GZA
GeoEnvironmental, Inc.

Engineers and Scientists

VIA EMAIL

December 13, 2006
File No. 04.0023171.06 C

Mr. Richard Fuller, Chairman and Director
The Blacksmith Institute
Two Park Avenue, 29th Floor
New York, New York 10016

Re: Remedial Pilot Study
Chromium Contamination Area
Noraiakheda, Kanpur, Uttar Pradesh, India

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Dear Mr. Fuller:

GZA GeoEnvironmental, Inc. (GZA) of the United States of America, as a remedial design engineering consultant, and EcoCycle India Private Limited (ECI) of Bangalore, India, as an affiliate remedial product supplier of EcoCycle Corporation of Japan (ECJ), are pleased to submit to The Blacksmith Institute (Blacksmith) this letter report summarizing the methods, results, and conclusions of a Remedial Pilot Study carried out at the Chromium Contamination Area in the Noraiakheda neighborhood of Kanpur, Uttar Pradesh, India (Study Area). The Remedial Pilot Study was performed to collect pre-design level performance data for evaluating whether an enhanced biological remediation (bioremediation) strategy could reduce the hexavalent chromium, Cr (VI) concentration in Study Area overburden groundwater and advance the Chromium Contamination Area toward closure. GZA has have prepared this letter report based on various conference calls with Blacksmith and Mr. R. K. Singh, Ph.D. (Scientist and Quality Manager) of the Central Pollution Control Board [CPCB]) of Lucknow, India (CPCB-Lucknow), as well as a September 13, 2005 meeting with Blacksmith at its New York City office. GZA notes that CPCB-Lucknow provided considerable scheduling, logistical, field staffing, analytical, Computer Aided Design, data summary, and regulatory support for this project. In fact, given the collaborative nature of this project, hereafter, "Project Team" refers to this partnering relationship among GZA (remedial design engineering consultant), CPCB-Lucknow (regulatory authority), and ECI (remedial product supplier) in carrying out the Remedial Pilot Study at the Study Area. Our work and this letter report are subject to the attached Limitations.

This letter report is organized into the following sections:

- Background Information – General background information on the Study Area and suspected contaminant sources;
- Technical Approach – A summary of the technical approach for the Remedial Pilot Study;
- Methods – Summary of pilot study methods;
- Results and Discussion – Presentation and discussion of the Remedial Pilot Study results;
- Conceptual Remedial Approach – A conceptual remedial approach, based on pilot study results, to advance the Study Area towards closure; and

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- Conclusions and Recommendations – Conclusions regarding Remedial Pilot Study results and recommendations for future Study Area work based on those results.

The following items are attached, each prepared by CPCB-Lucknow in collaboration with GZA:

- Data Summary Table of remedial pilot study performance data;
- Figures:
  - Locus Map of Kanpur in Uttar Pradesh, India,
  - Map of Kanpur City depicting location of Study Area,
  - Study Area Map depicting location of Remedial Pilot Study,
  - Well Field Exploration Location Plan, relative to the general direction of overburden groundwater flow,
  - Baseline Groundwater Elevation Contour Plans,
  - Baseline Hexavalent Chromium Isoconcentration Plan,
  - Baseline Total Organic Carbon Isoconcentration Plan,
  - Post-Injection Groundwater Elevation Contour Plans,
  - Post-Injection Total Organic Carbon Isoconcentration Plans, and
  - Post-Injection Hexavalent Chromium Isoconcentration Plans;
- Boring Logs for four new wells installed in the Study Area and an existing piezometer;
- Summary of Site Hydrogeologic Information; and
- Study Area Baseline Chemical Parameter Ranges for Soil.

BACKGROUND INFORMATION

Based upon Blacksmith's "Polluted Places" Internet site[1] and other information sources we have reviewed as well as our January-February 2006 visit to the Study Area, we understand that Kanpur is the largest and most industrialized city in the state of Uttar Pradesh, the fifth largest and most populous state of India located in the northern reaches of the subcontinent (Refer to the attached Locus Map of Kanpur, Uttar Pradesh). Kanpur occupies an area of just over 1,000 square kilometers, has a population of about 2.4 million residents (based upon a 1991 census), and is considered by some to be the most contaminated city of India.[2] Kanpur is situated in the Indo-Gangetic plain on the banks of the Ganga River, the largest river of Uttar Pradesh, at an elevation of approximately 126 meters above mean sea level. Refer to the attached Base Map of Noraiakheda Area, Kanpur and the attached Location Plan of Pilot Study site, Noraiakheda Area for plans depicting the approximate location of the Study Area.

During the British colonial period, Kanpur was reportedly known as the "Manchester of the East" due to the presence of many cotton mills. Following decline of the textile industry, Kanpur became better known for its leather industry established in about 1857. At the present time, more

[1] Uniform resource locator (URL): *http://www.pollutedplaces.org/region/south_asia/india/kanpur.shtml* (Polluted Places, Site Dossier, Kanpur, Uttar Pradesh, India)

[2] URLs: *http://en.wikipedia.org/wiki/Kanpur* (Kanpur, From Wikipedia—The Free Encyclopedia), *and http:/experts.about.com/e/k/ka/Kanpur.htm*. (All Experts, Kanpur Encyclopedia).

than 350 tanneries are located in the eastern part of the city and many of which release untreated effluent into the Ganga River. The tanneries, or the local suppliers of tanning agents such as basic chromium sulfate, produce a toxic sludge containing Cr (VI), arsenic, cadmium, zinc, mercury, nickel, copper, and cobalt, which have deleteriously impacted the water supply and impacted human health. A treatment plant, built in the 1990s, has reportedly done little to reduce contamination in tannery effluent and reportedly mixes effluent with urban sewage and the blended wastewater is treated via an Upflow Anaerobic Sludge Blanket System (UASB) in a dedicated treatment plant with a capacity of about 36 million liters per day. In accordance with system design, a bulk of treated wastewater is utilized for irrigation; however, given limited irrigation, excess wastewater is discharged to the Ganga River. Wastewater periodically contains significant concentrations of total chromium, on the order of 2 to 5 milligrams per liter (mg/L) as a result of inadequate chrome recovery and pre-treatment by individual tanneries.

Pollutants associated with the leather tanning industry have deleteriously impacted Kanpur's shallow groundwater system. For example, in 2003, CPCB-Lucknow discovered that Cr (VI) has impacted water supply wells in the Noraiakheda neighborhood, a settlement of some 30,000 residents. The source of that plume was apparently an old chemical manufacturing facility where toxic sludge had been released over a decade ago. Five piezometers were reportedly installed in that area to evaluate the spatial extent of the Cr (VI) condition. However, until that problem is addressed, local residents have no alternative but to continue using contaminated groundwater from Cr (VI)-impacted water supply wells. Moreover, while Cr (VI) has impacted the shallow overburden groundwater system, it has reportedly yet to significantly impact the deeper groundwater system that Kanpur relies on for much of its potable water needs. The protection of this deeper groundwater system from Cr (VI) contamination is, therefore, of critical importance.

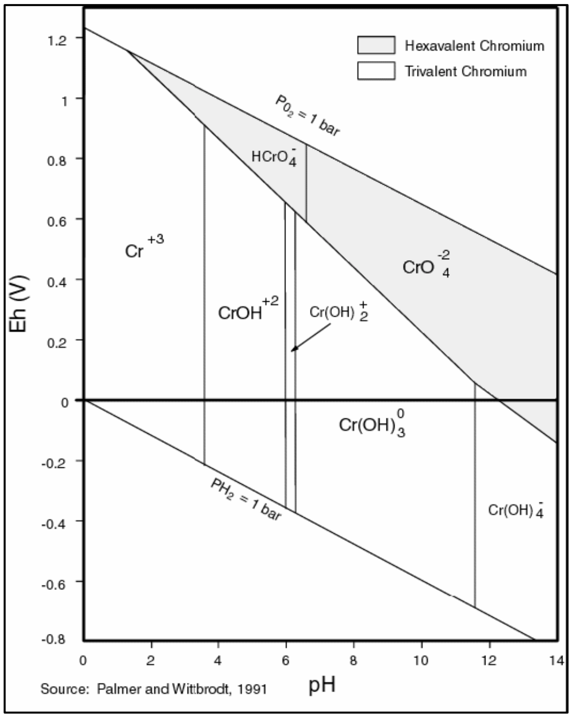
In the Jajmau neighborhood, on the eastern outskirts of Kanpur, the lack of treatment facilities for organized disposal of tannery wastes, which is currently under development outside the city limits, led to tannery sludge being dumped in temporary locations with unrestricted public access. Approximately 25 villages located downstream of the tanneries have reportedly been impacted by untreated tannery effluent. These villages reportedly have no electrical or telephone connections and poor sanitary conditions. Use of contaminated water for irrigation and other purposes by villagers, as well as uncontrolled dumping of toxic Cr (VI)-impacted sludge in that community, have created potential exposure pathways to the local population.

TECHNICAL APPROACH

Cr (VI)[3] is a mutagenic, teratogenic, carcinogenic, soluble, and readily mobile cation that exists under the aerobic, chemically oxidizing conditions of many overburden groundwater systems. Even so, Cr (VI) can be biogeochemically transformed to its relatively innocuous, insoluble, and immobile trivalent state, Cr (III)[4] under anaerobic, chemically reducing conditions.[5]

[3] With Cr in the +6 valence state.
[4] With Cr in the +3 valence state.
[5] URL: *http://www.epa.gov/ttnatw01/hlthef/chromium.html* (Chromium Compounds Hazard Summary-Created in April 1992; Revised in January 2000)

The transformation of Cr (VI) to Cr (III) is ostensibly an irreversible biogeochemical reaction under most naturally-occurring environmental conditions. According to EPA (2000),[6] the biochemical reduction of Cr (VI) primarily yields amorphous chromium precipitates such as chromium hydroxide ($Cr(OH)_3^0$), with chromium as Cr (III). Included below is an Eh – pH stability field diagram for chromium developed by Palmer and Wittbrodt (1991):[7]



As shown on the diagram, the amorphous chromium hydroxide precipitate Cr $(OH)_3^0$, with chromium existing in the trivalent (+3 valence) state, is stable at a wide range of pH and Eh values spanning the typical ranges of these parameters within overburden groundwater. Chromates, however, with chromium existing in the hexavalent (+6 valence) state, are only stable at very high Eh values at pH values approaching neutrality. For example, Cr $(OH)_3^0$, as shown above, is stable at pH values ranging from about 6 to 12 standard units and at Eh values ranging from about -0.7 to + 0.6 volts (-700 to +600 millivolts, mV). Therefore, the conversion of Cr (VI) to Cr (III) generally yields amorphous chromium precipitates that are fixed onto formation matrices, with chromium as Cr (III). Such precipitates are generally stable and immobile and cannot readily be converted back to mobile Cr (VI) by natural processes.

In-situ bioremediation is a remedial approach that leverages the biogeochemical relationship between Cr (VI) and Cr (III) and could potentially address the Cr (VI) condition in Kanpur groundwater.

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[6] EPA, 2000, In situ treatment of soil and groundwater contaminated with chromium technical resource guide, EPA 625/R-00/005, 84 p.

[7] Palmer, C.D. and P.R. Wittbrodt, 1991, Processes affecting the remediation of chromium-contaminated sites, Environmental Health Perspectives. v. 92

Implementation of an *in-situ* bioremediation approach would involve providing an electron donor remedial additive to the Cr (VI)-impacted groundwater system to stimulate transformation of Cr (VI) to Cr (III).[8] In addition to reducing chromium toxicity, this transformation mechanism immobilizes a bulk of chromium contamination *in-situ* by fixing it onto the formation matrix. In general, this reaction is irreversible under nearly all naturally-occurring environmental settings.

METHODS

The Remedial Pilot Study involved the following two tasks, each of which is discussed below:

- **Task 1** – Background Data Review; and
- **Task 2** – Remedial Pilot Study Implementation and Reporting.

TASK 1 – BACKGROUND DATA REVIEW

GZA, in collaboration with CPCB-Lucknow, reviewed the work performed to date to characterize hydrogeologic conditions in the Study Area as well as the magnitude and extent of Cr (VI) contamination. The purpose of this review was twofold:

- Development of a preliminary conceptual site model (CSM) of Cr (VI) fate and transport and an assessment of the risk Cr (VI) contamination poses to potential sensitive receptors in the Study Area; and
- Finalization of pilot study conceptual design consistent with the preliminary CSM.

TASK 2 – REMEDIAL PILOT STUDY IMPLEMENTATION AND REPORTING

The Remedial Pilot Study objective was to evaluate the efficacy of *in-situ* bioremediation for addressing the Cr (VI) contamination condition within Study Area overburden groundwater. The study involved installation of a well field in a portion of the highly Cr (VI)-impacted groundwater system in the Study Area that was selected based on **Task 1** results. The well field included four new injection/monitoring wells as well as an existing piezometer (hereafter, Skolast piezometer), with well screens intersecting the same laterally-continuous Cr (VI)-impacted hydrostratigraphic unit. That piezometer is located on a parcel operated by M/s Skolast (I) Pvt. Ltd., a safety footwear manufacturer located in the Noraiakheda (Panki) neighborhood of Kanpur.[9] The selection rationale for locating the pilot study on the Skolast parcel is as follows:

- While the parcel was secure from unauthorized vehicular and pedestrian traffic, it was readily accessible to the Project Team for the pilot study and includes a roofed storage area where equipment/supplies could be temporally stored to facilitate logistics. In addition, the property operator approved access for the purpose of performing the study;

[8] While contaminants other than Cr (VI) may also be present within the Study Area, Cr (VI) was the primary contaminant of concern focused on by the Remedial Pilot Study because of its ubiquitous presence at moderate to relatively high concentrations that pose risk to potential sensitive receptors.

[9] Street address: M/s Skolast (I) Pvt. Ltd., E-19, Panki Industrial Area, Site-I, Dadanagar, Panki, Kanpur, Uttar Pradesh, India.

- The highest reported detected concentration of Cr (VI) in overburden groundwater for the Study Area (10.6 mg/L) was for a groundwater sample collected from the Skolast piezometer, suggesting the Skolast parcel to be in the general vicinity of a Cr (VI) source area, such that Remedial Pilot Study results would be conservative;[10]
- According to the boring log for the Skolast piezometer provided by CPCB-Lucknow, the well screen intersects sand lenses, interlayered between clay and/or clayey caliche, at a depth interval consistent with sand lenses reportedly encountered at comparable depth intervals in other parts of the Study Area, therefore, subsurface conditions for the Skolast property are likely representative;
- According to CPCB-Lucknow, the sand lenses screened by the Skolast piezometer have moderately high horizontal hydraulic conductivity, with relatively slow seepage velocities. Therefore, the formation would likely support batch electron donor delivery based on our experience with hundreds of *in-situ* remedial pilot studies; and
- Of ten well locations in the Study Area where Cr (VI) has been detected above analytical reporting limits (RLs),[11] groundwater sampling results for nitrate and sulfate reflect the third highest detected concentration for each anion (*i.e.*, about 6.2 mg/L nitrate versus an arithmetic mean concentration of 5.8 mg/L for those ten wells; and about 123 mg/L sulfate versus an arithmetic mean concentration of 111 mg/L), such that Remedial Pilot Study results are conservative. Therefore, if the *in-situ* bioremediation approach is effective in an area of high terminal electron acceptor (TEA) concentration, then it would likely be as or more effective in areas of lower concentration given TEAs can potentially interfere with biotic as well as abiotic transformation mechanisms for Cr (VI).

Based on these collective factors, the Project Team selected the Skolast parcel at which to carry out the pilot study.

The electron donor remedial additive selected for the Remedial Pilot Study was Electron Donor Compound – Metal (EDC-M), which is manufactured by ECJ and was provided pro bono for this pilot study. EDC-M is a food-grade remedial additive formulated to stimulate the transformation of Cr (VI) to Cr (III). EDC-M was selected for use during the pilot study based on its reportedly successful track record in Japan for metals remediation as well as the cost effectiveness of remedial biotechnology in contrast to other treatment technologies.

The Remedial Pilot Study included EDC-M injection into overburden wells to stimulate Cr (VI) transformation to Cr (III), and groundwater monitoring of the injection/monitoring wells to evaluate bioremediation performance. The pilot study was carried out by the Project Team in general accordance with GZA's December 5, 2006 proposal to Blacksmith entitled "Proposal for Remedial Pilot Study Services (Remedial Pilot Study), Kanpur Chromium Contamination Area, Kanpur, India," with the following notable exceptions:

- Well yield was determined to be too low to practically support the conceptual design, which assumed batch remedial additive injection into a single well. To compensate for the low well yield, which could have added a week or more to the injection schedule, the

[10] *i.e.,* if the Remedial Pilot Study is effective in the general vicinity of this "hot spot", then it would likely be effective in areas of lower Cr (VI) concentrations.

[11] Refer to "Groundwater Quality in Noraiakheda Area, Panki, Kanpur (Period January – March 2005), available at CPCB-Lucknow.

Project Team revised the injection strategy from batch delivery to one well to recirculated delivery[12] to two upgradient wells, such that the injection could be completed within the planned project schedule; and

- CPCB-Lucknow performed six groundwater sampling rounds (*i.e.*, one baseline and five post-injection rounds) instead of four rounds (*i.e.*, one baseline and three post-injection rounds) to provide increased validation of Remedial Pilot Study results.

Remedial Pilot Study details are briefly summarized below.

Program Preparation

The Project Team coordinated Study Area access, scheduling, and logistical preparation in advance of the field work, and carried out a drilling program to establish a pilot study well field. The well field included the following four new wells as well as the existing Skolast piezometer:

- Injection Well (IW);
- Sidegradient Monitoring Well (SMW);
- Downgradient Well No. 1 (DW-1); and
- Downgradient Well No. 2 (DW-2).

Refer to the attached Well Field Exploration Location Plan, prepared by CPCB-Lucknow, depicting well locations at the Skolast parcel relative to the general direction of overburden groundwater flow in the Study Area.

The drilling program was designed by GZA, in collaboration with CPCB-Lucknow, following the **Task 1** review of available hydrogeologic data for the Study Area. Blacksmith retained M/s Drinking Water Organisation of Lucknow, Uttar Pradesh, India to carry out the drilling program consistent with the Project Team's conceptual design. The drilling program was carried out using water rotary drilling techniques to advance each borehole to its termination depth of about 47.2 meters below ground surface (bgs) from January 24, 2006 to February 3, 2006, and was observed by CPCB-Lucknow and GZA. Please refer to the attached Boring Logs, prepared by CPCB-Lucknow, for drilling program details.

Baseline Monitoring

The baseline monitoring program was designed by GZA in consultation with ECI and carried out by CPCB-Lucknow, which included pre-injection sampling of the well field to establish baseline conditions for the pilot study from which to evaluate bioremediation performance. Baseline monitoring parameters included the following metals and indicator parameters:[13]

[12] *i.e.*, extracting groundwater from a downgradient location, amending it with remedial additive, and simultaneously injecting it at an upgradient location.

[13] While methane was a requested analyte, it was not within the capability of the analytical laboratory.

- Metals:
  - Total chromium (Total Cr)
  - Cr (VI)
  - Dissolved arsenic
  - Dissolved zinc
  - Dissolved mercury
  - Dissolved nickel
  - Dissolved copper
  - Dissolved cobalt
  - Dissolved iron
  - Dissolved manganese
- Indicator Parameters:
  - Dissolved oxygen (DO)
  - Redox potential (Eh)
  - pH
  - Total organic carbon (TOC)
  - Nitrate
  - Sulfate
  - Sulfide
  - Methane

Baseline groundwater quality sampling was performed using a modified low-flow sampling technique. Baseline results are summarized in the attached Data Summary Table, and the analytical laboratory reports are on file at CPCB-Lucknow.

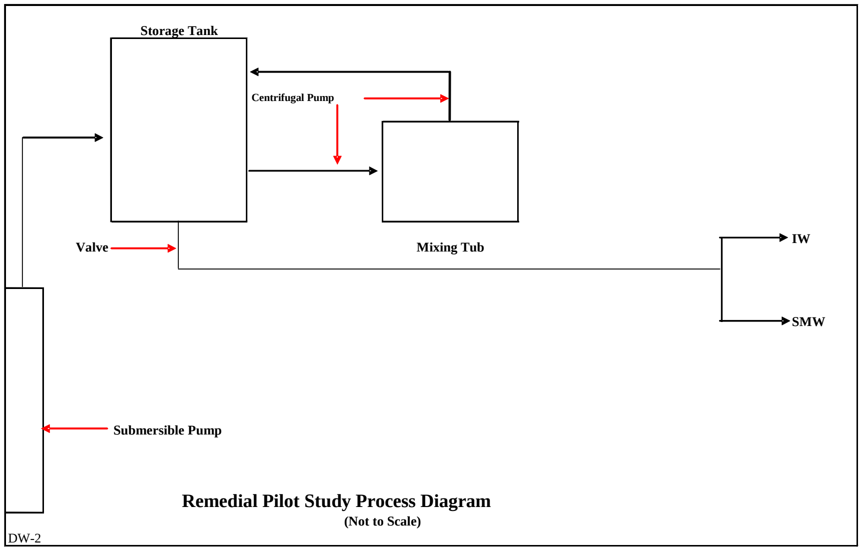
In addition to the collection of groundwater quality samples, CPCB-Lucknow carried out an elevation level survey of the well field, including baseline static groundwater levels, to tie the well field into the existing well network in the Study Area.

Remedial Additive Injection

The injection program was designed by GZA, in collaboration with ECI, and carried out by GZA and CPCB-Lucknow using a recirculation approach. The program included the following:

- Construction of the following recirculation system occurred on February 7 and 8, 2006:
  - A 3,000-Liter capacity storage tank with a control valve at the bottom for temporary storage and injection of EDC-M-amended groundwater into the IW and SMW,
  - A mixing tub for blending remedial additive into groundwater,
  - Two centrifugal pumps, with associated hosing/fittings, connecting the storage tank and mixing tub[14] to agitate remedial additive-amended groundwater and facilitate mixing,
  - A submersible pump for extracting groundwater from DW-2 and pumping it to the storage tank,
  - Plastic pipe recirculation manifold system connecting the groundwater extraction well (DW-2) with the storage tank to fill the tank, and the storage tank with the IW (and later the SMW) for injecting EDC-M-amended groundwater, and
  - Please find below a Remedial Pilot Study Process Diagram conceptually depicting the layout of the recirculation system components:

[14] *i.e.*, one pumping from the storage tank to the mixing tub and the other from the tub to the tank to facilitate remedial additive dissolution.



Remedial Pilot Study Process Diagram
(Not to Scale)

- Once assembled, the recirculation system was initially operated without remedial additive amendment for about three hours on February 9, 2006 to evaluate system components under steady state recirculation conditions in preparation for the electron donor injection.[15] Initially, the system achieved a recirculation rate of up to about 4 to 8 liters per minute (LPM) by injecting only into the IW. To increase the recirculation rate, GZA and CPCB-Lucknow adjusted the pumping configuration and split injection flow between the IW and the SMW, which ultimately achieved a recirculation rate up to about 22 LPM under steady state conditions, or about 11 LPM per well;

- Once steady state conditions were achieved, remedial additive was blended into groundwater extracted from DW-2 using two counter-circulating centrifugal pumps connecting the mixing tub and storage tank to agitate the mixture and facilitate EDC-M dissolution; and

- Remedial additive injection into the IW and SMW was carried out for about 43.5 hours at a flow rate of between about 4 to 21 LPM (mean of about 15 LPM), for a total injection load of about 540 kilograms of EDC-M dissolved in about 40,000 liters of recirculated groundwater. Note that EDC-M is formulated with two components, EDC-M1 and EDC-M2, each of which is packaged separately and injected sequentially (*i.e.*, EDC-M1 before EDC-M2). For the pilot study injection, about 210 kilograms of EDC-M1 were injected first, diluted in about 12,000 liters of recirculated groundwater, followed by about 330 kilograms of EDC-M2, diluted in about 28,000 liters of groundwater, in consideration of ECI's recommendations.

Performance Monitoring

GZA developed the performance monitoring program in collaboration with CPCB-Lucknow, and CPCB-Lucknow carried it out. Performance monitoring included five rounds of post-injection groundwater sampling of the well field on February 9, 2006, February 24, 2006, April 10, 2006, April 28, 2006, and May 26, 2006. Post-injection sampling was reportedly performed at the same well locations and for the same parameters as baseline sampling (see the Baseline Monitoring

[15] *i.e.*, constant flow rate and no significant changes in hydraulic head for either the extraction well or the injection well(s) over the period of interest.

section above), and was reportedly carried out also using a modified low flow sampling technique. Post-injection groundwater sampling results are summarized in the attached Data Summary Table, and the analytical laboratory reports are on file at CPCB-Lucknow.

