

REMEDIAL OPTIONS EVALUATION

Appleton Wire
Former Albany International
Chrome Plant
908 North Lawe Street
Appleton, Wisconsin
WDNR ERP# 02-45-000015

Prepared for the
WISCONSIN DEPARTMENT OF NATURAL RESOURCES

March 30, 2016

Ms. Jennifer Borski
Wisconsin Department of Natural Resources
625 East County Road Y, Suite No. 700
Oshkosh, WI 54901-9731

Re: Remedial Options Evaluation
Appleton Wire, Former Albany International Chrome Plant Appleton, WI
WDNR ERP# 02-45-000015

Dear Ms. Borski:

Enclosed, please find Badger Laboratories and Engineering Co., Inc.'s "Remedial Options Evaluation Report" for the Appleton Wire, Former Albany International Chrome Plant, 908 North Lawe Street, Appleton, Wisconsin.

If you have any questions or require additional information, feel free to contact me.

Very truly yours,

Badger Laboratories and Engineering Co., Inc.



David J. Casper
Project Manager

Encl: "Remedial Options Evaluation Report"

This report presents an evaluation of options for the remediation of Chromium contamination present at the Appleton Wire - Former Albany International Chrome Plant Appleton, WI (the site).

Much of the discussion of chromium contamination remediation technologies found in this report has been taken from two publications on the subject. These publications are:

“In Situ Treatment Of Soil And Groundwater Contaminated With Chromium Technical Resource Guide”; compiled by the Center for Environmental Research Information National Risk Management Research Laboratory Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268 and

“Remediation of Metals-Contaminated Soils and Groundwater,” October 1997 by Cynthia R. Evanko, Ph. D. and David A. Dzombak, Ph. D., P.E. of the Carnegie Mellon University Department of Civil and Environmental Engineering Pittsburgh, PA

I. SITE/PROJECT BACKGROUND

The Appleton Wire, Former Albany International, Chrome Plant, located at 908 North Lawe, Appleton, Wisconsin, was utilized as a chrome plating facility from 1963 to 1982. The chrome plant building and a parking lot north of the building were sold to Valley Cast in 1984. The address of the Valley Cast portion of the site is 908 North Lawe Street. The loading dock area near the chrome plating area was referred to as 831 North Meade Street. An office building and parking lot south of the former chrome plant were sold to Appleton Papers (now Appvion) between 1985 and 1990. The address of the office building is 714 East Hancock Street. Reporting related to the release of chromium on the site has been referenced under the Meade Street, Hancock Street and Lawe Street addresses. As of June, 2009, the physical address (for reporting purposes) of the former chrome plant site was changed to 908 North Lawe Street.

Valley Cast became a fully owned subsidiary of Outokumpu in 1985. The facility name was changed to Outokumpu in 2001. In 2006, the company was sold and currently operates under the name Luvata Appleton.

In 1985, Valley Cast employees noted groundwater collecting in the basement of the building. Subsequent tests indicated concentrations of chromium in the collected groundwater.

STS Consultants, Inc. conducted an investigation of the former chrome plant site on January 19, 1987. The purpose of the investigation was to determine the horizontal and vertical extent of the chromium contamination and to evaluate the effectiveness of the facility's basement sump to collect contaminated groundwater from the north and south sides of the building.

The results of the 1987 investigation indicated that the chromium contamination appeared limited to areas along the northeast and southeast ends of the building, to a depth of approximately 15-feet below grade. The existing basement sump was found to be adequate for collection of groundwater along the south end of the building. The consultant proposed installation of a collection system along the north side of the building to improve groundwater collection.

In 1988, a chemical precipitation process was installed to treat the groundwater collecting in the facility basement sump. The system was operated until 1998, when it was replaced by an ion exchange treatment system.

In 1992, a groundwater collection system was installed along the north side of the building. The system consists of approximately 110 feet of perforated piping, placed 14 feet below grade. The piping empties into a manhole, located at the northeast corner of the facility. Collected groundwater is pumped from the manhole to two storage tanks, located in the basement of the facility. Groundwater flowing to the basement sump is also pumped to the storage tanks.

In 2003, eleven geoprobe monitoring wells were installed in and around the two source areas in an attempt to better define the vertical and horizontal extent of the chromium contamination. Periodic sampling was conducted from the geoprobe monitoring wells until their abandonment in April 2008.

In June of 2009, Monitoring well MW-19 and Piezometer MW-19A were installed inside the former chrome plant building which is now used by Luvata as warehouse space. They were first sampled on July 13, 2009.

Between May 12, 2014 and May 14, 2014, eleven push probe borings were placed in the interior of the former chrome plant building and current Luvata Appleton production area to further delineate the extent of the subsurface Chromium contamination. As part of the investigation, Monitoring Well MW-20 and Piezometer MW-20A were installed in the former warehouse area. Monitoring well MW-21 and Piezometer MW-21A were installed in the Luvata production area. The Geoprobe and monitoring well locations are shown on Figure #1.

The results of the May, 2014 investigation indicated that subsurface chromium contamination was present in the northeastern portion of the Luvata Appleton warehouse area. Several former employees were interviewed regarding these findings and it was discovered that there had been a second plating operation to the north of the main chrome plating line. Groundwater samples collected from monitoring wells MW-20 and MW-20A, in the area of the second plating line, recorded high levels of total chromium.

Groundwater sampling conducted in the Luvata production area at Monitoring Wells MW-21 and MW-21A, recorded little to no total chromium. With the data provided by the addition of the 4 monitoring wells in 2014, the extent of the chromium contamination has been confirmed to lie solely under the warehouse building. Figure #2 is an isoconcentration map of the chromium contamination

II. CURRENT BATCH TREATMENT PROCESS

A. Groundwater Treatment System

The impacted groundwater on the site is collected in a basement sump and a groundwater collection system (French Drain). The collected water is pumped to two, 2000-gallon storage tanks, located in the basement of the facility. The groundwater is treated in batches at the operator's discretion. Prior to initiation of the treatment process, the pH in the basement storage tanks is adjusted to a pH of 4.00 to maximize the efficiency of the ion exchange resin. The water is pumped at a flow rate of 8-12 gallons per minute through a series of filters and two (2) ion exchange canisters. The water then flows to another tank where the pH is readjusted to a pH between 6.0 and 7.0. The treated water then decants to the City of Appleton Sanitary Sewer System.

B. Permit Monitoring and Reporting

The discharge from the groundwater treatment system is tested for Hexavalent Chromium during each batch discharge. The effluent is tested monthly for Total Chromium and annually for the parameters required in the City of Appleton's Industrial Use Permit, which is reissued annually for the site in May.

The Wisconsin DNR requires submittal of semi-annual operation and maintenance summary reports. These reports consist of a review of the treatment process, an overview of operation and maintenance activities, a summary of the treatment system analytical results and a summary of the analytical results from the groundwater monitoring wells.

III. GROUNDWATER SAMPLING

A. Groundwater Sampling

A total of 16 groundwater monitoring wells and piezometers now exist on the former chrome plant property to monitor the subsurface chromium contamination. Additionally, the groundwater collection system (French Drain) and basement sump are monitored to track the effectiveness of the treatment system.

Monitoring devices MW-19 and MW-19A were installed on June 30, 2009. They were first sampled on July 13, 2009. Monitoring Wells MW-20, MW-20A, MW-21 and MW-21A (installed between May 12 and 14, 2014) were first sampled on June 2, 2014.

Groundwater levels are measured in the monitoring wells and piezometers relative to the north side of the top of the well casing. The groundwater elevations are collected from each monitoring well prior to sampling. A dedicated 12-volt submersible pump is installed in each well. Each well is slowly pumped dry, allowed to recharge and sampled. Purge water is collected and treated in the treatment system.

The monitoring well locations and soil boring locations are shown on Figure #1. The two source area wells (MW-05 and MW-05A) are sampled quarterly. The remainder of the monitoring wells are sampled annually. Graphs of the chromium contaminant concentrations for

each monitoring well, the building sump and French Drain are contained in Appendix A. A graph of the historical groundwater elevation data collected from each monitoring well during the quarterly sampling is also provided in Appendix A.

B. Groundwater Sampling Results

The collected groundwater samples are analyzed for Total and Hexavalent chromium. Additionally, field analysis is conducted at each well for temperature, pH and conductivity. Observations for color, turbidity and odor are recorded during sampling.

On October 20, 2015, Monitoring Well MW-05 and MW-5A were sampled. MW-05 had exceedances of the NR 140.10 Enforcement Standard (ES) for Total Chromium, at 604 ug/l. MW-05A had a Preventive Action Limit (PAL) exceedance of 16 ug/l MW-05A).

On April 21, 2015, all 16 groundwater monitoring wells were sampled. Exceedances of the ES for Total Chromium were found in MW-04 (576 ug/l), MW-19 (18,587 ug/l) and in MW-20 (248,900 ug/l). MW-18A contained a PAL exceedance of 15 ug/l No exceedances of the ES or Preventive Action Limit (PAL) were noted in any of the remaining 12 monitoring wells. A chromium isoconcentration map from the April 2015 sampling is shown on Figure #2.

- II. Samples are collected from the Manhole (French Drain) and basement Collection Sump monthly. All samples collected from the Manhole and basement Collection Sump during the 2015 had exceedances of the ES for Total Chromium.

A review of the historical analytical data shows decreasing concentrations of chromium in monitoring wells MW-1, MW-2, MW-2A, MW-05, MW-05A, MW-10R, MW-17, MW-17A, MW-18, MW-20, MW-20A, MW-21 and MW-21A. Historical data from the French Drain and Building Sump also show stable or decreasing chromium concentrations.

The yearly chromium removal quantities were calculated utilizing the monthly analytical data and flow quantities from the building sump and French Drain.

In 2015, 8.59 pounds of chromium was removed from the building sump and 1.30 pounds of chromium were removed from the French Drain. This totals to 9.89 pounds of chromium removed by the system. The pounds of chromium removed is calculated using the chromium concentrations (in mg/L) from the sump and French Drain from each months sampling; times the total volume (in millions of gallons) of groundwater treated during each month from the two extraction points; times 8.34 pounds per gallon of water treated.

IV. GROUNDWATER COLLECTION SYSTEM

The groundwater collection system (French Drain) was installed in 1992 to collect contaminated groundwater from the north side of the property. The collection system consists of approximately 110-feet of perforated piping, placed 14-feet below grade. The collected groundwater flows by gravity to a collection sump, where it is pumped to the storage tanks in the basement of the facility. The collection trench creates a capture zone for contaminated groundwater along the north end of the building.

The building sump creates a capture zone for contaminants along the south side and under the building. The building sump is located at the northeast corner of the building basement. Two smaller collection sumps were placed at low spots in the basement floor (one in 2007, the other in 2009). These sumps are used only to collect spills to the basement floor, which are pumped back to the storage tanks. The two sumps have no function in the collection and treatment of impacted groundwater.

V. Remedial Options Discussion

Several technologies exist for the remediation of metals-contaminated soil and water. These technologies are contained within five categories of general approaches to remediation: isolation, immobilization, toxicity reduction, physical separation and extraction. These are the same general approaches used for many types of contaminants in the subsurface. (LaGrega et al., 1994). As is usually the case, combinations of one or more of these approaches are often used for more cost-effective treatment of a contaminated site

The evaluation of remedial options at this site has at its core the comparison of the fundamental attributes of technology performance, feasibility, and cost. In addition the factors of environmental safety (avoidance of unforeseen or uncontrolled impacts of the technologies)

and regulatory acceptance, were considered in the evaluation. The remedial options evaluated in this report were compared for these attributes with the current treatment option of groundwater pump and treat, for the remediation of Hexavalent Chromium, Cr(VI). Both in situ and ex situ technology alternatives were reviewed. A number of in situ technologies use chemical reduction/fixation for chromium remediation. These include geochemical fixation, reactive barriers, reactive zones, and natural attenuation.

A. In Situ Remediation

In situ remediation technologies offer the potential for significant cost savings over ex situ technologies because in situ techniques are usually associated with lower labor and energy requirements for implementation. This section discusses the status of in situ technologies which are currently available for metal remediation at contaminated sites.

1. Hexavalent Chromium Characteristics & In Situ Remediation Techniques

Hexavalent Chromium Cr(VI) (Chromate) is: highly soluble, highly mobile (moving at essentially the same rate as groundwater), and does not readily reduce to Cr(III).

Palmer and Wittbrodt (1991) claim that chromium exists in several oxidation states ranging from 0 to 6. Under reducing conditions, Cr(III) is the most thermodynamically stable oxidation state. However, Cr(VI) can remain stable for significant periods of time. In soils and aquifer systems, the most prevalent forms are the trivalent and hexavalent oxidation states.

