Ro 458

Bruce W. Page Consulting

ENVIRONMENTAL CHEMICAL ENGINEERING

March 20, 2003

Alameda County

MAR 2 4 2003

Environmental Health

Mr. Scott Seery, CHMM
Alameda County Department of
Environmental Health
1131 Harbor Bay Parkway, Suite 250
Alameda, California 94502-6577

Subject: Former Glovatorium – 3815 Broadway
Oakland, California

Dear Mr. Seery:

On March 7, 2003 SOMA Environmental Engineering completed their report entitled "Groundwater Flow, Chemical Transport and Bioattenuation Modeling" for the subject site. In that report, SOMA recommended "that the future groundwater monitoring events be conducted on a semi-annual basis." In a telephone conversation today, you agreed with that recommendation.

Since the most recent monitoring was in January 2003, we will schedule the next event for July 2003. This schedule is open to revision in the future if circumstances change.

Sincerely,

Bruce W. Page

Bruce W. Page, Ph.D.

cc: Mr. Stuart Depper, Clean Tech Machinery
Mr. Albert M. Cohen, Smiland & Khachigian
Ms. Betty Graham, Regional Water Quality Control Board
Dr. Mansour Sepehr, SOMA Environmental Engineering
Mr. Peter W. McGaw, Archer·Norris

ENVIRONMENTAL ENGINEERING, INC
2680 Bishop Drive • Suite 203 • San Ramon, CA 94583
TEL (925) 244-6600 • FAX (925) 244-6601

GROUNDWATER FLOW, CHEMICAL TRANSPORT AND BIOATTENUATION MODELING

FOR THE

Former Glovatorium Facility
3815 Broadway
Oakland, California

March 7, 2003

Project 01-2512

Prepared for
Smiland and Khachigian
601 West Fifth Street, 7th Floor
Los Angeles, California 90071

Prepared by
SOMA Environmental Engineering, Inc.
2680 Bishop Drive, Suite 203
San Ramon, California 94583

SOMA
ENVIRONMENTAL ENGINEERING, INC
2680 Bishop Drive • Suite 203 • San Ramon, CA 94583
TEL (925) 244-6600 • FAX (925) 244-6601

Alameda County
MAR 12 2003
Environmental Health

March 7, 2003

Project: 01-2512

Mr. Scott Seery, CHMM
Alameda County Department of
Environmental Health
1131 Harbor Bay Parkway, Suite 250
Alameda, California 94502-6577

Subject: Site Located at 3815 Broadway, Oakland, California
Former Glovatorium Facility

Dear Mr. Seery:

Enclosed for your review is a copy of SOMA's report entitled "Groundwater Flow, Chemical Transport and Bioattenuation Modeling" for the subject property.

Thank you for your time in reviewing our report. Please do not hesitate to call me at (925) 244-6600, if you have any questions or comments.

Sincerely,

Mansour Sepehr, Ph.D.,P.E.
Principal Hydrogeologist

Mansour Sepehr
No. C042928
Exp. 3-31-04

Enclosure

cc: Mr. Stuart Depper, Clean Tech Machinery w/enclosure
Mr. Albert M. Cohen, Smiland & Khachigian w/enclosure
Ms. Betty Graham, Regional Water Quality Control Board w/enclosure
Dr. Bruce Page, Bruce W. Page Consulting w/enclosure
Mr. Peter W. McGaw, ARCHER.NORRIS w/enclosure

Certification

This report has been prepared by SOMA Environmental Engineering, Inc. for Smiland & Khachigian, to comply with the Alameda County Department of Environmental Health's requirements based on our approved workplan dated June 15, 2001.

Mansour Sepehr, Ph.D., P.E.
Principal Hydrogeologist

REGISTERED PROFESSIONAL ENGINEER
MANSOUR SEPEHR
No. C042928
Exp. 3-31-04
CIVIL
STATE OF CALIFORNIA

Table of Contents

List of Tables

List of Figures

List of Figures (Continued)

List of Figures (Continued)

1.0 INTRODUCTION

This report has been prepared by SOMA Environmental Engineering, Inc. (SOMA) for the Law Offices of Smiland and Khachigian on behalf of their client, the owners of the former Glovatorium. The property, the former Glovatorium, is located at 3815 Broadway Avenue, Oakland, California (the "Site"). The Site is located in an area consisting primarily of commercial and residential uses. Figure 1 illustrates the vicinity of the Site.