Data Analysis and Report Preparation

GZA reviewed and analyzed Remedial Pilot Study performance data, in collaboration with CPCB-Lucknow, and prepared this letter report summarizing pilot study methods, results, and conclusions, and providing remedial recommendations to advance the Study Area toward closure based on those results. Please refer to GZA's December 5, 2006 proposal for additional information on Remedial Pilot Study methods.

RESULTS AND DISCUSSION

Results of **Tasks 1** (Background Data Review) and **2** (Remedial Pilot Study Implementation and Reporting) are included in this section of the letter report, which includes a Preliminary CSM developed by the Project Team and a summary and discussion of pilot study results.

PRELIMINARY CONCEPTUAL SITE MODEL

Based on our review of the information obtained during **Task 1** as well the attached Boring Logs for the four new pilot study wells, the geology of the Study Area includes up to about 500 meters of alluvial-fluvial-derived unconsolidated sediments of Quaternary age, which is underlain by granitic bedrock likely of the Bundelkhand complex. The overburden hydrostratigraphy within the Study Area includes two notable groundwater flow systems, each of which can be classified as overburden aquifers given each system is used for water supply:

- A deep regional flow system occurring in stratified sand at a depth greater than about 300 meters bgs; and
- Local/intermediate flow systems occurring in sand lenses at shallower depth intervals.

The regional flow system within the deep overburden is hydraulically confined and characterized by an approximately 100-meter-thick laterally continuous and generally transmissive stratified sand unit overlying granitic bedrock likely of the Archaean-age Bundelkhand complex.[16] The regional flow system occurs at a depth of about 300 to 500 meters bgs. The subordinate local and intermediate flow systems in the shallow overburden are generally at least partially hydraulically confined and characterized, at least at the scale of the pilot study, by relatively continuous transmissive sand lenses, interlayered clay and/or clayey caliche, to a depth of up to about 300 meters bgs. Based on our understanding of the regional hydrogeologic conditions for the overburden groundwater system, GZA believes that the vertical hydraulic gradient in the general Study Area vicinity to be downward, consistent with groundwater recharge conditions. GZA notes that the hydrostratigraphy encountered via the four new pilot study wells as well as the existing Skolast piezometer is consistent with a local or intermediate groundwater flow system (refer to the attached Boring Logs prepared by CPCB-Lucknow). Water supply wells are installed in both the shallow local/intermediate groundwater flow systems serving residential or

[16] For additional information, please refer to Ganga Action Plan Support Project's "Kanpur Ganga, Ganga Action Plan Support Project- Kanpur, Project Planning And Coordination Unit" web page entitled "Other Important Projects" (Uniform Resource Locator: *http://www.kanpurganga.com/other_important_projects.htm*).

small community users and the deep regional flow system serving industrial, municipal, or large community users in the Study Area, and both present potential sensitive receptors owing to the current Cr (VI) condition in shallow overburden groundwater.

With respect to Cr (VI) contamination in Study Area overburden groundwater, the highest detected concentrations are typically for samples collected from the local and intermediate groundwater flow systems in the shallow overburden at depths ranging from about 20 to 50 meters bgs. While the deep regional groundwater flow system has reportedly not yet been impacted by Cr (VI) contamination from the shallow local and intermediate flow systems, there is the potential for downward advection of Cr (VI), driven by downward vertical hydraulic gradients, to deleteriously impact groundwater quality of the deep flow system. Therefore, it is imperative that Cr (VI) contamination in the shallow groundwater flow systems be addressed before it impacts the deep flow system, notwithstanding the current unacceptable risk Cr (VI) poses to potential sensitive receptors of shallow overburden groundwater in the Study Area.

PERFORMANCE DATA

Baseline and post-injection performance monitoring results for the Remedial Pilot Study are summarized in the attached Data Summary Table. Observations regarding these performance data are summarized below.

Cr (VI) Data

As shown on the Data Summary Table, baseline Cr (VI) concentrations ranged from 8.16 mg/L to 12.55 mg/L (arithmetic mean: 10.74 mg/L)[17] for groundwater samples collected from all five wells, whereas post-injection concentrations for the same well locations ranged from non-detectable above the analytical RL of 0.03 mg/L to 4.17 mg/L (geometric mean: 0.71 mg/L) over the pilot study duration, which is consistent with an overall 93 percent reduction ($\%_{Reduction}$) in Cr (VI) concentration. The magnitude of the overall $\%_{Reduction}$ is consistent with the biochemical transformation of Cr (VI) to Cr (III), driven by electron donor amendment.

Post-injection Cr (VI) results are summarized below on a round-specific basis:

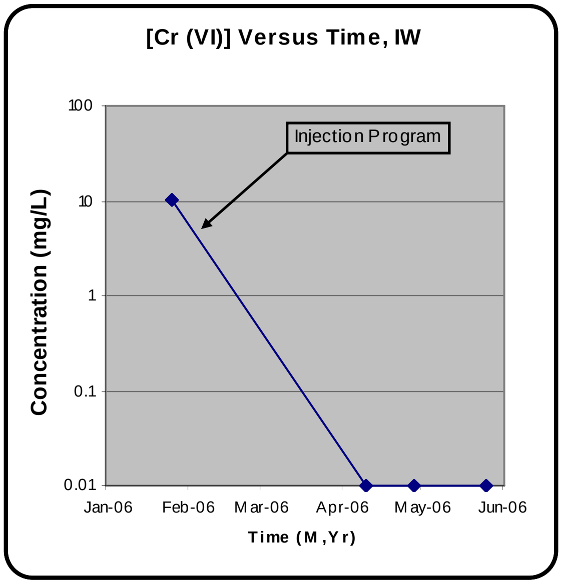
- For the first post-injection sampling round, detected Cr (VI) concentrations ranged from 0.23 to 4.17 mg/L, reflecting an up to two orders of magnitude decrease in Cr (VI) concentrations within about two weeks of the injection program;
- For the second post-injection round, Cr (VI) concentrations ranged from non-detectable above analytical RLs to 0.32 mg/L Cr (VI), reflecting an up to three orders of magnitude decrease in Cr (VI) concentrations within about four weeks of the injection program;
- For the third post-injection sampling round, Cr (VI) concentrations were non-detectable above analytical RLs, reflecting a three orders of magnitude decrease in Cr (VI) concentrations within about ten weeks of the injection program;
- For the fourth post-injection sampling round, Cr (VI) concentrations were non-detectable above analytical RLs, reflecting a three orders of magnitude decrease in Cr (VI) concentrations within about 13 weeks of the injection program; and

[17] GZA's statistical approach for estimating means herein as well as percent reductions assumes a value of 0.01 mg/L Cr (VI) for managing non detects above the analytical RL of 0.03 mg/L. Also note that means, referenced herein, generally refer to arithmetic mean measurements of central tendency when data vary by less than about an order of magnitude, or geometric mean measurements when data vary by more than an order of magnitude.

- For the fifth post-injection round, Cr (VI) concentrations ranged from non-detectable above analytical RLs to 0.67 mg/L Cr (VI), reflecting an up to three orders of magnitude decrease in Cr (VI) concentrations within about 17 weeks of the injection program.

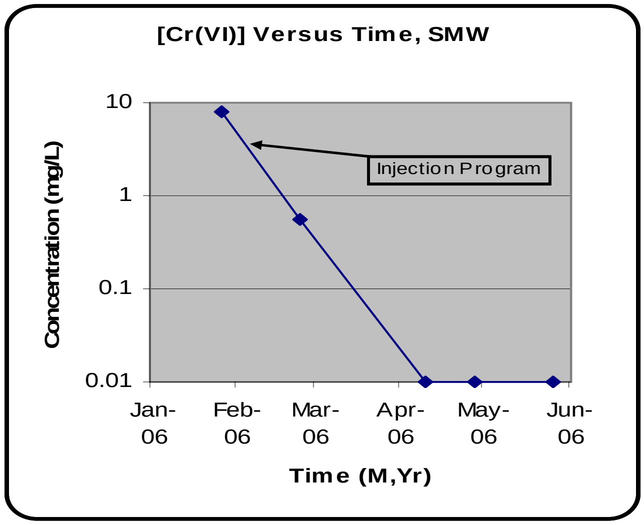
GZA notes the following Cr (VI) concentration trends for baseline and post-injection performance monitoring results on a well-specific basis:

- IW: The baseline concentration was 10.01 mg/L, whereas the three rounds of post-injection monitoring did not detect Cr (VI) above analytical RLs, reflecting a 99.9 $\%_{Reduction}$ in Cr (VI) concentration for this well location over the pilot study duration. The following is a semi-log plot of the performance monitoring Cr (VI) concentration versus time data for the IW: (*Note: Our plotting approach for handling non detects above analytical RLs conservatively assumed a Cr (VI) concentration of 0.01 mg/L Cr (VI) for the non detect.*)



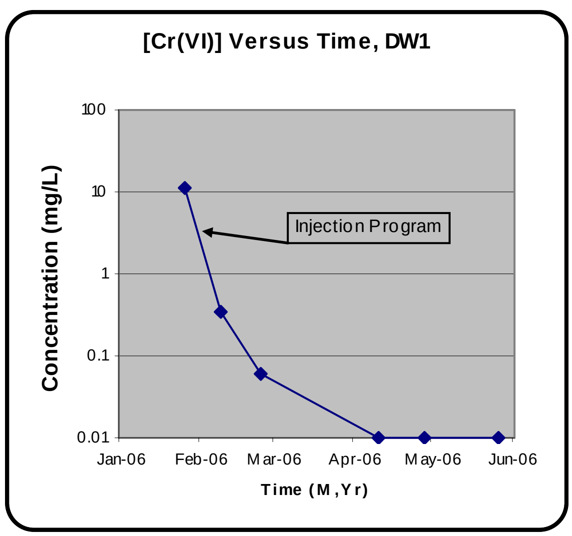
As shown on this semi-log plot, there was a three order of magnitude decrease in Cr (VI) concentration within about ten weeks of the pilot study injection resulting in three consecutive rounds of non detect Cr (VI) for the remainder of the pilot study duration, which GZA directly attributes to electron donor amendment;

- SMW: The baseline concentration was 8.16 mg/L, whereas the first round of post-injection monitoring detected Cr (VI) at 0.56 mg/L and the last three rounds did not detect Cr (VI) above analytical RLs, reflecting a 93.1 $\%_{Reduction}$ to 99.9 $\%_{Reduction}$ in Cr (VI) concentration for this well location over the pilot study duration. The following is a semi-log plot of the performance monitoring Cr (VI) concentration versus time data for the SMW: (*Note: Our plotting approach for handling non detects above analytical RLs conservatively assumed a Cr (VI) concentration of 0.01 mg/L Cr (VI) for the non detect.*)



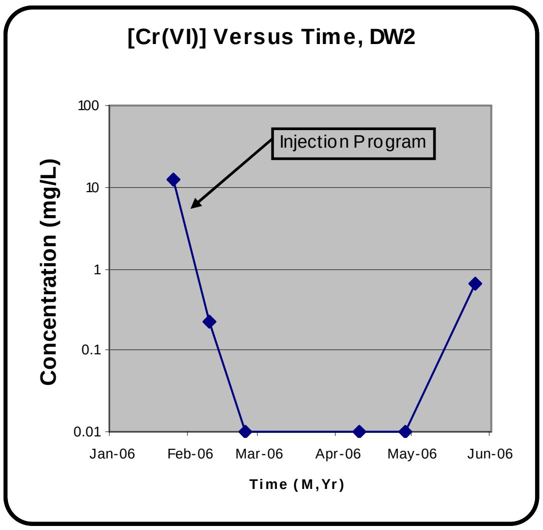
As shown on this plot, there was an order of magnitude decrease in Cr (VI) concentration within about four weeks of the pilot study injection, and then about a two order of magnitude decrease resulting in three consecutive rounds of non detect Cr (VI) for the remainder of the pilot study, which GZA directly attributes to electron donor amendment;

- DW-1: The baseline concentration was 11.2 mg/L, whereas the first round of post-injection monitoring detected Cr (VI) at 0.34 mg/L, the second post-injection round detected Cr (VI) at 0.06 mg/L, and the last three rounds did not detect Cr (VI) above analytical RLs, reflecting a 97.0 $\%_{Reduction}$ to 99.9 $\%_{Reduction}$ in Cr (VI) concentration for this well location over the pilot study duration. The following is a semi-log plot of the performance monitoring Cr (VI) concentration versus time data for DW-1: (*Note: Our plotting approach for handling non detects above analytical RLs conservatively assumed a Cr (VI) concentration of 0.01 mg/L Cr (VI) for the non detect.*)



As shown on this semi-log plot, there was a two order of magnitude decrease in Cr (VI) concentration within about four weeks of the pilot study injection, and then about an order of magnitude decrease resulting in three consecutive rounds of non detect Cr (VI) for the remainder of the pilot study, which GZA directly attributes to electron donor amendment;

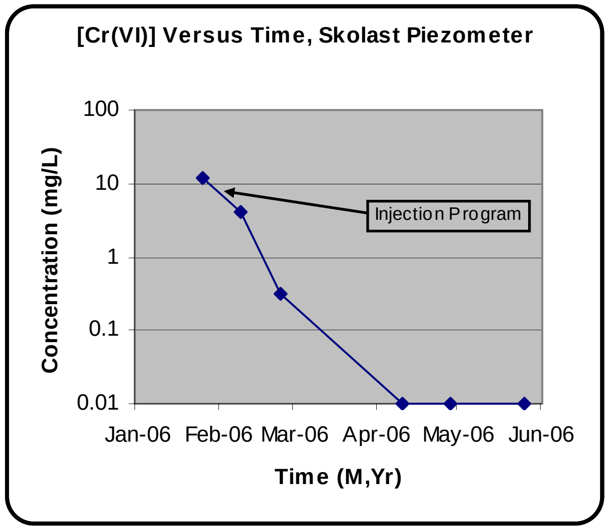
- DW-2: The baseline concentration was 12.55 mg/L, whereas the first round of post-injection monitoring detected Cr (VI) at 0.23 mg/L, the next three rounds not detect Cr (VI) above analytical RLs, and the last round detected Cr (VI) at 0.67 mg/L, reflecting a 94.7 $\%_{Reduction}$ to 99.9 $\%_{Reduction}$ in Cr (VI) concentration for this well location over the pilot study duration. The following is a semi-log plot of the performance monitoring Cr (VI) concentration versus time data for DW-2: (*Note: Our plotting approach for handling non detects above analytical RLs conservatively assumed a Cr (VI) concentration of 0.01 mg/L Cr (VI) for the non detect.*)



As shown on this semi-log plot, there was a nearly two order of magnitude decrease in Cr (VI) concentration within about two weeks of the pilot study injection, and then about an order of magnitude decrease resulting in two consecutive rounds of non detect Cr (VI), which GZA attributes to electron donor amendment. For the fifth post-injection sampling round (week 17), GZA observed nearly a two order of magnitude increase in Cr (VI) concentration to 0.67 mg/L that is graphically overstated by the semi-log plotting method. GZA attributes this apparent rebound to either analytical variability or Cr (VI) advection to the DW-2 location, and not to chemical oxidation of Cr (III) to Cr (VI) given there was no significant (order of magnitude or greater) increase in total Cr concentration[18] at this well location that would be consistent with that transformation pathway; and

- Skolast piezometer: The baseline concentration was 11.8 mg/L, whereas the first round of post-injection monitoring detected Cr (VI) at 4.17 mg/L, the second post-injection round detected it at 0.32 mg/L, and the last three rounds did not detect Cr (VI) above analytical RLs, reflecting a 64.7 $\%_{Reduction}$ to 99.9 $\%_{Reduction}$ in Cr (VI) concentration for this well location over the pilot study duration. The following is a semi-log plot of the performance monitoring Cr (VI) concentration versus time data for the Skolast piezometer: (*Note: Our plotting approach for handling non detects above analytical RLs conservatively assumed a Cr (VI) concentration of 0.01 mg/L Cr (VI) for the non detect.*)

[18] Refer to the attached semi log plot of Total Cr. Versus time included in the "Total Cr Data" section of this letter report.



As shown on this semi-log plot, there was a two order of magnitude decrease in Cr (VI) concentration within about four weeks of the injection, and then about an order of magnitude decrease resulting in three consecutive rounds of non detect for the remainder of the pilot study duration, which GZA directly attributes to electron donor injection.

CPCB-Lucknow also prepared the attached Baseline Hexavalent Chromium Isoconcentration Plan and five Post-Injection Hexavalent Chromium Isoconcentration Plans corresponding with the five rounds of post-injection monitoring. As shown on the Baseline Hexavalent Chromium Isoconcentration Plan, the highest Cr (VI) concentration was near DW-2, and four of the five detected baseline Cr (VI) concentrations[19] were on the same order of magnitude. The Post-Injection Hexavalent Chromium Isoconcentration Plans reflect the sequential reduction[20] in Cr (VI) concentration resulting from the pilot study injection. The final Post-Injection Hexavalent Chromium Isoconcentration Plan, reflecting Cr (VI) concentrations 106 days following the pilot study injection, reflects a rebound in the Cr (VI) concentration for the groundwater sample collected from DW-2, the well with the highest baseline Cr (VI) concentration. GZA's explanation for the apparent rebound was discussed previously.

The Remedial Pilot Study performance monitoring data collectively demonstrated broad reductions in Cr (VI) concentrations over the study duration, which GZA directly attributes to electron donor amendment. Significantly, Cr (VI) concentrations for the entire well field decreased below the target remedial goal of 0.05 mg/L[21] for all post-injection groundwater samples collected from the well field within about ten weeks of the injection program. With respect to the apparent rebound in Cr (VI) concentration at DW-2 observed at week 17 following the pilot study injection, the rebound seems anomalous based on the fact that results for groundwater samples collected for all other wells from the second post-injection sampling round forward did non detect Cr (VI) above analytical RLs. Overall, the Cr (VI) performance monitoring results are clearly consistent with enhanced bioremediation, driven by electron donor injection within the Study Area, consistent the Remedial Pilot Study technical approach.

[19] *i.e.*, DW-2, IW, DW-1, and Skolast piezometer
[20] *i.e.*, from 7 to 78 days following completion of electron donor amendment.
[21] *i.e.*, the Indian Standard for Drinking Water Quality for Cr (VI).

With respect to the potential re-oxidation of Cr (III) to Cr (VI), once injected electron donor has become depleted, the biochemical reduction of Cr (VI), as discussed previously, primarily yields amorphous precipitates with chromium as Cr (III). Such precipitates are generally stable at a wide range of pH[22] and Eh[23] values spanning the typical ranges of these parameters within overburden groundwater. For example,

- The pH of baseline groundwater samples collected from the pilot study well field ranged from about 6.7 to 7.0 standard units (Data Summary Table) and the pH for samples collected from the general site vicinity range from about six to eight (Site Hydrogeologic Information, Baseline Chemical Parameters [Groundwater]). GZA notes that the measured pH values for these samples were within the stability range of 6 to 12 standard units, which is consistent with Cr (III) stability and not geochemical reversal to Cr (VI). Hence, the ambient pH condition of overburden groundwater in the Study Area appears conducive to Cr (III) stability following Cr (VI) transformation; and
- The Eh of baseline samples collected from pilot study wells ranged from about +105 mV to +118 mV (Data Summary Table) and the Eh for samples collected from the general site vicinity range from about +100 mV to +120 mV (Site Hydrogeologic Information, Baseline Chemical Parameters [Groundwater]). GZA notes that the measured Eh values for these samples were well within the stability range of -700 to +600 mV, which is also consistent with Cr (III) stability. Hence, the ambient Eh condition of overburden groundwater in the Study Area appears conducive to Cr (III) stability following Cr (VI) transformation.

Therefore, based on the pH and Eh data for overburden groundwater in the general Study Area, once Cr (VI) has been biochemically reduced to Cr (III), the reaction is generally irreversible.

Total Cr Data

As shown on the Data Summary Table, baseline Total Cr concentrations ranged from 12.88 to 19.49 mg/L (arithmetic mean: 15.80 mg/L)[24] for groundwater samples collected from all five wells, whereas post-injection concentrations for the same well locations ranged from 0.08 mg/L to 10.66 mg/L (geometric mean: 1.21 mg/L), which is consistent with an overall $92\%_{\text{Reduction}}$ in the Total Cr concentration. The magnitude of this overall $\%_{\text{Reduction}}$ is ostensibly the same as the overall reduction observed for Cr (VI), and is consistent with the biochemical transformation of more mobile Cr (VI) to immobile Cr (III), driven by electron donor injection.

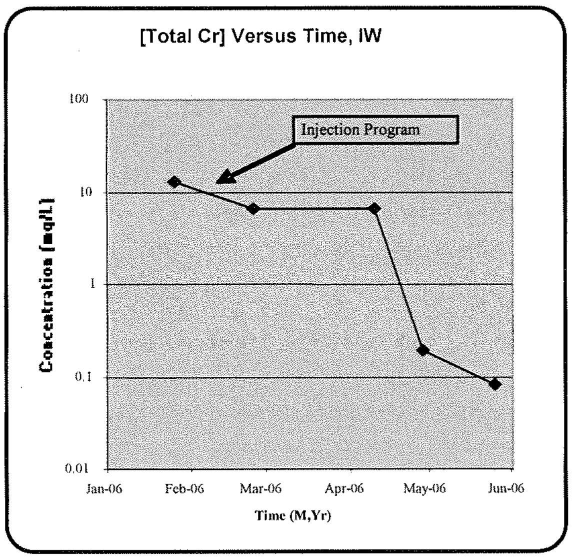
Total Cr results on a round-specific basis are summarized as follows for the five rounds of post-injection monitoring:

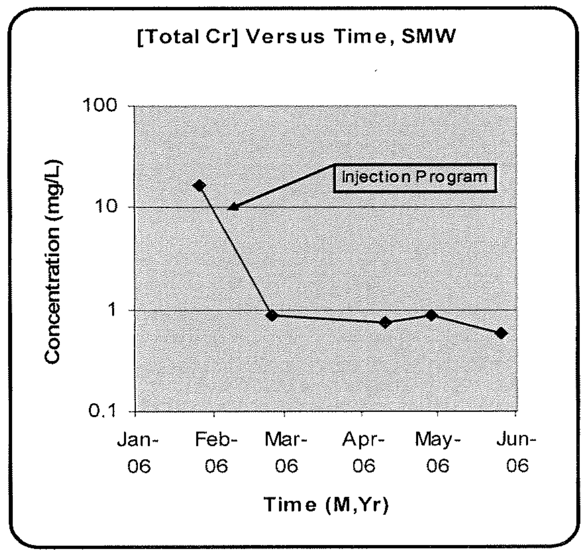
- For the first post-injection sampling round, detected Total Cr concentrations ranged from 9.09 to 10.66 mg/L (arithmetic mean: 9.97 mg/L), reflecting a 37 percent (%) decrease in mean Total Cr concentrations within about two weeks of the injection program;
- For the second post-injection sampling round, Total Cr concentrations ranged from 0.46 to 7.79 mg/L Total Cr (geometric mean: 2.02 mg/L), reflecting an 87% decrease in Total Cr concentrations within about four weeks of the injection program;

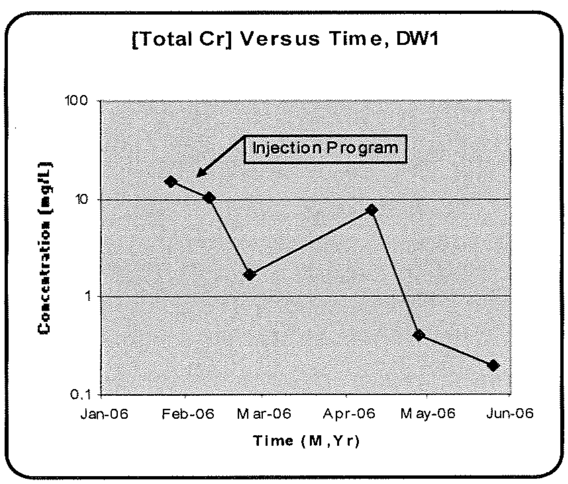
[22] *i.e.*, 6 to 12 standard units.
[23] *i.e.*, -0.7 to + 0.6 volts (-700 to +600 mV).
[24] Our statistical approach for estimating means as well as or percent reductions assumes a value of 0.01 mg/L Cr (VI) for managing non detects above the analytical RL of 0.03 mg/L.