Chromium has a unique geochemical behavior in natural water systems. Cr(III) is the most common form of naturally occurring chromium, but is largely immobile in the environment, with natural waters having only traces of chromium, unless the pH is extremely low. Under strong oxidizing conditions, chromium is present in the Cr(VI) state and persists in anionic form as chromate. Natural chromates are rare. However, the use of Cr(VI) in several major industries, including metal plating facilities, has the potential to introduce high concentrations of oxidized chromium to the environment (Rouse and Pyrih, 1990; Palmer and Wittbrodt, 1991).

The chemistry of aqueous chromium in an aquifer is complicated, interactive between soil and water, and cyclic in the reactions that occur as they relate to solid and dissolved phases and the various oxidation states present.

The existence of the $\text{Cr}(\text{OH})_3$ species as the primary precipitated product in the process of reducing $\text{Cr}(\text{VI})$ to $\text{Cr}(\text{III})$ is paramount to the viability of in situ treatment using either Permeable reactive Barrier (PRB) or reactive zone technologies.

According to Bartlett (1991), the following conditions exist: “ $\text{Cr}(\text{VI})$ is the most oxidized, mobile, reactive, and toxic chromium state. In general, under non-polluting conditions, only small concentrations of $\text{Cr}(\text{VI})$ species exist [the result of oxidation of natural $\text{Cr}(\text{III})$], with $\text{Cr}(\text{III})$ species being the most prevalent forms. $\text{Cr}(\text{III})$ species may be oxidized to $\text{Cr}(\text{VI})$ by oxidizing compounds that exist in the soil (i.e., manganese dioxide - MnO_2), while at the same time $\text{Cr}(\text{VI})$ species may be reduced to $\text{Cr}(\text{III})$ by MnO_2 in the presence of reduced manganese oxide (MnO) and organic acids from soil organic matter.”

In addition, the reduction of $\text{Cr}(\text{VI})$ to $\text{Cr}(\text{III})$ in soils will most likely occur as a result of reduction by soil organic matter (including humic acid, fulvic acid, and humin), soluble ferrous iron [$\text{Fe}(\text{II})$], and reduced sulfur compounds

a. In Situ Soil Cation Exchange

In addition to soil cation exchange mechanisms for $\text{Cr}(\text{III})$ species adsorption, soil anion exchange is possible for adsorption of $\text{Cr}(\text{VI})$ anions. Griffin et al. (1977) studied the effect of pH on the adsorption of $\text{Cr}(\text{VI})$ by the clay minerals kaolinite and montmorillonite, and found adsorption was highly pH dependent; the adsorption of $\text{Cr}(\text{VI})$ decreased as pH increased, and the predominant $\text{Cr}(\text{VI})$ species adsorbed was HCrO_4^- . Bartlett and Kimble (1976) also found that while chromate is tightly bound compared to anions such as Cl^- or NO_3^- , the presence of orthophosphate prevented the adsorption of $\text{Cr}(\text{VI})$ anions, presumably by competition for the adsorption sites. They concluded that the behavior of $\text{Cr}(\text{VI})$ remaining in soils is similar to that of orthophosphate, but unlike phosphate, $\text{Cr}(\text{VI})$ is quickly reduced by soil organic matter, thus becoming immobilized. $\text{Cr}(\text{VI})$ they state, will remain mobile only if its concentration exceeds both the adsorbing and the reducing capacities of the soil.

b. Permeable Treatment Walls/Permeable Reactive Barriers (PRBs)

Treatment walls remove contaminants from groundwater by degrading, transforming, precipitating or adsorbing the target solutes as the water flows through permeable trenches containing reactive material within the subsurface (Vidic and Pohland, 1996). Several methods are available for installation of permeable treatment walls, some of which employ slurry wall construction technology to create a permeable reactive curtain. The reactive zone can use physical, chemical and biological processes, or a combination of these. The groundwater flow through the wall may be enhanced by inducing a hydraulic gradient in the direction of the treatment zone or channeling ground-water flow toward the treatment zone (NRC, 1994).

Several types of treatment walls have been tried for arresting transport of metals in groundwater at contaminated sites. Trench materials investigated include zeolite, hydroxyapatite, elemental iron, and limestone (Vidic and Pohland, 1996). Applications of elemental iron for chromium (VI) reduction and limestone for lead precipitation and adsorption are described below.

i. Elemental Iron

Trenches filled with elemental iron have shown promise for remediation of metals contaminated sites. While investigations of this technology have focused largely on treatment of halogenated organic compounds, studies have been performed to assess the applicability to remediation of inorganic contaminants (Powell et al., 1994).

Low oxidation-state chemical species serve as electron donors for the reduction of higher oxidation-state contaminants. This ability can be exploited to remediate metals that are more toxic and mobile in higher oxidation states, such as Cr(VI). Results of column experiments performed by Powell et al. (1994) and batch experiments performed by Cantrell et al. (1995) showed that chromate reduction was enhanced in systems containing iron filings in addition to the natural aquifer material. Advantage is taken of this chemical reaction when employing permeable reactive barrier (PRB) in situ treatment of ground water. Zero-valent iron (Fe⁰) metal is used to reduce Cr(VI) to Cr(III) and complex the Cr(III) as a Fe(III) hydroxide coprecipitate.

ii. Limestone Barriers

The use of limestone treatment walls has also been proposed for sites with metals contamination. Chromium hydroxide solid solutions may precipitate as coprecipitates with other metals, rather than pure $\text{Cr}(\text{OH})_3$. This is especially true if oxidized iron [Fe(III)] is present in the aquifer; it will generate an amorphous hydroxide coprecipitate in the $\text{Cr}_x\text{Fe}_{1-x}(\text{OH})_3$ form (Palmer and Wittbrodt, 1991).

This chemical reaction is particularly important due to the potential for Fe(II) to be oxidized to the ferric state. Fe(II) is the most common oxidation state of dissolved iron in natural subsurface waters as well as aquifer minerals.

iii. Physical Barriers

Subsurface physical barriers may be used to isolate contaminated soil and water by controlling the movement of groundwater at a contaminated site. These barriers are designed to reduce the movement of contaminated groundwater from the site, or to restrict the flow of uncontaminated groundwater through the contaminated site (Rumer and Ryan, 1995).

Barriers may be installed downstream of the source area or completely surrounding the site. The use of circumferential barriers can prevent the escape of contamination from the site by using an infiltration barrier and collection system to create a hydraulic gradient in the inward direction. Vertical barriers are limited to depths achievable with backhoe excavation technology for trenches, i.e., to about 30 feet (U.S. EPA, 1985).

c. Solidification/Stabilization

Solidification and stabilization (S/S) immobilization technologies are the most commonly selected treatment options for metals-contaminated sites (Conner, 1990). Solidification involves the formation of a solidified matrix that physically binds the contaminated material. Stabilization, also referred to as fixation, usually utilizes a chemical reaction to convert the waste to a less mobile form. The general approach for solidification/stabilization treatment processes involves mixing or injecting treatment agents to the contaminated soils.

The dominant mechanism by which metals are immobilized is by precipitation of hydroxides within the solid matrix (Bishop et al., 1982; Shively et al., 1986).

S/S technologies are not useful for some forms of metal contamination, such as species that exist as anions (e.g., Cr(VI), arsenic) or metals that don't have low-solubility hydroxides (e.g., mercury). S/S may not be applicable at sites containing wastes that include organic forms of contamination, especially if volatile organics are present. Mixing and heating associated with binder hydration may release organic vapors.

d. Chemical Treatment

Chemical reactions can be initiated that are designed to decrease the toxicity or mobility of metal contaminants. The three types of reactions that can be used for this purpose are oxidation, reduction, and neutralization reactions. Chemical oxidation changes the oxidation state of the metal atom through the loss of electrons. Commercial oxidizing agents are available for chemical treatment, including potassium permanganate, hydrogen peroxide, hypochlorite and chlorine gas. Reduction reactions change the oxidation state of metals by adding electrons. Commercially available reduction reagents include alkali metals (Na, K), sulfur dioxide, sulfite salts, elemental iron and ferrous sulfate. Changing the oxidation state of metals by oxidation or reduction can detoxify, precipitate, or solubilize the metals (NRC, 1994).

Chemical neutralization is used to adjust the pH balance of extremely acidic or basic soils and/or groundwater. This procedure can be used to precipitate insoluble metal salts from contaminated water, or in preparation for chemical oxidation or reduction.

Chemical treatment can be performed ex situ or in situ. However, in situ chemical agents must be carefully selected so that they do not further contaminate the treatment area. The primary problem associated with chemical treatment is the nonspecific nature of the chemical reagents. Oxidizing/reducing agents added to the matrix to treat one metal will also target other reactive metals and can make them more toxic or mobile (NRC, 1994). Also, the long-term stability of reaction products is of concern since changes in soil and water chemistry might reverse the selected reactions.

Chemical treatment is often used as pretreatment for S/S and other treatment technologies. Reduction of Cr(VI) to Cr(III) is the most common form of chemical treatment and is necessary for remediation of wastes containing Cr(VI) by precipitation or S/S. Chromium in its Cr(III) form is readily precipitated by hydroxide over a wide range of pH values. Acidification may also be used to aid in Cr(VI) reduction. (Smith et al., 1995).

e. Biological Treatment

Biological treatment technologies are available for remediation of metals-contaminated sites (Schnoor, 1997). These technologies are more commonly used for the remediation of organic contaminants. They can be applied for metal remediation in some situations, although most applications to date have been at the bench and pilot scale. Biological treatment exploits natural biological processes that allow certain plants and microorganisms to aid in the remediation of metals. These processes occur through a variety of mechanisms, including adsorption, oxidation and reduction reactions, and methylation (Means and Hinchee, 1994).

Bioaccumulation, and Phytoremediation technologies are largely in the developmental stage and many are being field tested at a variety of sites in the U.S. and in Europe. Because full-scale applications of these technologies are just being initiated, limited cost and performance data are available.

f. In Situ Soil Flushing

In situ soil flushing has been selected for treatment at some sites contaminated with metals. This technology has been applied mostly at sites containing organic forms of contamination (NRC, 1994), *and limited information is available on the application of this technology to metals-contaminated sites.*

The United Chrome Products Superfund site in Corvallis, Oregon is being remediated using in situ soil flushing technologies. The general approach to remediation of this site has been removal of the more soluble, mobile and toxic form of chromium, Cr(VI), by flushing the contaminated region with water to solubilize Cr(VI), with subsequent extraction of the chromium-containing water for treatment. Remediation at this site began in 1985 and has combined a variety of technologies to aid remediation by in situ soil flushing. The technologies used have included infiltration basins and trenches to

flush contaminated soils, a 23-well ground-water extraction network to remove contaminated groundwater and recharge water, on-site treatment of wastewater, and off-site disposal of contaminated soil and debris (Sturges et al., 1992).

This full-scale application of in situ soil flushing with water as the flushing solution appears to be successful for removal of Cr(VI) from coarse soils of relatively high hydraulic conductivity. The in situ soil flushing procedure used at this site leaches contaminants from the unsaturated and saturated zones, and provides for recharge of the groundwater to the extraction wells. This cleanup operation has removed significant amounts of chromium from the soil and groundwater and the ground-water pumping strategy has achieved hydraulic containment of the plume. Cr(VI) levels in water retrieved by the extraction wells decreased from more than 5000 mg/L to approximately 50 mg/L during the first two and one half years of operation. Average chromium concentrations in the plume decreased from 1923 mg/L to 207 mg/L after flushing the first one and one half pore volumes (approximately 2.6 million gallons for one pore volume). These rapid removal rates are expected to continue for the first few pore volumes of treatment until Cr(VI) removal begins to tail off to the asymptotic level. Tailing results from slow desorption from soil particles, dissolution of solid phase contaminants, and release of contaminants from the fine pores in the soil matrix. Tailing is commonly observed in situ soil flushing applications and usually represents the practical limit for remediation via pump and treat methods (Sturges et al., 1992).

B. Ex Situ Remediation

a. Physical Separation Soil Washing

Soil washing can be used to remove metals from the soil by chemical or physical treatment methods in aqueous suspension. Soil washing is an ex situ process that requires soil excavation prior to treatment.

b. Pump & Treat

Applicable to many sites is a pump-and-treat method. The technology works by extracting contaminated groundwater, usually over long time periods, and providing hydraulic control (containment) of a contaminant plume. Initially, the concentration of the contaminant is high in the effluent, but with continued pumping, the concentration

decreases significantly. These residual concentrations remain above the MCLs, and can persist for long periods of time, called “tailing.”

