Completeness

Completeness is defined as the percentage of measurements judged to be valid compared to the total number of measurements made for a specific sample matrix and analysis. The required completeness for this project is shown in **Table 2.** Completeness, expressed as a percentage, is calculated using the following formula:

$$\text{Completeness} = \frac{\text{Valid Measurements}}{\text{Total Measurements}} \times 100\%$$

QA objectives are satisfied if the percent completeness is 90 percent or greater. 318 out of 327 measurements made during this verification project were determined to be valid, for a completeness of 97.2 percent. Therefore, the completeness objective was satisfied.

#### 3.3.3.4 Comparability

Comparability is a qualitative measure designed to express the confidence with which one data set may be compared to another. Sample collection and handling techniques, sample matrix type, and analytical method all affect comparability. Comparability was achieved during this verification test by the use of consistent methods during sampling and analysis and traceability of standards to a reliable source.

#### 3.3.3.5 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter being tested. For this verification project, one field duplicate sample was collected from each sample location and sent to the laboratory for analysis. Representativeness was calculated as an RPD of these field duplicates. A total of 92 representativeness calculations were performed. All but three of the results were within the limits identified in the verification test plan [Ref. 1]. These results consisted of a fluoride, a sulfate, and a cyanide sample. Excluding these three results from the data set had no effect on the reported conclusions. The results of these calculations are summarized in **Appendix C**.

#### 3.3.3.6 Sensitivity

Sensitivity is the measure of the concentration at which an analytical method can positively identify and report analytical results. The sensitivity of a given method is commonly referred to as the detection limit. Although there is no single definition of this term, the following terms and definitions of detection were used for this project.

**Instrument Detection Limit** (IDL) is the minimum concentration that can be differentiated from instrument background noise; that is, the minimum concentration detectable by the measuring instrument.

**Method Detection Limit** (MDL) is a statistically determined concentration. It is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero, as determined in the same or a similar sample matrix. In other words, this is the lowest concentration that can be reported with confidence. It is directly affected by the IDL. The MDLs for this verification project are shown in **Table 2**.

**Method Reporting Limit** (MRL) is the concentration of the target analyte that the laboratory has demonstrated the ability to measure within specified limits of precision and accuracy during routine laboratory operating conditions. [This value is variable and highly matrix dependent. It is the minimum concentration that will be reported without qualifications by the laboratory.] The MRLs for this verification project are shown in **Table 2**.

| Measurement | Matrix | Method | Units | Method of Determination | MDL | MRL | Precision (RPD) | Accuracy % Recovery | Completeness |
|---|---|---|---|---|---|---|---|---|---|
| TOC | Aqueous | EPA 9060 | mg/L | Combustion / Oxidation | 1.0 | 10.0 | < 30 | 70–130 | 90 |
| O&G (as HEM) | Aqueous | EPA 1664 | mg/L | Gravimetric | 5.00 | 5.00 | < 30 | 61–127 | 90 |
| Metals (- Hg) | Aqueous | EPA | mg/L | ICP-AES | 0.001- | 0.004– | < 30 | 70–130 | 90 |
| Hg | Aqueous | EPA | mg/L | Manual Cold Vapor | 0.0002 | 0.0002 | < 30 | 70–130 | 90 |
| Total Sulfide | Aqueous | EPA | mg/L | Titrimetric, Iodine | 1.000 | 0.5 | < 30 | 70–130 | 90 |
| Total Cyanide | Aqueous | EPA | mg/L | Colorimetric, Automated | 0.005 | 0.005 | < 30 | 61–113 | 90 |
| Chloride | Aqueous | EPA | mg/L | Ion Chromatography | 0.020 | 1.0 | < 30 | 70–130 | 90 |
| Sulfate | Aqueous | EPA | mg/L | Ion Chromatography | 0.040 | 1.0 | < 30 | 10–170 | 90 |
| Nitrate | Aqueous | EPA | mg/L | Ion Chromatography | 0.010 | 1.0 | < 30 | 70–130 | 90 |
| Fluoride | Aqueous | EPA | mg/L | Ion Chromatography | 0.020 | 0.2 | < 30 | 16–178 | 90 |
| Total Alkalinity | Aqueous | EPA | mg/L | Colorimetric (Methyl | 1.00 | 1.0 | < 30 | 70–130 | 90 |
| Dissolved Silica | Aqueous | EPA | mg/L | Colorimetric | 2.0 | 1.0 | < 30 | 70–130 | 90 |
| TSS | Aqueous | EPA | mg/L | Gravimetric | 4.00 | 5.0 | < 30 | N/A | 90 |
| TDS | Aqueous | EPA | mg/L | Gravimetric | 10.00 | 5.0 | < 30 | N/A | 90 |
| Total Residual $Cl_2$ | Aqueous | EPA | mg/L | DPD-Colorimetric | 0.01 | 0.01 | < 2 | N/A | 90 |
| Flow Rate | Aqueous | EPA 3.1.9 | L/hr | Ultrasonic Flowmeter | 0.3–3.6 | 0.3–3.6 | < 1 | N/A | 90 |
| Temperature | Aqueous | EPA | °C | Thermometric | 0.1 | 0.1 | < 1 | N/A | 90 |
| pH | Aqueous | EPA | pH | Electrometric | 0.01 | 0.01 | < 0.2 | N/A | 90 |
| Specific Cond. | Aqueous | EPA | µS/cm | Wheatstone Bridge-Type | 1.0 | 1.0 | < 2 | N/A | 90 |
| Membrane Flux | Aqueous | - | gfd | Calculated | N/A | N/A | N/A | N/A | N/A |

EPA/821/C-99/004: EPA Methods and Guidance for Analysis of Water
EPA SW-846: EPA Test Methods for Evaluating Solid Waste
ICP-AES: Inductively Coupled Plasma-Atomic Emission Spectroscopy
N/A: Not applicable

**Table 2: QA Objectives for Precision, Accuracy, and Detection Limits**

# 4.0 VERIFICATION DATA

## 4.1 Analytical Results

A complete summary of analytical data for the HERO™ verification test is presented in **Table 3** and **Table 4** Samples were collected over a four-day period and analyzed for the parameters identified. During the four-day verification test, daily grab samples were collected from the HERO™ system influent, coded as "HERO IN"; the HERO™ system effluent, coded as "HERO EFF"; the HERO™ system RO waste solution, coded as "RO Waste"; the separate copper recovery WAC unit influent, coded as "WAC IN"; and the separate copper recovery WAC unit effluent, coded as "WAC EFF." Average values calculated for both operations' IN and EFF are also shown. The KCP water quality recycle standard results, obtained from sampling the KCP's tap water on a previous visit to KCP, are coded as "STD" in the table. The samples coded "FB" are field blank samples collected on the last day of testing utilizing store-bought deionized water.

The primary contaminants of the post-conventionally-treated KCP wastewater that are preventing the water from being recycled are Ba, Ca, Cu, Mo, Ni, Na, TDS, chloride, nitrate (as N), sulfate and total alkalinity. The separate copper recovery WAC unit influent and effluent were analyzed only for copper.

| | WAC IN | | | | | WAC EFF | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Day ➔** | **1** | **2** | **3** | **4** | **Avg** | **1** | **2** | **3** | **4** | **Avg** |
| **Copper** | 0.472 | 0.493 | 0.486 | 0.470 | **0.480** | 0.252 | 0.367 | 0.296 | 0.229 | **0.286** |

NOTE: All measurements are in mg/L.