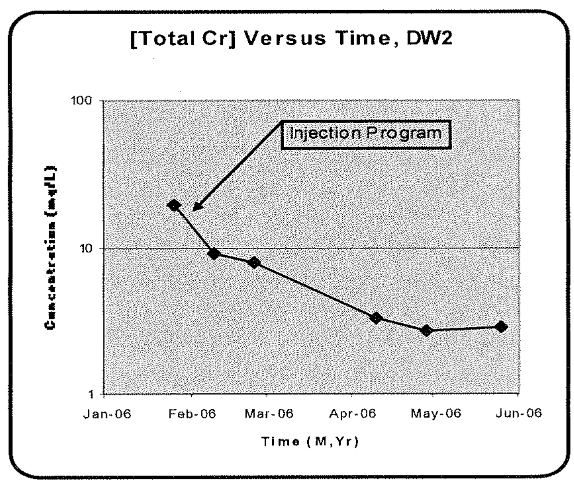
- For the third post-injection sampling round, Total Cr concentrations ranged from 0.19 to 7.78 mg/L (geometric mean: 1.27 mg/L), reflecting a 92% decrease in Total Cr concentration within about ten weeks of the injection program;
- For the fourth post-injection sampling round, Total Cr concentrations ranged from 0.08 to 2.71 mg/L (geometric mean: 0.84 mg/L), reflecting a 95% decrease in Total Cr concentrations within about 13 weeks of the injection program; and
- For the fifth post-injection sampling round, Total Cr concentrations ranged from 0.12 to 2.87 mg/L (geometric mean: 0.41 mg/L), reflecting a 97% decrease in Total Cr concentrations within about 17 weeks of the injection program.

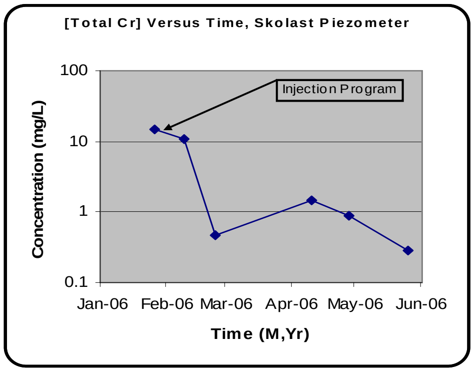
The following are semi-log plots of the performance monitoring Total Cr concentration versus time data for the five pilot study wells on a well-specific basis:











As shown on these semi-log Total Cr versus time plots, there was an up to two orders of magnitude reduction in the Total Cr concentration with time for all five well locations during the pilot study duration, which is consistent with the biochemical transformation of aqueous soluble Cr (VI) to the aqueous insoluble Cr (III), driven by electron donor amendment, consistent the Remedial Pilot Study technical approach.

Indicator Parameter Data

Biological transformation Indicator Parameters

The following table summarizes the statistical data including the value range, mean,[25] and percent change ($\%_{Change}$)[26] for the biological transformation indicator parameters DO, Eh, sulfate, nitrate, iron, manganese, and TOC, which are generally the primary factors that control the biologically-mediated transformation of Cr (VI) to Cr (III):

SAMPLING ROUND	MINIMUM VALUE	MAXIMUM VALUE	MEAN	$\%_{Change}$
DO, mg/L				
Baseline	3.2	4.9	4.3	--
1	3.4	3.8	3.6	-16
2	0.9	3.0	2.3	-47
3	0.8	1.7	1.0	-77
4	1.2	1.8	1.4	-67
5	0.8	1.5	1.2	-72
Eh, mV				
Baseline	+105	+118	+111	--
1	-18	-12	-15	-114
2	-93	-13	-41	-137
3	-140	-36	-72	-165
4	-394	-88	-190	-271
5	-234	-1	-55	-150

[25] Mean refers to arithmetic or geometric mean, as appropriate, for the respective value relative to baseline.
[26] $\%_{Change}$ refers to the percent difference between the mean value and its respective baseline mean value for the same parameter.

SAMPLING ROUND	MINIMUM VALUE	MAXIMUM VALUE	MEAN	% Change
Sulfate, mg/L				
Baseline	139	394	260	--
1	183	352	291	+12
2	140	270	205	-21
3	35.18	95.33	68	-74
4	28.94	148.88	77	-70
5	55	161	89	-66
Nitrate, mg/L				
Baseline	2.2	9.79	5.2	--
1	1.46	6.09	3.2	-39
2	1.05	1.73	1.4	-73
3	0.52	1.4	1.0	-81
4	0.25	1.73	0.9	-83
5	0.23	2.15	1.0	-81
Dissolved Iron, mg/L				
Baseline	0.17	5.2	1.3	--
1	16.82	37.13	27.4	+2,008
2	4.7	351.65	35.2	+2,608
3	6.7	100.6	23.3	+1,692
4	5.99	54.27	19.0	+1,362
5	4.03	27.12	11.4	+777
Dissolved Manganese, mg/L				
Baseline	0.03	0.3	0.1	--
1	2.42	11.76	7.7	+7,600
2	1.68	71.0	19.7	+19,600
3	2.63	15.08	7.2	+7,100
4	1.71	4.91	3.4	+3,300
5	0.74	2.51	1.7	+1,600
TOC, mg/L				
Baseline	34.46	52.14	44.4	--
1	38.21	51.35	45.6	2.7
2	34.22	51.64	44.3	-0.2
3	208.16	446.84	302.6	+582
4	30.38	128.37	66.0	+49
5	39.23	98.3	69.7	+57

Note: Sampling Round Nos. 1 through 5 refer to the five post-injection sampling rounds.

As tabulated above, the indicator parameters DO (up to 77% reduction), Eh (up to 271% reduction), sulfate (up to 74% reduction), and nitrate (up to 83% reduction) each exhibited a decreasing trend with time, relative to baseline conditions, over the pilot study duration. This trend of decreasing DO, Eh, sulfate, and nitrate values with time is directly consistent with the development of anaerobic, chemically reducing conditions stimulated by electron donor amendment. The reduction in DO, sulfate, and nitrate concentrations are consistent with the microbial metabolic processes of aerobic mineralization, sulfate reduction, and nitrate reduction, respectively. The reduction in Eh values with time is consistent with the development of chemically reducing conditions owing to electron donor amendment perturbing the groundwater system by scavenging TEAs such as DO, nitrate, oxidized metals, and sulfate.

The indicator parameters dissolved iron, dissolved manganese, and TOC exhibited a generally increasing trend over the pilot study duration consistent with the typical response of groundwater systems to electron donor amendment. With respect to these metals, the increased dissolved iron concentration is consistent with the enhanced biochemical reduction of insoluble ferric iron (III) to soluble ferrous iron (II), mediated by iron-reducing bacteria. The increased dissolved manganese concentration is consistent with the enhanced biochemical reduction of insoluble manganese (IV) to soluble manganese (II), mediated by manganese-reducing bacteria. In the case of both iron and manganese oxide reduction, transformation was stimulated by electron donor amendment, which provided the organic carbon driving biochemical reduction. GZA notes that liberated ferrous iron (II) and manganese (II) are expected to be respectively oxidized to ferric iron (III) and manganese (IV), and then re-sorbed onto the formation matrix once they migrate beyond the anaerobic, chemically reducing treatment zone affected by electron donor amendment into the initially aerobic, chemically oxidizing reaches of the shallow overburden groundwater system. These oxidation reactions are expected to be nearly instantaneous at the temporal/spatial scale of interest.

With respect to TOC, the increased concentration is consistent with EDC-M amendment, as TOC is a suitable surrogate measurement. GZA notes that TOC concentrations did not generally begin to increase until about week 10, at which time there was an order of magnitude spiked increase in concentration for the groundwater samples collected at all locations of the well field.

CPCB-Lucknow also prepared the attached Baseline Total Organic Carbon Isoconcentration Plan and five Post-Injection Total Organic Carbon Isoconcentration Plans corresponding with the five rounds of post-injection monitoring. As shown on the Baseline Total Organic Carbon Isoconcentration Plan, the highest baseline TOC concentration was located in the vicinity of SMW, and the detected TOC concentrations were on the same order of magnitude. The Post-Injection Total Organic Carbon Isoconcentration Plans reflect the general increase in TOC concentrations resulting from the pilot study injection. The latter Post-Injection Hexavalent Chromium Isoconcentration Plan set suggests that the recirculation delivery approach was effective in propagating electron donor throughout the desired treatment area.

The indicator parameter, sulfide, was also analyzed as part of performance monitoring. Sulfide was not detected above analytical RLs during baseline groundwater sampling; however, it was detected at concentrations ranging from 0.5 mg/L (February 24, 2006; DW-2) to 34.2 (April 28, 2006; IW) during post-injection sampling. The increased sulfide concentration with time, in response to electron donor amendment, represents a secondary line of evidence that sulfate reduction was stimulated by electron donor amendment, and is consistent with the generally depressed sulfate concentrations, in response to the pilot study injection, as discussed above.

Collectively, these indicator parameters are generally consistent with conditions conducive for the microbially-mediated transformation of Cr (VI) to Cr (III), driven by electron donor amendment during the pilot study.

In addition to the biological transformation indicator parameters, GZA offers the following observations regarding the general water quality indicator parameters ph and specific conductivity for groundwater samples collected from the pilot study well field:

- pH values, in standard units, for baseline groundwater samples ranged from about 6.7 (IW) to 7.0 (DW-1 and DW-2), whereas values for post-injection samples ranged from about 4.6 (February 24, 2006; IW) to 7.5 (April 28, 2006; Skolast piezometer). Post-injection values for groundwater samples collected from the IW, SMW, DW-1, and DW-2 were typically lower than the baseline values approaching neutrality for these same locations, likely reflecting organic acid fermentation products of the remedial additive as well as biogenic production of carbon dioxide from remedial additive mineralization to yield carbonic acid. Despite the general post-injection decrease in pH for the groundwater samples collected from these wells, the values generally remained within the pH range considered conducive for microbial activity and did not appear to become inhibiting. Importantly, GZA understands that subsurface soils in the Site Vicinity contain significant bulk fraction of calcium carbonate, which serves as a natural buffering agent to maintain pH near baseline values. The baseline pH value for the groundwater sample collected from the Skolast piezometer was generally similar to the post-injection pH values for the same well, likely reflecting its respective location within the well field (*i.e.*, the most downgradient well); and

- Specific conductivity values for baseline groundwater samples ranged from about 865 (IW) to 1,450 (Skolast piezometer) microsiemens per centimeter (*u*s/cm), whereas values for post-injection samples ranged from about 962 (May 26, 2006; SMW) to 10,160 (February 24, 2006; IW) *u*s/cm. Post-injection specific conductivity values for groundwater samples collected from the IW, SMW, DW-1, and DW-2 were typically lower than baseline values, likely reflecting the total dissolved solid contribution to groundwater from remedial additive amendment. The baseline specific conductivity value for the groundwater sample collected from the Skolast piezometer was generally similar to the post-injection specific conductivity values for the same well, likely reflecting the piezometer's respective location within the well field (*i.e.*, the most downgradient location).

Other Metals Data

GZA offers the following observations regarding the analytical laboratory results for nickel, copper, cobalt, zinc, mercury, and arsenic:

- Nickel was generally detected during baseline sampling and up to the first two rounds of post-injection sampling at concentrations exceeding analytical RLs; however, it was generally not detected above analytical RLs for the last three rounds of post-injection sampling. According to CPCB-Lucknow, there is currently no established Indian Standard for Drinking Water Quality for that metal;

- Baseline and post-injection groundwater sampling results detected copper at relatively variable concentrations, with most detected concentrations exceeding the established Indian Standard for Drinking Water Quality of 0.05 mg/L for copper;

- Baseline groundwater sampling results did not detected cobalt above analytical RLs; however, it was detected at concentrations exceeding analytical RLs during up to two post-injection sampling rounds. According to CPCB-Lucknow, there is currently no established Indian Standard for Drinking Water Quality for that metal;

- Baseline and post-injection sampling results detected zinc at variable concentrations that did not exceed the Indian Standard for Drinking Water Quality of 5.0 mg/L;

- Baseline groundwater sampling results did not detect mercury above analytical RLs; however, mercury was detected at concentrations exceeding analytical RLs during up to two post-injection sampling rounds, with all detected concentrations exceeding the Indian Standard for Drinking Water Quality of 0.001 mg/L for that metal. Significantly, analytical results for the final two post-injections sampling rounds did not detect mercury above respective analytical RLs; and

- The baseline sampling result for arsenic were non detect above analytical RLs for all well field locations; whereas post-injection results for the last two consecutive rounds of monitoring (*i.e.*, April 28, 2006 and May 26, 2006) detected arsenic at concentrations ranging from 0.04 mg/L (May 26, 2006; SMW) to 0.1 mg/L (April 28, 2006 and

May 26, 2006; Skolast piezometer and DW-1, respectively), suggesting that electron donor amendment liberated arsenic either at or in excess of the Indian Standard for Drinking Water Quality of 0.05 mg/L for that metal, but generally not by more an order of magnitude. According to Brömssen (1999),[27] based on a study of arsenic mobility in India and Bangledesh, the development of anaerobic conditions stimulates the biochemical reduction of secondary ferric, aluminum, and/or manganese oxide coatings on the formation matrix, thereby liberating adsorbed arsenic from those coatings. However, the baseline overburden groundwater system is generally aerobic[28] and chemically oxidizing[29] and arsenic is readily adsorbed onto metal oxide coatings of formation matrices existing under such conditions. Therefore, the liberated arsenic is expected to be re-sorbed onto the formation matrix once it migrates beyond the influence of the anaerobic, chemically reducing treatment zone, affected by electron donor amendment, into the aerobic, chemically oxidizing conditions of the overburden groundwater system. Hence, GZA believes the elevated arsenic concentration associated with the pilot study injection program to be short lived and primarily constrained to the area of influence of the anaerobic treatment program.

Groundwater Elevation Data

Baseline and Post-Injection Groundwater Elevation Contour Plans are attached. As shown in the Baseline Groundwater Elevation Contour Plans, baseline groundwater flow was generally toward the south to southwest, trending roughly parallel with the canal to the east. As shown in the Post-Injection Groundwater Elevation Contour Plans, the groundwater flow net initially[30] reflected a groundwater depression in the general vicinity of the extraction well (DW-2), owing to groundwater pumping during recirculation, followed by variable flow directions that ultimately[31] resulted in a general flow reversal from the baseline direction of south to southwest, to the final apparent post-injection direction of north to northeast. Groundwater flow nets, following remedial injection programs, typically equilibrate to baseline conditions within a few weeks based on our experience. Therefore, the baseline and post-injection groundwater elevation contour plan sets are more consistent with conditions unrelated to the Remedial Pilot Study, such as the pumping of nearby shallow wells to meet potable/process water demand, irrigation associated with local agriculture, or variation in canal or other surface water stage.

PROPOSED CONCEPTUAL REMEDIAL APPROACH

Based on the positive results of the Remedial Pilot Study, GZA recommends a full-scale remedial program to advance the Study Area toward closure. The remedial program would focus on contaminant mass reduction in the identified Cr (VI) source areas directly impacting the local and intermediate groundwater flow systems. The remedial program would be focused on contaminant mass reduction in the identified source areas given that contaminant plumes, once source mass is

[27] Brömssen, M.V., 1999, Genesis of high arsenic groundwater in the Bengal Delta Plains, West-Bengal and Bangladesh, in Thesis, Division of Land and Water Resources, Department of Civil and Environmental Engineering, Royal Institute of Technology, Stockholm, Sweden, 49 p.

[28] *i.e.*, DO concentrations ranging from 3.2 to 4.9 mg/L (arithmetic mean of 4.3 mg/L) for baseline groundwater samples collected from pilot study wells (refer to the "Biological transformation Indicator Parameters" section of this letter report).

[29] *i.e.*, Eh values ranging from +105 to +118 mV (arithmetic mean of +111 mV) for baseline groundwater samples collected from pilot study wells (refer to the "Biological transformation Indicator Parameters" section of this letter report).

[30] *i.e.*, seven days following completion of the injection program.

[31] *i.e.*, 106 days following completion of the injection program

removed/treated, typically stop expanding and then begin to contract owing to the combined affects of natural attenuation processes. Therefore, a source-area focused remedial program could cost-effectively remove Cr (VI) contaminant mass in the Study Area.

The primary objective of the remedial program would be the reduction of risk posed by the Cr (VI)-impacted shallow groundwater system to the following potential sensitive receptors:

- Residential or small community water supply wells installed in the shallow overburden groundwater system used to supply potable water to local residents given the presence of Cr (VI) at concentrations exceeding the respective Indian Standard for Drinking Water Quality of 0.05 mg/L Cr (VI); and
- Industrial, municipal, or large community potable water supply wells installed in the deeper, regional groundwater flow system. While water quality of the regional groundwater flow system has reportedly not yet been impacted by the shallow Cr (VI) contaminant condition, the possibility exists for vertical migration of Cr (VI) from the shallow Cr (VI)-impacted unit to the deep regional flow system driven by the generally downward hydraulic gradient, which could have a significant, deleterious impact upon that natural resource.

Given that CPCB-Lucknow is performing a hydrogeologic investigation to further evaluate the magnitude and extent of overburden soil and groundwater contamination by Cr (VI) and other contaminants in the Study Area, GZA requested that they develop the attached Site Hydrogeologic Information and Study Area Baseline Chemical Parameter Ranges for Soil information packages[32] to establish the contaminant hydrogeologic assumptions upon which GZA could base our Proposed Conceptual Remedial Approach to advance the Study Area toward closure.

Based on review of the information provided by CPCB-Lucknow, the preliminary CSM for the Study Area, and the positive results of the Remedial Pilot Study, GZA proposes carrying out a full-scale remedial program to protect potential sensitive receptors within the Study Area. The remedial program would include the following four main tasks, each of which is expanded upon below:

- <u>Data Gap Investigation</u>, which would refine the preliminary CSM and form the basis for the remedial design;
- <u>Preparation of a Remedial Action Plan (RAP)</u>, which would propose the final remedial design based on the results of the Remedial Pilot Study and the Data Gap Investigation, as well as the revised CSM;
- <u>RAP Implementation</u>, which would involve implementation of the remedial program proposed in the RAP; and
- <u>Performance Monitoring</u>, which would involve implementation of the performance monitoring program proposed in the RAP.

[32] Please note that both information packages were prepared by CPCB-Lucknow in consultation with GZA.

DATA GAP INVESTIGATION

A Data Gap Investigation would be performed to finalize the preliminary CSM for the Study Area. The investigation would focus on clarifying subsurface hydrogeologic and contaminant conditions at potential Cr (VI) source areas in the Study Area as well as delineating the spatial extent of overburden groundwater contamination. The Data Gap Investigation would include the following:

- File reviews of pertinent historical records and interviews with certain officials having knowledge of disposal practices of Cr (VI)-impacted waste in the Study Area. GZA would also include remote sensing to help determine the spatial extent of identified disposal areas depending on the availability of high and low altitude photographs, infrared photographs, and other similar resources having coverage of areas of interest. The focus of this work phase would be the identification of potential Cr (VI) source areas in the Study Area to help select drill target locations for supplemental soil/groundwater quality sampling;
- Supplemental soil/groundwater quality sampling to better delineate the spatial extent of contamination, focusing on identified source areas based on drill target locations as well as contingency targets identified during the file reviews, interviews, and remote sensing work;
- Supplemental hydraulic testing to obtain further design data for the RAP, which would likely include the performance of hydraulic tests at up to about ten wells in the Study Area to evaluate horizontal hydraulic conductivity under constant head pumping conditions;
- Level survey of newly installed wells to tie them into the existing well network; and
- Update of the CSM of Cr (VI) fate and transport for the Study Area, and characterization of the unacceptable risk chromium contamination may pose to potential sensitive receptors.

Prior to start of the Data Gap Investigation, GZA would recommend development of a work plan for approval by CPCB-Lucknow and stakeholders. The work plan would include the proposed methods of the investigation, exploration locations, and an implementation schedule. The work plan would include a Quality Assurance Project Plan (QAPP) describing the specific procedures by which sampling and analytical procedures would be documented. QAPP activities would include setting data quality objectives; establishing standard operating procedures; and analysis of blank, spike, or duplicate samples.

RAP PREPARATION

Following the Data Gap Investigation, GZA would recommend development of a RAP, which would include a preliminary design for the remedial program based on the revised CSM as well as the results of the Remedial Pilot Study presented herein. RAP preparation would include the following main elements:

- Review of background information on hazardous material/waste storage/disposal practices in the Study Area and the investigations completed to date to determine the spatial extent and magnitude of Cr (VI) contamination, including both source and dissolved-phase mass. The review would include a summary of the methods and results of the Data Gap Investigation;

- A remedial options evaluation to optimize the *in-situ* bioremediation approach. The review would include a cost benefit analysis of various remedial approaches, within the framework of the updated CSM, to select the most cost-effective remedial approach to advance the Study Area toward closure. Given the encouraging Remedial Pilot Study results, the remedial options evaluation would include an evaluation of different remedial additives (including EDC-M) available at the time of implementation that can stimulate the biochemical reduction of Cr (VI) to Cr (III) on a cost benefit basis to select the most cost effective additive for a full-scale *in-situ* bioremediation program as well as an appropriate dosage rate;[33]
- A preliminary remedial design to advance the Study Area toward closure, including remedial performance standards and target remedial goals. The design will address area of influence issues for the injection program;
- A proposed performance monitoring program specifying sampling locations, analytes, and sampling frequency to evaluate remedial performance;
- Proposed implementation schedule;
- Review of potentially applicable regulations given the preliminary remedial design;
- A project reporting schedule, which would likely include data submittals following scheduled performance monitoring rounds and annual reports summarizing project results and proposing additional work, if warranted, at the conclusion of each calendar year for the project duration; and
- Preparation of a Public Involvement Plan (PIP) to solicit feedback on the proposed remedial design from the public, non governmental groups, and other stakeholders. The PIP would include a meeting schedule and periodic status reports at appropriate project milestones.

RAP IMPLEMENTATION

Once approved by CPCB-Lucknow and identified stakeholders, GZA recommends that the remedial work proposed in the RAP be implemented in accordance with the approved implementation schedule. Based on the Site Hydrogeologic Information and Study Area Baseline Chemical Parameter Ranges for Soil information packages provided by CPCB-Lucknow, GZA preliminarily assumes the remedial program would include electron donor injections targeted at about ten vadose zone Cr (VI) source areas and about twenty phreatic zone areas of elevated Cr (VI) concentrations. Based on the information provided by CPCB-Lucknow, we assume the vadose zone Cr (VI) source areas would include at least 50,000 kilograms of electron donor and that treatment would take up to about six months to complete, and the phreatic zone areas of elevated Cr (VI) concentrations would include at least 200,000 kilograms of electron donor and that treatment would take up to about 18 months to complete. *GZA notes that the actual remedial program may vary significantly based on the results of the Data Gap Investigation and the revised CSM.*

[33] ECI reports that while the EDC-M used for this Remedial Pilot Study was manufactured in Japan and shipped to the Study Area for the pilot study, ECI reports it would be manufactured in India in the future to reduce unit cost. ECI indicates they are committed to providing remedial additive on a cost-competitive basis for the Indian market.

PERFORMANCE MONITORING

Once the RAP is approved by CPCB-Lucknow and identified stakeholders, performance monitoring would be implemented in accordance with the RAP. GZA assumes performance monitoring would include triannual groundwater sampling (three times per year) for Cr (VI) and Total Cr at up to about 50 monitoring wells in the Study Area for about five years and monitoring of a subset of those locations for the indicator parameters listed in the Baseline Monitoring section of this letter report. Because electron donor amendment program may temporarily mobilize arsenic within the area of influence of the anaerobic treatment zone, GZA recommends that performance monitoring include arsenic to address that issue.

FULL-SCALE REMEDIAL PROGRAM OPINION OF COST

At the request of Blacksmith, GZA has included an order-of-magnitude opinion of cost for carrying out the conceptual remedial program described herein. The opinion of cost is presented to facilitate a remedial options evaluation to compare *in-situ* bioremediation with alternative remedial technologies and select an appropriate remedy to advance the Study Area toward closure and should not be considered a budget estimate for implementing the described remedial program. Our order-of-magnitude opinion of cost is summarized below by task:

TASK	ASSUMPTIONS[34]	SUBTOTAL ($)
Data Gap Investigation	• Work Plan preparation, up to two weeks of engineering.	$10,000
	• File Reviews, Interviews, Remote Sensing; up to one month of engineering.	$20,000
	• Supplemental soil/groundwater quality sampling, up to four months of engineering.	$200,000
	• Supplemental hydraulic testing, up to one week of engineering.	$15,000
	• Level Survey, up to one week of engineering.	$5,000
	• CSM Update, up to two months of engineering.	$30,000
RAP Preparation	• Up to three months of engineering analysis.	$50,000
RAP Implementation	• RAP Implementation assumes: - About six months of vadose zone injections at up to about ten locations; - About 18 months of phreatic zone injections at up to about 20 locations; and • Remedial additive unit cost ranging from about \$0.10[35] to \$3.00[36] per pound, depending on the results of the remedial options evaluation.	$1,025,000 to $3,060,000
Performance Monitoring	• Performance monitoring assumes triannual monitoring (three times per year) for Cr (VI) and Total Cr at up to about 50 monitoring wells for five years and a subset of locations for indicator parameters.	$200,000
Contingency	• 10% of total to address uncertainty	$160,000 to $360,000
	TOTAL	$1,715,000 to $3,950,000

[34] Assumptions assume direct project collaboration with CPCB-Lucknow consistent with that provided for the Remedial Pilot Study described herein.