Groundwater flows not only in response to an extraction well, but also to the natural hydraulic gradient. As a result, not all of the water in the vicinity of an extraction well enters the well. There is a limited area, the capture zone, from which the water is captured, and a stagnation point, located downgradient from the well, where the velocity toward the well equals the velocity induced by the natural gradient. The net velocity is zero, and there is little change in the concentration of the contaminant during the pump-and-treat remediation. In addition, the groundwater velocity of a volume of water moving from the edge of the plume to the extraction well is greater than a volume of water traveling along a streamline on the outside of the capture zone. The time it takes the contaminated water to flow is controlled by the thickness of the aquifer, the rate of groundwater extraction, the natural groundwater gradient, and the gradient induced or impacted by other injection/extraction wells.

Geologic materials are typically heterogeneous; groundwater moves through higher permeable layers while water in lower permeable layers remains immobile. Contaminants that have remained in the subsurface for extended periods of time migrate to the lower permeable layers by molecular diffusion. During pump-and-treat, clean water is moved through the more permeable layers at a relatively high rate, while removal of the contaminants from the lower permeable lenses is limited by the rate of diffusion into the higher permeable layers; thus maintaining the concentration of the contaminant, often above the established MCL.

The use of in situ technologies such as chemical enhancement of the pump-and-treat method (the addition of reductant or extracting agent) may be desirable to overcome the tailing phenomenon and reduce the overall time required for remediation. However, the cause of tailing at a given site needs to be determined and quantified. For example, if the tailing is controlled by physical processes such as differential travel time along streamlines, or heterogeneity of the soil, then chemical enhancement may not be advantageous. Further, regulatory agencies may require the removal of the chemical enhancer. This is especially true if the chemical enhancer or its byproducts exceed the concentration(s) of applicable water quality standards.

Typically, chromium contaminated sites consist of three zones: (1) source zone soils where the concentrated waste resides; (2) the

concentrated portion of the groundwater plume; and (3) the diluted portion of the groundwater plume. Applying conventional pump-and-treat remediation methods to all three regions would be highly inefficient. An integrated technology approach would probably be best suited for full-scale site remediation

VI. CONCLUSIONS AND RECOMMENDATIONS

Two rounds of groundwater sampling were conducted during the reporting period from January 1, 2015 through the end of 2015. During both sampling events, groundwater samples collected from the contaminant source area monitoring wells (MW-05, MW-19, MW-19A, MW-20, MW-20A), had residual chromium contamination above the WDNR NR140.10 Enforcement Standards (ES). All monthly samples collected during the monitoring period from the French Drain and Collection Sump had exceedances of the NR 140.10 ES for Total Chromium.

Data collected to date, shows stable, if not decreasing, concentrations of chromium in the groundwater monitoring wells, French Drain and Sump.

A review of available in situ and ex situ Chromium remediation approaches reveals that many of these approaches are either not applicable, potentially less effective than the current pump and treat system, or non-implementable at this site.

Isolation technologies are unnecessary at this site since there is ample evidence from numerous rounds of groundwater sampling that the contaminant plume is well contained on the site. Perimeter wells have revealed little or no Chromium contamination has reached the property boundaries, and what little contamination was originally found in these perimeter wells is decreasing over time.

For these same reasons, contaminant plume immobilization is not an appropriate goal for this site. Currently, Chromium contaminated groundwater is flowing into the site's collection system and is being effectively treated in the pump and treat system. The movement of this groundwater containing Chromium into the collection/treatment system is reducing the Chromium mass on the site as evidenced by the reduction in Chromium contamination in the monitoring wells over time.

Attempts to reduce the toxicity of the groundwater through the use of PRBs containing elemental Iron, zeolites or limestone, or the injection

of oxidizing compounds does not appear to provide a great advantage over the current pump and treat system. Currently, the water withdrawn from the site through the collection system is effectively treated and discharged. The concentrations of Cr (IV) in the influent to the treatment system remain significantly high to speak against the “tailing phenomenon” that is normally addressed with barrier wall or injection technologies.

The installation of physical barriers to contain or control groundwater movement on the site would be detrimental to the current effectiveness of the existing pump and treat system.

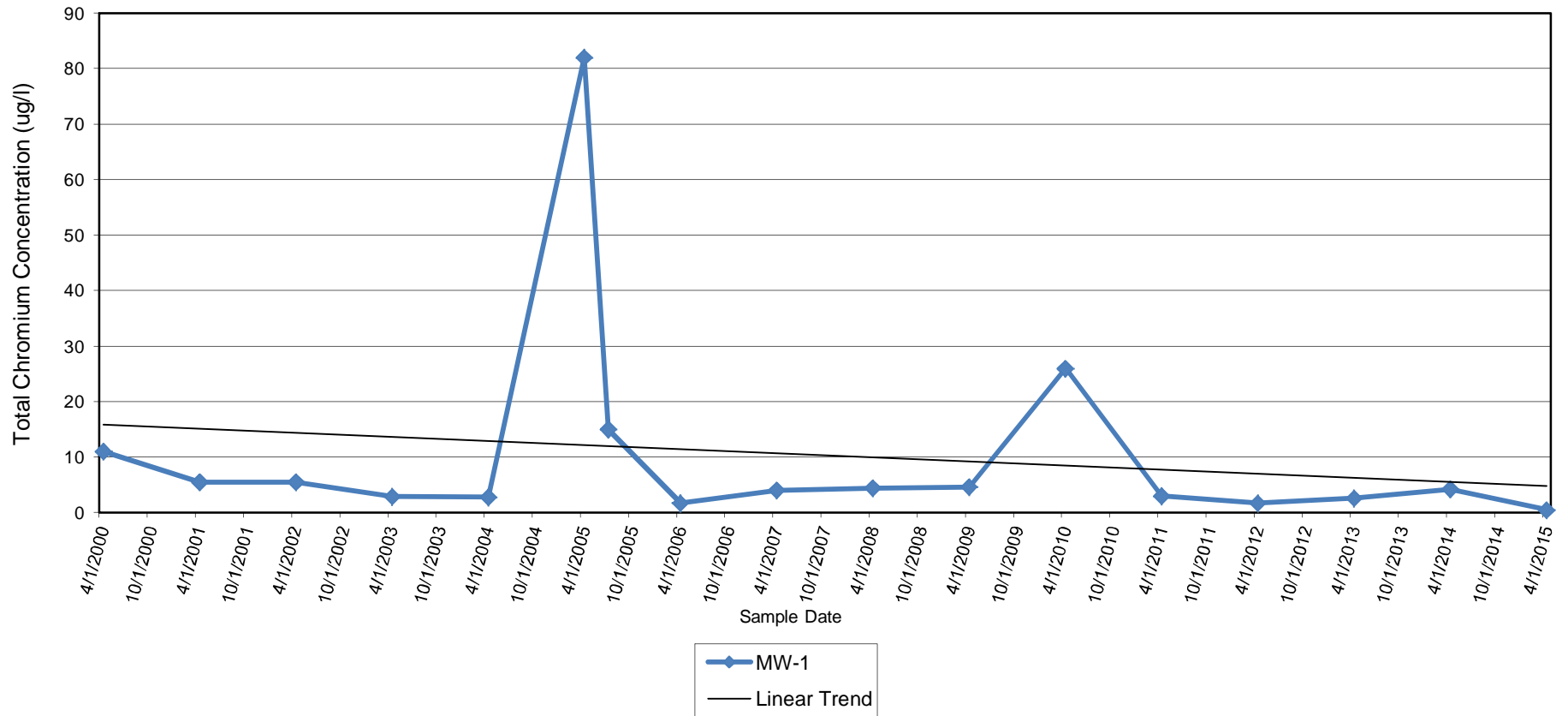
Biological approaches to Chromium (IV) remediation are unproven in heavy clay soils on a project scale and were not considered for this site.

Soil flushing appears to be technology that is straightforward, easily implementable and complimentary to the current pump and treat/collection system that exists at the site. In the past, there were attempts to enhance the flushing of the soil through the use of surface sprinklers on the south side of the site in the grassed areas. These attempts did not appear to have any impact on the influent concentrations of Hex Chrome into the treatment system and were abandoned.

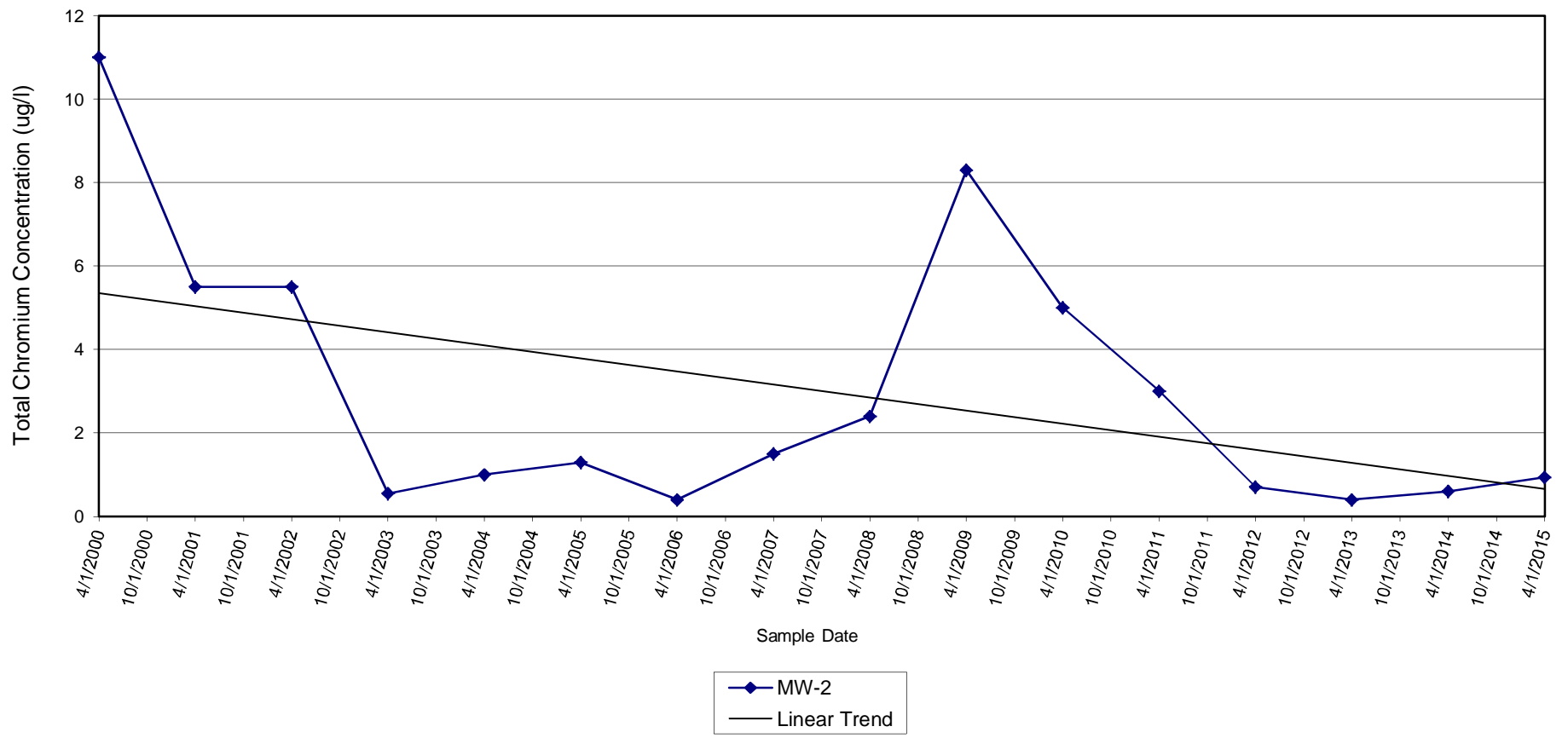
Based upon the historical analytical results from the groundwater monitoring wells and treatment systems, Badger Laboratories and Engineering Co., Inc., recommends continued operation of the groundwater treatment system at the Appleton Wire, Former Albany International Chrome Plant.