SOMA's workplan dated June 15, 2001, as approved by the Alameda County Health Care Services (ACHCS) on August 27, 2001, proposed a two-phase approach for assessing the nature and extent of the soil and groundwater contamination and defining the Site's regulatory status. The first phase included the installation of additional groundwater monitoring wells, soil and groundwater sampling, conducting hydraulic testing, and a sensitive receptor survey. Phase II of the workplan included defining the Site's regulatory status by conducting groundwater flow, chemical fate and transport modeling, and a Risk-Based Corrective Action (RBCA) document. SOMA's "Report on Conducting Additional Field Investigation to Evaluate the Site's Conceptual Model," dated January 3, 2002 described the results of the investigations conducted in Phase I. The modeling aspect of Phase II was conducted using the results collected in Phase I and the analytical data from quarterly monitoring events. This report describes the results of the groundwater flow, chemical transport and bioattenuation modeling as part of the second phase of investigations as described in the workplan.

1.1 Site Description

The Site is located between Manila Avenue and Broadway, near the intersection of 38th Street in Oakland, California. The ground surface of the Site is covered with concrete and asphalt and slopes gently southwest, with surface elevations

ranging from approximately 78 to 84 feet above mean sea level (msl).
A 54-inch inside-diameter storm drain culvert passes under the property, from Manila Avenue on the west to 38th Street on the south. The storm drain closely follows the path of a historical creek that appears on old maps of the area. The depth of the storm drain invert is approximately 8.5 feet under the sidewalk on the eastern side of Manila Avenue and approximately 13.2 feet below ground surface (bgs) at the far end, approximately 60 feet south of GW-4. In addition to a storm drain system, a 10-inch diameter cast iron sanitary sewer conduit runs in a westerly direction from the on-site building and discharges into the sanitary sewer line, which runs north to south along Manila Avenue. The floor drain inside the building is less than 2 feet bgs. However, the depth of the sanitary sewer line inside the building gradually increases and then slopes more steeply downward near the western wall of the building, where it plunges underneath the 54-inch storm drain (LFR, January 2001). Figure 2 shows the location of the sanitary sewer line.

Reportedly, there were six underground storage tanks (USTs) at the Site. Two USTs were located under the sidewalk on 38th Street and four USTs were located inside the building. The volumes of the USTs have been variously reported as ranging from 800 gallons to 5,000 gallons. They reportedly contained Stoddard solvent, fuel oil and possibly waste oil. In August 1997, the six USTs were abandoned in-place by backfilling the tanks with either cement-sand slurry or pea gravel. In addition, there are three USTs associated with the neighboring property owned by Earl Thompson, Sr., under the sidewalk on 38th Street.

The surrounding properties are primarily commercial, businesses and residential housing. TOSCO Marketing Company (TOSCO) is located north and up-gradient of the Site, at 40th Street and Broadway and contains a number of groundwater monitoring wells. Figure 2 shows the location of the main building and the on-site and off-site groundwater monitoring wells. The groundwater monitoring wells are currently monitored on a quarterly basis. Past groundwater monitoring events have indicated the presence of volatile organic compounds (VOCs) and petroleum hydrocarbons in the groundwater beneath the Site. The source of the contamination is believed to be the former USTs, which were used to store Stoddard solvent and VOCs at the Site. There also has been testimony in the on-going litigation concerning the Site that there were releases from the piping on the washer system and from washing the floors with Stoddard solvent.

1.2 Background

The following is a brief description of site investigations conducted by other environmental firms and SOMA.