[35] This unit cost is based on the use of carbohydrate-based materials and twice the electron donor load of EDC-M to account for potentially lower relative performance.

[36] This unit cost is based on EDC-M, manufactured by ECI in India.

Because investigative work by CPCB-Lucknow is ongoing, the underlying assumptions for this opinion of cost will almost certainly be revised as additional hydrogeologic data are gathered and analyzed. *GZA's opinion of cost is implicitly linked to the assumptions included in the Site Hydrogeologic Information prepared by CPCB-Lucknow, the preliminary CSM included herein, our proposed remedial approach given the positive pilot study result, and our remedial experience at hundreds of similar sites in the USA and internationally, and would need to be revised as additional hydrogeologic data are collected*. GZA notes that the RAP would include an updated opinion of cost based on Data Gap Investigation results and the revised CSM.

CONCLUSIONS AND RECOMMENDATIONS

The pertinent conclusions of the Remedial Pilot Study are as follows:

- Cr (VI) contamination in the local and intermediate groundwater flow systems poses unacceptable risk to:
  - Potential sensitive receptors for shallow overburden groundwater owing to its presence at concentrations exceeding the Indian Standard for Drinking Water Quality, and
  - The deep, regional groundwater flow system owing to potential for vertical migration from the shallow Cr (VI)-impacted groundwater flow system driven by the generally downward hydraulic gradient; and
- Electron donor amendment stimulated the biologically-mediated transformation of up to about 99.9% of mobile and toxic Cr (VI) mass to immobile and nontoxic Cr (III) during the 17-week pilot study. In fact, laboratory analysis of groundwater samples collected from four of five well field locations during the last post-injection sampling round did not detect Cr (VI) at concentrations exceeding Indian Standard for Drinking Water Quality. Indicator parameter data were consistent with Cr (VI) transformation to Cr (III) owing to microbially-mediated processes in accordance with the Remedial Pilot Study technical approach.

Based on the positive results of the Remedial Pilot Study and the preliminary CSM developed as part of this work, GZA recommends implementing a full-scale remedial program in the Study Area as expeditiously as practical to advance it toward closure, which would include the following proposed tasks described herein: 1) Data Gap Investigation; 2) Preparation of a RAP; 3) RAP Implementation; and 4) Performance Monitoring.

ACKNOWLEDGEMENTS

GZA would like to acknowledge the respective contributions of CPCB-Lucknow and ECI/ECJ to this Remedial Pilot Study. As previously mentioned, Mr. R. K. Singh, Ph.D. of CPCB-Lucknow and his staff provided considerable scheduling, logistical, field staffing, analytical, Computer Aided Design, data summary, and regulatory overview support for the Remedial Pilot Study. Their exemplary support was continuous and of the highest quality throughout the project. Indeed, the Remedial Pilot Study could not have been executed without the invaluable support of Dr. Singh and his CPCB-Lucknow staff. ECI/ECJ provided the remedial additive, EDC-M, pro bono for the study as discussed above in **Task 2** (Remedial Pilot Study Implementation and Reporting). In addition to providing EDC-M, Mr. Shrihari Chandraghatgi, Ph.D. of ECJ provided

pro bono product support throughout the work scoping phase of the project as well as review comments on this letter report. GZA sincerely appreciates the respective contributions of CPCB-Lucknow and ECI/ECJ to this Remedial Pilot Study.

GZA very sincerely appreciates the opportunity to be of service to The Blacksmith Institute on this most important project. Should you have any questions or require additional information, please contact the undersigned at your convenience.

Very truly yours,

GZA GEOENVIRONMENTAL, INC.

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Attachments: Limitations
Data Summary Table
Figures
Boring Logs
Summary of Site Hydrogeologic Information
Study Area Baseline Chemical Parameter Ranges for Soil

cc: R.K. Singh, Ph.D., CPCB-Lucknow

LIMITATIONS

GEOHYDROLOGICAL LIMITATIONS

1. The conclusions and recommendations submitted in this report are based in part upon the data obtained from a limited number of soil samples from widely spaced subsurface explorations. The nature and extent of variations between these explorations may not become evident until further investigation. If variations or other latent conditions then appear evident, it will be necessary to reevaluate the recommendations of this report.

2. The generalized soil profile described in the text is intended to convey trends in subsurface conditions. The boundaries between strata are approximate and idealized and have been developed by interpretations of widely spaced explorations and samples; actual soil transitions are probably more gradual. For specific information, refer to the boring logs.

3. Water level readings have been made in the test pits, borings, and/or observation wells at times and under conditions stated on the exploration logs. These data have been reviewed and interpretations have been made in the text of this report. However, it must be noted that fluctuations in the level of the groundwater may occur due to variations in rainfall and other factors different from those prevailing at the time measurements were made.

4. Except as noted within the text of the report, no quantitative laboratory testing was performed as part of the site assessment. Where such analyses have been conducted by an outside laboratory, GZA GeoEnvironmental, Inc. (GZA) has relied upon the data provided, and has not conducted an independent evaluation of the reliability of these data.

5. The conclusions and recommendations contained in this report are based in part upon various types of chemical data and are contingent upon their validity. These data have been reviewed and interpretations made in the report. As indicated within the report, some of these data are preliminary "screening" level data, and should be confirmed with quantitative analyses if more specific information is necessary. Moreover, it should be noted that variations in the types and concentrations of contaminants and variations in their flow paths may occur due to seasonal water table fluctuations, past disposal practices, the passage of time, and other factors. Should additional chemical data become available in the future, these data should be reviewed by GZA, and the conclusions and recommendations presented therein modified accordingly.

6. Chemical analyses have been performed for specific parameters during the course of this study, as detailed in the text. It must be noted that additional constituents not searched for during the current study may be present in soil and groundwater at the site.

7. It is recommended that this firm be retained to provide further engineering services during design, implementation, and/or construction of any remedial measures, if necessary. This is to observe compliance with the concepts and recommendations contained herein and to allow design changes in the event that subsurface conditions differ from those anticipated.

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DATA SUMMARY TABLE

Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

DATA SUMMARY TABLE

Location Specifc Format

Location : Injection Well (IW)

DATE	SWL	pH	DO	Eh	Cond	S^{2-}	SO_4^{2-}	NO_3	TOC	Cr^{+6}	T-Cr	Fe	Mn	Ni	Cu	Co	Zn	Hg	As
26.01.06	11.15	6.91	4.14	118	865	ND	139	3.52	34.46	10.01	12.88	0.17	0.06	0	0.01	0	0.08	ND	ND
09.02.06	11.82	Sampling was not possible due to excessive foaming																	
24.02.06	12	4.6	0.9	-25	10160	**	270	**	34.22	**	6.42	351.65	71	0.34	0.53	0.54	2.13	**	**
10.04.06	12	6.96	1.7	-140	3870	5.96	35.18	0.92	420.21	ND	0.19	40.45	15.08	ND	1.58	ND	1.16	0.04	ND
28.04.06	12.39	6.71	1.6	-163	2290	34.2	28.94	0.25	72.89	ND	0.08	9.94	2.98	ND	0.15	ND	0.96	ND	0.06
26.05.06	13.12	6.45	1	-110	1140	3.3	61	0.23	82.39	ND	0.12	7.16	1.9	ND	0.06	ND	0.03	ND	0.08

Location : Side Gradient Monitoring Well (SMW)

DATE	SWL	pH	DO	Eh	Cond	S^{2-}	SO_4^{2-}	NO_3	TOC	Cr^{+6}	T-Cr	Fe	Mn	Ni	Cu	Co	Zn	Hg	As
26.01.06	11.55	6.94	4.8	115	1014	ND	263	5.45	52.14	8.16	16.39	0.31	0.06	0	0.03	0	0.07	ND	ND
09.02.06	11.93	Sampling was not possible due to excessive foaming																	
24.02.06	12.6	6.06	1.8	-93	3290	1	140	1.73	46.23	0.56	0.86	67.95	11.11	0.05	0.2	0.02	0.14	**	**
10.04.06	11.95	6.55	1	-70	1535	3.73	60.41	1.03	211.71	ND	0.47	14.68	2.91	ND	0.94	ND	0.17	0.06	ND
28.04.06	12.55	6.74	1.8	-196	1019	1.2	77.38	0.55	30.38	ND	0.87	7.03	3.33	ND	0.08	ND	0.33	ND	0.05
26.05.06	12.98	6.62	1.4	-234	962	6.2	161	1.4	39.23	ND	0.57	5.03	0.74	ND	0.05	ND	0.03	ND	0.04

Location : Downgradient Well No. 1 (DW-1)

DATE	SWL	pH	DO	Eh	Cond	S^{2-}	SO_4^{2-}	NO_3	TOC	Cr^{+6}	T-Cr	Fe	Mn	Ni	Cu	Co	Zn	Hg	As
26.01.06	11.35	7.04	4.6	105	1120	ND	214	2.2	52.02	11.2	15.28	0.27	0.03	0.02	0.4	0	0.23	ND	ND
09.02.06	12.19	5.83	3.7	-18	2250	2.24	337	1.46	51.35	0.34	10.16	37.13	11.76	0.05	0.08	0.03	0.28	ND	ND
24.02.06	12.4	6.39	2.9	-49	1657	0.6	142	1.05	51.64	0.06	1.68	19.78	7.95	0	0.04	0	0.25	0.05	ND
10.04.06	12.2	6.44	0.8	-70	2380	10.2	58.57	0.52	446.84	ND	7.78	100.6	11.04	ND	0.6	ND	0.22	0.08	ND
28.04.06	12.78	6.52	1.3	-394	1309	6.8	31.32	0.52	128.37	ND	0.4	17.94	3.83	ND	0.12	ND	0.32	ND	0.08
26.05.06	13	6.24	1.2	-128	1216	92	76	1.3	98.3	ND	0.2	13.71	2.51	ND	ND	ND	0.19	ND	0.1

Location : Downgradient Well No. 2 (DW-2)

DATE	SWL	pH	DO	Eh	Cond	S^{2-}	SO_4^{2-}	NO_3	TOC	Cr^{+6}	T-Cr	Fe	Mn	Ni	Cu	Co	Zn	Hg	As
26.01.06	11.52	7.02	4.9	112	1256	ND	289	4.89	46.04	12.55	19.49	5.2	0.3	0.01	0.07	0	0.19	ND	ND
09.02.06	12.07	6.15	3.4	-15	1838	12.16	352	2.09	47.33	0.23	9.09	16.82	8.82	0.01	0.03	0.02	0.18	ND	ND
24.02.06	12.35	6.42	2.7	-24	2080	0.5	236	1.33	50.28	ND	7.79	24.45	7	0.03	0.01	0.003	0.09	0.06	ND
10.04.06	11.98	6.58	0.8	-43	1454	4.26	92.98	1.4	225.9	ND	3.3	17.17	4.26	ND	0.09	ND	0.19	0.09	ND
28.04.06	12.54	6.78	1.2	-110	968	8.24	96.09	1.27	41.6	ND	2.71	5.99	1.71	ND	0.08	ND	1.09	ND	0.05
26.05.06	12.98	6.48	0.8	-1	1039	ND	93	2.15	61.6	0.67	2.87	4.03	0.87	ND	0.02	ND	0.02	ND	0.07

Location : Skolast Piezometer (PM)

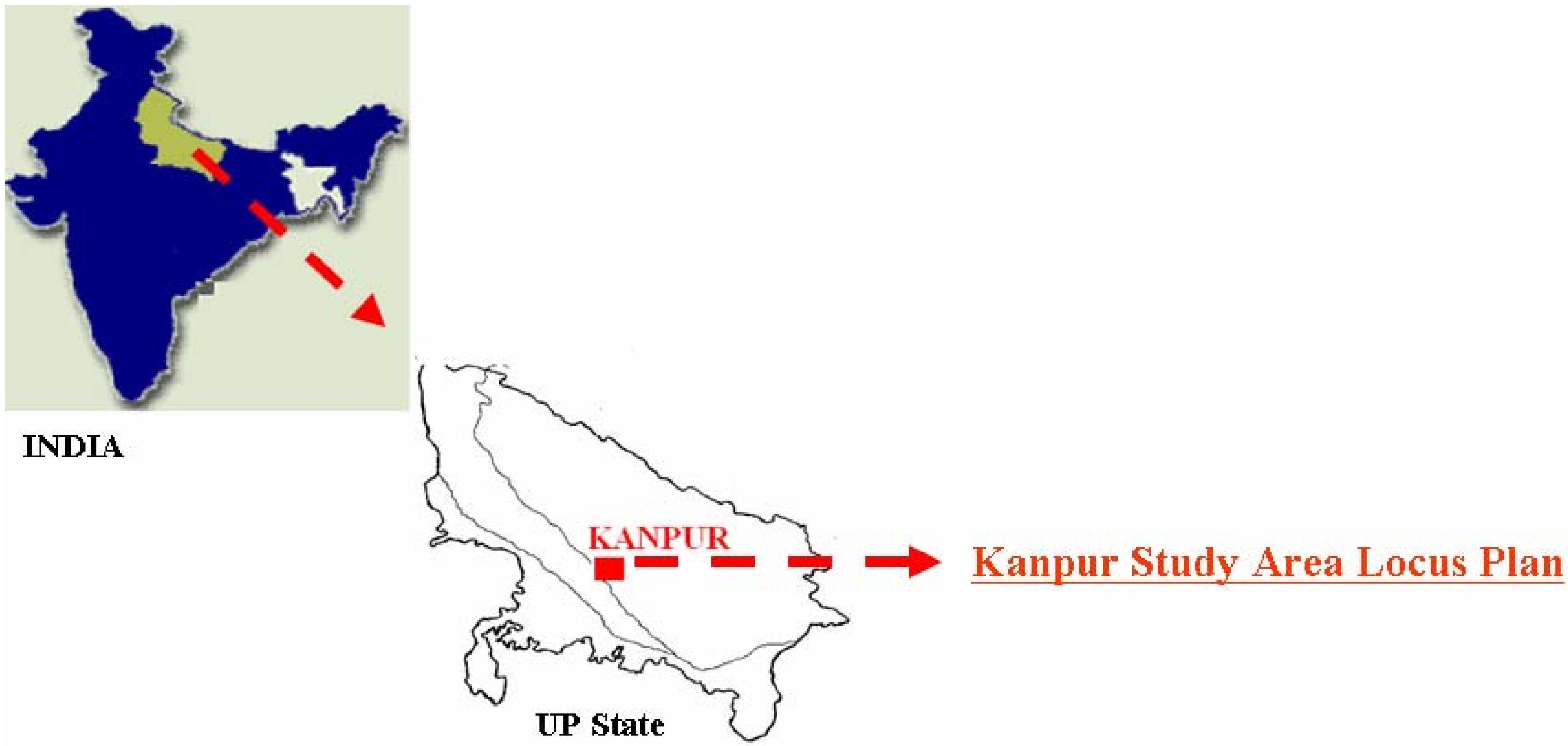
DATE	SWL	pH	DO	Eh	Cond	S^{2-}	SO_4^{2-}	NO_3	TOC	Cr^{+6}	T-Cr	Fe	Mn	Ni	Cu	Co	Zn	Hg	As
26.01.06	11.77	6.73	3.2	105	1450	ND	394	9.79	37.57	11.8	14.94	0.66	0.15	0.04	0.08	0	0.12	ND	ND
09.02.06	10.78	6.74	3.8	-12	1330	0.85	183	6.09	38.21	4.17	10.66	28.36	2.42	0.11	1.8	0	1.01	ND	ND
24.02.06	11.8	7.16	3	-13	1563	ND	235	1.34	39.2	0.32	0.46	4.7	1.68	0.04	0.1	0	0.11	0.01	ND
10.04.06	11.87	6.75	0.8	-36	1376	3.98	95.33	1.31	208.16	ND	1.44	6.7	2.63	ND	0.87	ND	0.23	0.02	ND
28.04.06	12.15	7.51	1.3	-88	1438	7.7	148.88	1.73	56.92	ND	0.9	54.27	4.91	ND	0.84	ND	0.65	ND	0.1
26.05.06	12.87	7.4	1.5	-156	1372	2.7	55	0.35	66.86	ND	0.28	27.12	2.36	0.05	1.06	ND	0.29	ND	0.05

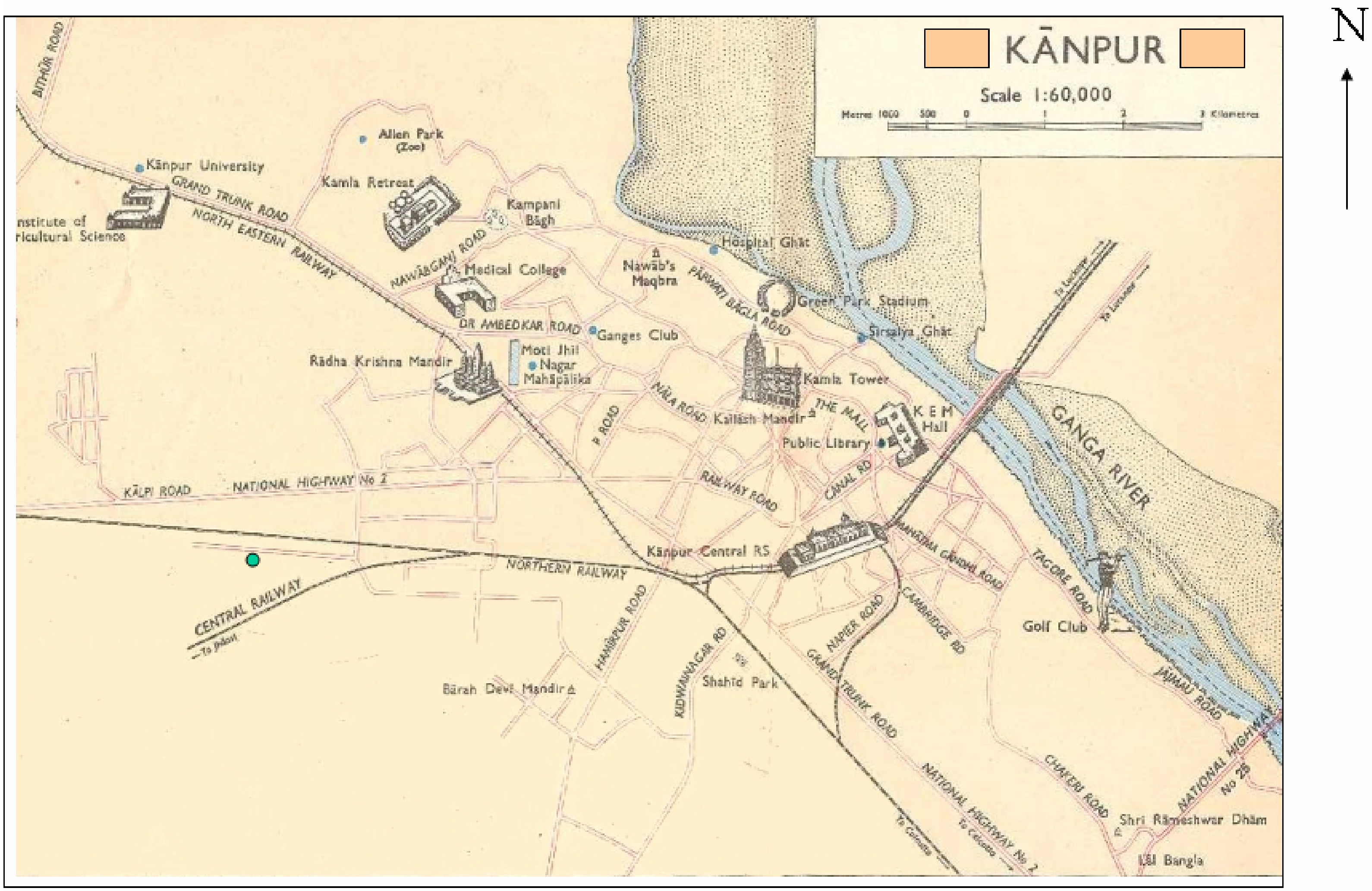
Note : 1. Results of heavy metals, except Cr(VI), are reported as Total Dissolved metals, analyzed on AAS (Flame mode)

a) SWL : Static water level in meters below ground level
b) Eh in mV
c) Conductivity in μS /cm
d) All others except pH in mg/l
e) ND: Not detectable ;
*f) ** : could not be done due to excessive turbidity*

FIGURES

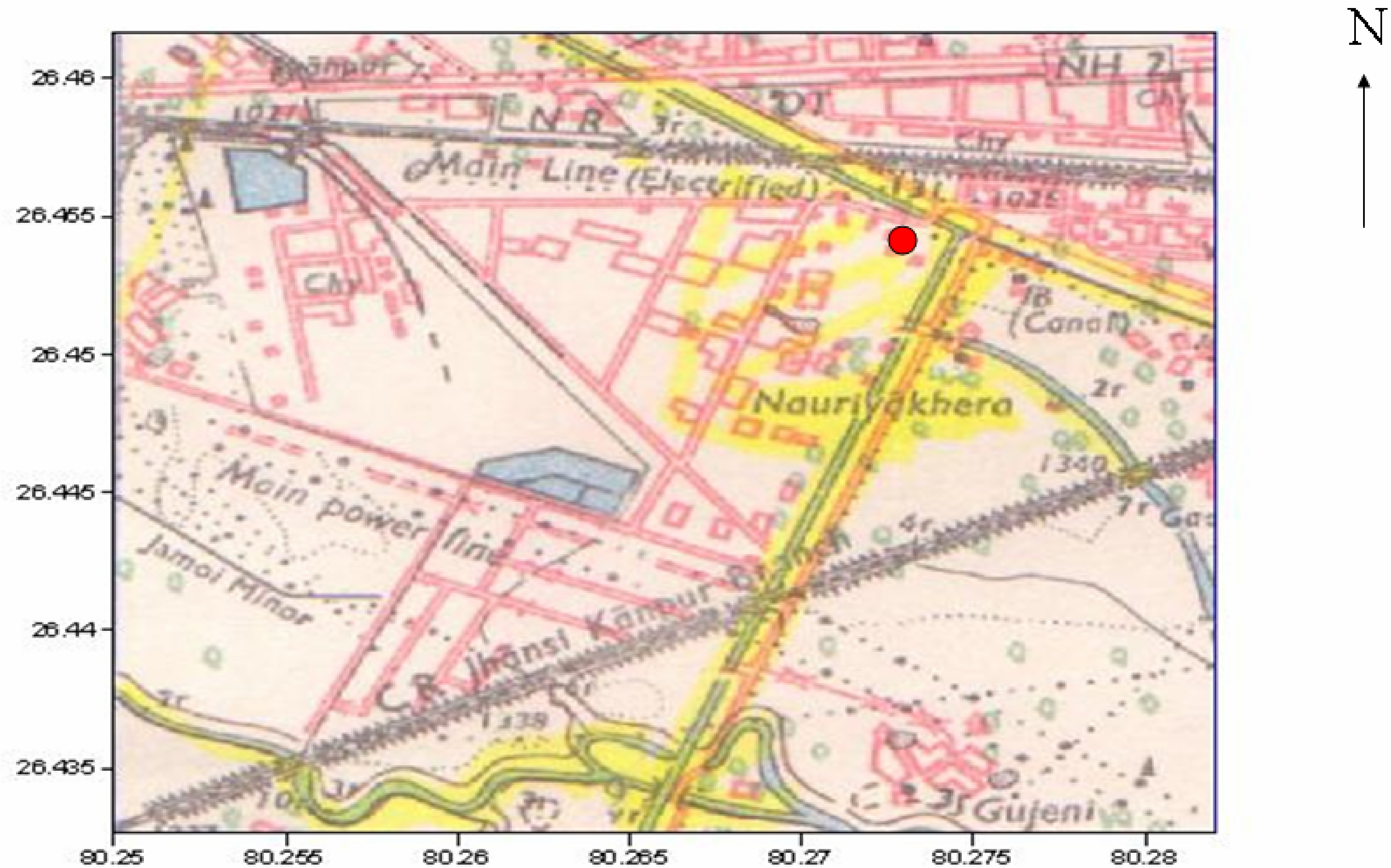
Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.