**Table 3. Summary of Analytical Results – Copper Recovery WAC**

| | HEROÔ IN | | | | | HEROÔ EFF | | | | | RO Waste | | | | | STD | FB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Day →** | **1** | **2** | **3** | **4** | **Avg** | **1** | **2** | **3** | **4** | **Avg** | **1** | **2** | **3** | **4** | **Avg** | **-** | **-** |
| **Aluminum** | <0.075 | <0.075 | <0.075 | <0.075 | <0.075 | <0.075 | <0.075 | <0.075 | <0.075 | <0.075 | <0.075 | 0.435 | 0.472 | 1.24 | <0.56 | <0.075 | <0.075 |
| **Arsenic** | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 | <0.085 |
| **Barium** | 0.0286 | 0.0187 | 0.0226 | 0.0248 | 0.024 | <0.004 | <0.004 | <0.004 | <0.004 | <0.004 | 0.0195 | 0.0179 | 0.0905 | 0.0532 | 0.045 | 0.0185 | <0.004 |
| **Cadmium** | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 |
| **Calcium** | 131 | 88.7 | 105 | 124 | 112.2 | 0.121 | 0.172 | 0.227 | 0.217 | 0.2 | 9.06 | 21.5 | 336 | 298 | 166.1 | 31.8 | <0.100 |
| **Chromium** | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | 0.0312 | 0.0218 | 0.0229 | 0.0255 | 0.025 | <0.007 | <0.007 |
| **Copper** | <0.01 | <0.01 | <0.01 | 0.0453 | <0.019 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.025 | 0.025 | 0.0101 | 0.0562 | 0.029 | <0.01 | <0.01 |
| **Iron** | <0.04 | <0.04 | 0.045 | <0.04 | <0.041 | <0.04 | <0.04 | <0.04 | <0.04 | <0.04 | 0.0559 | <0.04 | 0.0527 | <0.04 | <0.047 | 0.0429 | <0.04 |
| **Lead** | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 |
| **Magnesium** | <0.050 | 0.186 | 0.175 | <0.050 | <0.115 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | 3.36 | 1.06 | <1.13 | 6.88 | <0.050 |
| **Manganese** | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | 0.0072 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 |
| **Mercury** | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.000 | <0.0002 |
| **Molybdenum** | 0.203 | 0.447 | 0.193 | 0.166 | 0.252 | <0.020 | <0.020 | <0.020 | <0.020 | <0.020 | 3.4 | 9.79 | 3.22 | 1.6 | 4.502 | <0.020 | <0.020 |
| **Nickel** | <0.03 | 0.0322 | <0.03 | <0.03 | <0.031 | <0.03 | <0.03 | <0.03 | <0.03 | <0.03 | 0.131 | 0.239 | 0.129 | 0.0933 | 0.119 | <0.03 | <0.03 |
| **Silver** | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | 0.0301 | 0.0114 | 0.0135 | 0.0071 | 0.016 | <0.007 | <0.007 |
| **Sodium** | 60.9 | 40.9 | 42.9 | 80.3 | 56.2 | 19.1 | 11.2 | 7.0 | 8.7 | 11.5 | 1,760 | <0.15 | <0.15 | <0.15 | <440.1 | 31.6 | 0.249 |
| **Tin** | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 | <0.250 |
| **Zinc** | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 | <0.100 |
| **TDS** | 607 | 404 | 430 | 667 | 527 | 59 | 24 | 16 | 44 | 36 | 6,870 | 5,870 | 4,600 | 3,430 | 5,192 | 246 | 90 |
| **TSS** | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 | 5.0 | <5.0 | <5.0 | <5.0 | <5.0 | <5.0 |
| **TOC** | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | 103.0 | <10.0 | 47.7 | <10.0 | <42.7 | <10.0 | <10.0 |
| **O&G** | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 |
| **Chloride** | 13.9 | 13.5 | 12.0 | 36.0 | 18.8 | <1.00 | <1.00 | <1.00 | <1.00 | <1.00 | 276 | 359 | 229 | 244 | 277 | 17.8 | <1.00 |
| **Fluoride** [1] | 1.06 | 0.713 | 0.784 | 0.734 | 0.80 | 0.961 | <0.200 | 0.220 | <0.200 | <0.395 | 16.4 | 12.4 | 13.0 | 8.5 | 12.6 | 1.5 | <0.200 |
| **Nitrate as N** | 4.9 | 4.9 | 4.27 | 4.26 | 4.6 | 1.79 | 1.80 | 1.65 | <1.0 | <1.56 | 76.9 | 100.0 | 61.9 | 42.6 | 70.4 | 2.13 | <1.0 |
| **Sulfate** [1] | 178 | 90.8 | 123 | 191 | 145.7 | <1.00 | <1.00 | <1.00 | <1.00 | <1.00 | 3,090 | 2,420 | 2,220 | 1,480 | 2,302 | 93.9 | <1.00 |
| **Sulfide** | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 | <0.500 |
| **Total Alkalinity** | 189 | 151 | 151 | 104 | 149 | 58.3 | 24.1 | 15.2 | 21.9 | 29.9 | 363 | 574 | 121 | 96.5 | 288.6 | 46 | <1.00 |
| **Total Cyanide** | <0.005 | <0.005 | 0.0122 | <0.005 | <0.007 | <0.005 | <0.005 | <0.005 | <0.005 | <0.005 | 0.121 | 0.0078 | 0.076 | 0.0894 | 0.074 | 0.0212 | <0.005 |
| **Dissolved Silica** | 4.00 | <1.0 | 4.39 | 4.77 | <3.54 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 40.3 | 46.4 | 39.1 | 34.7 | 40.1 | 5.73 | <1.0 |

NOTE: All measurements are in mg/L.

[1] This data is an estimate only, due to a wide range of accuracy used by the lab

**Table 4. Summary of Analytical Results – HEROÔ**

## 4.2 Process Measurements

Certain process measurements were taken on a daily basis during verification testing. These data have been consolidated and are summarized in **Table 5**. Aqueous temperature and pH measurements were taken using a hand-held digital thermometer/pH meter. Aqueous flow rates were scheduled to be measured using a portable ultrasonic flow meter. However, due to the configuration of the wastewater piping inside the HERO™ pilot trailer, measurements with the portable device were not possible. Flow measurements were recorded from the in-pipe pulse flowmeters integral to the Hydrometrics HERO™ pilot trailer. Specific conductivity was measured using a Wheatstone Bridge-Type hand-held instrument, and total residual chlorine was measured using a field DPD-Colorimetric reagent meter.

| | Day | Temperature (°C) | pH | Flow Rate (gpm) | Specific Conductivity (■S/cm) | Total Residual Chlorine (mg/L) |
|---|---|---|---|---|---|---|
| **HERO™ IN** | 1 | 30.5 | 11.07 | 18.0 | 1,323 | 0.01 |
| | 2 | 31.4 | 10.59 | 17.9 | 876 | <0.01 |
| | 3 | 30.1 | 11.11 | 17.9 | 1,041 | 0.02 |
| | 4 | 29.4 | 11.09 | 16.7 | 1,224 | 0.03 |
| | Avg. | 30.4 | 11.97 | 17.6 | 1,116 | <0.02 |
| **HERO™ EFF** | 1 | 32.0 | 10.43 | 17.4 | 218 | 0.02 |
| | 2 | 31.4 | 10.08 | 16.5 | 124 | 0.01 |
| | 3 | 31.0 | 10.41 | 16.9 | 142 | 0.01 |
| | 4 | 30.0 | 10.11 | 15.7 | 83 | 0.01 |
| | Avg. | 31.1 | 10.26 | 16.6 | 142 | 0.01 |
| **RO Waste** | 1 | 32.7 | 9.40 | 0.82 | 8,620 | 0.01 |
| | 2 | 32.3 | 10.09 | 1.06 | 7,450 | 0.03 |
| | 3 | 31.6 | 10.62 | 1.3 | 7,273 | <0.01 |
| | 4 | 31.1 | 10.80 | 2.4 | 3,120 | <0.01 |
| | Avg. | 31.9 | 10.23 | 1.4 | 6,616 | <0.02 |
| **WAC IN** | 1 | 32.3 | 10.48 | 15 (mL/min) | 942 | <0.01 |
| | 2 | 29.5 | 10.04 | 16 (mL/min) | 916 | <0.01 |
| | 3 | 28.5 | 10.08 | 15 (mL/min) | 900 | <0.01 |
| | 4 | 26.7 | 9.75 | 17 (mL/min) | 850 | <0.01 |
| | Avg. | 29.3 | 10.09 | 15.75 (mL/min) | 902 | <0.01 |
| **WAC EFF** | 1 | 33.8 | 10.49 | 15 (mL/min) | 953 | 0.02 |
| | 2 | 29.1 | 10.09 | 16 (mL/min) | 924 | <0.01 |
| | 3 | 27.9 | 10.11 | 15 (mL/min) | 934 | <0.01 |
| | 4 | 25.9 | 9.88 | 17 (mL/min) | 876 | <0.01 |
| | Avg. | 29.2 | 10.14 | 15.75 (mL/min) | 922 | <0.01 |
| **STD** | - | 32.5 | 7.83 | - | 441 | 2.14 |
| **FB** | - | 23.0 | 5.39 | - | 0.70 | <0.01 |

**Table 5. Summary of Process Measurements**

Membrane flux is calculated as the gal of permeate product per square foot of membrane per day (gfd). Increasing the flux results in lower capital costs and better effluent quality.

The HERO™ system reduces membrane fouling from scale, organics, and microbial growth by processing the wastewater at a high pH after metals removal. The HERO™ pilot system used for the verification test contains 1,468 $ft^2$ of membrane surface area. Membrane flux observed during the verification test was calculated to be 17.7 gfd (based on a 24-hour day). Compared to the accepted industry average membrane flux of 11 gfd [Ref. 3], this is 1.6 times better than the average traditional RO membrane flux.

The target wastewater flow rate range specified by Hydrometrics for the KCP's HERO™ system was 18 gpm. The target flow rate for the separate, bench-scale copper recovery WAC ion exchange unit was 15 mL/min. During operation of the system, operators adjusted the flow rates of the HERO™ and copper recovery WAC units within the recommended operating limits.

### 4.3 Wastewater Processing Data

Spent rinse water from the cyanide oxidation, chromium reduction, acid and caustic rinse water, and other finishing rinse water (aqueous degreasing, cleaning, and rinsing) are pumped at a rate of approximately 170 gpm into the conventional wastewater treatment system. According to a compilation of last years KCP historical records, an average of 86,000 gal of combined wastewater is treated by the KCP's conventional wastewater treatment system during the single 10-hour operating shift. The wastewater breakdown treated in the traditional KCP system during the verification test period is summarized in **Table 6**.

| Test Day | Wastewater Type | Gal Processed |
|---|---|---|
| **1** | Chromium | 12,000 |
| | Acid/Caustic | 23,000 |
| | Dilute Industrial | 38,000 |
| | **Subtotal** | **73,000** |
| **2** | Acid/Caustic | 34,000 |
| | Dilute Industrial | 133,000 |
| | **Subtotal** | **167,000** |
| **3** | Chromium | 15,000 |
| | Dilute Industrial | 104,000 |
| | **Subtotal** | **119,000** |
| **4** | Cyanide | 4,000 |
| | Acid/Caustic | 51,000 |
| | **Subtotal** | **55,000** |
| ***Test Period Total*** | | ***414,000*** |

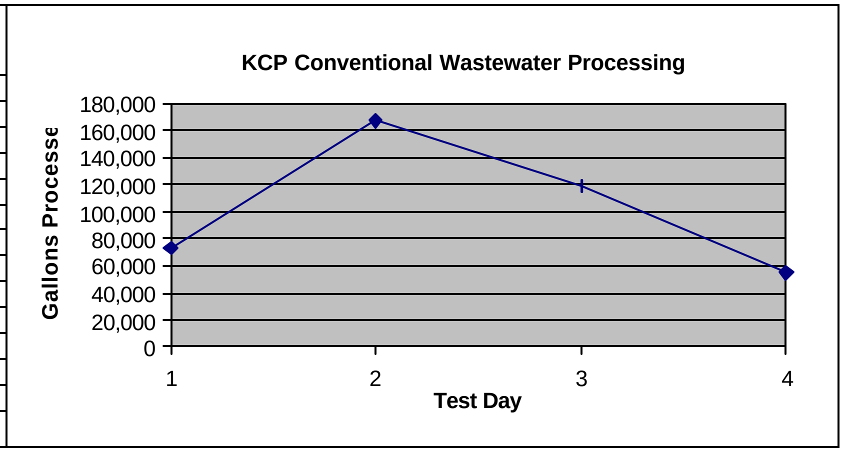


**Table 6. KCP Conventional Wastewater Processing**

The Hydrometrics HERO™ system processed a portion of the total KCP wastewater after it was processed by the conventional treatment system. While the KCP conventional wastewater treatment system processed approximately 170 gpm, the HERO™ system processed wastewater at approximately 17.6 gpm. A total of 33,286 gal of wastewater was treated during the verification test. The wastewater treated in the HERO™ system during the verification test period is summarized in **Table 7**.