In August 1997, Geosolv, LLC (Geosolv) initiated the first soil and groundwater investigation at the Site. Geosolv drilled fourteen soil borings to the approximate depths of 10 to 24 feet bgs using the direct push method. Seven of the soil borings (B-2, B-3, B-7 through B-10 and B-13) were converted into temporary groundwater monitoring wells where grab groundwater samples were collected. In September 1998, Geosolv conducted further soil and groundwater investigations by drilling twelve additional soil borings to approximate depths of 19 to 25 feet bgs. All twelve soil borings were converted into temporary groundwater sampling points, and are labeled E-15 through E-26. After collecting grab groundwater samples from the temporary "E" sampling points, they were abandoned and grouted.

In July 1999, based upon the request of the ACHCS, an investigation of potential groundwater preferential flow paths was initiated by LFR. LFR drilled ten soil borings (GW-1 through GW-8, GW-5A, and GW-6A) primarily along the 54-inch diameter storm drain and sanitary sewer systems to depths ranging from 8 to 20 feet bgs using a direct push drilling method. During drilling operations, soil samples were collected from various depth intervals. In August 1999, LFR collected grab groundwater samples from seven of the nine "GW" wells.

In January and April 2000, LFR conducted quarterly groundwater monitoring events at the Site. During the groundwater monitoring events, groundwater elevations were measured in the temporary sampling points installed by LFR and Geolsolv, and in off-site wells MW-8, MW-9 and MW-11 owned by TOSCO. Groundwater samples were collected from the temporary sampling points installed by LFR and from off-site well MW-11.

In July and August 2000, LFR installed four groundwater monitoring wells, LFR-1 through LFR-4, and conducted the Third Quarter 2000 groundwater monitoring event. This was the first sampling event in which bioattenuation parameters were collected. The measured bioattenuation parameters included: dissolved oxygen (DO), nitrate (NO_3^-), sulfate (SO_4^{-2}) ferrous iron (Fe^{+2}), total iron, methane, oxidation-reduction potential (ORP), alkalinity, chloride, carbon dioxide, nitrite, sulfide, ethene, and ethane. The bioattenuation parameters provided a baseline for these parameters and a means to compare their concentrations at locations within the apparent source area against surrounding up-gradient, down-gradient, and cross-gradient locations. During this monitoring event, groundwater elevations were measured and groundwater samples were collected from the newly installed groundwater monitoring wells (LFR-1 through LFR-4), from temporary sampling points installed by LFR and Geosolv, and from off-site monitoring wells MW-8, MW-9, and MW-11 owned by TOSCO. However, no groundwater samples were collected from MW-8 or MW-9.

In late October and early November 2000, LFR conducted the Fourth Quarter 2000 groundwater monitoring event, including another bioattenuation study. During the fourth quarter monitoring event, LFR sampled nine groundwater monitoring wells and temporary groundwater sampling points and measured groundwater elevations in nineteen groundwater monitoring wells and temporary sampling points (LFR, January 2001).

In late January, LFR conducted the First Quarter 2001 groundwater monitoring event. However, SOMA prepared the First Quarter 2001 monitoring report (SOMA, May 2001). The results of the First Quarter 2001 groundwater monitoring event suggested the occurrence of strong anaerobic biodegradation activities and dechlorination of PCE beneath the Site.

The Second Quarter 2001 groundwater monitoring event was conducted by SOMA on April 26 and 27, 2001 and reported on July 5, 2001. During this period certain bioattenuation data, which proved to be less useful, were not collected. The results of the Second Quarter 2001 monitoring event indicated a strong occurrence of the dechlorination process of PCE in the subsurface.

The Third Quarter 2001 groundwater monitoring event was conducted by SOMA on July 26 and 27, 2001. During this monitoring event ten groundwater monitoring wells were sampled and depths to groundwater were measured in 20 groundwater monitoring wells and temporary sampling points. To better evaluate the bioattenuation parameters including DO, SOMA submitted a workplan to the ACHCS that proposed conducting additional investigations to better define the groundwater plume conditions and collecting additional data to conduct groundwater flow and chemical transport modeling and RBCA, in order to define the Site's regulatory status. Upon completion of the tasks described in the workplan, SOMA will decide whether active groundwater remediation is warranted.