INDIA
KANPUR
UP State
Kanpur Study Area Locus Plan



Map of Kanpur city depicting location of Study Area "●"

Source: Survey of India, Ministry of Science and Technology, Govt. of India

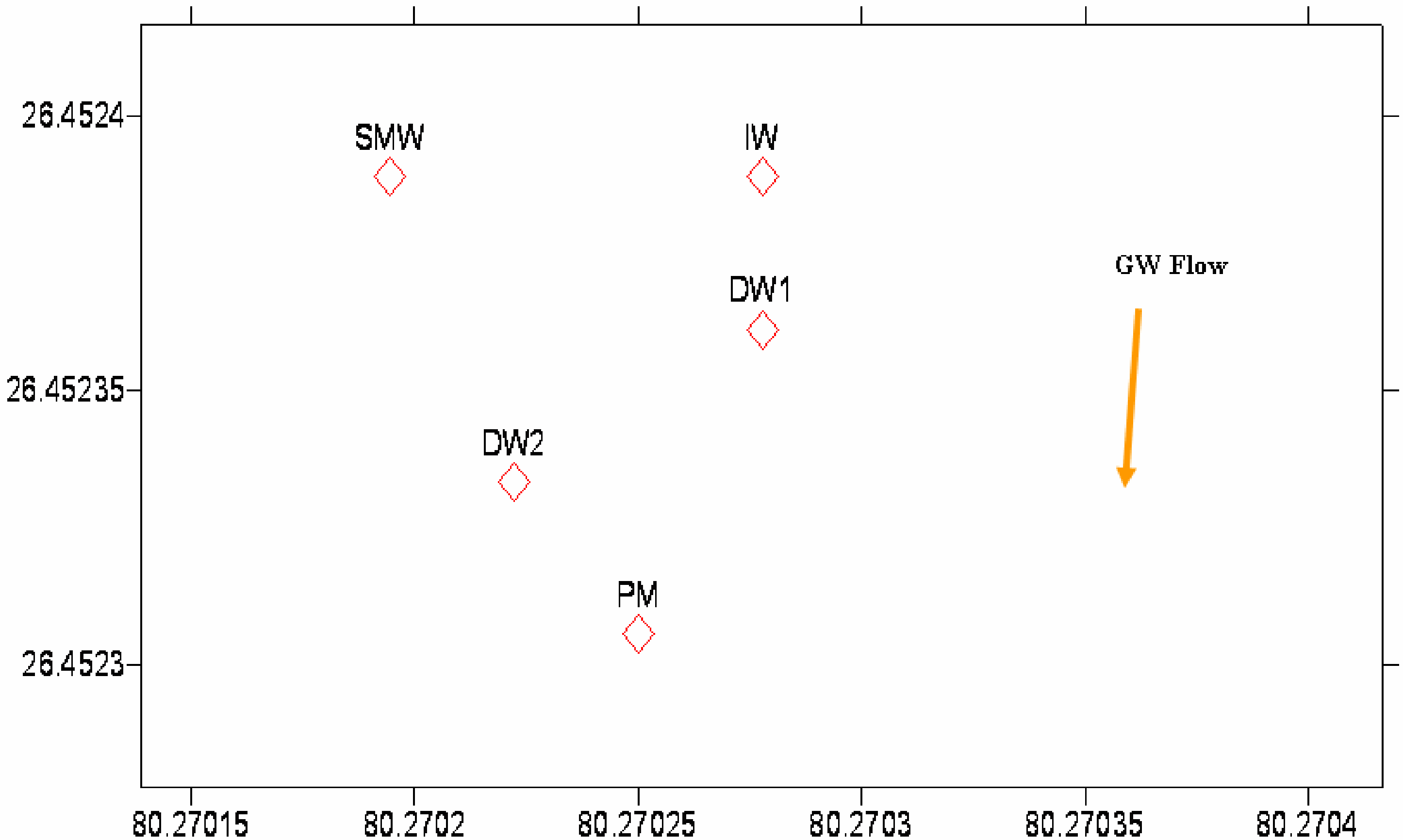


Study Area map depicting location of Remedial Pilot Study “ ● ”

Source: Survey of India, Ministry of Science and Technology, Govt. of India

Exclusively for Pilot Study area

Fig.:1a: Well Field Exploration Location Plan

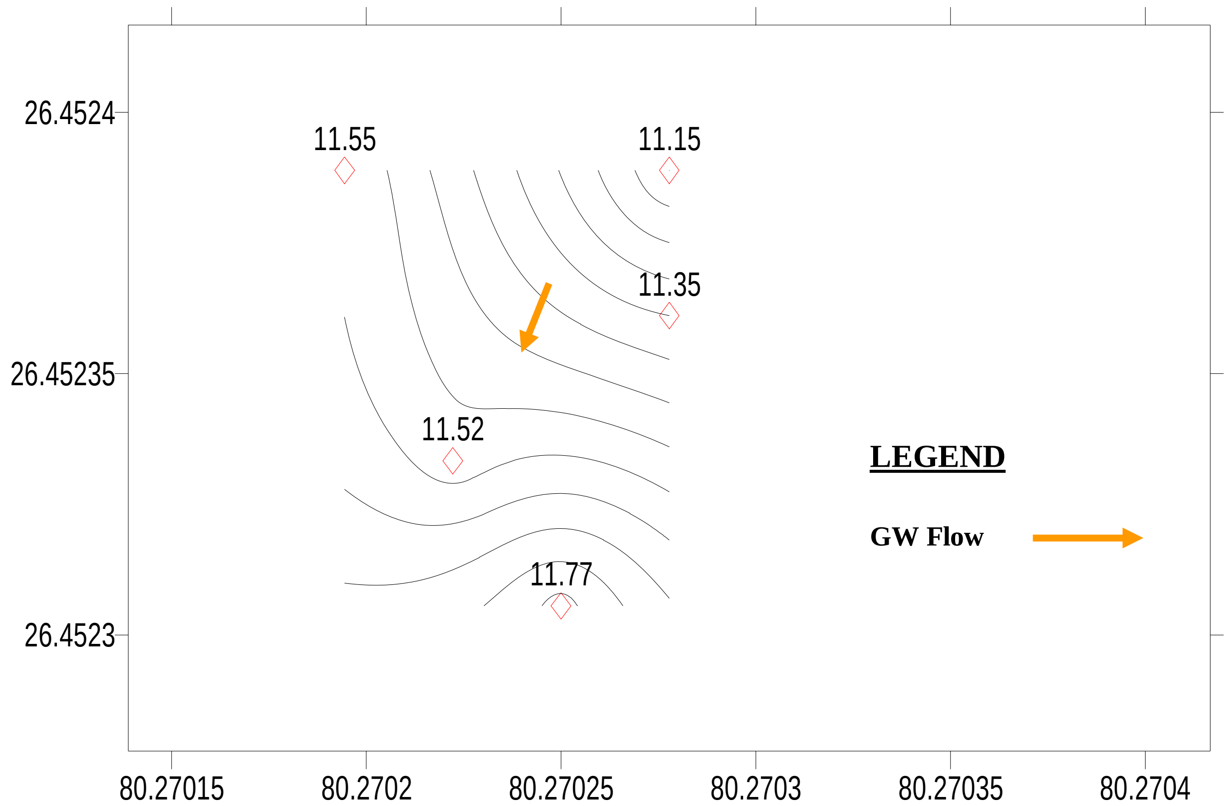


IW: Injection Well; SMW : Side Monitoring Well; DW1 / DW2: Down-gradient Monitoring Wells, PM: Piezometer

BASELINE GROUNDWATER ELEVATION CONTOUR PLANS

Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

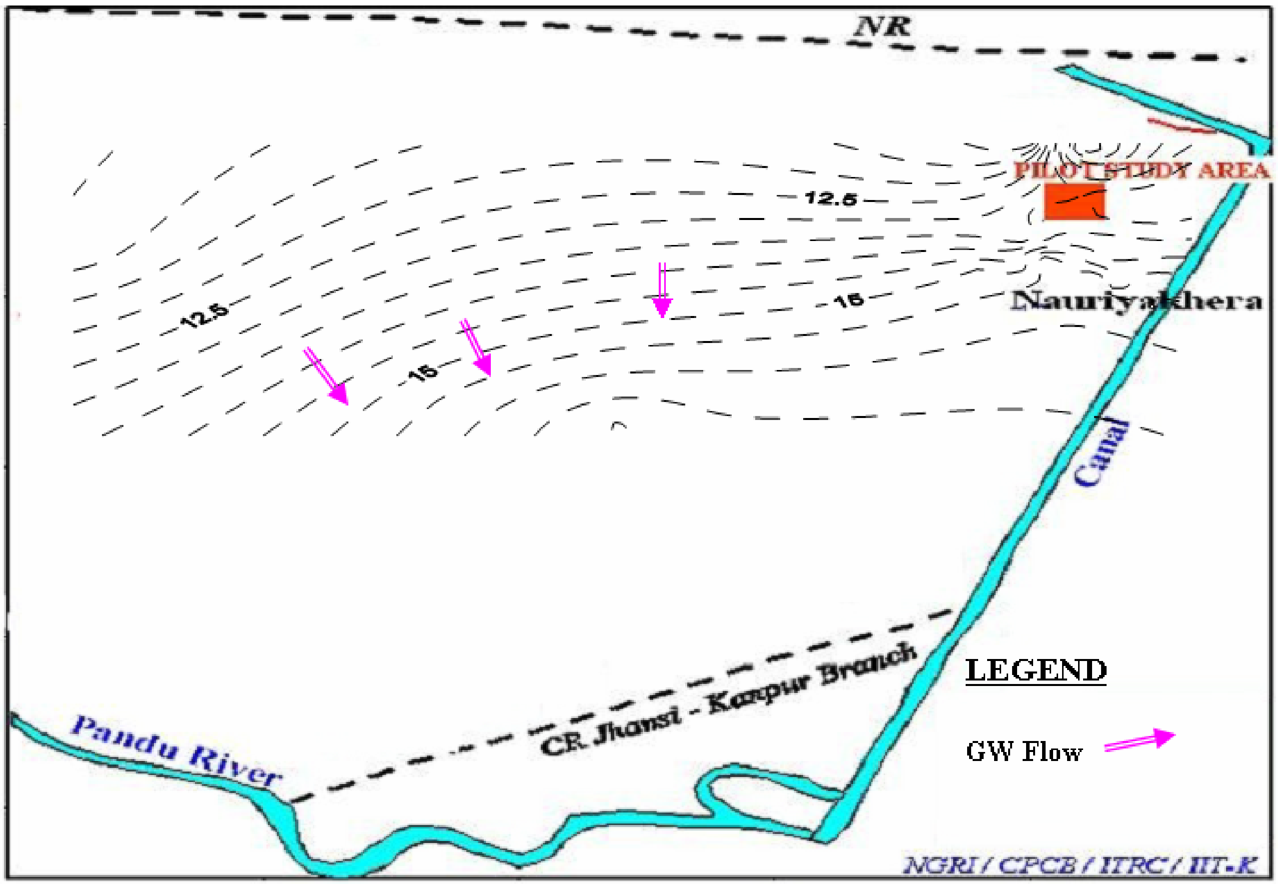
Fig: 2: Groundwater Elevation (DWL) – Pre Injection



Note : Contours plotted using DWL in meters below ground level

Fig.:2a : Groundwater Elevation (DWL) – Pre Injection

Regional Scenario*



Note : Contours plotted using DWL in meters below ground level

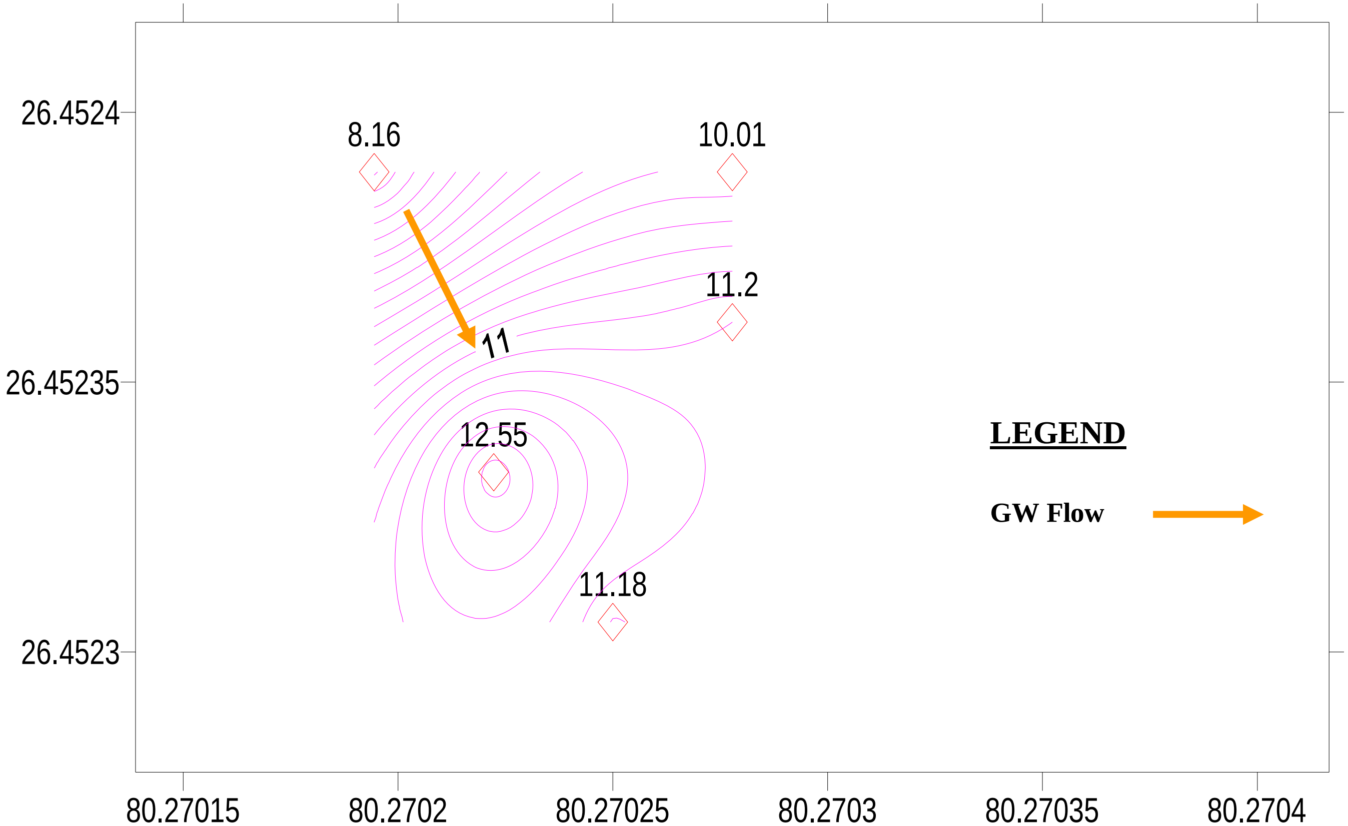
** Based on observations for wells other than those developed in the Pilot Study*

BASELINE HEXAVALENT CHROMIUM ISOCONCENTRATION PLAN

Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

sively for Pilot Study area

Fig.:3: Cr-VI – Pre Injection

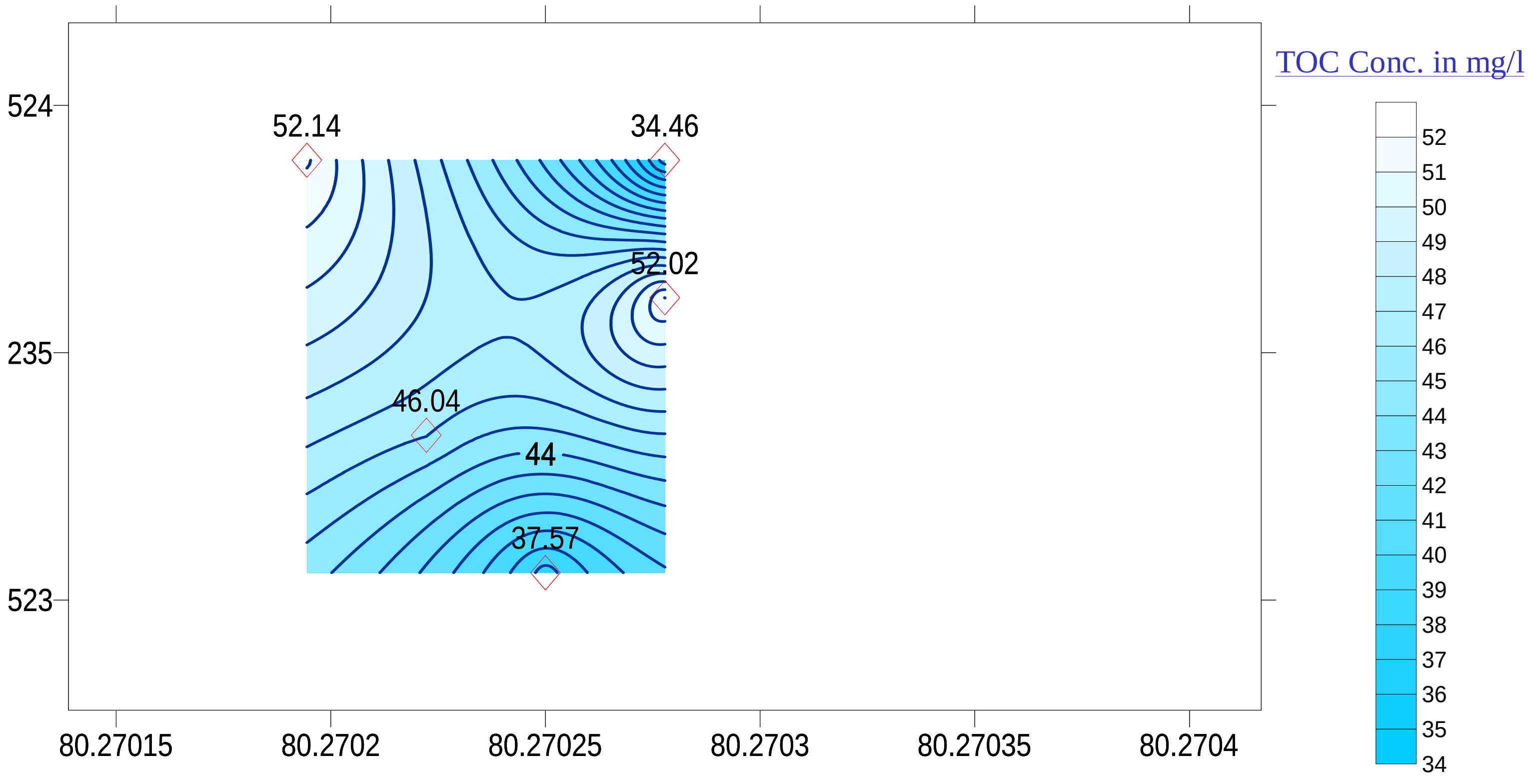


Note : Contours plotted using conc. of Cr-VI in mg/l

BASELINE TOTAL ORGANIC CARBON ISOCONCENTRATION PLAN

Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

Fig.:4: TOC – Pre Injection (on colour scale)

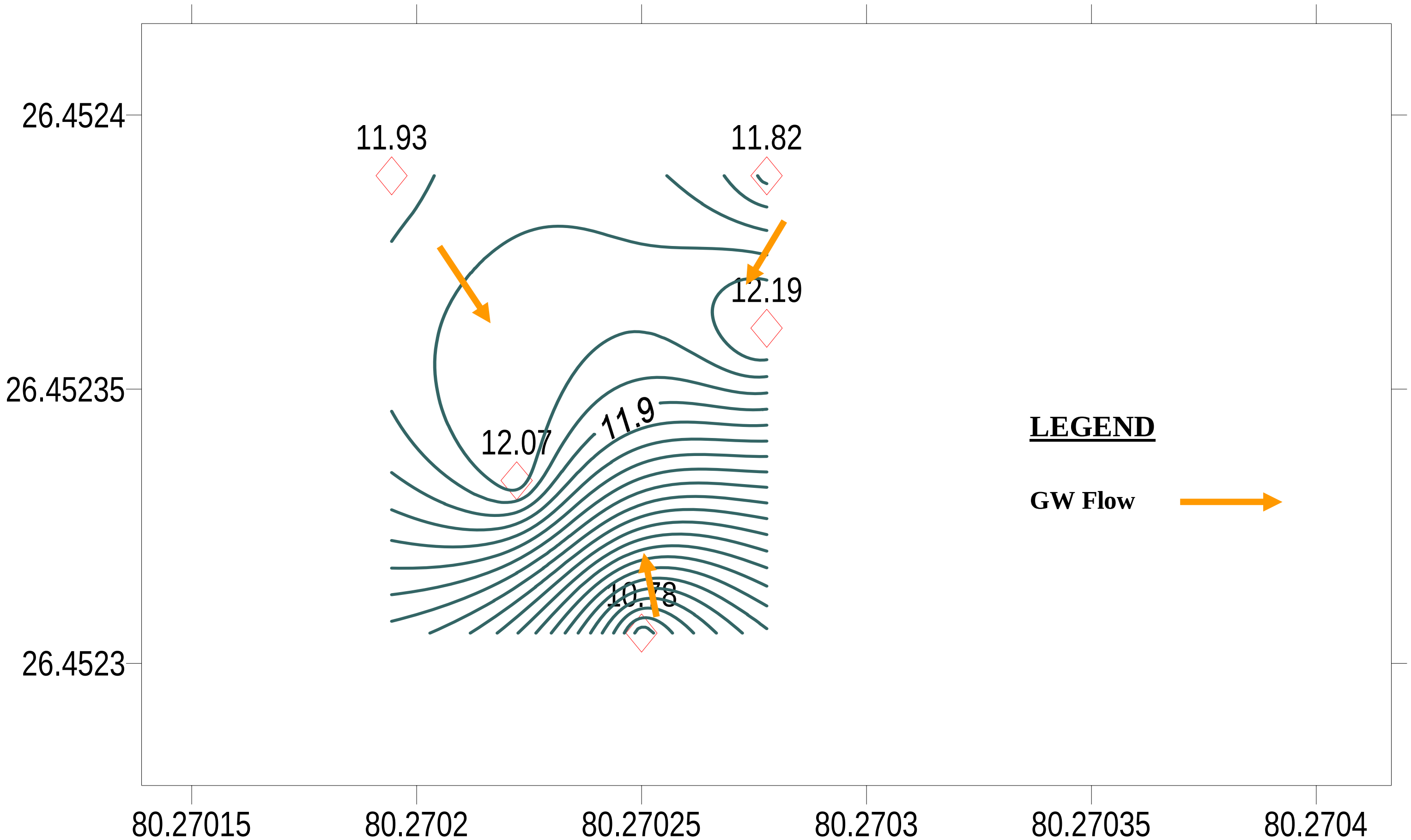


Note : Contours plotted using conc. of TOC in mg/l

POST-INJECTION GROUNDWATER ELEVATION CONTOUR PLANS

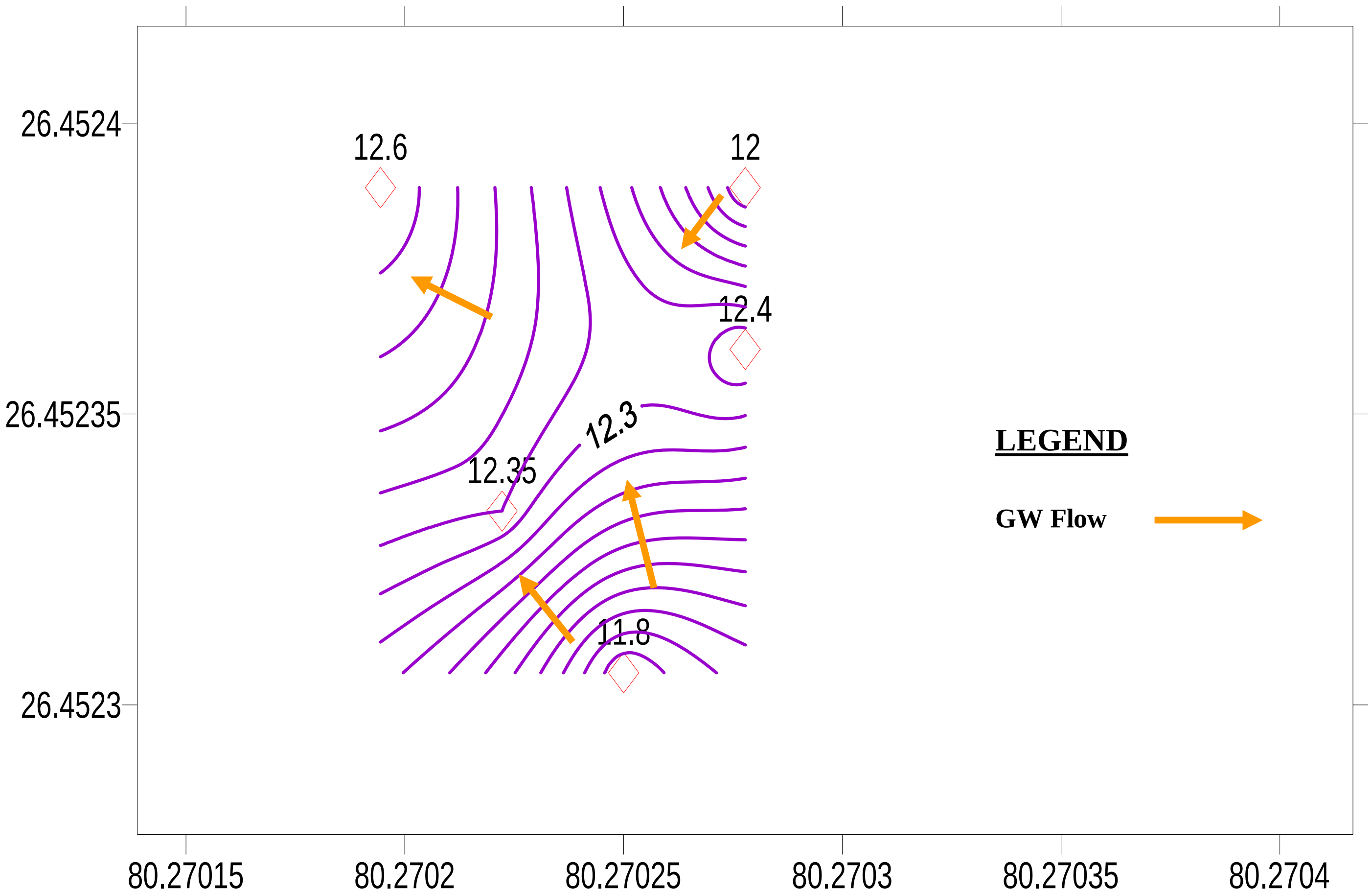
Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