Appendix A
Figures and Tables

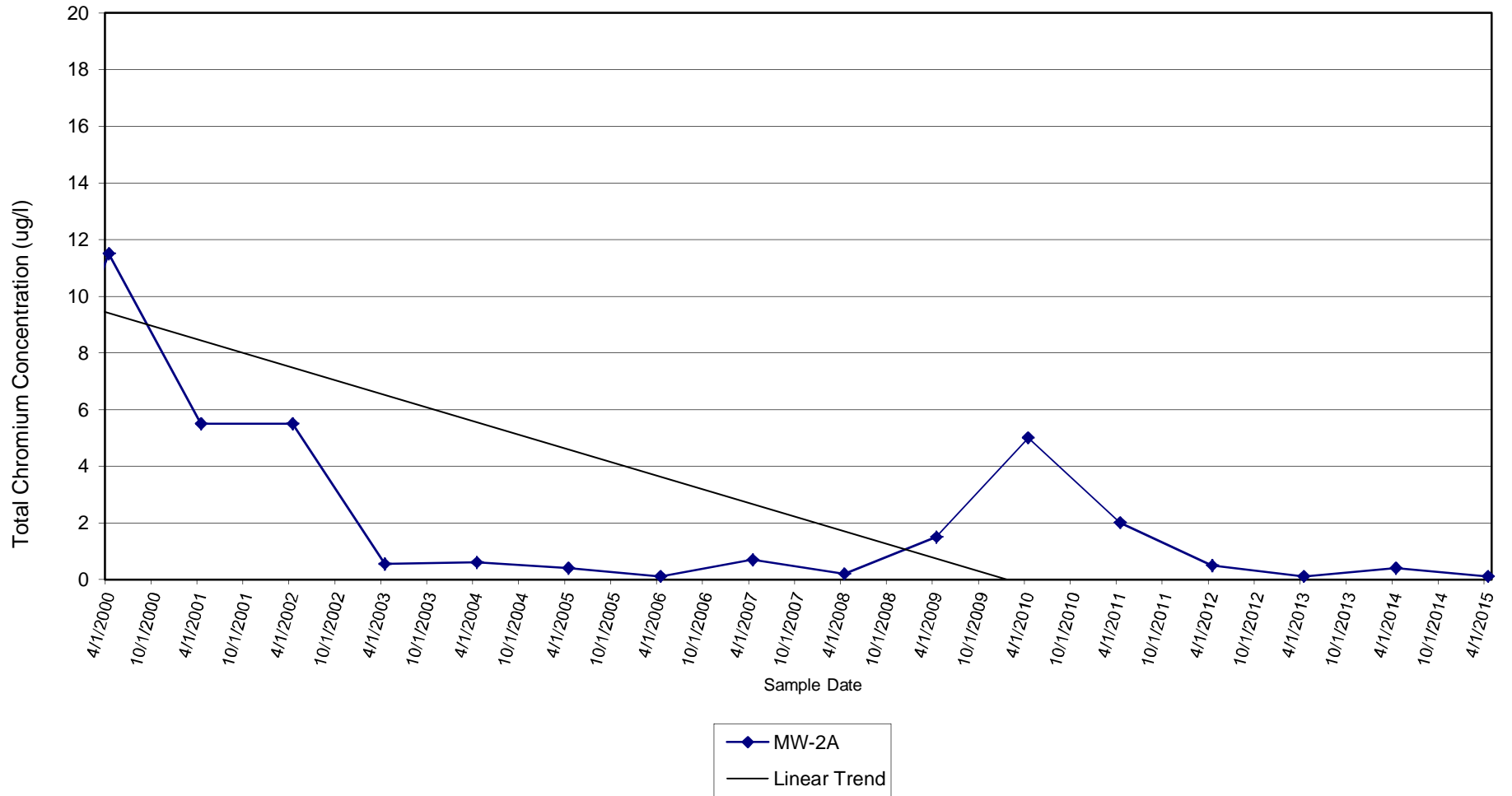
Albany International - Former Chrome Plant
Total Chromium Concentration vs Time



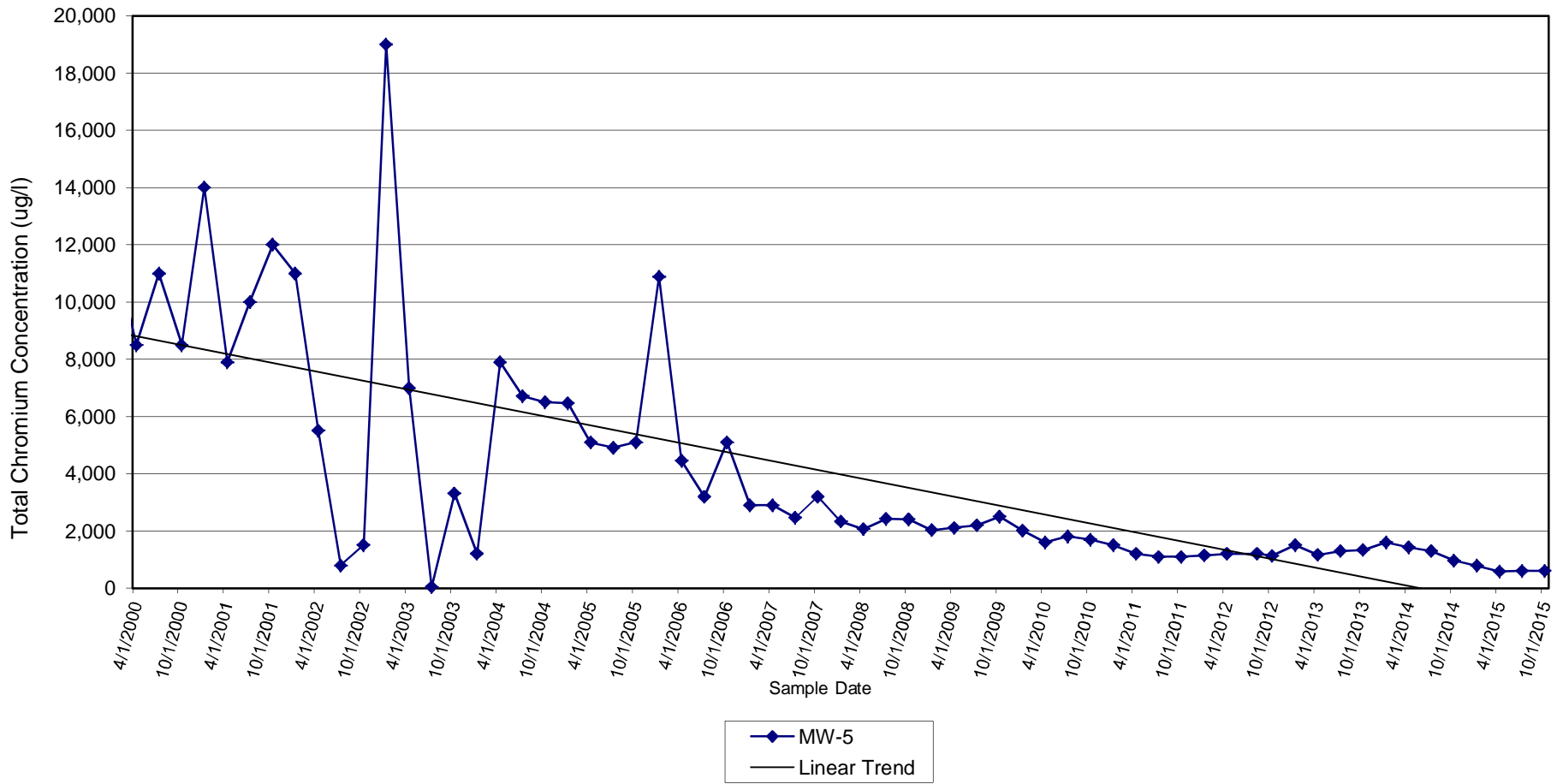
**Albany International - Former Chrome Plant
Total Chromium Concentration vs Time**



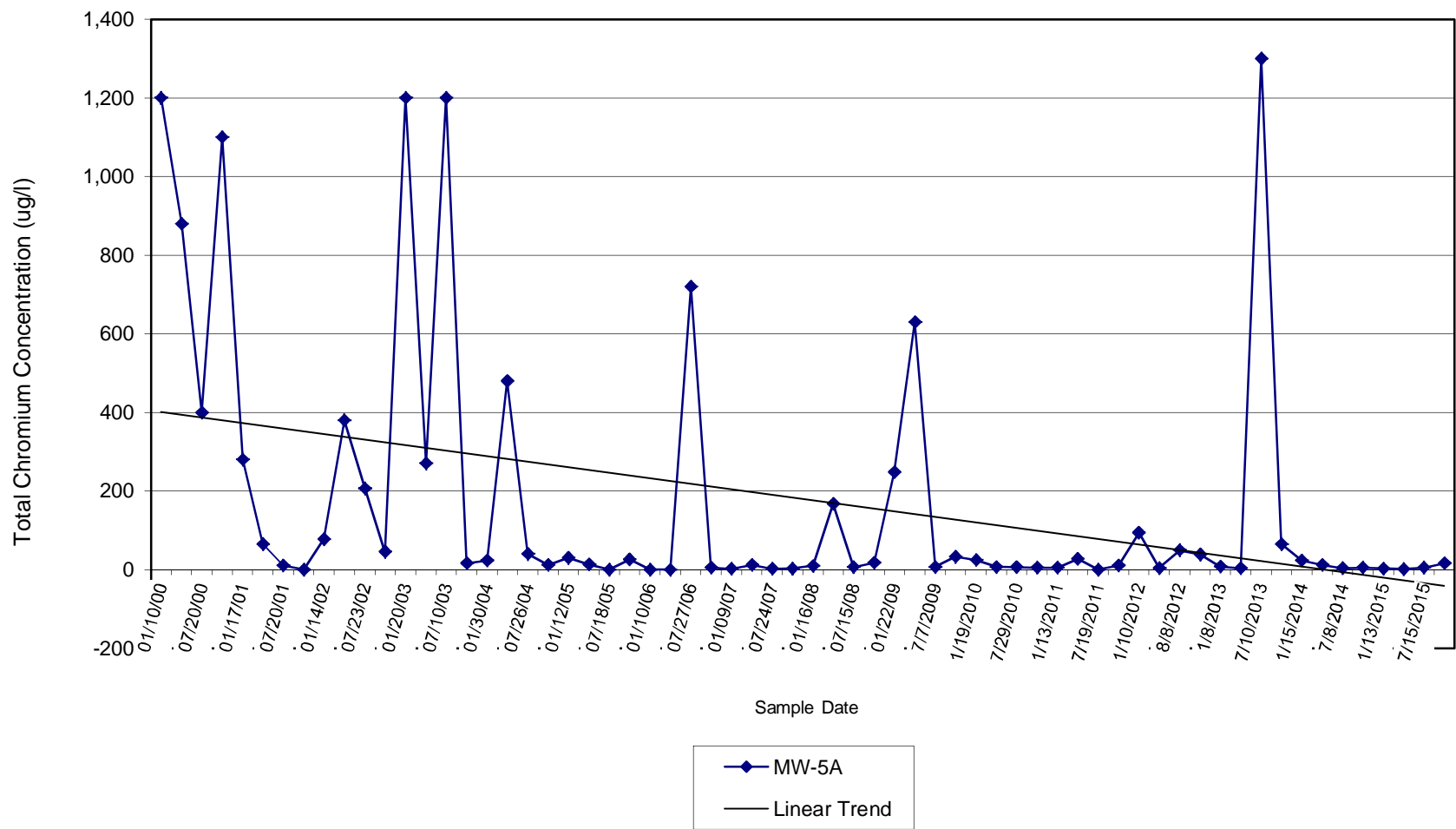
**Albany International - Former Chrome Plant
Total Chromium Concentration vs Time**