| Test Day | HERO™ Influent | HERO™ Effluent |
|---|---|---|
| **1** | 8,640 | 8,352 |
| **2** | 8,861 | 8,168 |
| **3** | 7,518 | 7,098 |
| **4** | 8,267 | 7,772 |
| **AVG** | **8,322** | **7,848** |
| ***TOTAL*** | ***33,286*** | ***31,390*** |

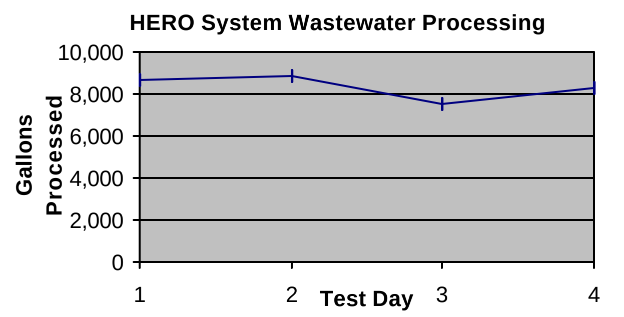


**Table 7. HEROÔ System Wastewater Processing**

## 4.4 Other Data

Other data collected during the course of the verification test are summarized in **Table 8**.

| Description | Value |
|---|---|
| Cost of NaOH (25 percent) | $0.047/pound (lb.) |
| NaOH used during verification test (25 percent) | 8.9 gal |
| Estimated* normalized cost of NaOH (25 percent) | $.2632/10,000 gal treated |
| Cost of NaCl (100 percent) | $0.035/ lb. |
| Estimated* normalized cost of NaCl (100 percent) | $1.47/10,000 gal treated |
| Cost of HCL (31.5 percent) | $0.042/gal |
| Estimated* normalized cost of HCL (100percent) | $0.8946/10,000 gal treated |
| Estimated* normalized cost of replacement RO membrane | $1.00/10,000 gal |
| Electricity by cost | $0.03816/kWh |
| Estimated* normalized power cost for HERO™ system | $1.40/10,000 gal treated |
| Total conventionally treated KCP wastewater during test | 414,000 gal |
| Normalized cost of sewer disposal of KCP wastewater | $14.70/10,000 gal |
| Normalized cost of raw tap water at KCP | $16.70/10,000 gal |
| Labor cost (loaded rate) | $32.00/hr |
| KCP IWPF operating schedule | 10 hrs./day, 7 days/week |
| Estimated* cost of full-scale 86,400 gpd HERO™ system | $216,000 |
| Estimated* installation cost of full-scale HERO™ system | $54,000 |

*Estimates provided by Hydrometrics, Inc.

**Table 8. Other Data Collected During Verification**

# 5.0 EVALUATION OF RESULTS

## 5.1 Wastewater & Copper Recovery

The main purpose of the HERO™ system is to recover the post-conventionally-treated KCP wastewater for in-facility recycling. Recycled water from the HERO™ system must meet the minimum quality standards equal to the Kansas City tap water that the KCP metal finishing operations utilize. Recovery of this wastewater is calculated by a relationship between the HERO™ system influent, effluent, and waste generation. The wastewater recovery is calculated and recorded by a chart recorder on the main control panel of the HERO™ system. The chart recorder's value was transcribed to the HERO™ system operator's daily checklist several times each day of the verification test.

The separate copper recovery WAC ion unit was sampled once each day of the verification test and analyzed for copper concentrations in the unit's influent and effluent. The ratio of these two analytical results yields the copper recovery efficiency of the WAC ion exchange unit. The equation for the copper recovery calculation is shown below. The recovery efficiency for the wastewater was calculated using a similar equation.

$$Cu_{re}\,(\%) = [[(Cu_{in} \times IN_{vol}) - (Cu_{eff} \times EFF_{vol})] / (Cu_{in} \times IN_{vol})] \times 100\%$$

where:

$Cu_{re}$ = copper recovery efficiency
$Cu_{in}$ = influent solution Cu concentration (mg/L)
$IN_{vol}$ = influent solution volume processed during the cycle (L)
$Cu_{eff}$ = effluent stream copper concentration (mg/L)
$EFF_{vol}$ = effluent volume collected during the cycle (L)

The water & copper recovery efficiencies are shown in **Table 9**.

| Test Day | Wastewater Recovery (%) | Copper Recovery (%) |
|---|---|---|
| **1** | 96.7 | 46.6 |
| **2** | 92.2 | 25.6 |
| **3** | 94.4 | 39.1 |
| **4** | 94.0 | 51.3 |
| ***AVG*** | ***94.3*** | ***40.6*** |
| **Std. Dev.** | **1.8** | **11.2** |

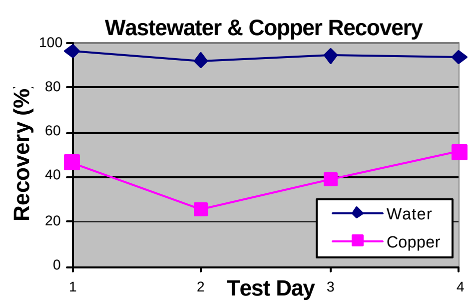


**Table 9. Wastewater & Copper Recovery Efficiency**

The average recovery percentage for the wastewater was high (94.3 percent), indicating that the HERO™ system was very efficient in recovering water for reuse within the facility. Copper recovery percentages from the separate WAC ion exchange unit were less pronounced (40.6 percent), showing that the HERO™ system did a fair job of recovering copper for resale or reuse. The relatively low concentration of copper in the influent could have had an effect on the copper recovery efficiency.

## 5.2 Contaminant Removal Efficiency

Since the wastewater that the HERO™ system processes has already been run through the KCP's traditional wastewater treatment process, the water already meets sewer discharge limits. Parameters such as barium, copper, iron, magnesium, molybdenum, nickel, chloride, sulfate, fluoride, cyanide, and dissolved silica were present in the HERO™ influent, but were at or below regulatory levels for sewer discharge. All of these parameters were virtually reduced to non-detectable levels by the HERO™ system. Also in the HERO™ system influent were calcium, sodium, TDS, nitrate (as N), and total alkalinity; these were within regulatory limits for discharge, but were preventing the post-conventionally-treated wastewater from meeting the KCP water quality recycle standards. The HERO™ system reduced all of these parameters below the acceptable limits, making the water acceptable for recycle within the KCP facility. The contaminant removal efficiencies were calculated for these primary contaminants of the post-conventionally-treated wastewater. The equation for TDS removal efficiency is shown below. Calcium, sodium, nitrate, and total alkalinity removal efficiencies were calculated using similar equations.

$$TDS_{re}\ (\%) = [[(TDS_{in} \times IN_{vol}) - (TDS_{eff} \times EFF_{vol})] / (TDS_{in} \times IN_{vol})] \times 100\%$$

where:

| | | |
|---|---|---|
| $TDS_{re}$ | = | TDS removal efficiency |
| $TDS_{in}$ | = | influent solution TDS concentration (mg/L) |
| $IN_{vol}$ | = | influent solution volume processed during the cycle (L) |
| $TDS_{eff}$ | = | effluent stream TDS concentration (mg/L) |
| $EFF_{vol}$ | = | effluent volume collected during the cycle (L) |

The contaminant removal efficiencies for these key parameters are shown in **Table 10**.

| | **Test Day** | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **1** | **2** | **3** | **4** | **AVG** | **Std. Dev.** |
| **Calcium – IN** | 131 | 88.7 | 105 | 124 | **112.2** | |
| **Calcium – EFF** | 0.121 | 0.172 | 0.227 | 0.217 | **0.2** | |
| **Calcium Recycle Std.** | 31.8 | 31.8 | 31.8 | 31.8 | **31.8** | |
| ***Removal Efficiency*** | *99.9 %* | *99.8 %* | *99.8 %* | *99.8 %* | ***99.8 %*** | **0.05** |
| **Sodium – IN** | 60.9 | 40.9 | 42.9 | 80.3 | **56.2** | |
| **Sodium – EFF** | 19.1 | 11.2 | 7.0 | 8.7 | **11.5** | |
| **Sodium Recycle Std.** | 31.6 | 31.6 | 31.6 | 31.6 | **31.6** | |
| ***Removal Efficiency*** | *69.7 %* | *74.8 %* | *84.6 %* | *89.8 %* | ***79.7 %*** | **9.13** |
| **Nitrate (as N) – IN** | 4.9 | 4.9 | 4.27 | 4.26 | **4.6** | |
| **Nitrate (as N) – EFF** | 1.79 | 1.80 | 1.65 | <1.0* | **<1.56** | |
| **Nitrate (as N) Recycle Std.** | 2.13 | 2.13 | 2.13 | 2.13 | **2.13** | |
| ***Removal Efficiency*** | *64.7 %* | *66.1 %* | *63.5 %* | *>77.9 %* | ***>68.0 %*** | **6.65** |
| **Total Alk. – IN** | 189 | 151 | 151 | 104 | **149** | |
| **Total Alk. – EFF** | 58.3 | 24.1 | 15.2 | 21.9 | **29.9** | |
| **Total Alk. Recycle Std.** | 46 | 46 | 46 | 46 | **46** | |
| ***Removal Efficiency*** | *70.2 %* | *85.3 %* | *90.5 %* | *80.2 %* | ***81.6 %*** | **8.66** |
| **TDS – IN** | 607 | 404 | 430 | 667 | **527** | |
| **TDS – EFF** | 59 | 24 | 16 | 44 | **36** | |
| **TDS Recycle Std.** | 246 | 246 | 246 | 246 | **246** | |
| ***Removal Efficiency*** | *90.6 %* | *94.5 %* | *96.5 %* | *93.8 %* | ***93.8 %*** | **2.45** |