Fig.: 5 : Groundwater Elevation (DWL) – Post Injection (1st Round)
(07days after injection of EDC)



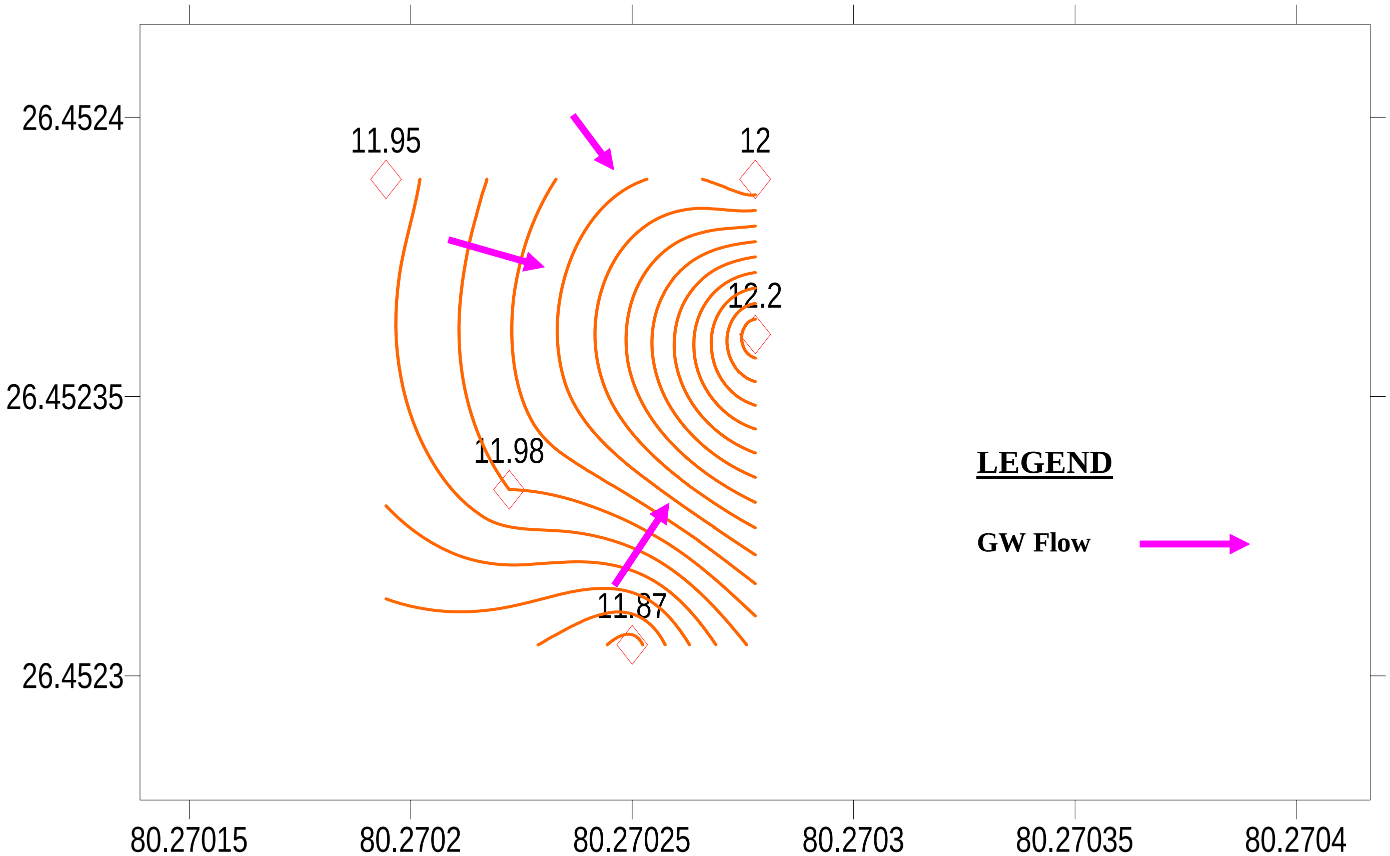
Note : Contours plotted using DWL in meters below ground level

Fig.: 6 : Groundwater Elevation (DWL) – Post Injection (2nd Round)
(15 days after injection of EDC)



Note : Contours plotted using DWL in meters below ground level

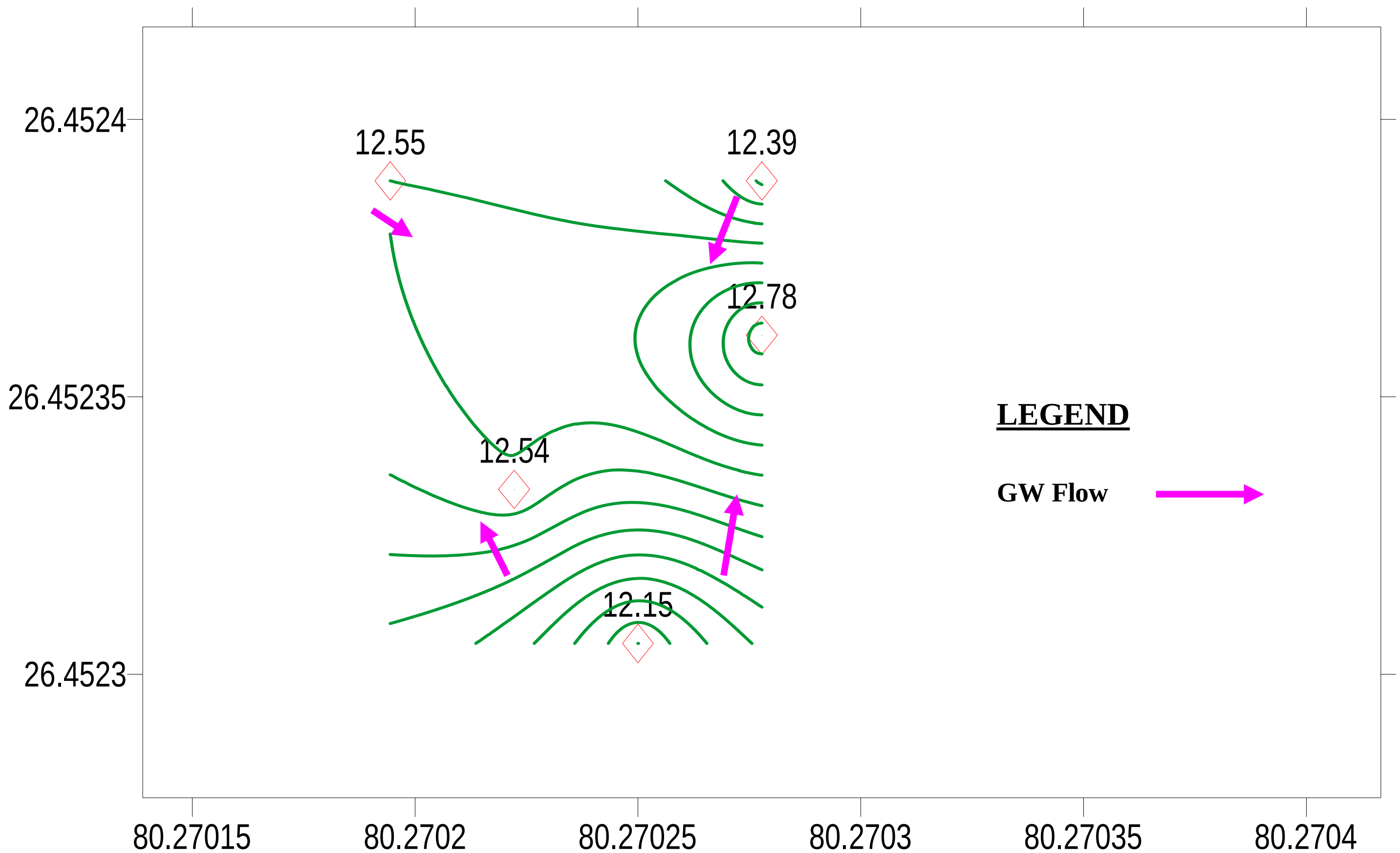
Fig.: 7 :Groundwater Elevation (DWL) – Post Injection (3rd Round)
(60 days after injection of EDC)



Note : Contours plotted using DWL in meters below ground level

Exclusively for Pilot Study area

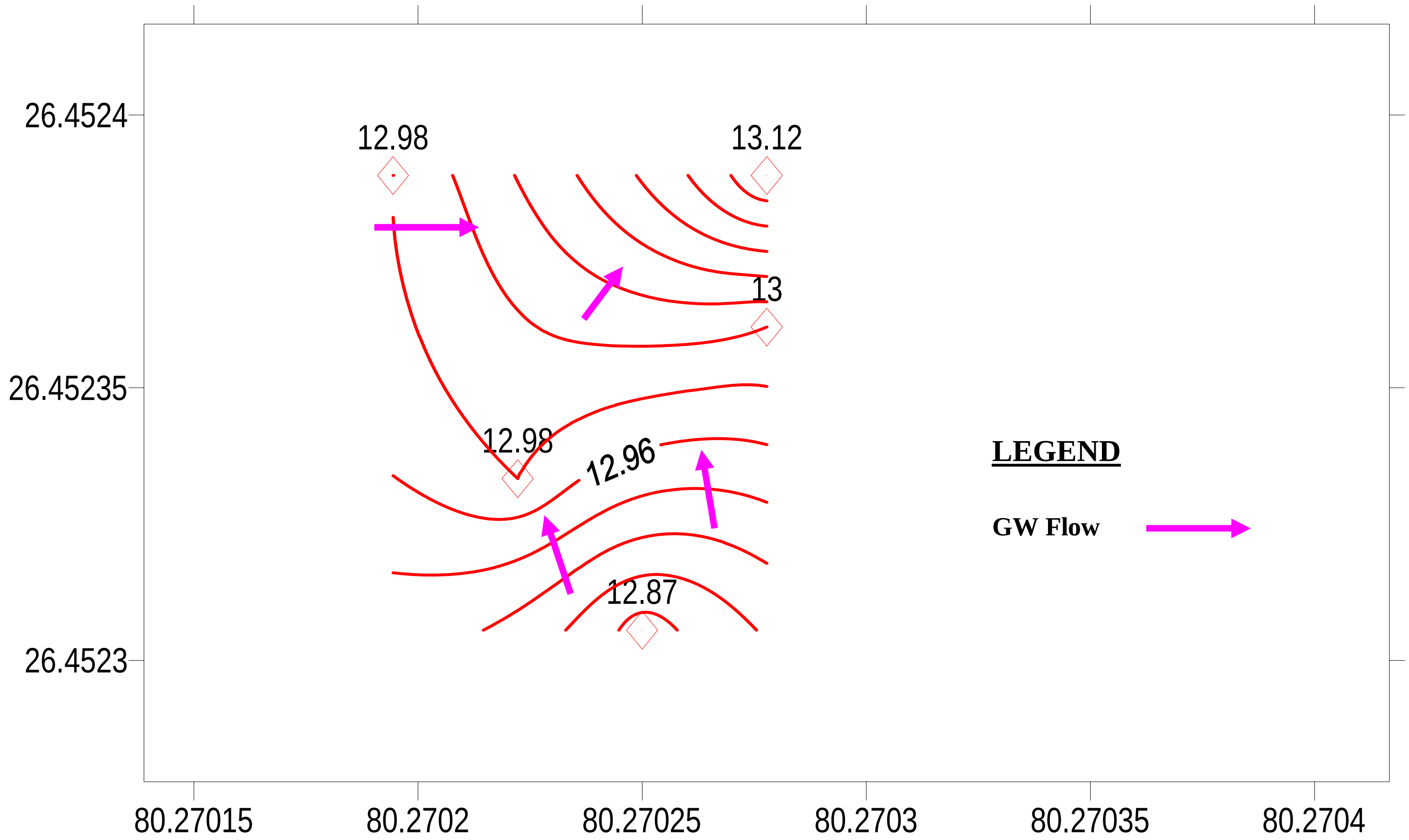
Fig.: 8 : Groundwater Elevation (DWL) – Post Injection (4th Round)
(78 days after injection of EDC)



Note : Contours plotted using DWL in meters below ground level

Exclusively for Pilot Study area

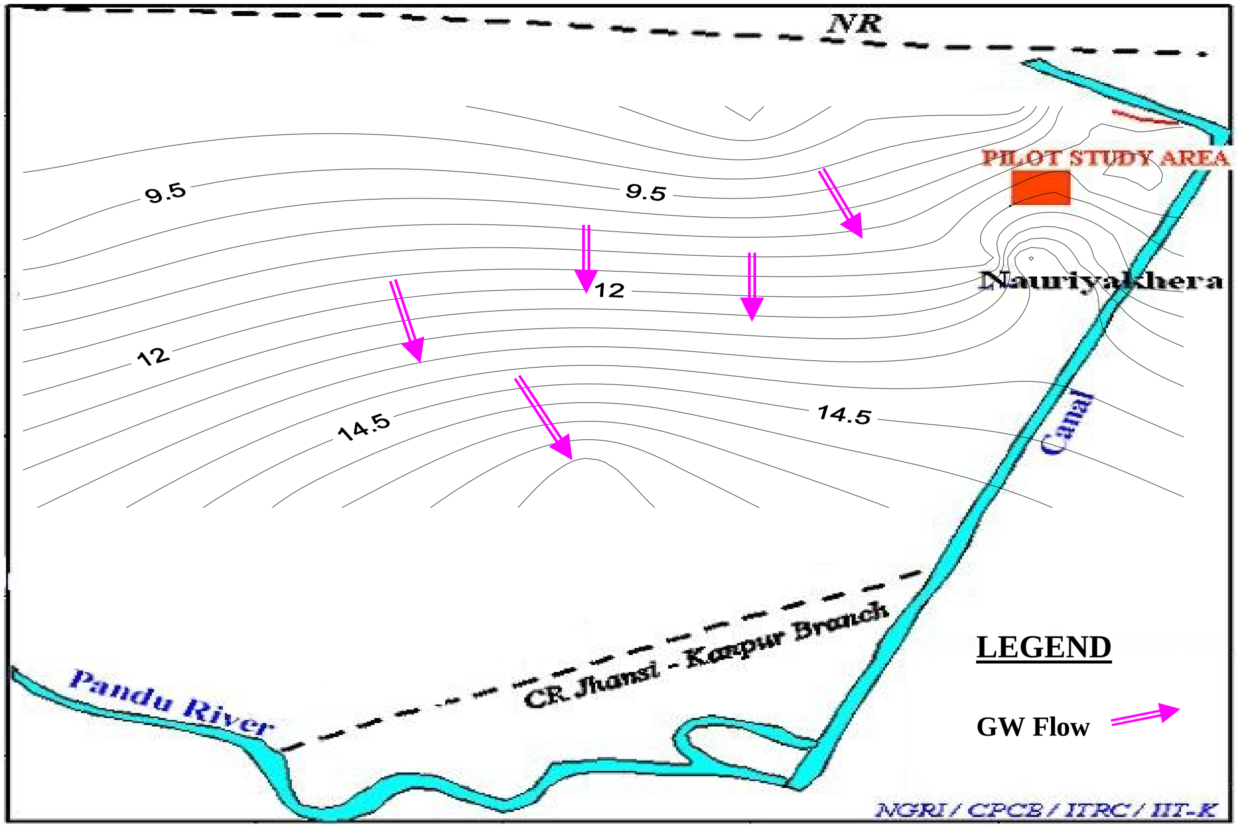
Fig.: 9 : Groundwater Elevation (DWL) – Post Injection (5th Round)
(106 days after injection of EDC)



Note : Contours plotted using DWL in meters below ground level

Fig.: 9 a: Groundwater Elevation (DWL) – Post Injection (after the 5th round)

Regional Scenario*



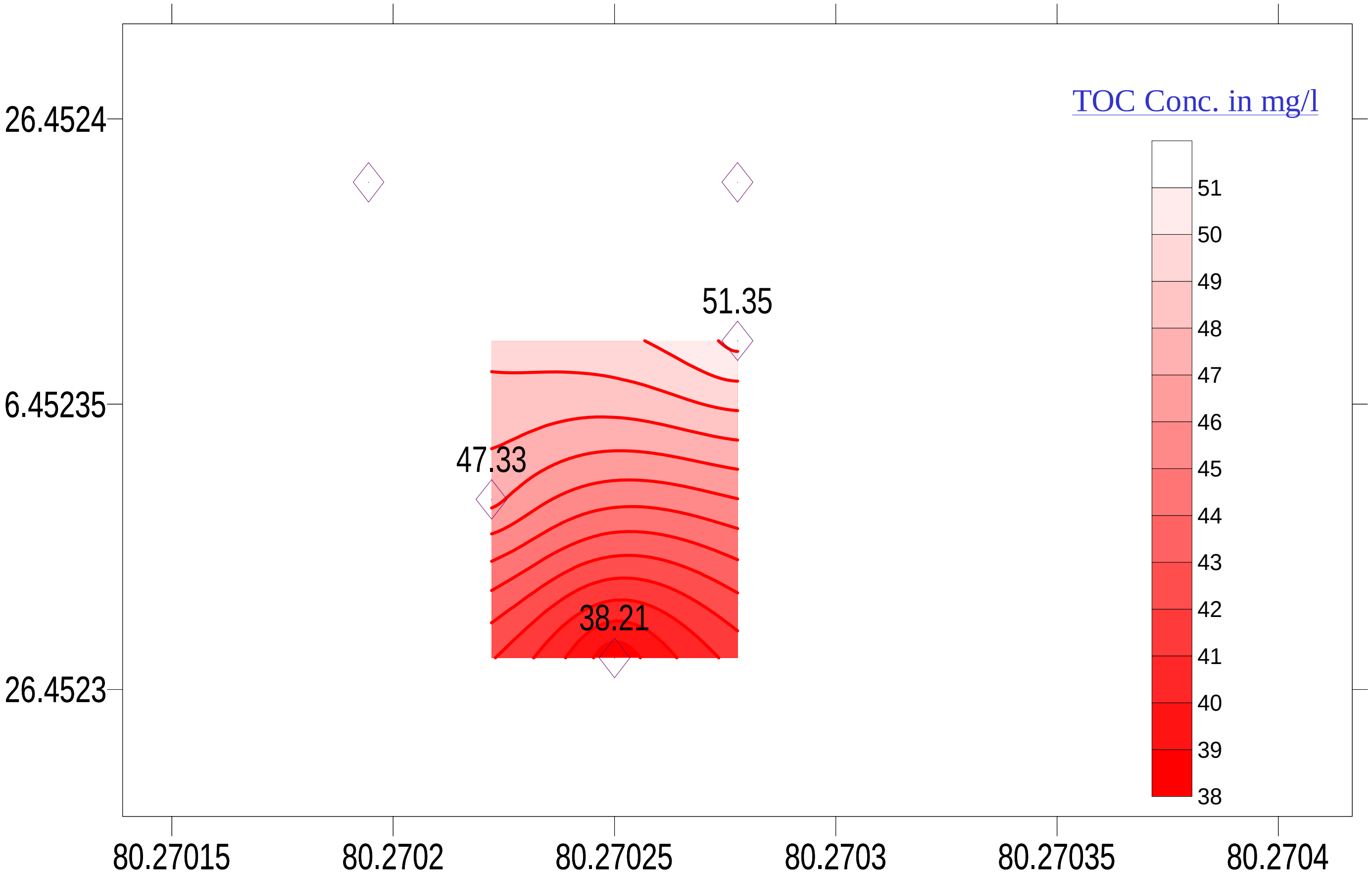
Note : Contours plotted using DWL in meters below ground level

** Based on observations for the wells other than those developed in the Pilot Study*

POST INJECTION TOTAL ORGANIC CARBON ISOCONCENTRATION PLANS

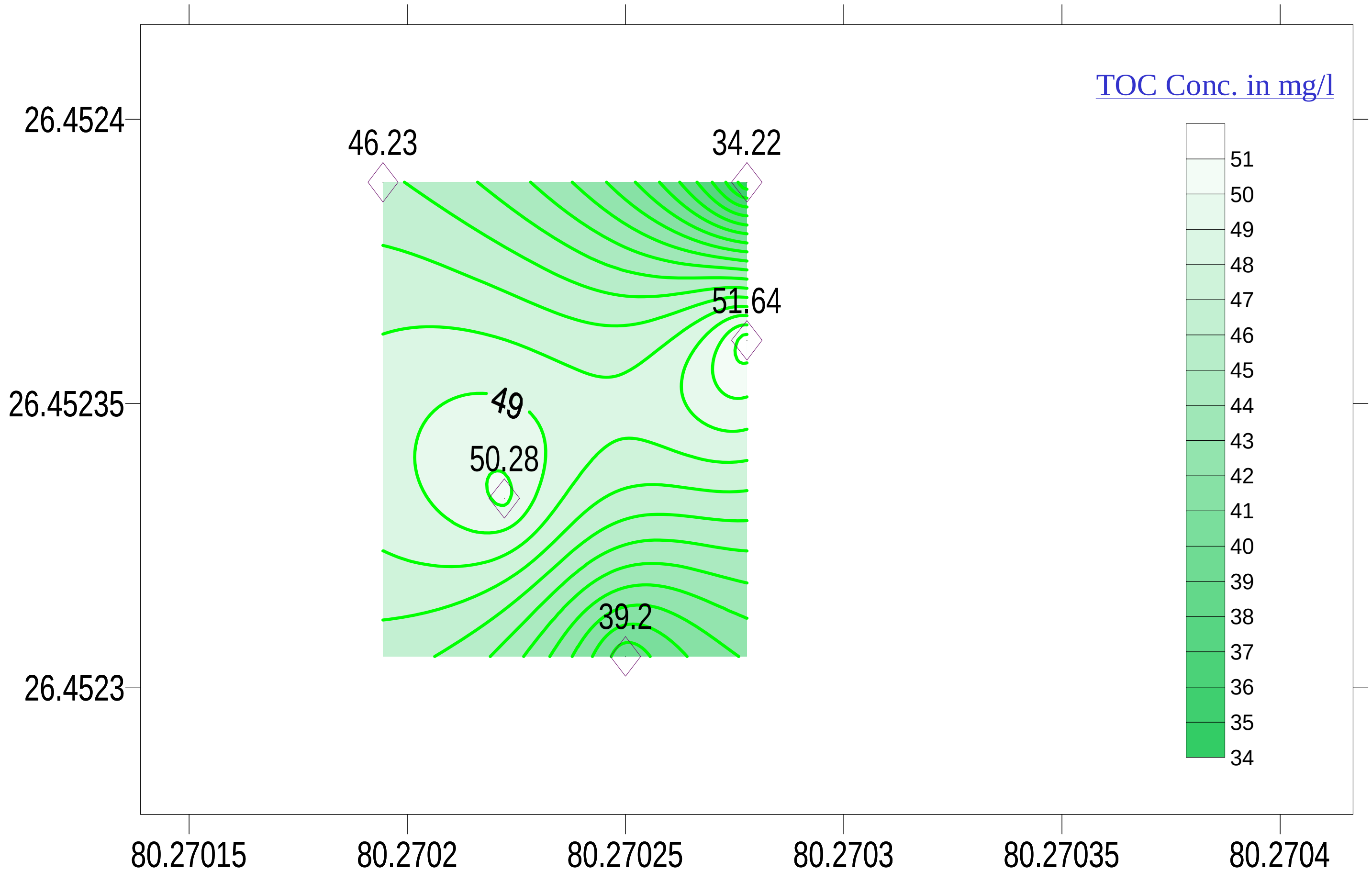
Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