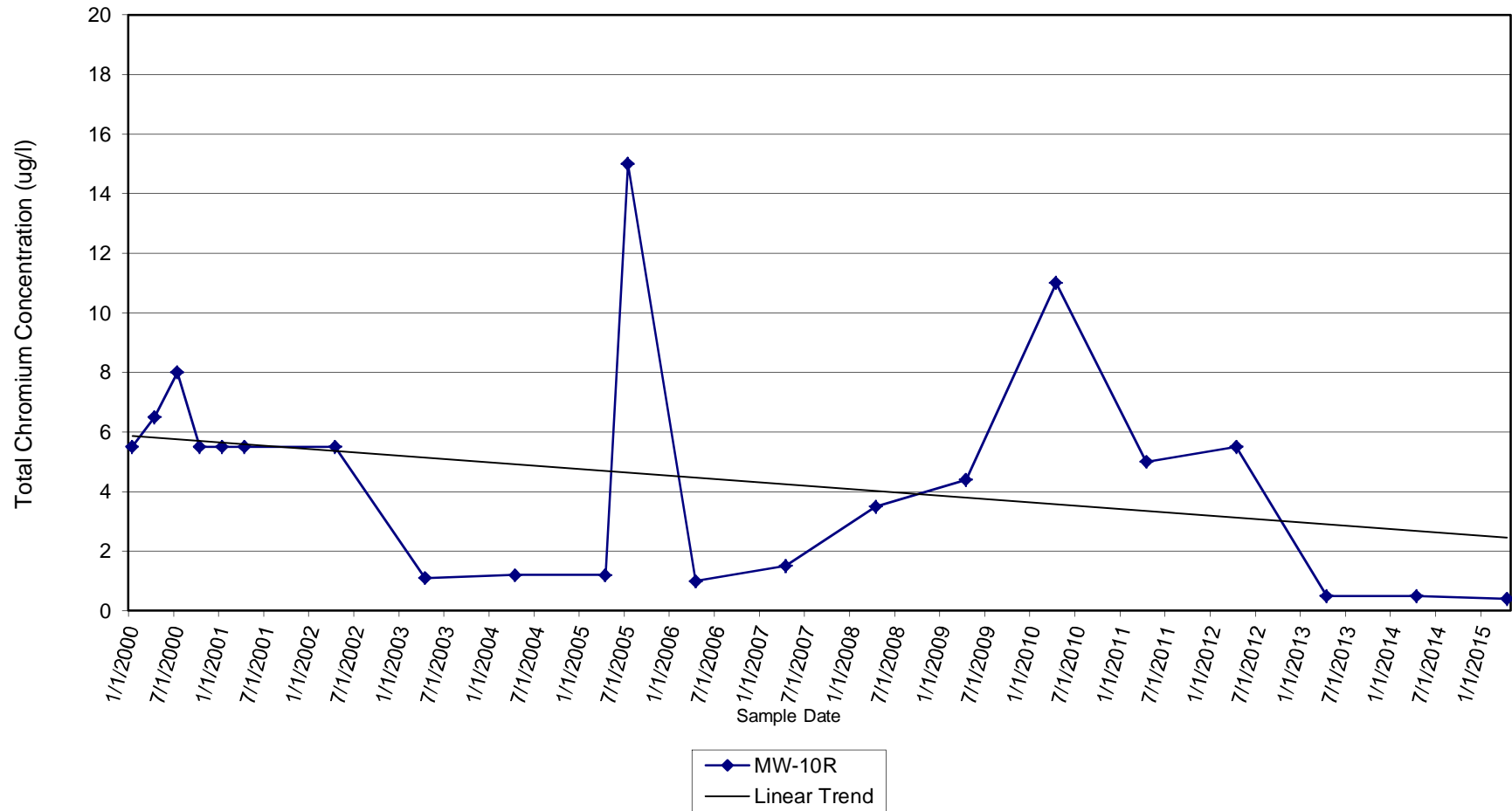
**Albany International - Former Chrome Plant
Total Chromium Concentration vs Time**



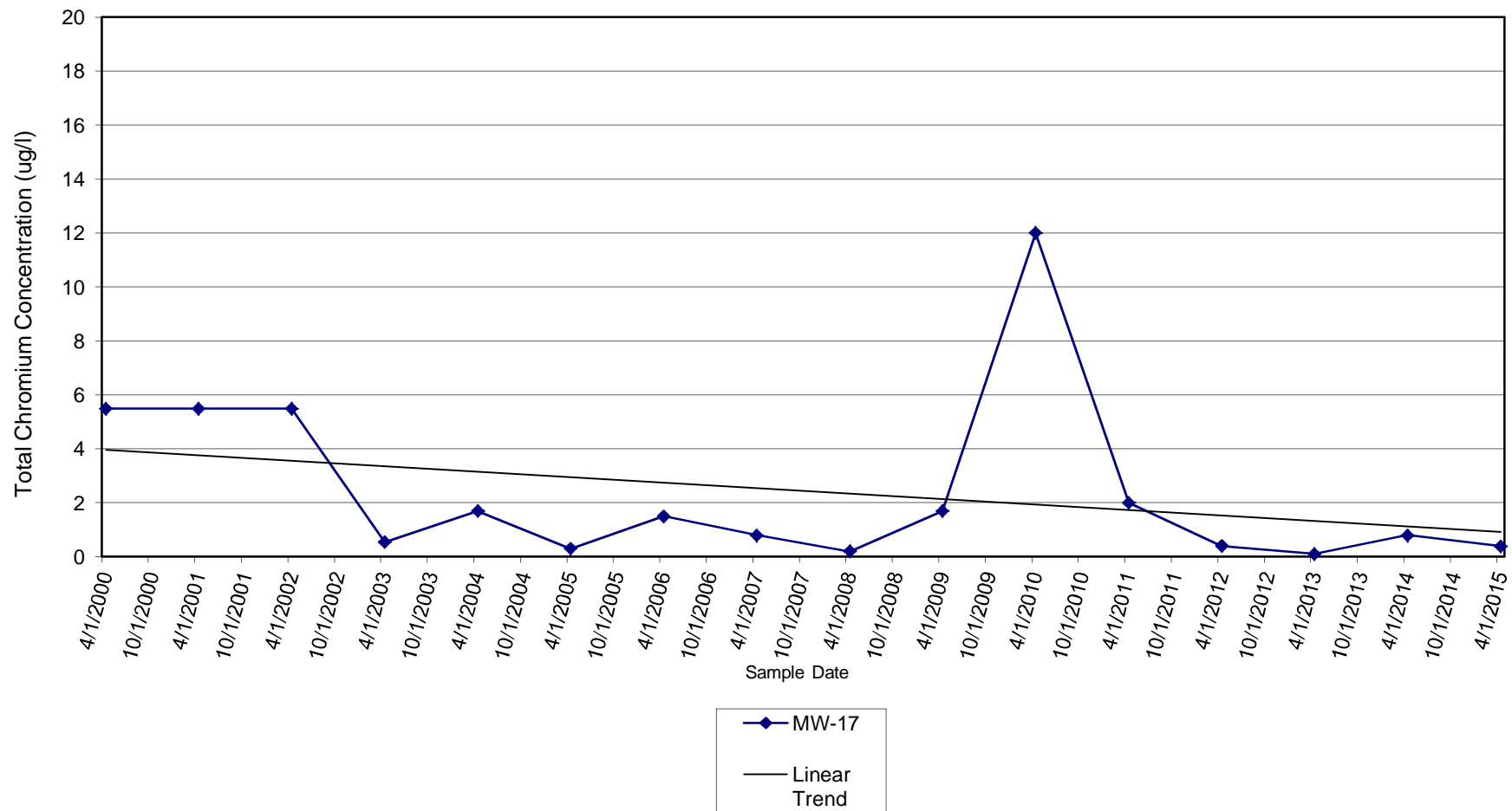
Albany International - Former Chrome Plant Total Chromium Concentration vs Time



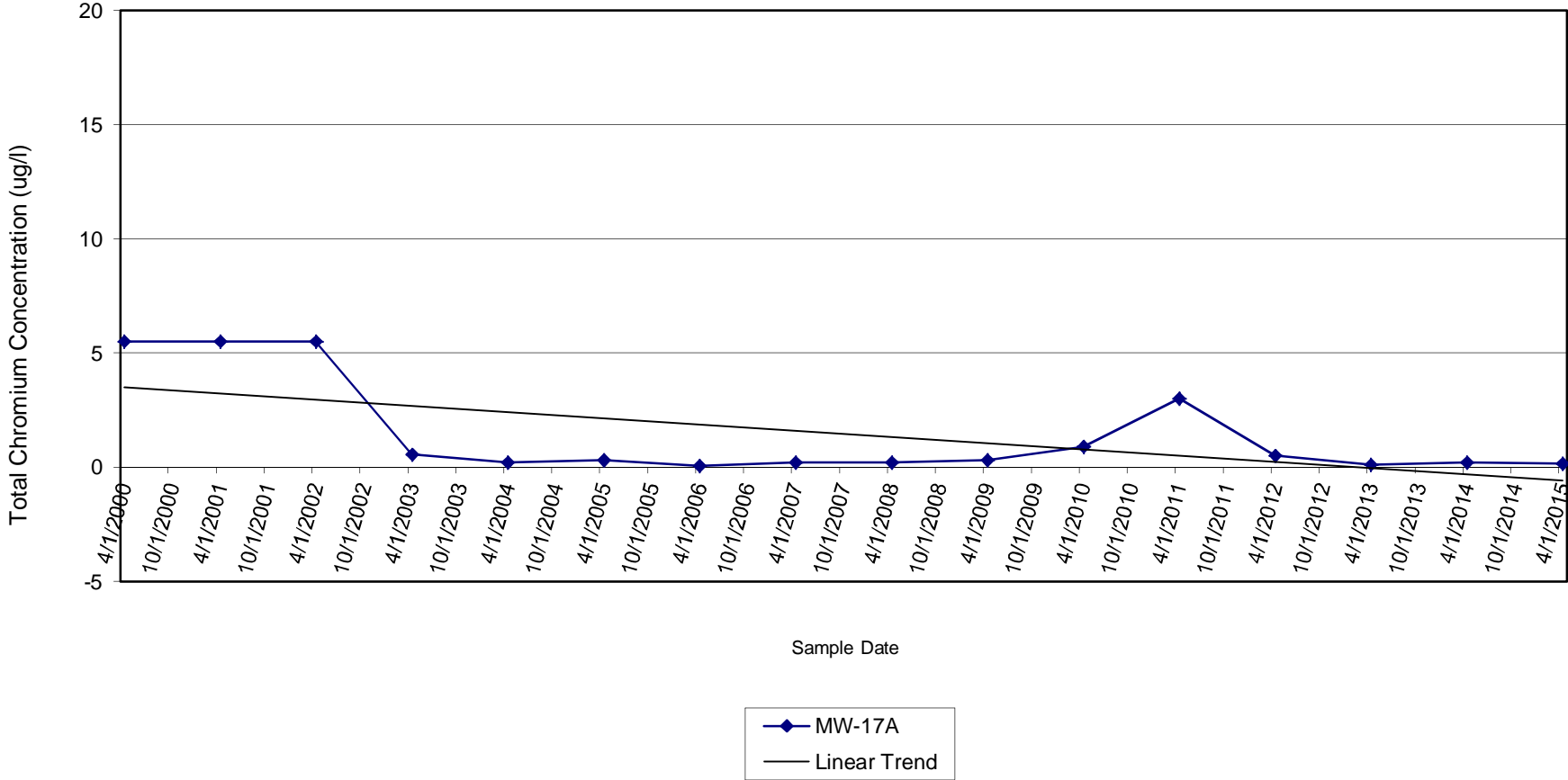
**Albany International - Former Chrome Plant
Total Chromium Concentration vs Time**