*Post-HERO™ treatment nitrate (as N) level was below laboratory MRL
NOTE: Parameter measurements are in mg/L unless noted otherwise

**Table 10. Contaminant Removal Efficiency**

### 5.3 Mass Balance

Mass balance calculations were performed to evaluate how effectively the sampling and analytical procedures account for certain key parameters. The equation for mass balance uses the equation for recovery efficiency (section 5.1) and adds a calculated term for the quantity of material contained in the RO waste stream at the end of the verification test. A calculated result of 100 percent indicates that the quantity of a particular parameter found in the wastewater influent (IN) is fully accounted for in the effluent (EFF) and RO waste (Waste). Mass balance values were calculated for the following key parameters: calcium, sodium, nitrate (as N), total alkalinity, and TDS. The mass balance equation for TDS is shown below. The mass balances for the other constituents were calculated using similar equations.

$$\text{mass bal. (\%)} = [[(TDS_{eff} \times EFF_{vol}) + (TDS_{waste} \times Waste_{vol})] / (TDS_{in} \times IN_{vol})] \times 100\%$$

where:

| | | |
|---|---|---|
| $TDS_{eff}$ | = | effluent stream TDS concentration (mg/L) |
| $EFF_{vol}$ | = | effluent volume collected during the cycle (L) |
| $TDS_{waste}$ | = | RO waste stream TDS concentration (mg/L) |
| $Waste_{vol}$ | = | waste stream volume (L) |
| $TDS_{in}$ | = | influent solution TDS concentration (mg/L) |
| $IN_{vol}$ | = | influent solution volume processed during the cycle (L) |

The mass balance results are shown in **Table 11**.

| Test Day | Calcium (%) | Sodium (%) | Nitrate (as N) (%) | Total Alkalinity (%) | TDS (%) |
|---|---|---|---|---|---|
| **1** | 0.4 | 162.1 | 106.9 | 38.6 | 61.0 |
| **2** | 1.6 | 25.3 | 154.8 | 37.2 | 91.6 |
| **3** | 23.4 | 15.4 | 141.8 | 15.3 | 81.2 |
| **4** | 34.7 | 10.2 | 165.8 | 33.1 | 80.1 |
| ***AVG*** | ***15.0*** | ***53.2*** | ***142.3*** | ***31.0*** | ***78.5*** |
| **Std. Dev.** | **16.8** | **72.8** | **25.6** | **10.8** | **12.8** |

**Table 11. Mass Balance Results**

The average mass balance result for TDS (78.5 percent) is within the acceptable percentage error of +/- 25, indicating that quantities of this parameter found in the influent (IN) are accounted for in the effluent (EFF) and RO waste (Waste) samples. The results for calcium, sodium, nitrate (as N), and total alkalinity were not within the acceptable percentage error. Primarily, these results can be attributed to the several steps of the HERO™ system that remove these types of contaminants during the normal operation of the equipment. The HERO™ system prefilter traps solids entrained in the wastewater. The HERO™ system's pretreatment SAC and WAC ion exchange units remove hardness and convert certain alkalinity compounds to carbon dioxide, which are then typically removed from the wastewater in the membrane degasifier. Since (1) the prefilters were not collected and sampled, (2) the SAC unit was only regenerated once during the test (right after the second day's sampling occurred), and (3) the WAC unit was not regenerated at all during the verification test period, much of the missing mass could be accounted for within these process vessels.

## 5.4 Energy Use

Energy requirements for operating the HERO™ pilot unit at the KCP included electricity for the four liquid feed pumps (HERO™ feed, pre-RO booster, RO feed pump, and RO booster pump). Electricity use was also estimated by Hydrometrics for HERO™ system instrumentation, compressed air and reagent feed pumps at 12.0 kWh/10,000 gal of treated wastewater. Electricity for the pilot trailer lighting and air conditioning was not included in the HERO™ system energy use calculations.

Liquid transfer pump electricity use was calculated by dividing the total horsepower (HP) of all system pumps (26.5) by 1.341 HP-hr/kWh. The result is 197.6 kWh/day, based on 10 hours per day (the standard operating time of the KCP wastewater treatment plant). Using this figure, and the amount of wastewater typically processed through the wastewater treatment plant (86,000 gpd), an electricity/processed wastewater ratio of 24.7 kWh/10,000 gal of treated wastewater was calculated, for an overall consumption of 36.7 kWh/10,000 gal of treated wastewater.

## 5.5 Operating and Maintenance Labor Analysis

Hydrometrics personnel operated the HERO™ pilot system during verification testing. The HERO™ system requires an operator during startup and shutdown. The startup and shutdown procedures are summarized in the test plan [Ref. 1]. During operation, the system is self-regulating; however, for testing purposes, a Hydrometrics operator was on-site at all times during the HERO™ system operation. The operational tasks performed by the Hydrometrics operator during the verification test period included:

- Daily inspections of the unit
- Recording of system parameters
- Filter change-outs
- Minor adjustments
- Chemical additions

Estimates by Hydrometrics and validation of the operating tasks listed above indicate that for a full-scale 86,400 gpd HERO™ system, approximately seven hours of operating & maintenance (O&M) labor each week would be required.

## 5.6 Chemical Use Analysis

Chemical additions to the HERO™ system typically include water softener salt (NaCl) to the SAC regeneration tank, hydrochloric acid (HCl) to backwash the WAC ion exchange unit, sulfuric acid ($H_2SO_4$) between the WAC ion exchange and membrane degasifier steps to lower the pH to 4.5 for complete carbon dioxide conversion in the degasifier unit, and sodium hydroxide (NaOH) between the membrane degasifier and RO steps in order to raise the pH to 10 to avoid bio-fouling and silica scaling, and enhance silt rejection.

Due to the SAC unit being out of commission for the first half of the test, the membrane degasifier unit being out of operation the entire test, and the WAC unit not requiring regeneration during the test, the only chemical additions made during the test were the NaOH additions for pH adjustment to 10 prior to entering the RO step. A total of 8.9 gal of NaOH was added to the water over the four-day verification test period. However, this is an increased NaOH dosage due to the SAC unit being out of service during the first portion of the verification test. For actual NaOH, NaCl, HCl, and $H_2SO_4$ chemical usage rates, Hydrometrics historical data was utilized. Estimates by Hydrometrics were determined, and normalized to treat 10,000 gal of wastewater similar in composition to the KCP's waste stream. $H_2SO_4$ was not required for the KCP's wastewater, since it already had a pH below 4.5 upon exiting the WAC step of the HERO™ system. Results for NaOH (25 percent), NaCl (100 percent) and HCL (31.5 percent) usage were calculated to be 5.6 lbs., 42 lbs., and 21.3 lbs. respectively. These numbers were utilized in the full-scale cost estimates and payback period calculation described in section 5.8.

Due to the small process scale, the chemical use for regeneration of the bench-scale copper recovery WAC ion exchange unit used during the KCP verification test was deemed insignificant. Thus, a resin regeneration and subsequent chemical use analysis was not conducted for the copper recovery process.

### 5.7 Waste Generation Analysis

A waste generation analysis was performed using operational data collected during the verification test period, and historical records from the KCP and Hydrometrics. The HERO™ system generates waste from several of its process steps, and combines them in a single waste stream. The most notable of these process streams is the RO reject waste solution. This is generated on a continual basis as the wastewater passes through the RO pressure vessels. During the verification test, approximately 2,653 gal of RO waste was generated while treating 33,286 gal of wastewater. This equates to an average of about one gal of waste for every 12.6 gal of wastewater treated, or a waste stream volume of 8 percent of the feed volume.

Implementation of the HERO™ system to recondition the wastewater for potential reuse within the KCP would eliminate the discharge of an average of 86,000 gpd of wastewater to the sanitary sewer. However, some of this waste reduction will be offset by the RO waste solution and WAC ion exchange backwash waste generated by the HERO™ system. Since the WAC ion exchange system was not backwashed during the verification test period, a theoretical extrapolation had to be considered. Calculations by Hydrometrics determined a WAC regeneration waste solution creation rate of approximately one gal for every 128.5 gal of wastewater processed, or a waste stream volume of 0.8 percent of the feed volume. Analytical characterization of this waste stream was not possible, but historical records of the HERO's™ WAC regeneration waste solution for similar wastewaters indicate that a standard dischargeable water-softener-like regeneration solution would be generated.

Waste from the pretreatment of the KCP wastewater, which is necessary to achieve the proper hardness-to-alkalinity ratio before entering the HERO™ system, consisted of backwash and rinse water from the multimedia filters and the SAC ion exchange unit. Since the SAC ion exchange unit was not in operation the first two days of the verification test, actual waste volumes were not obtainable during the test period. Hydrometrics has provided an estimate of approximately one gal of combined pretreatment waste for every 41.3 gal of wastewater processed, or a waste stream volume of 2.4 percent of the feed volume.

The combined HERO™ system waste stream would be a brine solution with a high hardness count, consisting primarily of sodium sulfate, but it may also contain heavy metals, suspended solids, O&G, biological materials, and other organic materials that have been removed from the wastewater. Hydrometrics claims that it is generally suitable for direct discharge to the sanitary sewer. Analytical testing of the RO waste portion of the combined waste stream, along with historical information regarding the WAC regeneration waste, supports this claim. The cumulative waste generation rate from the HERO™ system for the verification test was approximately one gal for every 8.93 gal of wastewater processed, for an overall sanitary sewer discharge waste reduction of 89 percent.