Fig.: 10 : TOC – Post Injection (1st Round)
(07 days after injection)



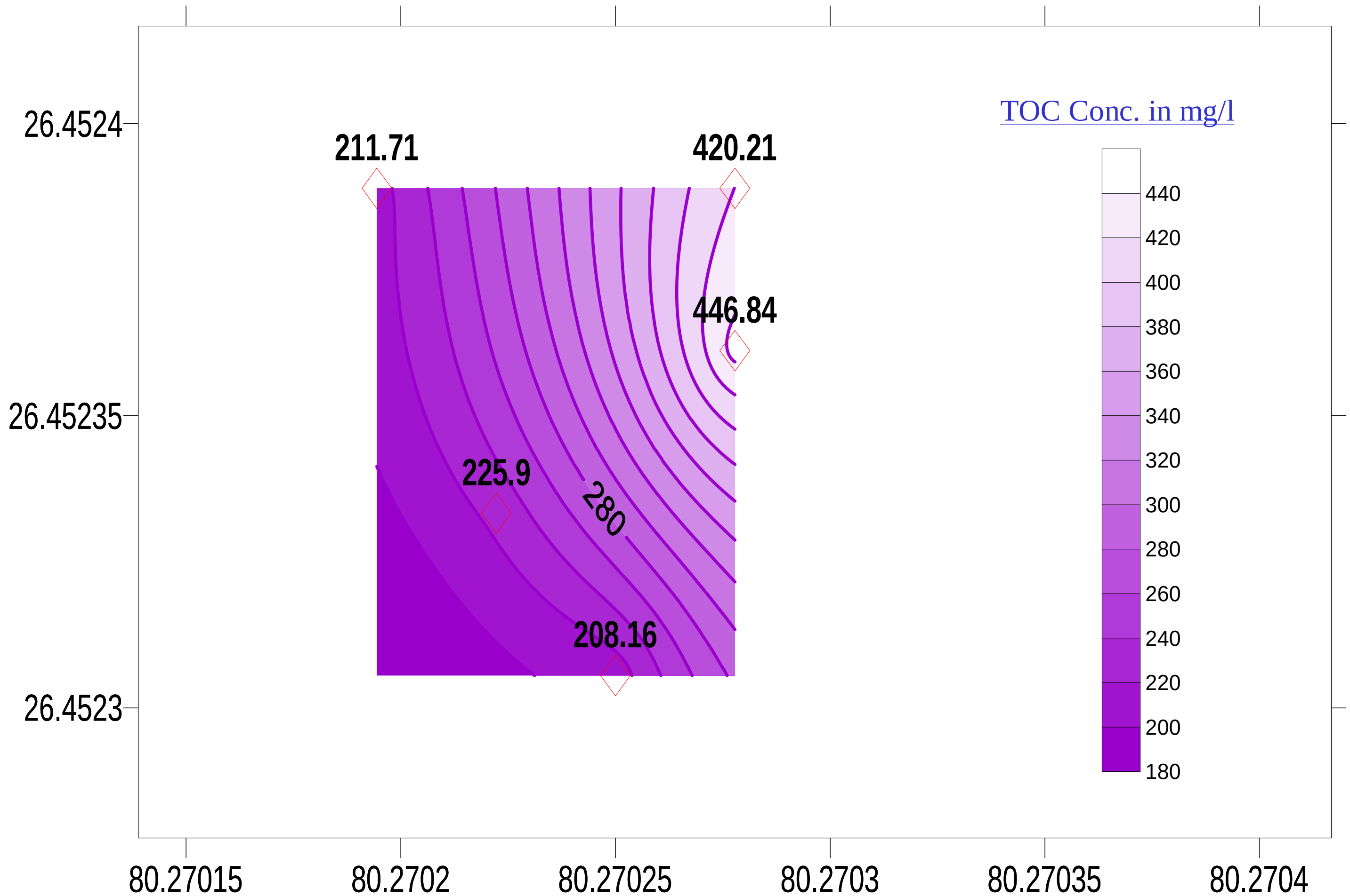
Note : a. Contours plotted using conc. of TOC in mg/l ;
b. Well IW and SMW could not be monitored due to excessive turbidity

Fig. : 11 : TOC – Post Injection (2nd Round)
(15 days after injection)



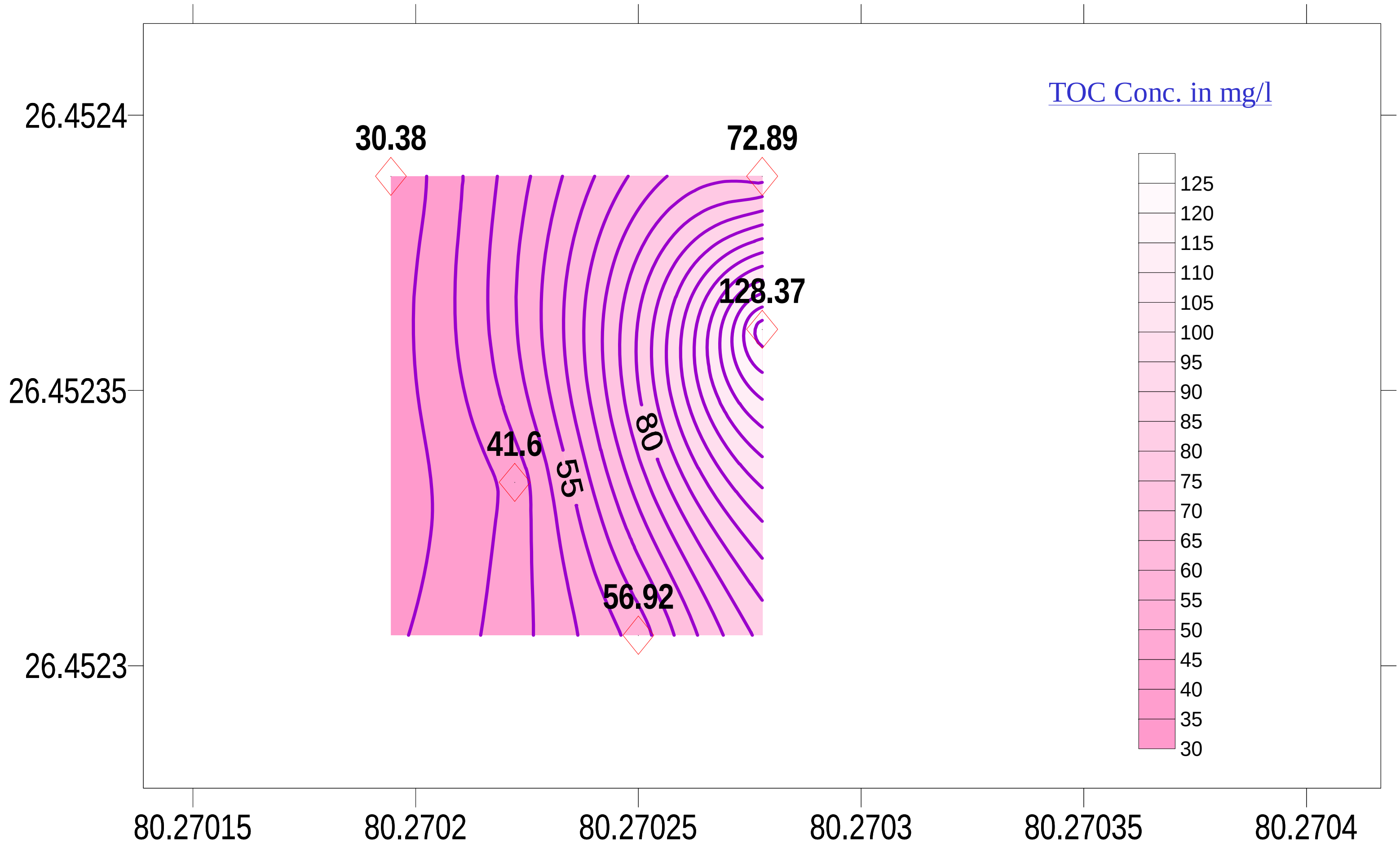
Note : Contours plotted using conc. of TOC in mg/l ;

Fig. : 12 : TOC – Post Injection (3rd Round)
(60 days after injection)



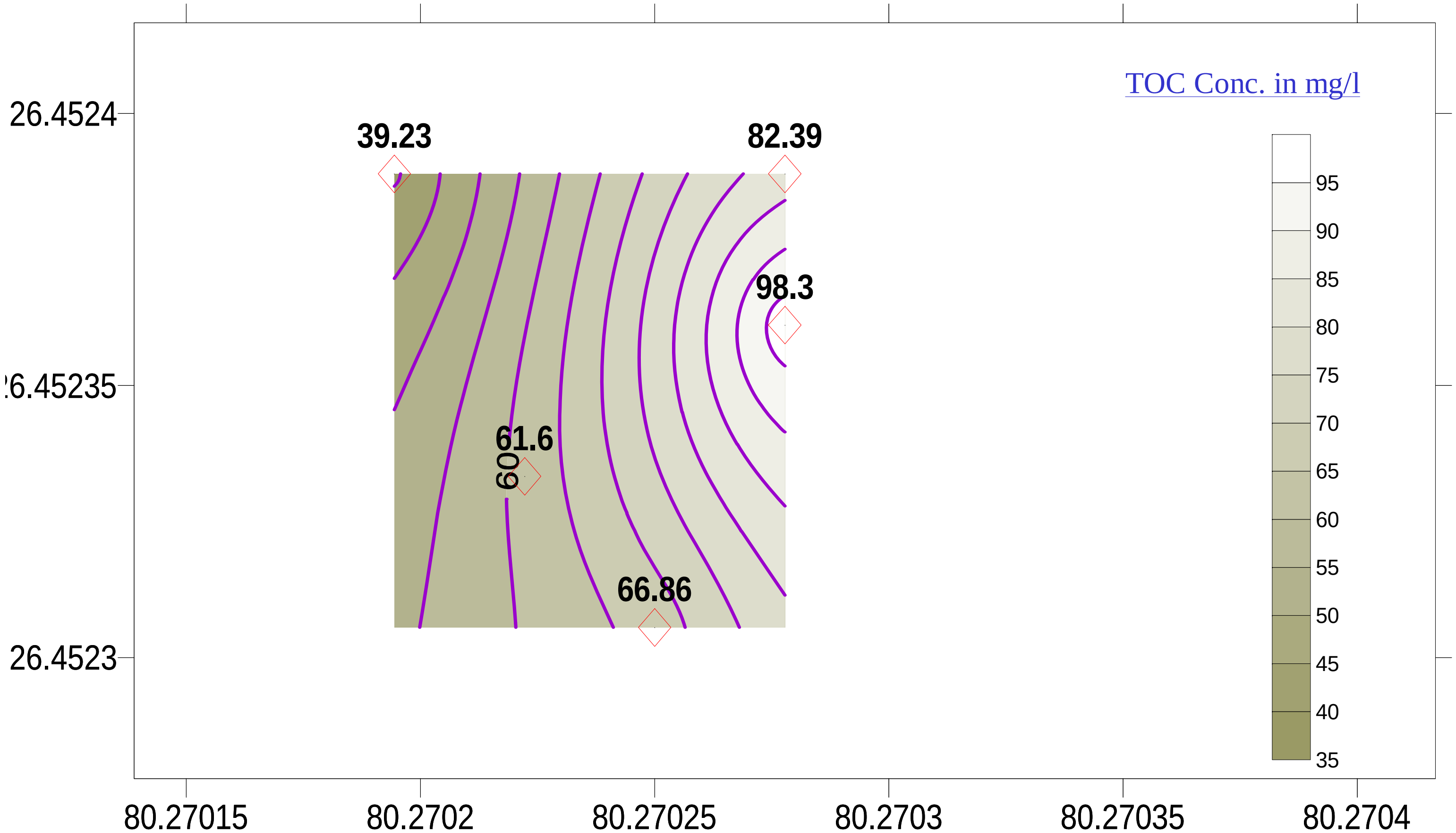
Note : Contours plotted using conc. of TOC in mg/l ;

Fig. : 13 : TOC – Post Injection (4th Round)
(78 days after injection)



Note : Contours plotted using conc. of TOC in mg/l ;

Fig. : 14 : TOC – Post Injection (5th Round)
(106 days after injection)

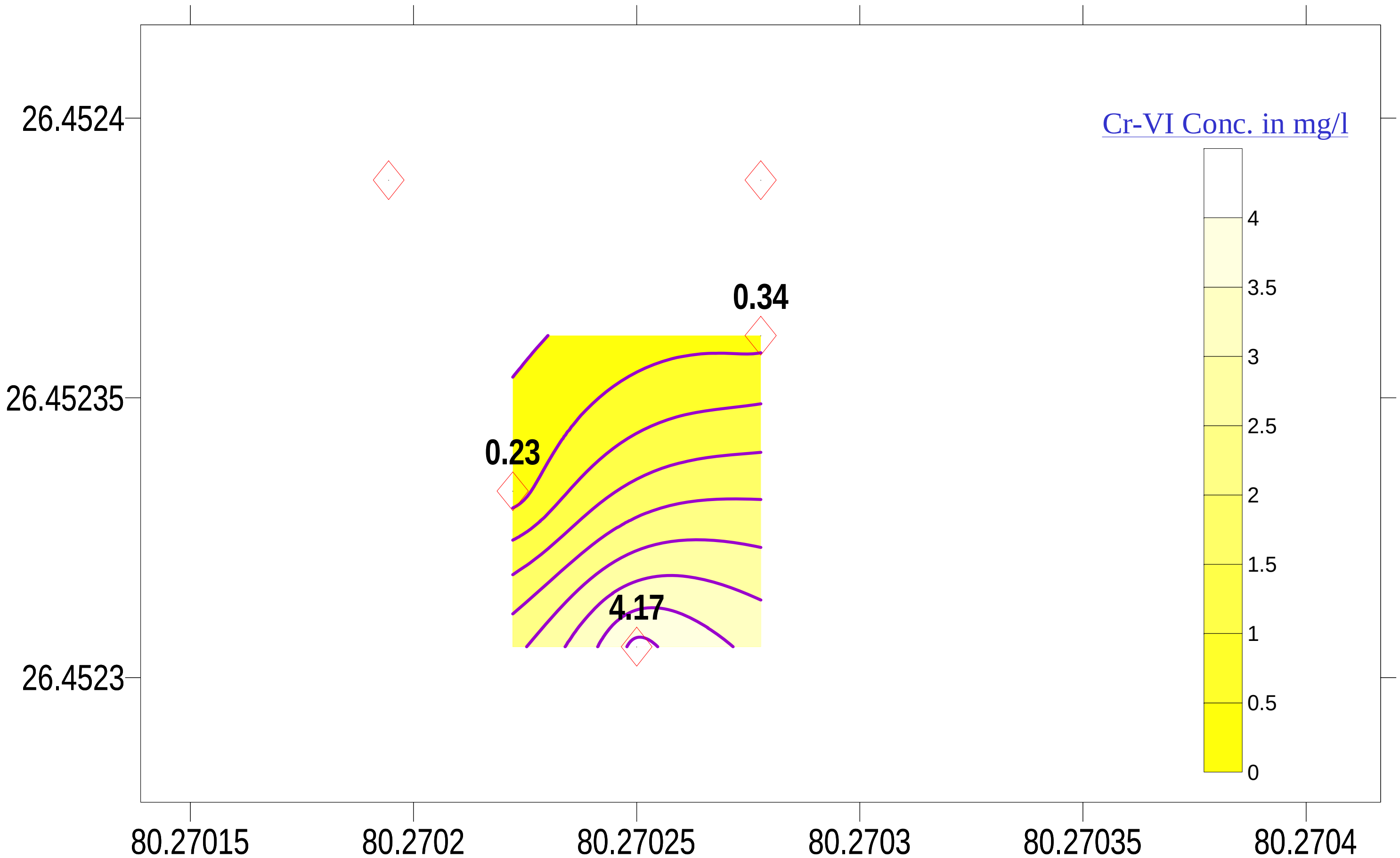


Note : Contours plotted using conc. of TOC in mg/l ;

POST INJECTION HEXAVALENT CHROMIUM ISOCONCENTRATION PLANS

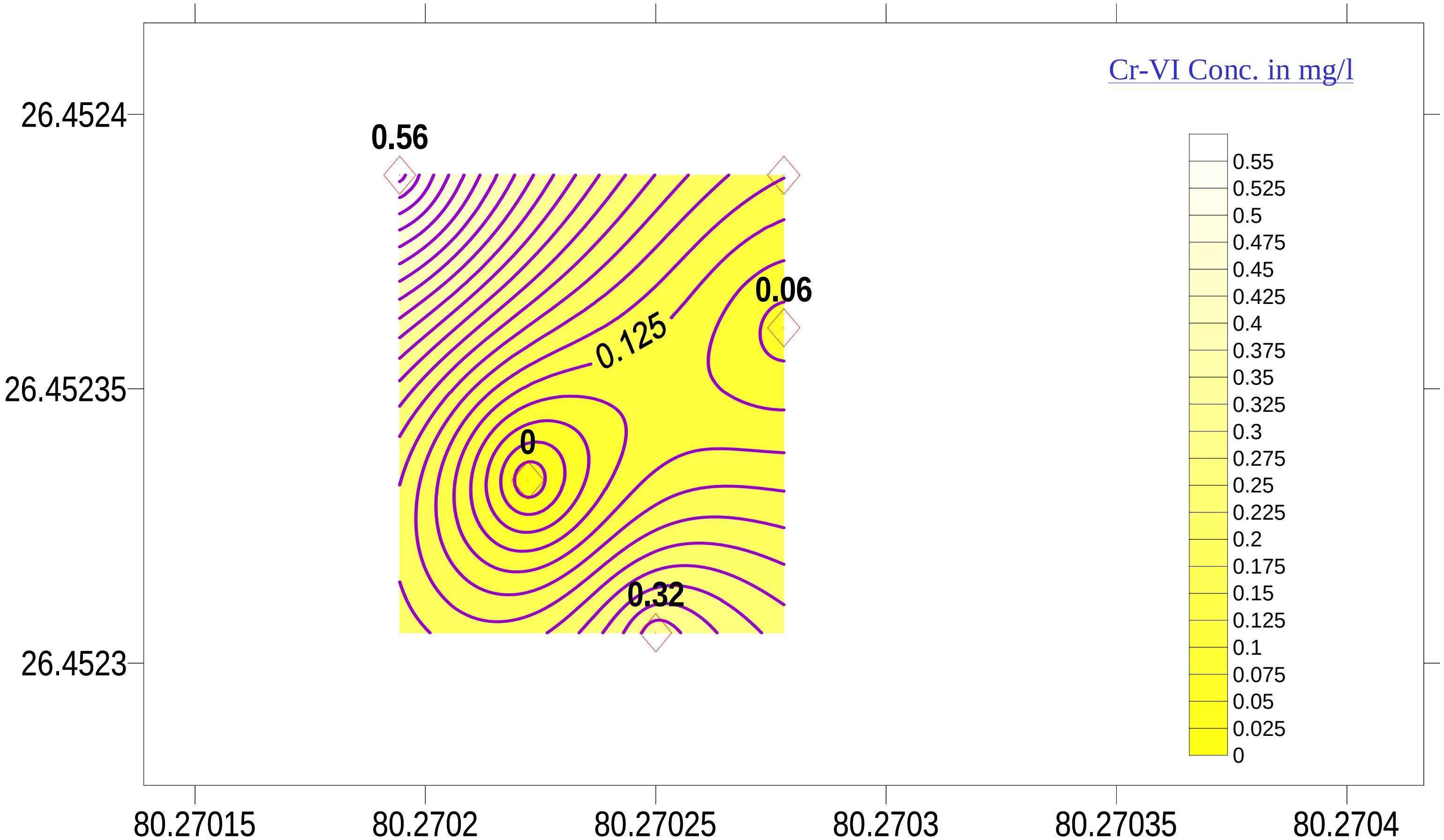
Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

Fig. : 15 : Cr-VI – Post Injection (1st Round)
(07 days after injection)



Note : a. Contours plotted using conc. of Cr-VI in mg/l ;
b. Wells IW and SMW could not be monitored due to excessive foaming

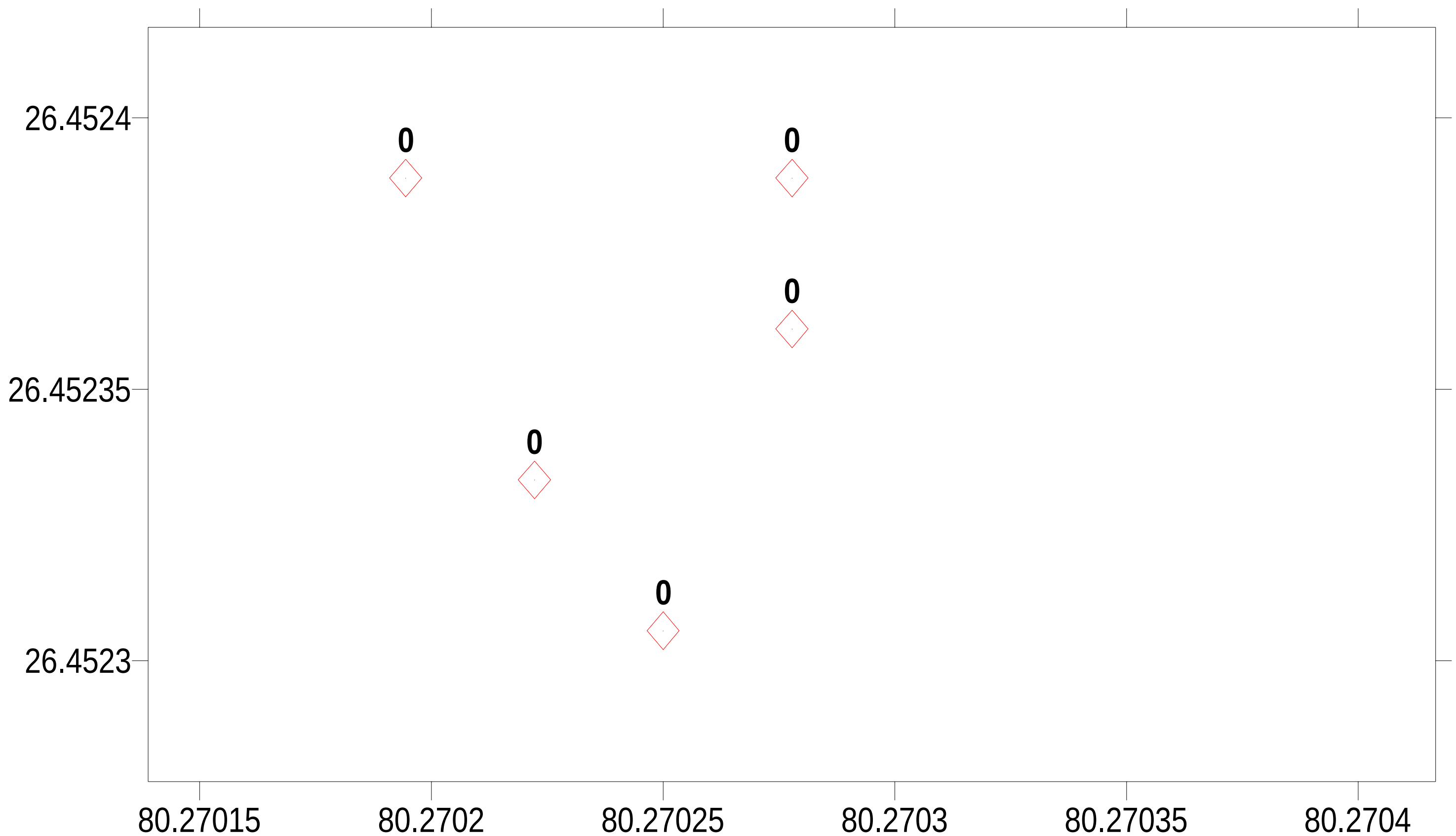
Fig. : 16 : Cr-VI – Post Injection (2nd Round)
(15 days after injection)



Note : a. Contours plotted using conc. of Cr-VI in mg/l ;
b. Sample from IW could not be analysed due to excessive turbidity