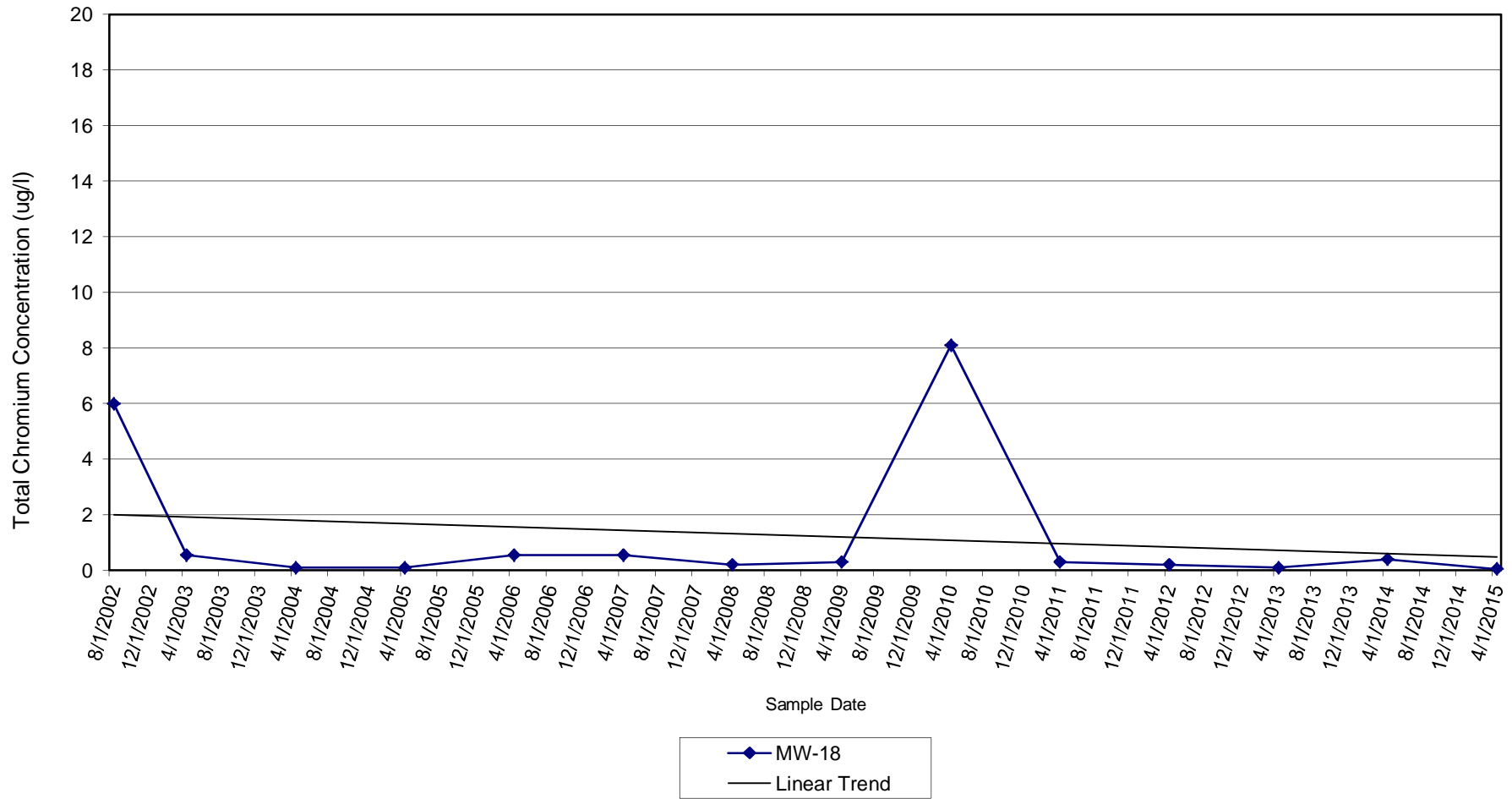
**Albany International - Former Chrome Plant
Total Chromium Concentration vs Time**



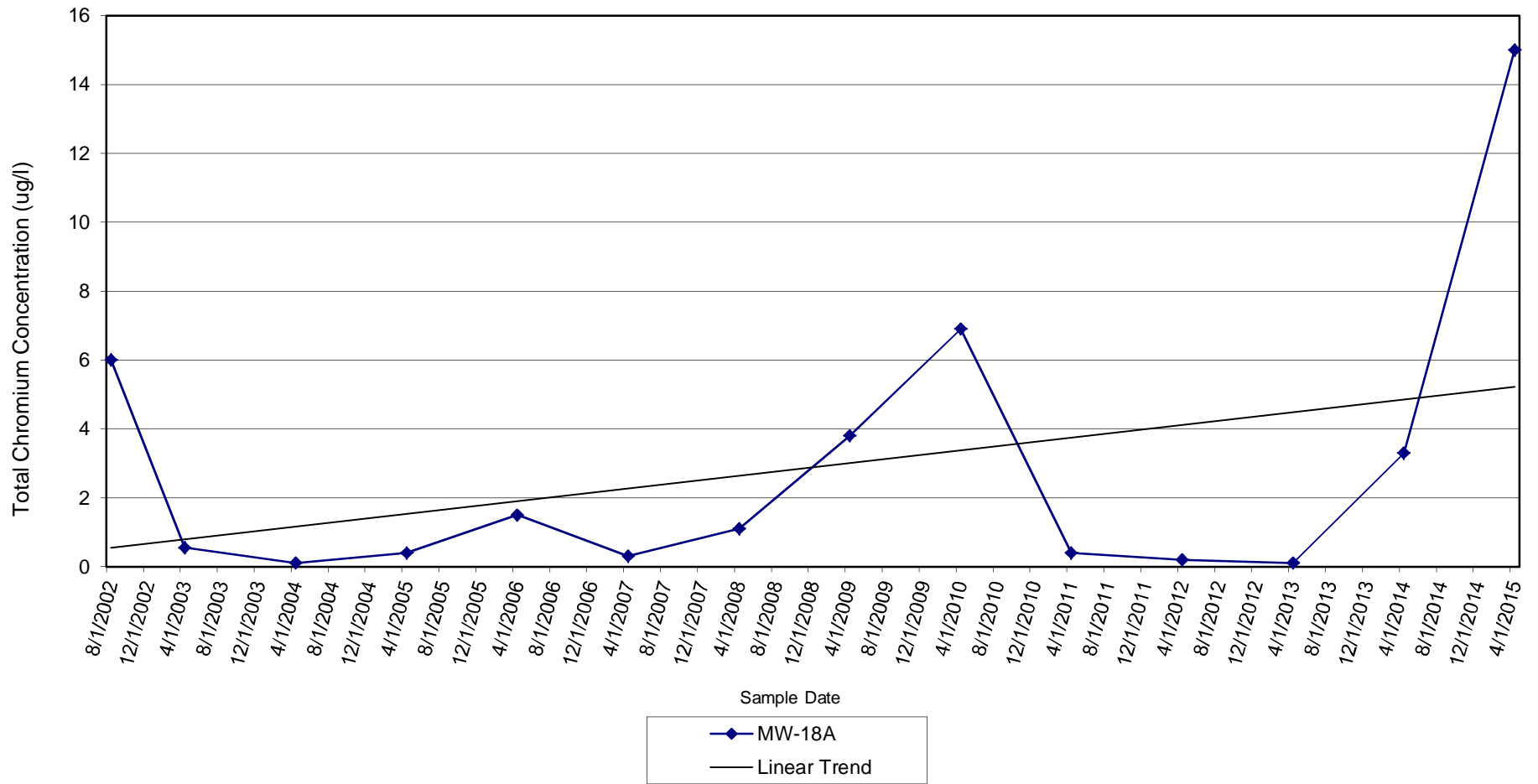
**Albany International - Former Chrome Plant
Total Chromium Concentration vs Time**



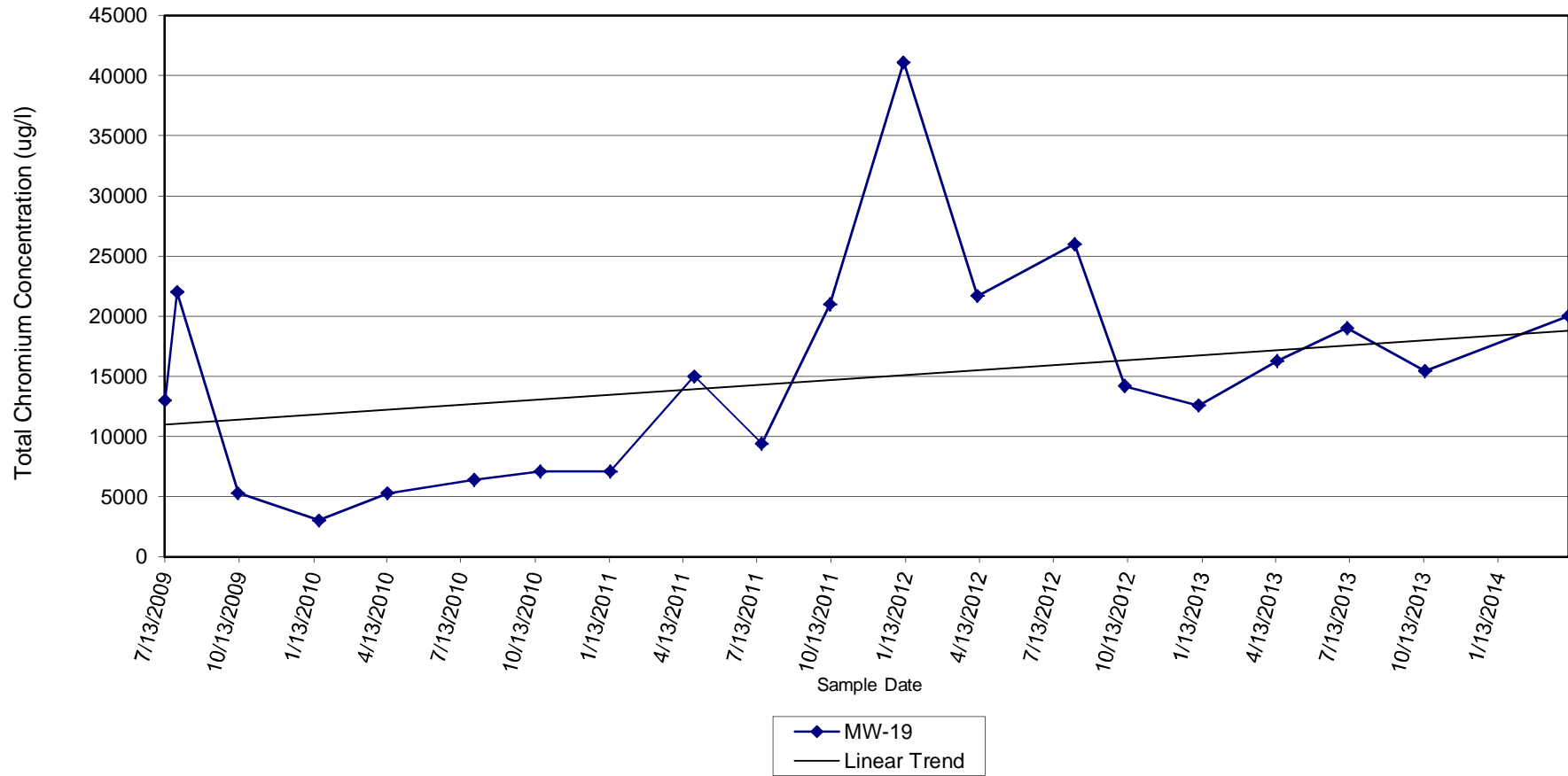
Albany International - Former Chrome Plant
Total Chromium Concentration vs Time



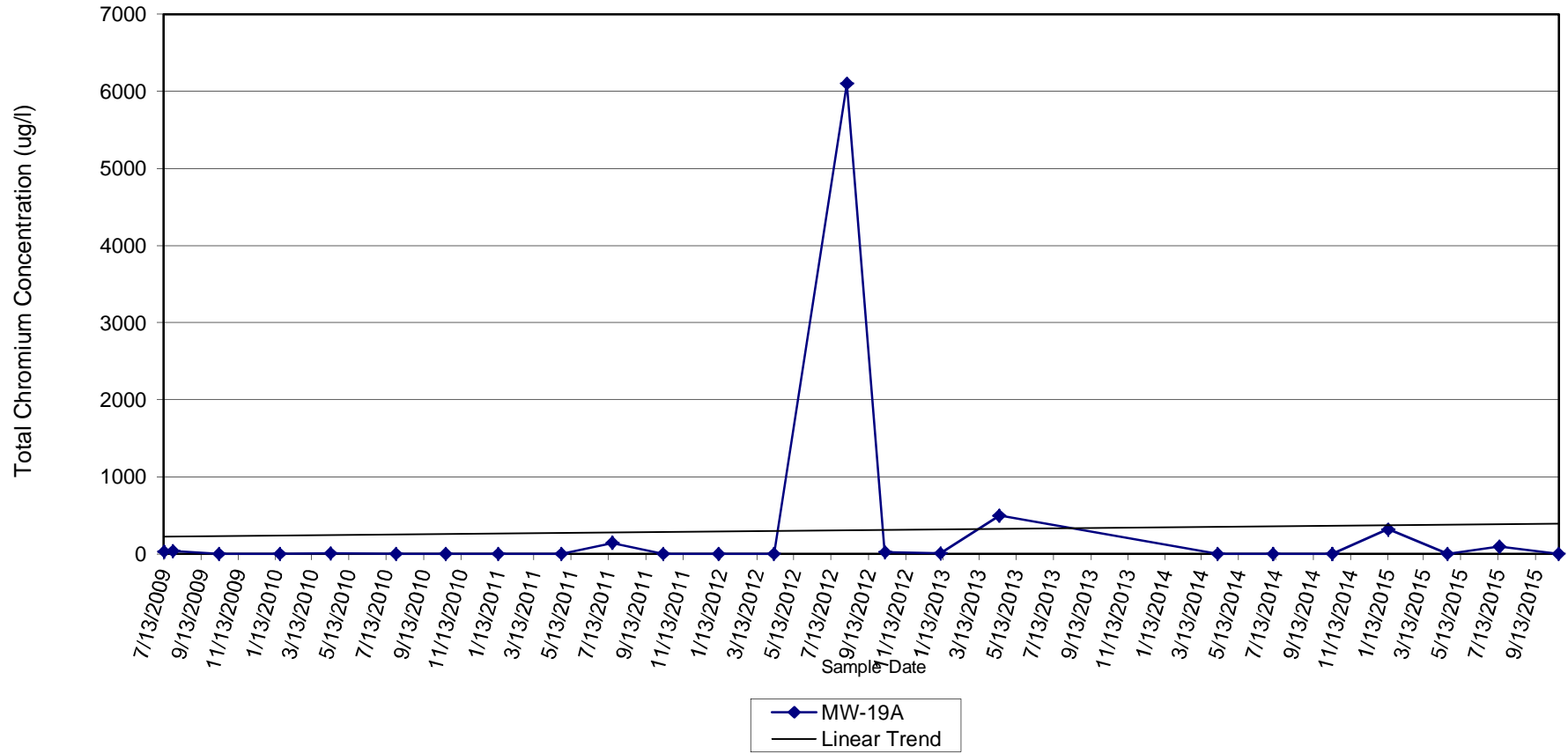
Albany International - Former Chrome Plant
Total Chromium Concentration vs Time