The WAC regeneration waste is generated in a batch mode, as the WAC resin becomes clogged with hardness and scale. However, for demonstration purposes, the WAC regeneration waste is reported as a normalized, per-gal waste in **Table 12**, and the results are summarized as well.

| Test Day | Wastewater Processed (gallons) | Pretreatment Wastes (Multimedia & SAC) (gallons) | WAC Regeneration Waste (gallons) | RO Waste (gallons) | Total Waste Generation (gallons) |
|---|---|---|---|---|---|
| 1 | 8,640 | 209* | 69* | 394 | 672 |
| 2 | 8,861 | 215* | 71* | 525 | 811 |
| 3 | 7,518 | 182* | 60* | 546 | 788 |
| 4 | 8,267 | 200* | 66* | 1,188 | 1,454 |
| *AVG* | *8,322* | *202** | *66** | *663* | *931* |
| **Total** | **33,286** | **806*** | **266*** | **2,653** | **3,725** |

*Estimates based on historical data and calculations provided by Hydrometrics, Inc.

**Table 12. Results of Waste Generation Analysis**

### 5.8 Cost Analysis

The estimated capital cost (2001) of a HERO™ system able to process the KCP average of 86,400 gpd of industrial wastewater, operating 24 hours per day, is $270,000 (includes $216,000 for the HERO™ system and $54,000 for installation costs).

Annual costs and savings associated with the high-pH RO wastewater treatment system are shown in **Table 13.** Since some cost items are normalized to the treated wastewater as measured in gal processed, and the workload varies from year to year, the figures in the table are based on a projected 31,390,000 gal of wastewater treated in a year (average 86,000/day, 365 days/year). The total average annual operating costs of the HERO™ system are approximately $38,499. The average sewage disposal costs at the KCP without the HERO™ system are typically $3,845/month (based on 86,000 gpd), and fresh water costs average $4,368/month (also based on 86,000 gpd), for a total average annual cost of $98,564. Therefore, use of the HERO™ system results in an estimated net annual savings of $60,065. The simple payback period is 4.5 years (capital cost/net annual savings).

The payback period at other facilities may vary depending on water and wastewater disposal cost. By achieving high water recovery, the approximate 5 percent reject (waste) stream can be more cost-effectively evaporated to assist in becoming a zero liquid discharge facility, if appropriate. At some facilities, it may be appropriate to treat dilute wastewater before clarification, thereby reducing clarifier costs. Also, the high-purity, low-hardness water used for recycle may improve the performance of cooling towers and other operations.

| | Without HEROô System | | | With HEROô System | | |
|---|---|---|---|---|---|---|
| **Item** | **Units** | **Unit Cost $/unit** | **Costs/yr $** | **Units** | **Unit Cost $/unit** | **Costs/yr $** |
| HERO™ system O&M labor (see section 5.5) | 0 | N/A | 0 | 365 hrs | 32.00 | 11,680 |
| NaCl additions (see section 5.6) | 0 | N/A | 0 | 131,838 lbs | 0.035 | 4,614 |
| HCl (31.5%) additions (see section 5.6) | 0 | N/A | 0 | 66,861 lbs | 0.042 | 2,808 |
| NaOH (25%) additions (see section 5.6) | 0 | N/A | 0 | 17,578 lbs | 0.047 | 826 |
| RO membrane replacement | 0 | N/A | 0 | 1,695 $ft^2$ of membrane | 1.85 | 3,136 |
| Electricity for HERO™ system (see section 5.4) | 0 | N/A | 0 | 115,201 kWh | 0.03816 | 4,396 |
| Sewer disposal fees (see section 5.8) | 31,390,000 gal | 0.00147 | 46,143 | 3,515,680 gal | 0.00147 | 5,168 |
| Fresh water purchase costs (see section 5.8) | 31,390,000 gal | 0.00167 | 52,421 | 3,515,680 gal | 0.00167 | 5,871 |
| **Total Costs** | | | **98,564** | | | **38,499** |

**Table 13. Annual Costs/Savings**

### 5.9 Project Responsibilities/Audits

Verification testing activities and sample analysis were performed according to section 6.0 of the verification test plan [Ref. 1].

In order to assess data quality, a single factor analysis of variance was performed on the laboratory results for total dissolved solids, total alkalinity, and nitrate concentration. The hypothesis tested was to determine for each analyte whether the influent concentrations were not in the same population as the effluent concentrations. For the number of samples, the minimum F value for 99 percent confidence was 13.75. The computed F value for TDS was 56.04; for alkalinity, 35.68; and for nitrates, 129.68. This means that, with over 99 percent confidence, the difference in the average concentration of these three analytes between the influent and effluent is due to the HERO™ technology.

There was a verification test audit conducted during the verification period for this technology. The audit was an external EPA Technical Systems Audit (TSA) conducted by a subcontractor, David Gratson of Neptune and Company, Inc., on July 24 & 25, 2001. There were no Findings, five Observations, and no Additional Technical Comments. All corrective actions were completed as instructed in the audit report issued by Mr. Gratson.

## 6.0 REFERENCES


1. Concurrent Technologies Corporation, "*Environmental Technology Verification Program for Metal Finishing Pollution Prevention Technologies Verification Test Plan, Evaluation of Hydrometrics, Inc. High Efficiency Reverse Osmosis (HERO*Ô*) Industrial Wastewater Treatment System,*" June 15, 2001.

2. Concurrent Technologies Corporation, "*Environmental Technology Verification Program Metal Finishing Technologies Quality Management Plan,*" Revision 1 – March 26, 2001.

3. Hydranautics, *"ROdesign7 – Comprehensive Reverse Osmosis Software Design Package."* Version 7.0 – Copyright 2000.

# APPENDIX A

# PRECISION CALCULATIONS

# PRECISION CALCULATIONS

| Laboratory ID | *CTC* ID | Parameter | Units | Sample Value | Duplicate Value | RPD % | RPD % Limits | RPD Met Y/N |
|---|---|---|---|---|---|---|---|---|
| 604477893 | 0724A | Mercury | mg/L | <0.0002 | <0.0002 | 0 | <30 | Y |
| 604476069 | 0724A | Aluminum | mg/L | <0.075 | <0.075 | 0 | <30 | Y |
| 604476069 | 0724A | Arsenic | mg/L | <0.085 | <0.085 | 0 | <30 | Y |
| 604476069 | 0724A | Barium | mg/L | 0.0268 | 0.0265 | 1 | <30 | Y |
| 604476069 | 0724A | Cadmium | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604476069 | 0724A | Calcium | mg/L | 131.0 | 133.0 | 1 | <30 | Y |
| 604476069 | 0724A | Chromium | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604476069 | 0724A | Copper | mg/L | <0.01 | <0.01 | 0 | <30 | Y |
| 604476069 | 0724A | Iron | mg/L | <0.04 | <0.04 | 0 | <30 | Y |
| 604476069 | 0724A | Lead | mg/L | <0.05 | <0.05 | 0 | <30 | Y |
| 604476069 | 0724A | Magnesium | mg/L | <0.05 | <0.05 | 0 | <30 | Y |
| 604476069 | 0724A | Manganese | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604476069 | 0724A | Molybdenum | mg/L | 0.203 | 0.206 | 2 | <30 | Y |
| 604476069 | 0724A | Nickel | mg/L | <0.03 | <0.03 | 0 | <30 | Y |
| 604476069 | 0724A | Silver | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604476069 | 0724A | Sodium | mg/L | 60.9 | 62.4 | 2 | <30 | Y |
| 604476069 | 0724A | Zinc | mg/L | <0.1 | <0.1 | 0 | <30 | Y |
| 604476069 | 0724A | Tin | mg/L | <0.25 | <0.25 | 0 | <30 | Y |
| 604477406 | 0724A | TDS | mg/L | 607 | 598 | 1 | <30 | Y |
| 604484758 | 0724A | Dissolved Silica | mg/L | 4.00 | 4.96 | 21 | <30 | Y |
| 604498097 | 0724A | O&G | mg/L | <5.0 | <5.0 | 0 | <30 | Y |
| 604476747 | 0724A | TOC | mg/L | <10.0 | <10.0 | 0 | <30 | Y |
| 604480301 | 0724A | Total Alk. | mg/L | 189 | 244 | 25 | <30 | Y |
| 604475996/604476002 | 0724A | Chloride | mg/L | 37.15 | 37.43 | 1 | <30 | Y |
| 604475996/604476002 | 0724A | Fluoride | mg/L | 2.749 | 2.771 | 1 | <30 | Y [1] |
| 604475996/604476002 | 0724A | Nitrate as N | mg/L | 7.909 | 7.893 | 0 | <30 | Y |
| 604475996/604476002 | 0724A | Sulfate | mg/L | 209.9 | 210.6 | 0 | <30 | Y [1] |
| 604484360/604484378 | 0724A | Cyanide | mg/L | 0.0816 | 0.0821 | 1 | <30 | Y |
| 604461863 | Batch | Cyanide | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604474429 | 0724B | Chloride | mg/L | <1.0 | <1.0 | 0 | <30 | Y |
| 604474429 | 0724B | Fluoride | mg/L | 0.961 | 0.920 | 4 | <30 | Y [1] |
| 604474429 | 0724B | Nitrate as N | mg/L | 1.79 | 1.79 | 0 | <30 | Y |
| 604474429 | 0724B | Sulfate | mg/L | <1.0 | <1.0 | 0 | <30 | Y [1] |
| 604474304 | 0725A | Mercury | mg/L | <0.0002 | <0.0002 | 0 | <30 | Y |
| 604475541 | 0725A | Aluminum | mg/L | <0.075 | <0.075 | 0 | <30 | Y |
| 604475541 | 0725A | Arsenic | mg/L | <0.085 | <0.085 | 0 | <30 | Y |
| 604475541 | 0725A | Barium | mg/L | 0.0187 | 0.0181 | 3 | <30 | Y |
| 604475541 | 0725A | Cadmium | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604475541 | 0725A | Calcium | mg/L | 88.7 | 85.7 | 3 | <30 | Y |
| 604475541 | 0725A | Chromium | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604475541 | 0725A | Copper | mg/L | <0.01 | <0.01 | 0 | <30 | Y |
| 604475541 | 0725A | Iron | mg/L | <0.04 | <0.04 | 0 | <30 | Y |
| 604475541 | 0725A | Lead | mg/L | <0.05 | <0.05 | 0 | <30 | Y |
| 604475541 | 0725A | Magnesium | mg/L | 0.186 | 0.178 | 4 | <30 | Y |
| 604475541 | 0725A | Manganese | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604475541 | 0725A | Molybdenum | mg/L | 0.447 | 0.420 | 6 | <30 | Y |
| 604475541 | 0725A | Nickel | mg/L | 0.0322 | 0.0303 | 6 | <30 | Y |
| 604475541 | 0725A | Silver | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604475541 | 0725A | Sodium | mg/L | 40.9 | 37.5 | 9 | <30 | Y |
| 604475541 | 0725A | Zinc | mg/L | <0.1 | <0.1 | 0 | <30 | Y |
| 604475541 | 0725A | Tin | mg/L | <0.25 | <0.25 | 0 | <30 | Y |
| 604474387 | 0725A | Sulfide | mg/L | <0.5 | <0.5 | 0 | <30 | Y |
| 604474346 | 0725A | TDS | mg/L | 404 | 384 | 5 | <30 | Y |
| 604498113 | 0725A | O&G | mg/L | <5.0 | <5.0 | 0 | <30 | Y |