After receiving approval on August 27, 2001, SOMA installed five groundwater monitoring wells, SOMA-1 through SOMA-5, at the Site on October 4, 11 and 12, 2001. During the installation of the groundwater monitoring wells, boreholes were continuously logged and soil samples were collected at 5-foot depth intervals. The objective of this investigation was to delineate the vertical extent of soil and groundwater contamination and install larger diameter monitoring wells at the suspected chemical source areas in order to collect more reliable bioattenuation parameters (i.e., DO) in the groundwater. SOMA's "Report on Conducting Additional Field Investigation to Evaluate the Site's Conceptual Model," dated January 3, 2002 described the results of the investigations conducted in Phase I of the workplan.

The Third Quarter 2001 groundwater monitoring event was conducted by SOMA on October 18 and 19, 2001. During this monitoring event 11 groundwater monitoring wells were sampled and depths to groundwater were measured in 20 groundwater monitoring wells and temporary sampling points.

The First Quarter 2002 groundwater monitoring event was conducted by SOMA on January 30 and 31, 2002. During this monitoring event 11 groundwater monitoring wells were sampled, depths to groundwater and free product were measured in 23 groundwater monitoring wells and temporary sampling points.

The Second Quarter 2002 groundwater monitoring event was conducted by SOMA on April 16 and 17, 2002. During this monitoring event 11 groundwater monitoring wells were sampled, depths to groundwater and free product were measured in 22 groundwater monitoring wells and temporary sampling points.

The Third Quarter 2002 groundwater monitoring event was conducted by SOMA on July 17 and 18, 2002. During this monitoring event, 11 groundwater monitoring wells were sampled, depths to groundwater and free product were measured in 23 wells and temporary sampling points.

The Fourth Quarter 2002 groundwater monitoring event was conducted by SOMA on October 22 and 23, 2002. During this monitoring event, 11 groundwater monitoring wells were sampled, depths to groundwater and free product were measured in 23 wells and temporary sampling points.

1.3 Site Geology and Hydrogeology

The Site is located on the alluvial plain between the San Francisco Bay shoreline and the Oakland hills. Surface sediments in the Site's vicinity consist of Holocene alluvial deposits that are representative of an alluvial fan depositional environment. These deposits consist of brown, medium dense sand that fines upward to sandy or silty clay. The pattern of stream channel deposition results in a three-dimensional network of coarse-grained sediments interspersed with finer grained silts and clays. The individual units tend to be discontinuous lenses aligned parallel to the axis of the former stream flow direction (LFR, 2001).

According to LFR, sediments encountered in soil borings at the Site are typical of those encountered in an alluvial fan depositional environment. The sediments are predominantly fine-grained, consisting of clay, silty clay, sandy clay, gravelly clay and clayey silt. Discontinuous layers of coarse-grained sediments (clayey sand, silty sand, and clayey gravel) generally also contain relatively high percentages of silt and clay, which tend to reduce their permeability. Based on previous investigations conducted by Geosolv and LFR, a relatively coarse-grained layer of silty sand, clayey sand, and clayey gravel was encountered in soil borings E-23, E-25, E-26, GW-2, GW-3, GW-7, and GW-8 at depths of approximately 4.5 to 14 feet bgs. A discontinuous layer of silty to clayey sand was encountered at depths of 17 to 21 bgs in borings B-11, E-23, E-25, GW-7 and GW-8.

Based on the October 2001 results of the field investigation conducted by SOMA, no major water-bearing zone at a deeper depth was encountered. However, as the lithological logs of the newly installed groundwater monitoring wells indicate, the water-bearing zone is composed of fine-grained, clayey silt sediments separated by very low permeable intervening clay layers, which in some locations are unsaturated. For instance, SOMA-5, which has been screened within a significantly thick clay layer beneath the first water-bearing zone from 21 to 26 feet bgs using the dual tubing method, was a dry well until the First Quarter 2002 sampling event. Due to the presence of unsaturated and low permeable intervening clay layers between the shallow and deep layers, there is a significant vertical downward gradient between the shallow and deep wells.