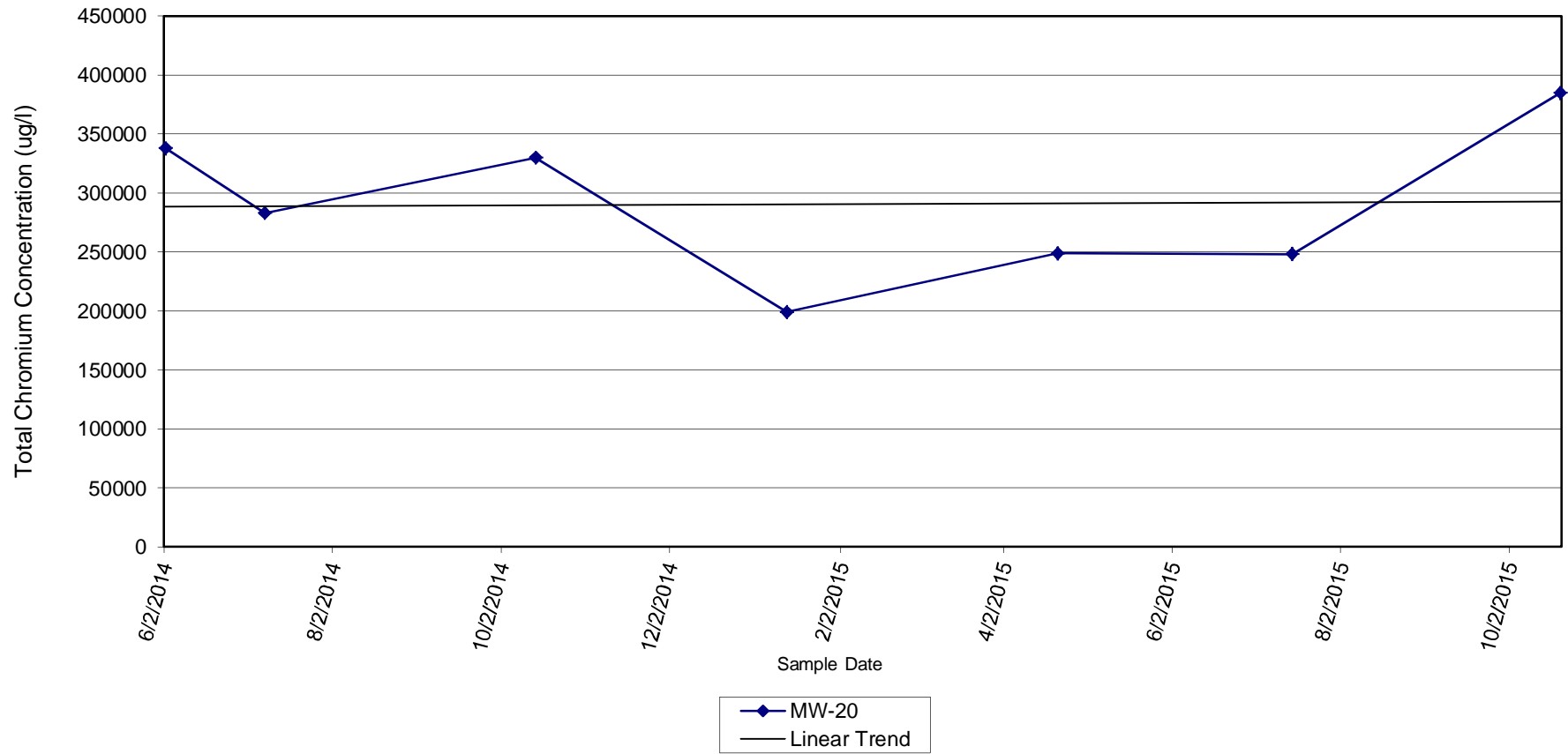
Albany International - Former Chrome Plant
Total Chromium Concentration vs Time



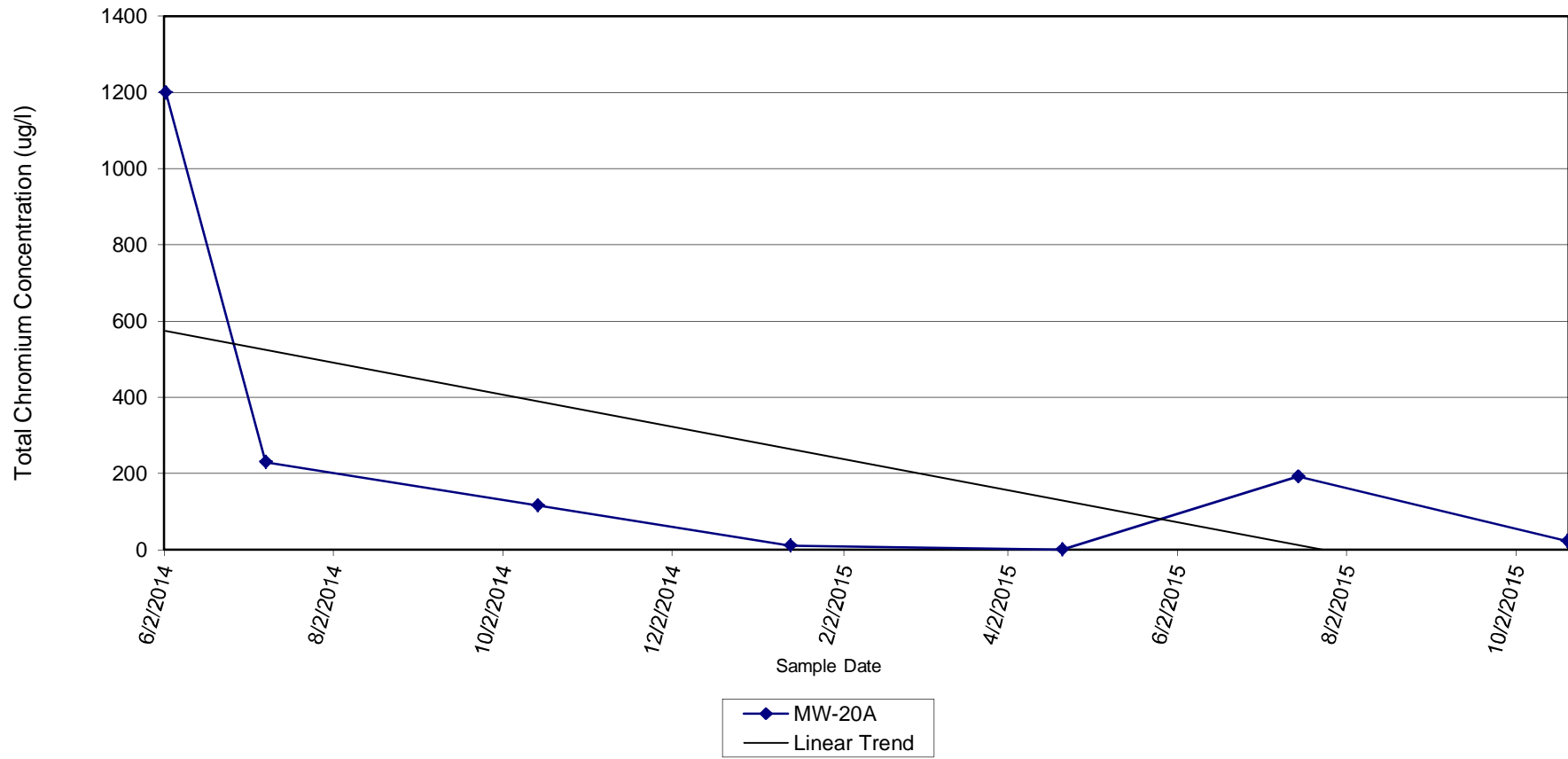
Albany International - Former Chrome Plant
Total Chromium Concentration vs Time



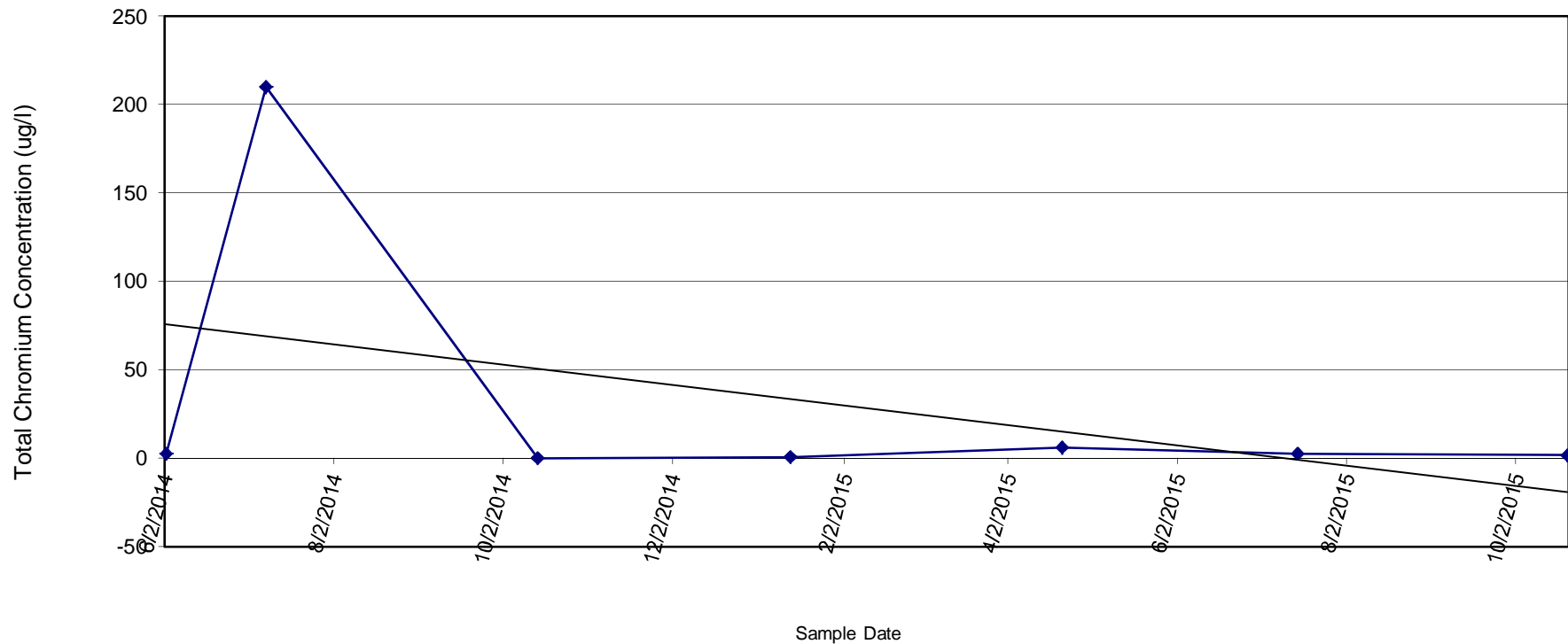
Albany International - Former Chrome Plant
Total Chromium Concentration vs Time