| Laboratory ID | *CTC* ID | Parameter | Units | Sample Value | Duplicate Value | RPD % | RPD % Limits | RPD Met Y/N |
|---|---|---|---|---|---|---|---|---|
| 604474361 | 0725A | TSS | mg/L | <5.0 | <5.0 | 0 | <30 | Y |
| 604484790 | 0725A | Dissolved Silica | mg/L | <1.0 | 1.72 | 172 [2] | <30 | N |
| 604474874 | 0725A | TOC | mg/L | <10.0 | <10.0 | 0 | <30 | Y |
| 604489963 | 0725A | Total Alk. | mg/L | 151 | 150 | 1 | <30 | Y |
| 604474437/604474445 | 0725A | Chloride | mg/L | 35.03 | 34.85 | 1 | <30 | Y |
| 604474437/604474445 | 0725A | Fluoride | mg/L | 2.330 | 2.308 | 1 | <30 | Y [1] |
| 604474437/604474445 | 0725A | Nitrate as N | mg/L | 8.618 | 8.563 | 1 | <30 | Y |
| 604474437/604474445 | 0725A | Sulfate | mg/L | 128.7 | 127.9 | 1 | <30 | Y [1] |
| 604484220/604484238 | 0725A | Cyanide | mg/L | 0.0986 | 0.0944 | 4 | <30 | Y |
| 604473975 | 0725B | Cyanide | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604480863 | 0726A | Mercury | mg/L | <0.0002 | <0.0002 | 0 | <30 | Y |
| 604475582 | 0726A | Aluminum | mg/L | <0.075 | <0.075 | 0 | <30 | Y |
| 604475582 | 0726A | Arsenic | mg/L | <0.085 | <0.085 | 0 | <30 | Y |
| 604475582 | 0726A | Barium | mg/L | 0.0226 | 0.0239 | 5 | <30 | Y |
| 604475582 | 0726A | Cadmium | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604475582 | 0726A | Calcium | mg/L | 105 | 108 | 3 | <30 | Y |
| 604475582 | 0726A | Chromium | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604475582 | 0726A | Copper | mg/L | <0.01 | <0.01 | 0 | <30 | Y |
| 604475582 | 0726A | Iron | mg/L | 0.045 | <0.04 | 11 | <30 | Y |
| 604475582 | 0726A | Lead | mg/L | <0.05 | <0.05 | 0 | <30 | Y |
| 604475582 | 0726A | Magnesium | mg/L | 0.175 | 0.194 | 10 | <30 | Y |
| 604475582 | 0726A | Manganese | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604475582 | 0726A | Molybdenum | mg/L | 0.193 | 0.193 | 0 | <30 | Y |
| 604475582 | 0726A | Nickel | mg/L | <0.03 | <0.03 | 0 | <30 | Y |
| 604475582 | 0726A | Silver | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604475582 | 0726A | Sodium | mg/L | 42.9 | 41.3 | 4 | <30 | Y |
| 604475582 | 0726A | Zinc | mg/L | <0.1 | <0.1 | 0 | <30 | Y |
| 604475582 | 0726A | Tin | mg/L | <0.25 | <0.25 | 0 | <30 | Y |
| 604475244 | 0726A | Sulfide | mg/L | <0.5 | <0.5 | 0 | <30 | Y |
| 604475137 | 0726A | TDS | mg/L | 430 | 404 | 6 | <30 | Y |
| 604475178 | 0726A | TSS | mg/L | <5.0 | <5.0 | 0 | <30 | Y |
| 604487488 | 0726A | Dissolved Silica | mg/L | 4.39 | 4.87 | 12 | <30 | Y |
| 604498139 | 0726A | O&G | mg/L | <5.0 | <5.0 | 0 | <30 | Y |
| 604476853 | 0726A | TOC | mg/L | <10.0 | <10.0 | 0 | <30 | Y |
| 604489971 | 0726A | Total Alk. | mg/L | 151 | 145 | 4 | <30 | Y |
| 604475483/604475491 | 0726A | Chloride | mg/L | 35.58 | 35.33 | 1 | <30 | Y |
| 604475483/604475491 | 0726A | Fluoride | mg/L | 2.607 | 2.604 | 0 | <30 | Y [1] |
| 604475483/604475491 | 0726A | Nitrate as N | mg/L | 8.299 | 8.268 | 0 | <30 | Y |
| 604475483/604475491 | 0726A | Sulfate | mg/L | 165.0 | 164.6 | 0 | <30 | Y [1] |
| 604484279/604484287 | 0726A | Cyanide | mg/L | 0.0984 | 0.0862 | 13 | <30 | Y |
| 604484295 | Batch | Cyanide | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604480889 | 0727A | Mercury | mg/L | <0.0002 | <0.0002 | 0 | <30 | Y |
| 604481002 | 0727A | Aluminum | mg/L | <0.075 | <0.075 | 0 | <30 | Y |
| 604481002 | 0727A | Arsenic | mg/L | <0.085 | <0.085 | 0 | <30 | Y |
| 604481002 | 0727A | Barium | mg/L | 0.0248 | 0.0229 | 8 | <30 | Y |
| 604481002 | 0727A | Cadmium | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604481002 | 0727A | Calcium | mg/L | 124 | 122 | 2 | <30 | Y |
| 604481002 | 0727A | Chromium | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604481002 | 0727A | Copper | mg/L | 0.0453 | 0.0440 | 3 | <30 | Y |
| 604481002 | 0727A | Iron | mg/L | <0.04 | <0.04 | 0 | <30 | Y |
| 604481002 | 0727A | Lead | mg/L | <0.05 | <0.05 | 0 | <30 | Y |
| 604481002 | 0727A | Magnesium | mg/L | <0.05 | <0.05 | 0 | <30 | Y |
| 604481002 | 0727A | Manganese | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604481002 | 0727A | Molybdenum | mg/L | 0.166 | 0.161 | 3 | <30 | Y |
| 604481002 | 0727A | Nickel | mg/L | <0.03 | <0.03 | 0 | <30 | Y |

| Laboratory ID | *CTC* ID | Parameter | Units | Sample Value | Duplicate Value | RPD % | RPD % Limits | RPD Met Y/N |
|---|---|---|---|---|---|---|---|---|
| 604481002 | 0727A | Silver | mg/L | <0.007 | <0.007 | 0 | <30 | Y |
| 604481002 | 0727A | Sodium | mg/L | 80.3 | 75.5 | 6 | <30 | Y |
| 604481002 | 0727A | Zinc | mg/L | <0.1 | <0.1 | 0 | <30 | Y |
| 604481002 | 0727A | Tin | mg/L | <0.25 | <0.25 | 0 | <30 | Y |
| 604483818 | 0727A | Sulfide | mg/L | <0.5 | <0.5 | 0 | <30 | Y |
| 604479154 | 0727A | TDS | mg/L | 667 | 646 | 3 | <30 | Y |
| 604479170 | 0727A | TSS | mg/L | <5.0 | <5.0 | 0 | <30 | Y |
| 604487504 | 0727A | Dissolved Silica | mg/L | 4.77 | 7.66 | 46 [2] | <30 | N |
| 604498170 | 0727A | O&G | mg/L | <5.0 | <5.0 | 0 | <30 | Y |
| 604490482 | 0727A | TOC | mg/L | <10.0 | <10.0 | 0 | <30 | Y |
| 604489989 | 0727A | Total Alk. | mg/L | 104.0 | 98.7 | 5 | <30 | Y |
| 604480541/604480558 | 0727A | Chloride | mg/L | 56.16 | 56.40 | 0 | <30 | Y |
| 604480541/604480558 | 0727A | Fluoride | mg/L | 2.679 | 2.683 | 0 | <30 | Y [1] |
| 604480541/604480558 | 0727A | Nitrate as N | mg/L | 8.578 | 8.582 | 0 | <30 | Y |
| 604480541/604480558 | 0727A | Sulfate | mg/L | 224 | 225 | 0 | <30 | Y [1] |
| 604480533 | Batch | Chloride | mg/L | 95.7 | 95.4 | 0 | <30 | Y |
| 604480533 | Batch | Fluoride | mg/L | <0.2 | <0.2 | 0 | <30 | Y [1] |
| 604480533 | Batch | Nitrate as N | mg/L | 2.08 | 2.08 | 0 | <30 | Y |
| 604480533 | Batch | Sulfate | mg/L | 177 | 176 | 0 | <30 | Y [1] |
| 604484311/604484329 | 0727A | Cyanide | mg/L | 0.0576 | 0.0822 | 35 [2] | <30 | N |
| 604484337 | 0727B | Cyanide | mg/L | <0.005 | <0.005 | 0 | <30 | Y |
| 604498782 | 0727FB | Total Alk. | mg/L | <1.0 | <1.0 | 0 | <30 | Y |

[1] This data is an estimate only, due to a wide range of accuracy used by the lab.

[2] The spike recovery was outside acceptable limits for the Matrix Spike due to matrix interference. The Laboratory Control Sample (LCS) was within acceptable limits showing that the laboratory was in control, and the data is acceptable.