According to the results of historical groundwater monitoring activities, groundwater occurs at 4 to 14 feet bgs. Based on the current and previous groundwater monitoring reports, groundwater flows from the northeast to the southwest with an approximate groundwater flow gradient of 0.019 ft/ft to 0.035 ft/ft. The results of the slug tests indicated that the hydraulic conductivity of the saturated sediments ranges between 1.2 x 10^{-4} and 6.9 x 10^{-4} cm/sec, which is equivalent to 0.34 ft/day to 1.95 ft/day. Using the average groundwater flow gradient of 0.027 and aquifer porosity of 0.32, the groundwater flow velocity ranges between 10.5 and 60.1 ft/year.

1.4 Laboratory Results from Past Monitoring Events

The results of past monitoring events indicated the presence of VOCs in the groundwater beneath the Site. The data collected to date regarding the distribution of tetrachloroethene (PCE) and other VOCs in the groundwater indicates that PCE has been degraded into some of its breakdown products. PCE typically degrades into trichloroethene (TCE), then cis-1,2-dichloroethene (cis-1,2-DCE) and trans-1,2-dichloroethene (at much lower concentrations than cis-1,2-DCE), then to vinyl chloride, ethane and ethene and finally carbon dioxide, water, and chloride. The biodegradation pathway of PCE is shown in Figure 3. This sequence of degradation would be anticipated where the biological reductive dehalogenation of PCE is occurring. Some of these breakdown products and relative concentrations are present at the Site. The presence of TCE in the apparent source area wells LFR-1 and SOMA-2 during sampling events indicates that PCE degradation is occurring. The presence of relatively high concentrations of cis-1,2-DCE in SOMA-2 and SOMA-3 and its presence in other wells such as LFR-1 and LFR-2 are also indicative of biodegradation. The strong occurrence of biodegradation processes in the subsurface was further evident by the depletion of PCE and TCE in some of the source area wells, which used to contain elevated levels of PCE.

1.5 Bioattenuation Parameter Analysis Results

Bioattenuation parameters were collected during the quarterly groundwater monitoring events beginning with the third quarter of 2000. The objective of the bioattenuation study was to evaluate whether intrinsic bioremediation processes are active at the Site. During the degradation process, the indigenous bacteria that exist in the subsurface consume electron acceptors such as DO. After the DO is consumed, anaerobic microorganisms typically use alternative electron acceptors in the following order of preference: nitrate, ferric iron, oxyhydroxide, sulfate, and, finally, carbon dioxide. The results of DO, nitrate, manganese, sulfate, ferrous iron, methane, and ORP measurements collected during the quarterly monitoring events indicate that conditions in the apparent source area are conducive to the reductive dechlorination processes. The evaluation of the distribution of these electron acceptors has provided the evidence that chlorinated and aliphatic hydrocarbon biodegradation is occurring beneath the Site.

2.0 SCOPE OF WORK

The primary purpose of this report is to describe the results of groundwater flow, chemical transport and bioattenuation modeling conducted as part of the second phase of investigations described in SOMA's June 15, 2001 workplan. The modeling was conducted in order to define the Site's regulatory status. The Site's regulatory status can lead to categorizing the Site as a "Low Risk" or "High Risk" chemical release Site, and that will in turn determine the remediation action to be taken.

During the quarterly monitoring events significant amounts of site-specific data were gathered to evaluate the natural attenuation processes in the subsurface. The natural attenuation processes (biodegradation, dispersion, sorption, volatilization) affect the fate and transport of chlorinated solvents in the subsurface. When these processes are shown to be capable of attaining site-specific remediation objectives in a time period that is reasonable compared to other alternatives, they may be selected alone or in combination with other more active remedies as the preferred remedial alternative. Monitored Natural Attenuation (MNA) refers specifically to the use of bioattenuation processes as part of the overall remediation of the Site. To evaluate whether MNA alone will be sufficient to restore groundwater quality beneath the Site, groundwater flow and chemical transport modeling was conducted. In conducting chemical transport modeling the following scenarios were simulated for a period of 30 years:

1. Using site-specific bioattenuation parameters gathered during quarterly groundwater monitoring events, the biodegradation processes of chlorinated solvents were used in simulations that will determine the future extent of chemical plumes beneath the Site. The bioattenuation model was used to provide results for this scenario. The bioattenuation model is a combination of the groundwater flow, chemical transport, and biodegradation models, used to simulate bioattenuation of the contaminants in the groundwater due to the processes of advection, dispersion, sorption and biodegradation using the electron acceptor technique.

2. Simulation of the future extent of chlorinated solvents using a decay rate, which is a function of half-life of each chemical. For this scenario, a combination of the groundwater flow model and the chemical transport

model was used. The groundwater flow model was used to simulate groundwater flow beneath and surrounding the Site. The chemical transport model was used for simulation of advection, dispersion, sorption and decay rate of each chemical in groundwater.

If the result of the first scenario indicates that MNA alone is not capable of restoring groundwater quality within a reasonable time frame, a remedial action such as groundwater extraction and treatment may be warranted in order to restore groundwater quality conditions to an acceptable level per RBCA recommendations.

3.0 GROUNDWATER FLOW AND CHEMICAL TRANSPORT MODELING

The following sections describe the methodology used to conduct groundwater flow and chemical transport modeling at the Site. The groundwater flow model was used to evaluate groundwater flow conditions beneath the Site. After calibrating the flow model, the chemical transport model was run using the two scenarios discussed above. The first scenario uses the BIOPLUME III model, which simulates the chemical transport processes of advection, dispersion, adsorption and the biodegradation processes using the electron acceptor methodology. The second scenario uses the transport model of MT-3D. The MT-3D model simulates the same advection, dispersion and sorption processes, but instead of using the electron acceptors methodology it uses a generalized "half-life" concept for each chemical.

The chemicals of concern in conducting the chemical transport modeling were PCE, TCE and cis-1,2-DCE.

3.1 Groundwater Flow Model Description

The U.S. Geological Survey (USGS) Modular Three-Dimensional Finite-Difference Ground-Water Flow Model ("MODFLOW," USGS, 1988) was used to simulate groundwater flow within the model domain beneath and surrounding the Site. MODFLOW is a finite-difference flow model designed to simulate in two dimensions (and in quasi-3-dimensional form) the response of a water-yielding unit to imposed stress conditions. MODFLOW may be used to simulate confined or unconfined (water table) conditions or a combination of both conditions. This model may also be used to simulate heterogeneous and anisotropic geologic units as well as geologic units with irregular boundaries. MODFLOW can be used to simulate a single-or a multi-layer system. It also permits leakage to and from drains, variable flux boundary conditions and well-discharge simulations.

For this study, MODFLOW was used to evaluate steady-state groundwater flow under ambient conditions. The model domain used in groundwater flow and chemical transport modeling is shown in Figure 4.

Groundwater flow modeling was accomplished through the following steps:

1. Conceptualizing a hydrogeologic flow regime;
2. Designing a finite-difference grid system;
3. Assigning model boundary conditions;
4. Assigning a hydraulic conductivity to aquifer materials; and
5. Calibrating the computer model using field-measured data.

These modeling steps are described in the following sections.

3.1.1 Hydrogeologic Flow Regime

The model domain illustrated in Figure 4 consists of a 500-foot by 300-foot area that includes the Site. In general, the depth to groundwater throughout the entire hydrologic cycle ranges between 7.5 and 14 feet beneath the Site. Groundwater generally flows from the northeast to the southwest beneath the Site with an approximate groundwater flow gradient of 0.019 ft/ft to 0.035 ft/ft.

For modeling purposes, it was assumed that the shallow groundwater zone beneath the study area consists of a single unconfined layer that is generally comprised of fine grained clayey silt sediments, which are separated by significantly lower permeable intervening clay layers, that are unsaturated in some areas. The thickness of this layer was assumed to be approximately 10 feet everywhere within the model domain.