Albany International - Former Chrome Plant
Total Chromium Concentration vs Time

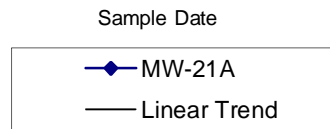
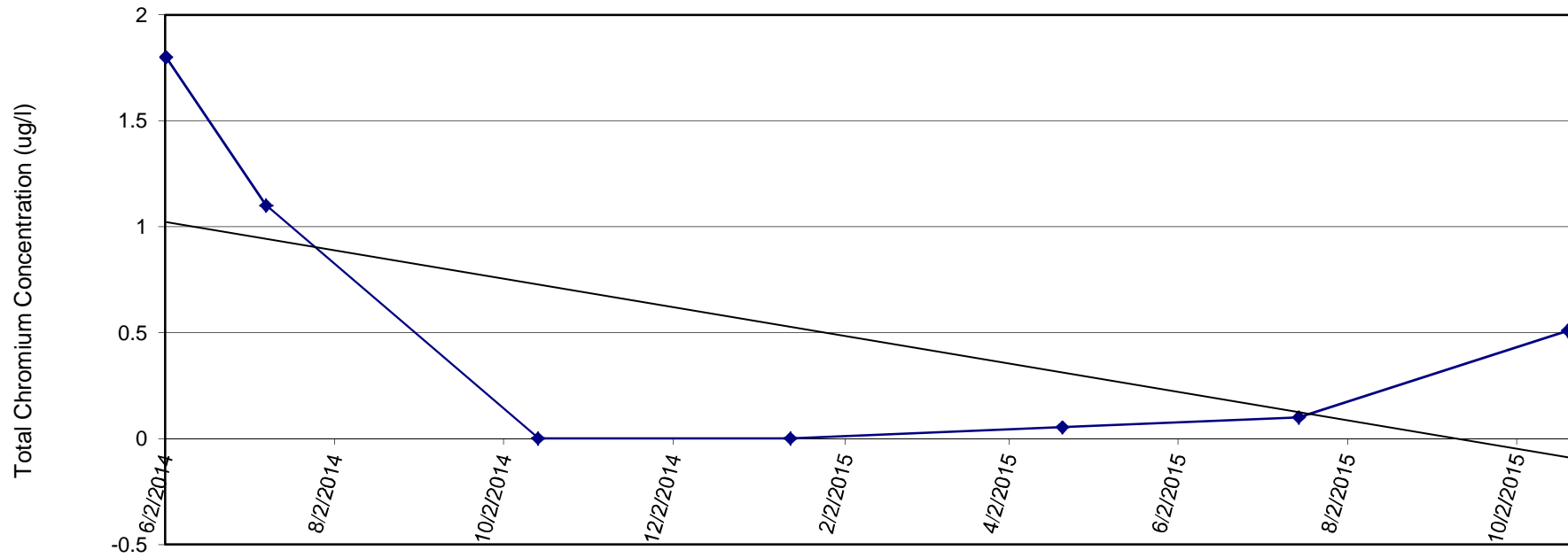


Albany International - Former Chrome Plant
Total Chromium Concentration vs Time

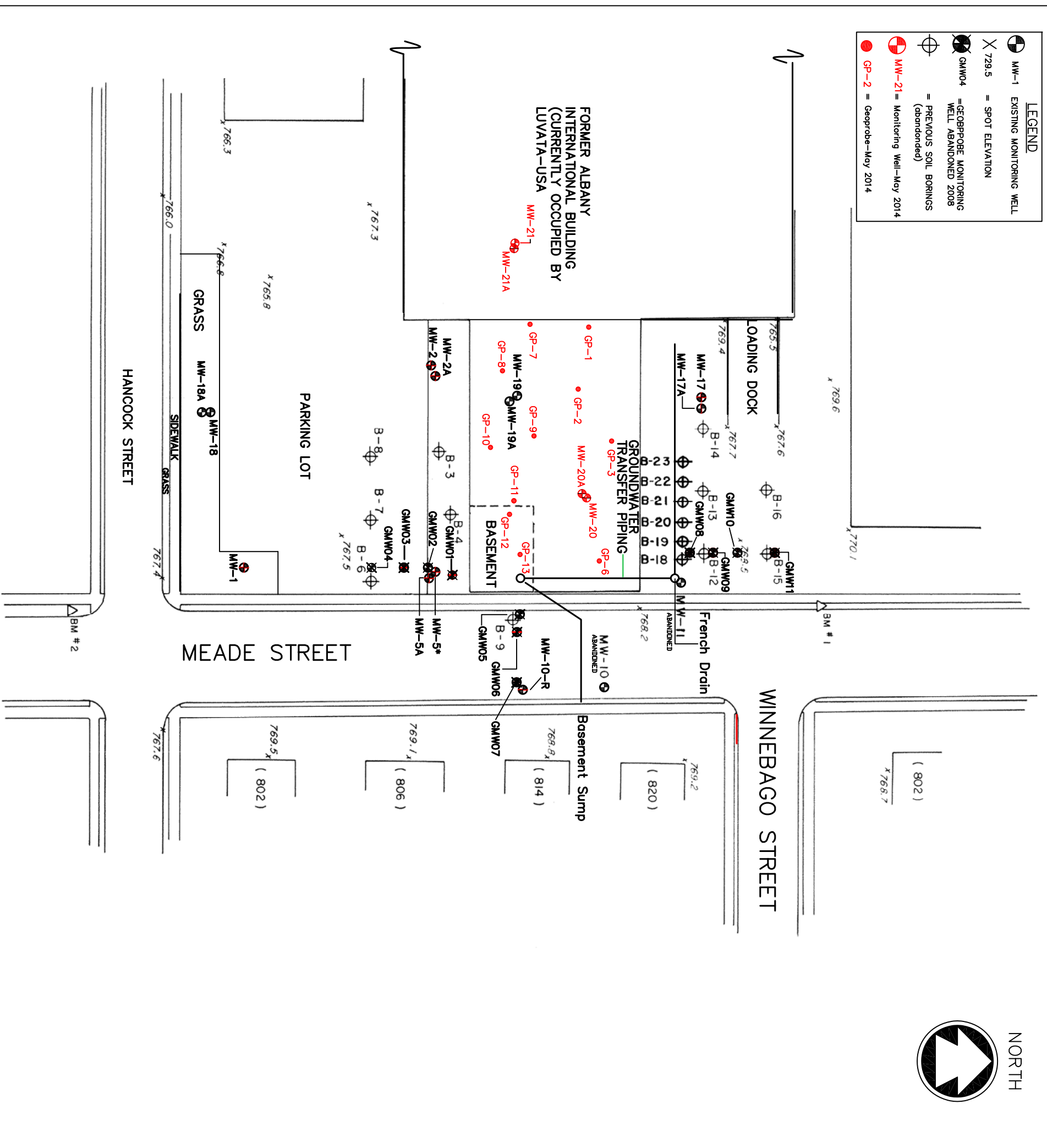


◆ MW-21
— Linear Trend

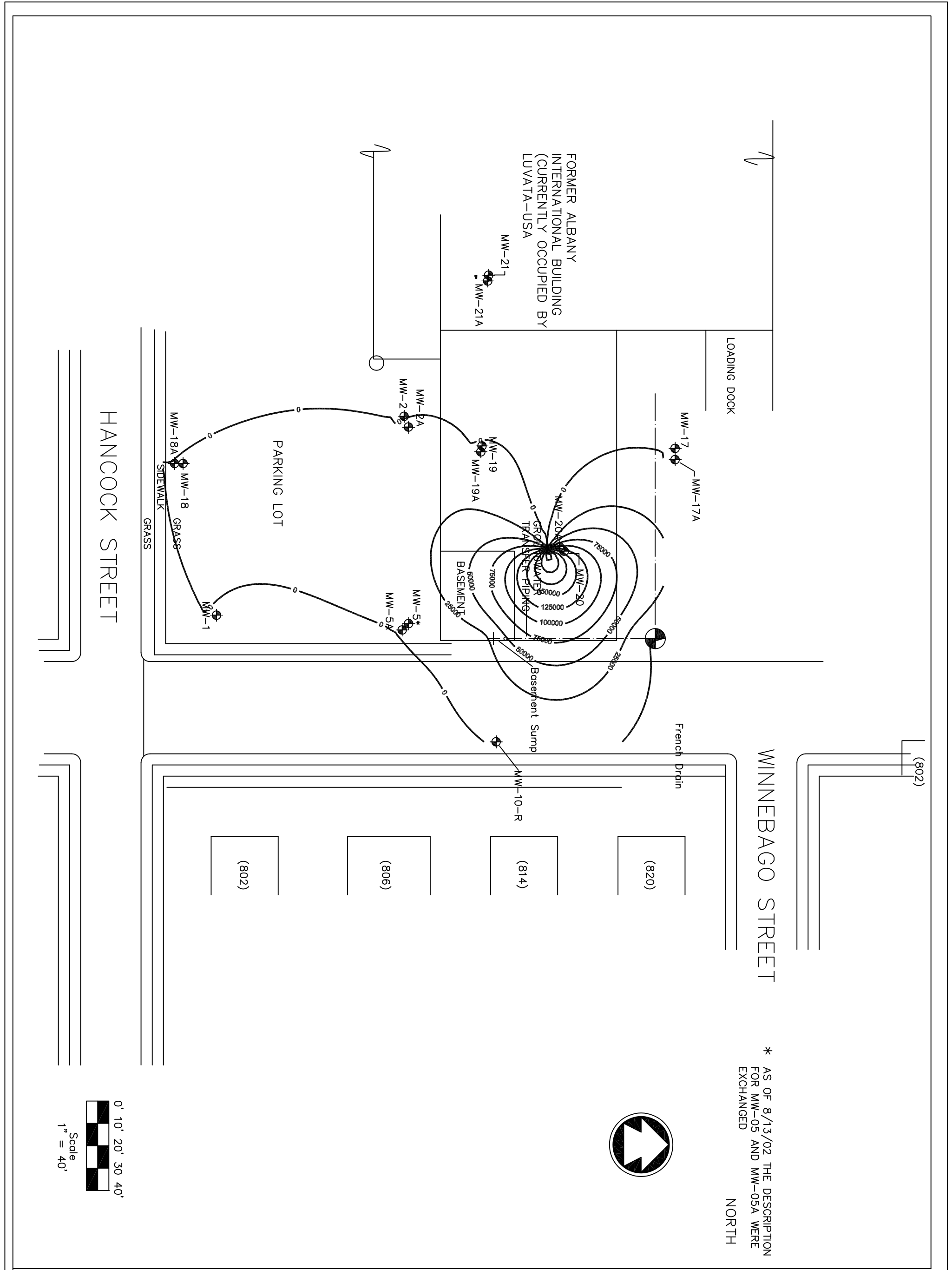
Albany International - Former Chrome Plant
Total Chromium Concentration vs Time



LEGEND	
	MW-1 EXISTING MONITORING WELL
	729.5 = SPOT ELEVATION
	GMW04 = GEOPROBE MONITORING WELL ABANDONED 2008
	= PREVIOUS SOIL BORINGS (abandoned)
	MW-21 = Monitoring Well - May 2014
	GP-2 = Geoprobe - May 2014

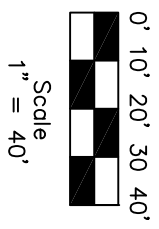


SCALE 1" = 80' DATE 8/18/09 PROJECT NO. Appleton Wire Former Albany International Chrome Plant	Appleton Wire Former Albany International Chrome Plant Site Map with Monitoring Wells Locations	DESIGNED BY _____	This drawing developed from base drawing provided by AECOM/STS by Badger Laboratories and Engineering Co. Inc.	Badger Laboratories & Engineering Co. Inc. 501 W. Bell St., Neenah WI 54956 TEL: (920) 729-1100 FAX: (920) 729-4945	NO. _____	DATE _____	REVISION OVERLY 2005 AERIAL
		DRAWN BY DJC			CHECKED BY DJC	NO. _____	DATE _____



* AS OF 8/13/02 THE DESCRIPTION FOR MW-05 AND MW-05A WERE EXCHANGED

NORTH



NO.	DATE	REVISION
	8/20/09	Overlay 2005 Aerial Photo

Badger Laboratories & Engineering Co. Inc.
 501 W. Bell St., Neenah WI 54956
 TEL: (920) 729-1100 FAX: (920) 729-4945

DESIGNED BY
 DRAWN BY
 D.J.C.
 CHECKED BY
 K.D.C.

This drawing developed from base drawing provided by McMahon Associates Inc. by Badger Laboratories and Engineering Co. Inc.

Appleton Wire Former Albany International Chrome Plant
 April 27, 2011 Groundwater
 Total Chromium Isoconcentration Map (ug/l)

SCALE
 NO SCALE
 DATE
 4/27/09
 PROJECT NO.
 Albany Int. Cr02

FIGURE NO.
 2

FILE NO.