# APPENDIX B

# ACCURACY CALCULATIONS

# ACCURACY CALCULATIONS

| *CTC* SAMPLE ID | Parameter | Units | Sample Value | Sample +Spike Value | Spike Value | Recovery % | Target % Recovery | Accuracy Met Y/N |
|---|---|---|---|---|---|---|---|---|
| 0724A | Mercury | mg/L | 0.00001481 | 0.009567 | 0.010000 | 96 | 70-130 | Y |
| 0724A | Aluminum | mg/L | 0 | 8.919 | 10.000 | 89 | 70-130 | Y |
| 0724A | Arsenic | mg/L | 0 | 0.9431 | 1.0000 | 94 | 70-130 | Y |
| 0724A | Barium | mg/L | 0.02678 | 0.9245 | 1.0000 | 90 | 70-130 | Y |
| 0724A | Cadmium | mg/L | 0.000049 | 0.09366 | 0.10000 | 94 | 70-130 | Y |
| 0724A | Calcium | mg/L | 130.9 | 138.1 | 10.0 | 72 | 70-130 | Y |
| 0724A | Chromium | mg/L | 0.002328 | 0.938600 | 1.000000 | 94 | 70-130 | Y |
| 0724A | Copper | mg/L | 0.005523 | 0.955400 | 1.000000 | 95 | 70-130 | Y |
| 0724A | Iron | mg/L | 0.02527 | 9.27300 | 10.00000 | 92 | 70-130 | Y |
| 0724A | Lead | mg/L | 0.001357 | 0.890500 | 1.000000 | 89 | 70-130 | Y |
| 0724A | Magnesium | mg/L | 0.03130 | 9.04700 | 10.00000 | 90 | 70-130 | Y |
| 0724A | Manganese | mg/L | 0.000747 | 0.930300 | 1.000000 | 93 | 70-130 | Y |
| 0724A | Molybdenum | mg/L | 0.2028 | 1.1110 | 1.0000 | 91 | 70-130 | Y |
| 0724A | Nickel | mg/L | 0.01577 | 0.96300 | 1.00000 | 95 | 70-130 | Y |
| 0724A | Silver | mg/L | 0.004051 | 0.099430 | 0.100000 | 95 | 70-130 | Y |
| 0724A | Sodium | mg/L | 60.930 | 70.870 | 10.000 | 99 | 70-130 | Y |
| 0724A | Zinc | mg/L | 0.009784 | 0.917500 | 1.000000 | 91 | 70-130 | Y |
| 0724A | Tin | mg/L | 0.009942 | 8.915000 | 10.000000 | 89 | 70-130 | Y |
| 0724A | Dissolved Silica | mg/L | 4.004 | 14.980 | 10.000 | 110 | 70-130 | Y |
| 0724A | O&G | mg/L | 0.8889 | 26.2500 | 40.0000 | 63 | 61-127 | Y |
| 0724A | TOC | mg/L | 7.53 | 12.54 | 5.00 | 100 | 70-130 | Y |
| 0724A | Chloride | mg/L | 13.90 | 37.15 | 25.00 | 93 | 70-130 | Y |
| 0724A | Fluoride | mg/L | 1.057 | 2.749 | 2.500 | 68 | 16-178 | Y [1] |
| 0724A | Nitrate as N | mg/L | 4.903 | 7.909 | 5.000 | 60 [2] | 70-130 | N |
| 0724A | Sulfate | mg/L | 178.4 | 209.9 | 50.0 | 63 | 10-170 | Y [1] |
| 0724A | Cyanide | mg/L | 0.0044 | 0.0816 | 0.1000 | 77 | 61-113 | Y |
| 0725A | Mercury | mg/L | 0.00000679 | 0.009087 | 0.0100000 | 91 | 70-130 | Y |
| 0725A | Aluminum | mg/L | 0 | 9.314 | 10.000 | 93 | 70-130 | Y |
| 0725A | Arsenic | mg/L | 0 | 0.9426 | 1.0000 | 94 | 70-130 | Y |
| 0725A | Barium | mg/L | 0.01869 | 0.9711 | 1.0000 | 95 | 70-130 | Y |
| 0725A | Cadmium | mg/L | 0.000049 | 0.09716 | 0.10000 | 97 | 70-130 | Y |
| 0725A | Calcium | mg/L | 88.72 | 95.27 | 10.00 | 66 [2] | 70-130 | N |
| 0725A | Chromium | mg/L | 0.000694 | 0.979400 | 1.000000 | 98 | 70-130 | Y |
| 0725A | Copper | mg/L | 0.0033 | 0.9856 | 1.0000 | 98 | 70-130 | Y |
| 0725A | Iron | mg/L | 0.03174 | 9.51200 | 10.00000 | 95 | 70-130 | Y |
| 0725A | Lead | mg/L | 0.000591 | 0.872400 | 1.000000 | 87 | 70-130 | Y |
| 0725A | Magnesium | mg/L | 0.1857 | 9.6280 | 10.0000 | 94 | 70-130 | Y |
| 0725A | Manganese | mg/L | 0.000612 | 0.973900 | 1.000000 | 97 | 70-130 | Y |
| 0725A | Molybdenum | mg/L | 0.4471 | 1.3950 | 1.0000 | 95 | 70-130 | Y |
| 0725A | Nickel | mg/L | 0.03224 | 1.02000 | 1.00000 | 99 | 70-130 | Y |
| 0725A | Silver | mg/L | 0.001981 | 0.100500 | 0.100000 | 98 | 70-130 | Y |
| 0725A | Sodium | mg/L | 40.90 | 49.55 | 10.00 | 87 | 70-130 | Y |
| 0725A | Zinc | mg/L | 0.01489 | 0.96330 | 1.00000 | 95 | 70-130 | Y |
| 0725A | Tin | mg/L | 0.02525 | 9.41800 | 10.00000 | 94 | 70-130 | Y |
| 0725A | Dissolved Silica | mg/L | 0.899 | 12.850 | 10.000 | 120 | 70-130 | Y |
| 0725A | O&G | mg/L | 1.222 | 39.470 | 40.000 | 96 | 61-127 | Y |
| 0725A | TOC | mg/L | 3.18 | 8.69 | 5.00 | 110 | 70-130 | Y |
| 0725A | Chloride | mg/L | 13.47 | 35.03 | 25.00 | 86 | 70-130 | Y |
| 0725A | Fluoride | mg/L | 0.7134 | 2.3300 | 2.5000 | 65 | 16-178 | Y [1] |
| 0725A | Nitrate as N | mg/L | 4.901 | 8.618 | 5.000 | 74 | 70-130 | Y |
| 0725A | Sulfate | mg/L | 90.77 | 128.70 | 50.00 | 76 | 10-170 | Y [1] |
| 0725A | Cyanide | mg/L | 0 | 0.0986 | 0.1000 | 94 | 61-113 | Y |
| 0726A | Mercury | mg/L | 0 | 0.009588 | 0.010000 | 96 | 70-130 | Y |