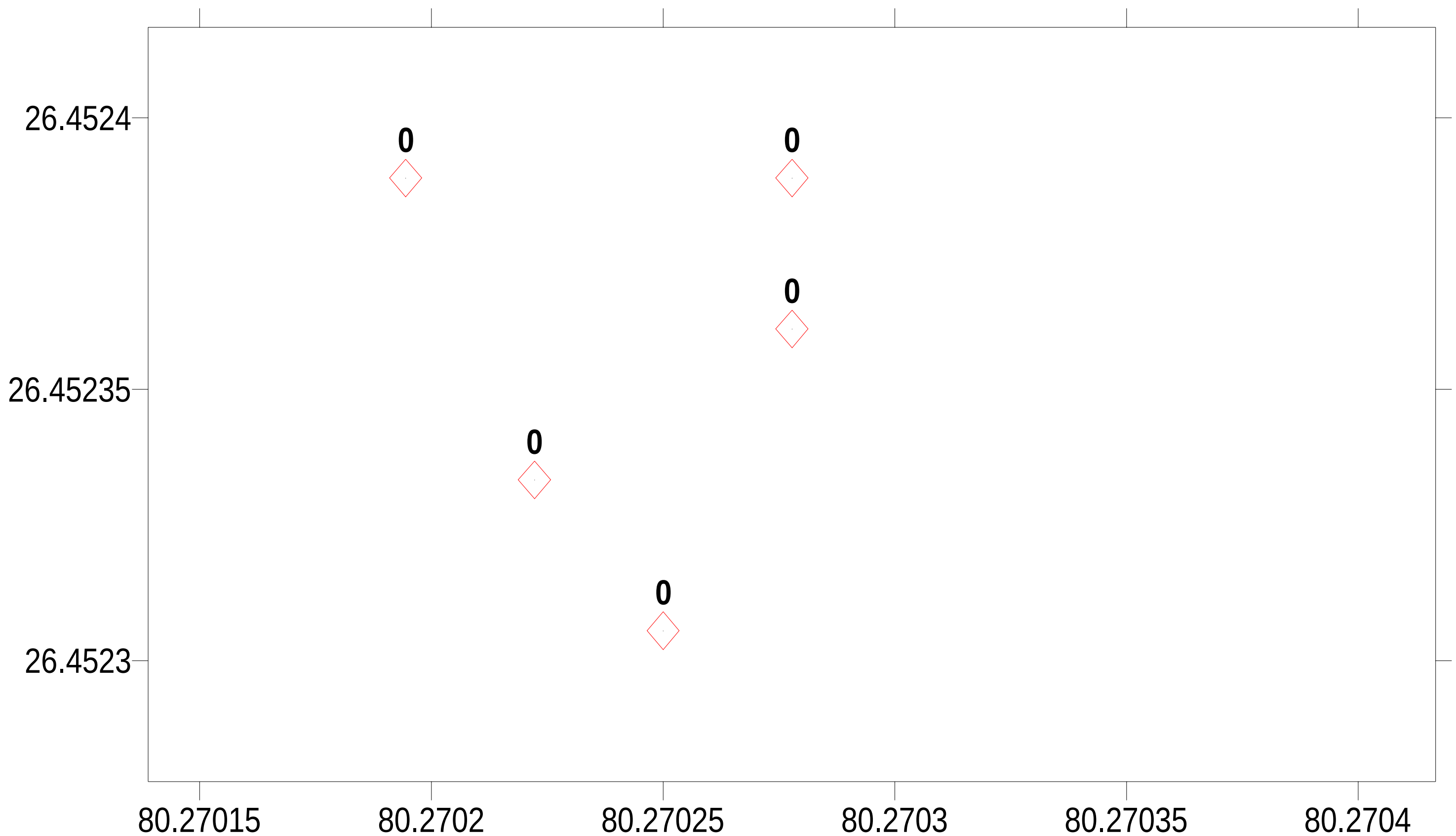
-

Fig. 17 : Cr-VI – Post Injection (3rd Round)
(60 days after injection)



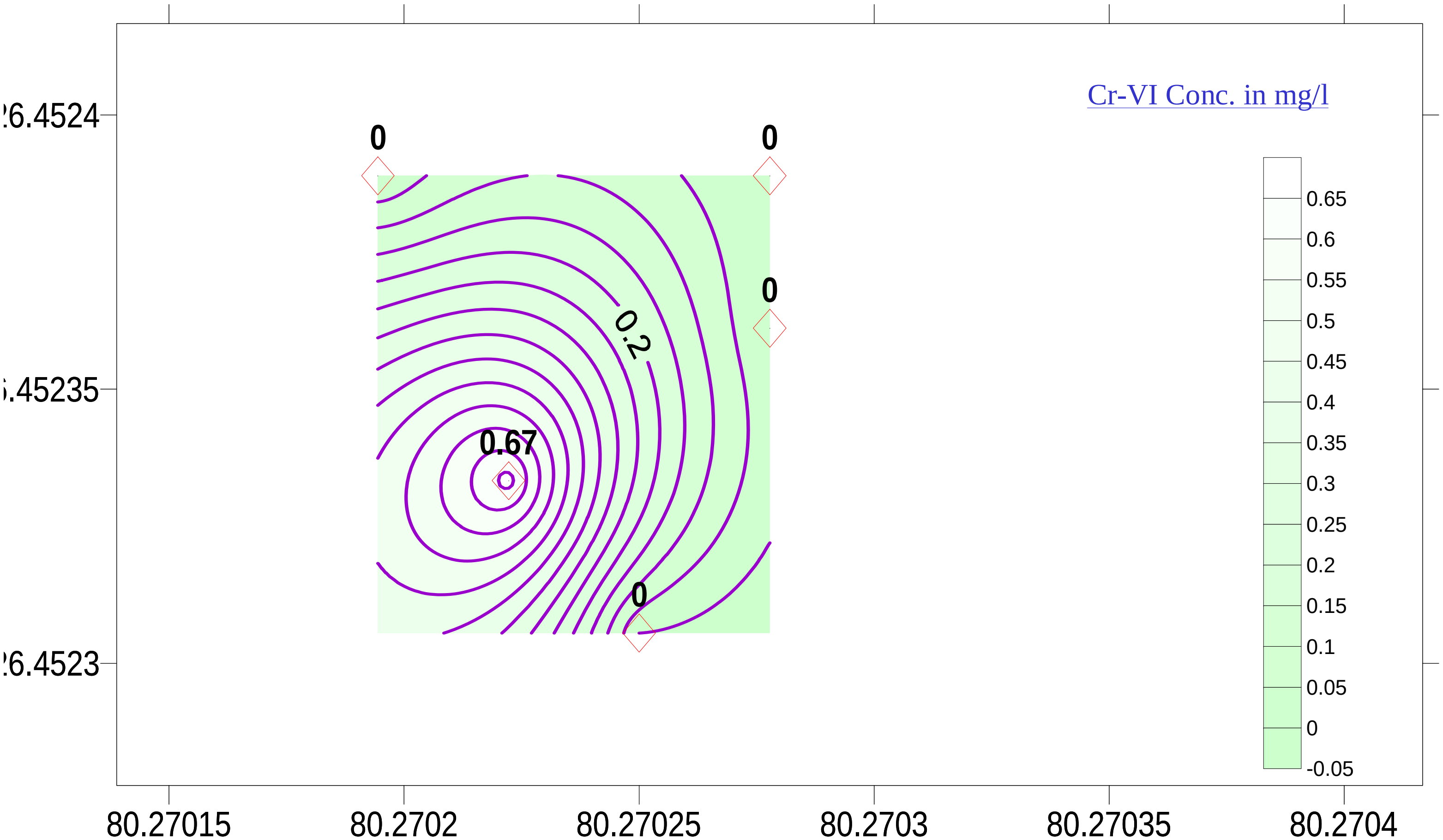
Note : Cr-VI ‘ NOT DETECTABLE’ in all the Wells

Fig. : 18 :Cr-VI – Post Injection (4th Round)
(78 days after injection)



Note : Cr-VI ‘ NOT DETECTABLE’ in all the Wells

Fig. : 19 : Cr-VI – Post Injection (5th Round)
(106 days after injection)



Note : Cr-VI rebounds in Well DW-2 and ' NOT DETECTABLE' in all the remaining Wells

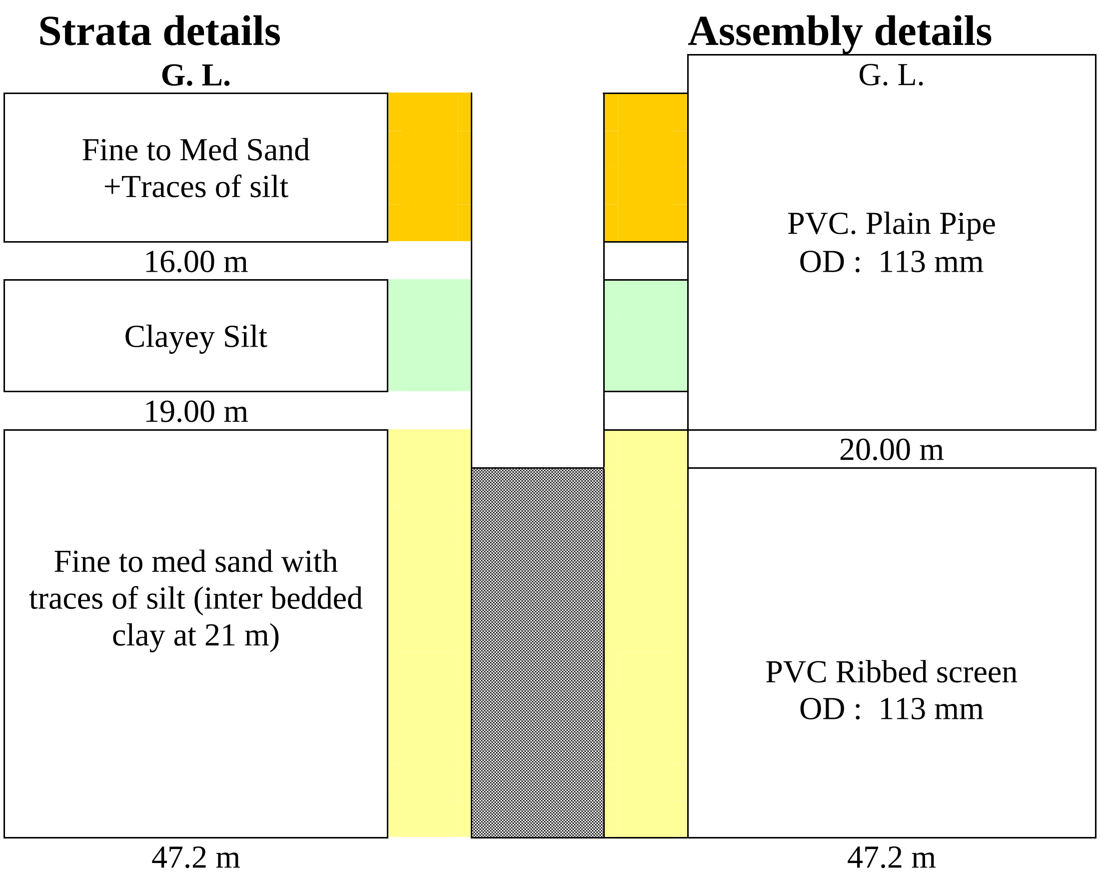
BORING LOGS

Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

Well Construction Details

(Similar for all 4 wells)

Bore Dia. / depth	Casing Dia. / length	Screen Dia. / length	SWL (m bgl)
200mm / 47.2.00 m	4” PVC / 20.00 m	4” Ribbed / 27.2 m	11.15-11.77 m



DESCRIPTION

G.L. to 16 m bgl.	--	------------	-	Annular space filling by Coarse sand and Native Clay
16 Mt to 19 m bgl.	--	------------	-	Bentonite Chips
19Mt to 47.2 m bgl.	--	------------	-	Coarse Sand
PVC Screen & Plain pipe	--	------------	-	113 mm OD
PVC screen slot size	--	------------	-	0.01”
PVC screen length	--	------------	-	27.2 m
Coarse sand size	--	------------	-	3.25 mm

m bgl.: meters below ground level

Well Construction Details

(Skolast Piezometer)

Bore Dia. / depth	Casing Dia. / length	Screen Dia. / length	SWL (m bgl)
200 mm / 50 m	113 mm PVC / 39 m	4” LCG / 6 m.	8 m.

Strata details

GL

9 m

Sand

12.8 m

Clay

19.2

Sand

30.5

Clay

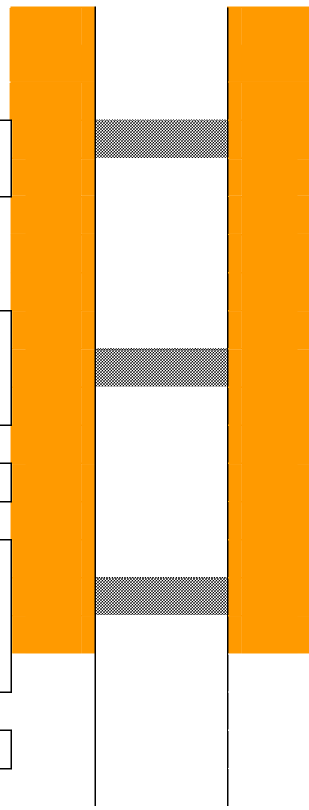
33.5 m

Sand

46.4

Clay Kankar

50 m



Assembly details

GL

PVC Plain Pipe OD 113 mm

9 m

4” LCG Screen

10.5 m

PVC Plain Pipe OD 113 mm

26 m

4” LCG Screen

27.5 m

PVC Plain Pipe OD 113 mm

42 m

4” LCG Screen

45 m

<u>DESCRIPTION</u>

G.L. to 45 m bgl	-- ------------	-	Annular space filling by Pea- Gravel
PVC Screen & Plain pipe	-- ------------	-	113 mm OD
PVC Screen slot size	-- ------------	-	0.75 mm
PVC Screen length	-- ------------	-	6 m

m bgl.: meters below ground level

SITE HYDROGEOLOGIC INFORMATION

Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

<u>Contaminant Hydro-geologic Information / assumptions for remedial implementation budget estimate</u>

<u>TECHNICAL INFORMATION</u>

A. Background

As identified in the scope of ongoing Kanpur Project, a macro-level study was carried out to locate monitoring locations for estimating groundwater quality. Simultaneous with the study, probable location of Cr-impacted areas were also broadly identified. In order to record actual site–specific details, especially for precise location of Cr impacted zones, it is proposed that a detailed inventory is carried out. Such inventory, which shall be helpful in bridging the 'data gaps,' may be followed by (vertical) profiling of soil by drilling bores and analyzing the soil matrix, to substantiate the estimations. The study referred above is included in the Budget estimate appended below.

B. Contaminant Information

As per series of investigations carried-out by Central Pollution Control Board, the Cr(VI) has been recorded up to a depth of 45 to 47 meters. Groundwater collected from deeper tube wells has not shown any appreciable concentration of Cr(VI). Cr(VI) impacted zones exist in Vadose as well as Phreatic zones; however, the concentration of Cr(VI) has been relatively higher in areas where Phreatic zones are identified as polluted. As far as the dimension of the study area for remediation is concerned, the relevant details as per crude estimate, pending actual detailed estimation, are as under:

B.1 Total Dimension

B.1.1 Vadose Zone

a. Horizontal Area: Approximately 5,000 square meter
(10 locations each of approximately 500 square meter)

b. Vertical Unsaturated thickness: 5 to 10 meters

c. Soil type: Fine to medium sand

B.1.2 Phreatic zone

a. Horizontal Area: Approximately 10,000 square meter
(20 locations each of approximately 500 square meter)

b. Vertical saturated thickness: 35 to 20 meters

c. Soil type: Fine to medium sand

C. Estimate of the conc. of MnO_2 in the Soil

Investigation of soil characteristics was carried out in Dec. 2005, by drilling 03 bores (each of 60 meters depth) in different locations within the study area (Norikheda) at Kanpur. At all these borings, 30 samples were drawn at 2-meter depth interval. The results of the study were statistically interpreted and are enclosed. Although the characteristics does not include 'Mn,' its analysis, as desired by you has been specially requested and the results shall be made available to you shortly. An estimation of MnO_2 shall be made with the help of the results. For the sample characteristics referred above, please refer to Tables No. 1, 2, and 3 enclosed.

D. Baseline Chemical Parameters (Groundwater)

SN	Parameter	Range of concentration
1	Cr(VI)	1 – 16 mg/l
2	Total Cr	2 – 22 mg/l
3	DO	3 – 4.5 mg/l
4	Eh	+ 100 to + 120 mV
5	Nitrate	3 – 40 mg/l (in certain areas goes as high as 60 mg/l)
6	Sulphate	100 – 400 mg/l
7	Methane	*
8	pH	6 – 8
9	Specific conductance	700 – 1400

***** *Regretted for non availability of data about methane*

E. Horizontal Hydraulic Conductivity

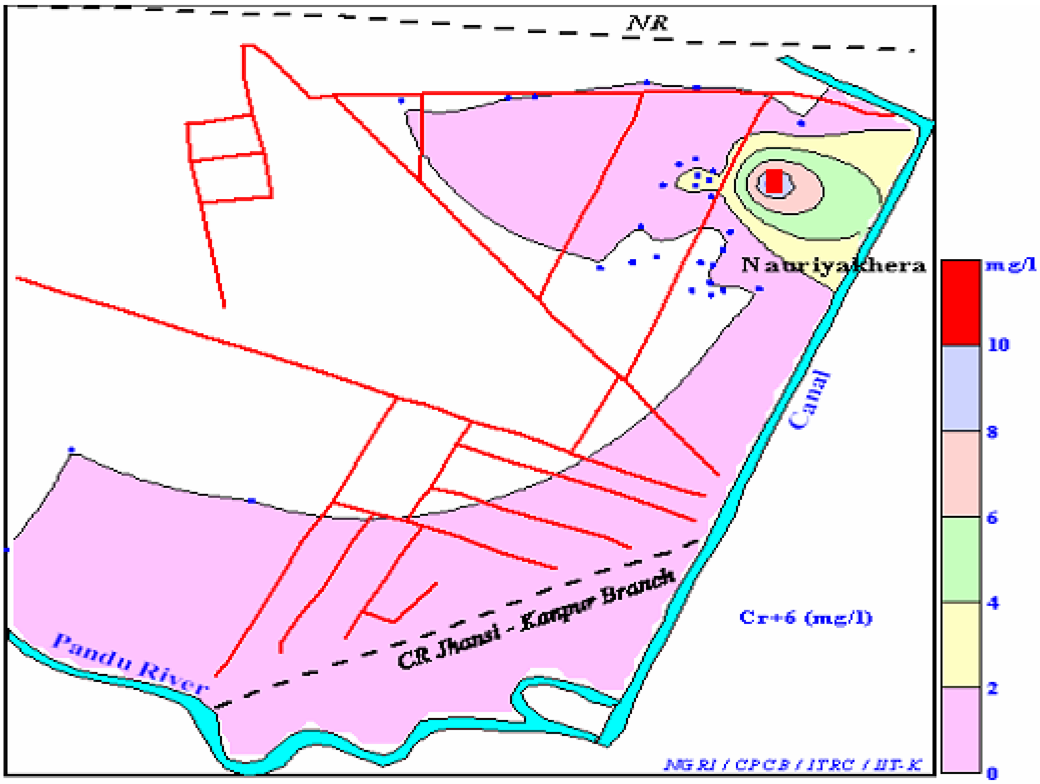
Hydraulic conductivity of the aquifers in the study area is of the order of 35.78 - 47.22 m/day (0.03 cm/sec).

F. Plan Depicting CR-VI conc. isopleths, groundwater flow direction and areas of Cr VI exceedances

For Cr(VI) isopleths please refer enclosed Fig.1 below.

Regional scenario of groundwater flow is depicted in Slides No. 7 and 16 in the ppt file Pilot-1

Fig.1: Cr(VI) Isopleths- Regional Scenario



STUDY AREA BASELINE CHEMICAL PARAMETER RANGES FOR SOIL

Prepared by Central Pollution Control Board of Lucknow, Uttar Pradesh, India.

Table-1

Location : near Sulabh Complex, N-Kheda, (30 Samples)

Reference level: 118.165 m aMSL, Lat. 26^0 26' 57" Long. 80^0 16' 05"

Parameter	Min	Max	Mean	S.D
PH	6.93	7.77	7.39	0.27
Conductivity (uS/cm)	86.8	270.0	180.1	37.8
Chloride (μg/g)	10.1	120.1	82.4	25.58
Fluoride (μg/g)	2.594	4.669	3.486	0.57
Sulphate (μg/g))	145.0	188.7	158.1	9.9
Phosphate (μg/g))	10.79	57.58	38.84	12.2
Nitrate-N (μg/g)	16.40	40.00	22.50	5.1
Nitrite-N (mg/Kg)	0.718	3.572	1.238	0.68
Ammonia-N (μg/g)	0.0	84.0	54.6	25.8
TOC (%)	0.293	0.741	0.501	0.1
Total Hard (μg/g)	90.00	360.00	165.00	50.97
Ca Hard. (μg/g)	40.00	130.00	93.70	20.42
Mg Hard. (mg/Kg)	20.00	250.00	71.33	47.76
Sodium (μg/g)	9.72	34.48	23.65	6.58
Potassium (μg/g)	1.77	13.94	5.49	2.32
Total Cr (μg/g)	10.625	44.125	25.681	9.000
Hexa. Cr (μg/g)	0.104	2.861	1.039	0.820
Lead (Pb) (μg/g)	6.742	26.06	13.28	4.02
Bulk Den. (g/cc)	1.159	1.524	1.320	0.080
Particle Den. (g/cc)	2.527	2.833	2.633	0.067

Table-2

Location : Open field adj Skolast, N-Kheda (30 Samples)

Reference level: 119 m aMSL, Lat. 26^0 27' 05" Long. 80^0 16' 18"

Parameter	Min	Max	Mean	S.D
pH	7.90	8.51	8.10	0.13
Conductivity (uS/cm)	81.7	317.0	160.6	53.8
Chloride (μg/g)	30.0	100.1	46.4	14.75
Fluoride (μg/g)	1.10	6.84	3.02	1.40
Sulphate (μg/g)	56.20	162.00	138.60	21.32
Phosphate (μg/g))	8.86	74.59	35.51	15.72
Nitrate-N (mg/Kg)	8.53	57.78	19.60	11.27
Nitrite-N (μg/g)	0.884	1.989	1.262	0.30
Ammonia-N (μg/g)	0.0	294.0	91.0	69.2
TOC (%)	0.234	0.683	0.462	0.13
Total Hard. (μg/g)	200.00	480.00	305.33	75.01
Ca Hard. (μg/g)	140.00	300.00	212.67	54.45
Mg Hard. (μg/g)	20.00	200.00	92.67	46.53
Sodium (μg/g)	7.34	228.00	30.43	50.41
Potassium (μg/g)	1.502	10.088	4.473	2.25
Total Cr (μg/g)	15.130	51.913	31.248	8.74
Hexa. Cr (μg/g)	0.217	4.226	1.039	0.82
Lead (Pb) (μg/g)	9.056	59.34	24.06	12.76
Bulk Den. (g/cc)	1.128	1.442	1.285	0.07
Particle Den. (g/cc)	2.451	2.805	2.640	0.10

Table-3

Location: Opp. My Car, adj Substation, N-Kheda ; (30 Samples)

Reference level: 120.460 m aMSL, Lat. 26^0 27' 13" Long. 80^0 16' 00"

Parameter	Min	Max	Mean	S.D
pH	6.52	8.16	7.71	0.50
Conductivity (uS/cm)	144.0	514.0	226.0	70.9
Chloride (μg/g)	60.1	300.3	84.4	44.74
Fluoride (μg/g)	1.53	5.96	4.32	1.05
Sulphate (μg/g)	30.5	125.5	66.9	28.47
Phosphate (μg/g)	17.08	61.46	28.43	9.46
Nitrate-N (μg/g)	21.73	70.40	39.30	12.05
Nitrite-N (μg/g)	0.959	7.722	2.506	1.42
Ammonia-N (μg/g)	0.0	154.0	41.5	43.6
TOC (%)	0.117	0.683	0.356	0.14
Total Hard. (μg/g)	280.00	600.00	374.67	79.30
Ca Hard. (μg/g)	120.00	460.00	244.00	63.50
Mg Hard. (μg/g)	20.00	280.00	130.67	68.63
Sodium (μg/g)	15.81	169	45.62	28.71
Potassium (μg/g)	4.092	95.64	9.624	16.348
Total Cr (μg/g)	17.08	43.21	27.95	7.57
Hexa. Cr (μg/g)	0.042	2.075	0.833	0.68
Lead (Pb) (μg/g)	9.76	21.26	14.02	2.68
Bulk Den. (g/cc)	1.184	1.457	1.325	0.08
Particle Den. (g/cc)	2.449	2.768	2.637	0.075