| *CTC* SAMPLE ID | Parameter | Units | Sample Value | Sample +Spike Value | Spike Value | Recovery % | Target % Recovery | Accuracy Met Y/N |
|---|---|---|---|---|---|---|---|---|
| 0726A | Aluminum | mg/L | 0 | 9.442 | 10.000 | 94 | 70-130 | Y |
| 0726A | Arsenic | mg/L | 0 | 0.9805 | 1.0000 | 98 | 70-130 | Y |
| 0726A | Barium | mg/L | 0.02264 | 1.01600 | 1.00000 | 99 | 70-130 | Y |
| 0726A | Cadmium | mg/L | 0 | 0.0989 | 0.1000 | 99 | 70-130 | Y |
| 0726A | Calcium | mg/L | 105.0 | 114.7 | 10.0 | 97 | 70-130 | Y |
| 0726A | Chromium | mg/L | 0.003091 | 1.004000 | 1.000000 | 100 | 70-130 | Y |
| 0726A | Copper | mg/L | 0.003477 | 1.01400 | 1.00000 | 101 | 70-130 | Y |
| 0726A | Iron | mg/L | 0.04496 | 9.96900 | 10.00000 | 99 | 70-130 | Y |
| 0726A | Lead | mg/L | 0 | 0.899 | 1.000 | 90 | 70-130 | Y |
| 0726A | Magnesium | mg/L | 0.1751 | 9.8460 | 10.0000 | 97 | 70-130 | Y |
| 0726A | Manganese | mg/L | 0.000639 | 0.997400 | 1.000000 | 100 | 70-130 | Y |
| 0726A | Molybdenum | mg/L | 0.1928 | 1.1560 | 1.0000 | 96 | 70-130 | Y |
| 0726A | Nickel | mg/L | 0.01037 | 1.02300 | 1.00000 | 101 | 70-130 | Y |
| 0726A | Silver | mg/L | 0.001676 | 0.102800 | 0.100000 | 101 | 70-130 | Y |
| 0726A | Sodium | mg/L | 42.91 | 50.61 | 10.00 | 77 | 70-130 | Y |
| 0726A | Zinc | mg/L | 0.01334 | 0.98010 | 1.00000 | 97 | 70-130 | Y |
| 0726A | Tin | mg/L | 0.01929 | 9.59600 | 10.00000 | 96 | 70-130 | Y |
| 0726A | Dissolved Silica | mg/L | 4.389 | 14.300 | 10.000 | 99 | 70-130 | Y |
| 0726A | O&G | mg/L | 0.6667 | 30.3300 | 40.0000 | 74 | 61-127 | Y |
| 0726A | TOC | mg/L | 3.19 | 7.85 | 5.00 | 93 | 70-130 | Y |
| 0726A | Chloride | mg/L | 12.04 | 35.58 | 25.00 | 94 | 70-130 | Y |
| 0726A | Fluoride | mg/L | 0.7839 | 2.6070 | 2.5000 | 73 | 16-178 | Y [1] |
| 0726A | Nitrate as N | mg/L | 4.267 | 8.299 | 5.000 | 81 | 70-130 | Y |
| 0726A | Sulfate | mg/L | 123.1 | 165.0 | 50.0 | 84 | 10-170 | Y [1] |
| 0726A | Cyanide | mg/L | 0.01224 | 0.09840 | 0.10000 | 86 | 61-113 | Y |
| 0727A | Mercury | mg/L | 0 | 0.009754 | 0.010000 | 98 | 70-130 | Y |
| 0727A | Aluminum | mg/L | 0 | 9.129 | 10.000 | 91 | 70-130 | Y |
| 0727A | Arsenic | mg/L | 0 | 0.9624 | 1.0000 | 96 | 70-130 | Y |
| 0727A | Barium | mg/L | 0.02475 | 0.98560 | 1.00000 | 96 | 70-130 | Y |
| 0727A | Cadmium | mg/L | 0.000593 | 0.095080 | 0.100000 | 94 | 70-130 | Y |
| 0727A | Calcium | mg/L | 124.5 | 135.0 | 10.0 | 105 | 70-130 | Y |
| 0727A | Chromium | mg/L | 0.001789 | 0.961400 | 1.000000 | 96 | 70-130 | Y |
| 0727A | Copper | mg/L | 0.0453 | 1.0140 | 1.0000 | 97 | 70-130 | Y |
| 0727A | Iron | mg/L | 0.01767 | 9.84200 | 10.00000 | 98 | 70-130 | Y |
| 0727A | Lead | mg/L | 0.002909 | 0.869800 | 1.000000 | 87 | 70-130 | Y |
| 0727A | Magnesium | mg/L | 0 | 9.296 | 10.000 | 93 | 70-130 | Y |
| 0727A | Manganese | mg/L | 0.000439 | 0.952700 | 1.000000 | 95 | 70-130 | Y |
| 0727A | Molybdenum | mg/L | 0.1661 | 1.0950 | 1.0000 | 93 | 70-130 | Y |
| 0727A | Nickel | mg/L | 0.01299 | 0.98250 | 1.00000 | 97 | 70-130 | Y |
| 0727A | Silver | mg/L | 0.00308 | 0.10320 | 0.10000 | 100 | 70-130 | Y |
| 0727A | Sodium | mg/L | 80.31 | 88.90 | 10.00 | 86 | 70-130 | Y |
| 0727A | Zinc | mg/L | 0.004257 | 0.929300 | 1.000000 | 92 | 70-130 | Y |
| 0727A | Tin | mg/L | 0.2069 | 9.6060 | 10.0000 | 96 | 70-130 | Y |
| 0727A | Dissolved Silica | mg/L | 4.77 | 15.58 | 10.00 | 108 | 70-130 | Y |
| 0727A | O&G | mg/L | 0.9091 | 26.4200 | 40.0000 | 64 | 61-127 | Y |
| 0727A | TOC | mg/L | 6.31 | 12.28 | 5.00 | 119 | 70-130 | Y |
| 0727A | Chloride | mg/L | 36.04 | 56.16 | 25.00 | 80 | 70-130 | Y |
| 0727A | Fluoride | mg/L | 0.7343 | 2.6790 | 2.5000 | 78 | 16-178 | Y [1] |
| 0727A | Nitrate as N | mg/L | 4.257 | 8.578 | 5.000 | 86 | 70-130 | Y |
| 0727A | Sulfate | mg/L | 190.7 | 224.0 | 50.0 | 67 | 10-170 | Y [1] |
| 0727A | Cyanide | mg/L | 0 | 0.0576 | 0.1000 | 58 [2] | 61-113 | N |

[1] This data is an estimate only, due to a wide range of accuracy used by the lab.

[2] The spike recovery was outside acceptable limits for the Matrix Spike due to matrix interference. The Laboratory Control Sample (LCS) was within acceptable limits showing that the laboratory was in control, and the data is acceptable.

# APPENDIX C

# REPRESENTATIVENESS CALCULATIONS

## REPRESENTATIVENESS CALCULATIONS

| *CTC* **ID SAMPLE →** | **0724A – HEROÔ IN** | | | **0724B – HEROÔ EFF** | | | **0725D – RO Waste** | | | **0726E – Cu Recovery WAC IN** | | | **0726F – Cu Recovery WAC EFF** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PARAMETER ↓** | ***Result*** | ***Dup. Result*** | ***% Diff.*** | ***Result*** | ***Dup. Result*** | ***% Diff.*** | ***Result*** | ***Dup. Result*** | ***% Diff.*** | ***Result*** | ***Dup. Result*** | ***% Diff.*** | ***Result*** | ***Dup. Result*** | ***% Diff.*** |
| Mercury (µg/L) | <0.200 | <0.200 | 0.0 | <0.200 | <0.200 | 0.0 | <0.200 | <0.200 | 0.0 | - | - | - | - | - | - |
| Aluminum (µg/L) | <75.0 | <75.0 | 0.0 | <75.0 | <75.0 | 0.0 | 435 | 458 | 5.2 | - | - | - | - | - | - |
| Arsenic (µg/L) | <85.0 | <85.0 | 0.0 | <85.0 | <85.0 | 0.0 | <85.0 | <85.0 | 0.0 | - | - | - | - | - | - |
| Barium (µg/L) | 26.8 | 25.7 | 4.2 | <4.0 | <4.0 | 0.0 | 17.9 | 19.7 | 9.6 | - | - | - | - | - | - |
| Cadmium (µg/L) | <5.0 | <5.0 | 0.0 | <5.0 | <5.0 | 0.0 | <5.0 | <5.0 | 0.0 | - | - | - | - | - | - |
| Calcium (µg/L) | 131000 | 129000 | 1.5 | 121 | 114 | 6.0 | 21500 | 21800 | 1.4 | - | - | - | - | - | - |
| Chromium (µg/L) | <7.0 | <7.0 | 0.0 | <7.0 | <7.0 | 0.0 | 21.8 | 22.3 | 2.3 | - | - | - | - | - | - |
| Copper (µg/L) | <10.0 | <10.0 | 0.0 | <10.0 | <10.0 | 0.0 | 25.0 | 26.1 | 4.3 | 486 | 504 | 3.6 | 296 | 295 | 0.3 |
| Iron (µg/L) | <40.0 | 48.7 | 19.6 | <40.0 | <40.0 | 0.0 | <40.0 | 52.9 | 27.8 | - | - | - | - | - | - |
| Lead (µg/L) | <50.0 | <50.0 | 0.0 | <50.0 | <50.0 | 0.0 | <50.0 | <50.0 | 0.0 | - | - | - | - | - | - |
| Magnesium (µg/L) | <50.0 | <50.0 | 0.0 | <50.0 | <50.0 | 0.0 | <50.0 | <50.0 | 0.0 | - | - | - | - | - | - |
| Manganese (µg/L) | <7.0 | <7.0 | 0.0 | <7.0 | <7.0 | 0.0 | <7.0 | <7.0 | 0.0 | - | - | - | - | - | - |
| Molybdenum (µg/L) | 203 | 205 | 1.0 | <20.0 | <20.0 | 0.0 | 9790 | 10100 | 3.1 | - | - | - | - | - | - |
| Nickel (µg/L) | <30.0 | <30.0 | 0.0 | <30.0 | <30.0 | 0.0 | 239 | 244 | 2.1 | - | - | - | - | - | - |
| Silver (µg/L) | <7.0 | <7.0 | 0.0 | <7.0 | <7.0 | 0.0 | 11.4 | 12.3 | 7.6 | - | - | - | - | - | - |
| Sodium (µg/L) | 60900 | 59800 | 1.8 | 19100 | 19000 | 0.5 | <150 | <150 | 0.0 | - | - | - | - | - | - |
| Zinc (µg/L) | <100 | <100 | 0.0 | <100 | <100 | 0.0 | <100 | <100 | 0.0 | - | - | - | - | - | - |
| Tin (µg/L) | <250 | <250 | 0.0 | <250 | <250 | 0.0 | <250 | <250 | 0.0 | - | - | - | - | - | - |
| Sulfide (mg/L) | <0.500 | <0.500 | 0.0 | <0.500 | <0.500 | 0.0 | <0.500 | <0.500 | 0.0 | - | - | - | - | - | - |
| TDS (mg/L) | 607 | 610 | 0.5 | 59.0 | 56.0 | 5.2 | 5870 | 5950 | 1.4 | - | - | - | - | - | - |
| TSS (mg/L) | <5.0 | <5.0 | 0.0 | <5.0 | <5.0 | 0.0 | 5.00 | <5.00 | 0.0 | - | - | - | - | - | - |
| Diss. Silica (mg/L) | 4.00 | 4.58 | 13.5 | <1.0 | <1.0 | 0.0 | 46.4 | 37.6 | 21.0 | - | - | - | - | - | - |
| O&G (mg/L) | <5.0 | <5.0 | 0.0 | <5.0 | <5.0 | 0.0 | <5.0 | <5.0 | 0.0 | - | - | - | - | - | - |
| Chloride (mg/L) | 13.9 | 13.9 | 0.0 | <1.0 | <1.0 | 0.0 | 359 | 355 | 1.1 | - | - | - | - | - | - |
| Fluoride (mg/L) | 1.06 | 1.06 | 0.0 | 0.961 | 0.513 | 60.8 | 12.4 | 12.3 | 0.8 | - | - | - | - | - | - |
| Nitrate as N (mg/L) | 4.90 | 4.91 | 0.2 | 1.79 | 1.79 | 0.0 | 100 | 99.8 | 0.2 | - | - | - | - | - | - |
| Sulfate (mg/L) | 178 | 180 | 1.1 | <1.0 | 6.33 | 145.4 | 2420 | 2390 | 1.2 | - | - | - | - | - | - |
| TOC (mg/L) | <10.0 | <10.0 | 0.0 | <10.0 | <10.0 | 0.0 | <10.0 | <10.0 | 0.0 | - | - | - | - | - | - |
| Total Alk. (mg/L) | 189 | 156 | 19.1 | 58.3 | 58.3 | 0.0 | 574 | 586 | 2.1 | - | - | - | - | - | - |
| Cyanide (mg/L) | <0.005 | <0.005 | 0.0 | <0.005 | <0.005 | 0.0 | 0.0078 | 0.014 | 56.9 | - | - | - | - | - | - |