3.1.2 Finite-Difference Grid System

The model domain was subdivided into a uniform finite-difference grid covering an area with dimensions of 500 feet by 300 feet, as shown in Figure 4. The grid is comprised of 12.5 feet by 10 feet cells arranged in 40 columns and 30 rows. By convention, the model solution nodes are considered to be located at the center of each cell.

3.1.3 Model Boundary Conditions

Water level data from monitoring wells located within the study area indicate that the groundwater flow direction underneath the Site is generally toward the southwest. Based on previous water level measurements, the groundwater flow gradient is relatively consistent and does not change significantly over time.

A general head boundary condition (GHB) was used along all four boundaries of the model domain. This boundary condition specifies that groundwater enters the model domain at a rate that is a function of the hydraulic conductivity of the sediments at the boundary, the cross-sectional area of the flow through the cell, and the hydraulic gradient at the edge of the model domain. Thus, flow conditions are considered to be continuous across the model boundary.

3.1.4 Hydraulic Conductivity of Aquifer Materials

The lithologic logs of sediments beneath the Site indicate that saturated sediments beneath the Site are composed of fine-grained clayey silt materials. The results of the slug tests indicate that the hydraulic conductivity of the saturated sediments range between 1.2 x 10^{-4} and 6.9 x 10^{-4} cm/sec, which is equivalent to 0.34 ft/day to 1.95 ft/day. Using the average groundwater flow gradient of 0.027 ft/ft and an aquifer porosity of 0.32, the groundwater flow velocity ranges between 10.5 and 60.1 ft/year.

3.1.5 Model Calibration Using Field Measured Data

Model calibration was performed to establish the model as adequately representing the actual groundwater flow system. The model was calibrated using water level measurement data from individual observation wells from the September 10, 2002 groundwater monitoring event. The groundwater flow model was calibrated by adjusting hydraulic input parameters (e.g., boundary conditions and hydraulic conductivity values) and comparing the resulting simulated values with observed groundwater elevations at each monitoring well location. Table 1 presents a comparison between the measured groundwater elevations and simulated groundwater elevations at monitoring well locations predicted by the calibrated groundwater flow model. The model is in good agreement with the measured values, with an average deviation from the observed values of 0.96 feet.

3.2 Chemical Transport Modeling

As discussed chemical transport modeling was conducted using two different models. The first model was BIOPLUME III while the second model was MT-3D. Both models use the same processes of advection, dispersion and sorption. The difference between the two models is the way they handle the biodegradation processes in simulation of future contaminant concentrations. The following is a brief description of the processes involved in chemical transport modeling.

Advection (i.e., mass transport of dissolved chemical species via bulk flow with the groundwater) is the dominant transport mechanism of dissolved chemicals in the groundwater. The two other primary processes that can influence the distribution of chemicals in groundwater are dispersion and sorption. Dispersion results from small-scale variations of groundwater flow velocity, which causes spreading of chemicals in a transverse direction or in the direction of groundwater flow. The process of sorption of chemicals onto sediments impedes the transport of those chemicals through soil and groundwater. The effects of sorption were simulated using the retardation coefficient, which is the ratio between the calculated groundwater velocity and the apparent chemical velocity in a particular porous medium. The following sections describe how dispersion and sorption processes were simulated in the chemical transport modeling.

The dispersion process is responsible for the spreading of contaminants over a greater region than would be predicted solely from the groundwater velocity vectors. Dispersion occurs both longitudinally and transversely to the flow direction. In this simulation, the porous medium was assumed to be isotropic and molecular diffusion was considered to be negligible relative to dispersion. Input data that controls the dispersion process includes values of longitudinal and transverse dispersivity of the water-yielding sediments. Actual measurement of dispersivity values requires intensive field studies and such field data were not available. For modeling purposes, the saturated sediments beneath the Site were assigned a value of 6.5 feet for longitudinal dispersivity. The ratio of the horizontal transverse dispersivity to the longitudinal dispersivity had a value of 0.1 and the ratio of the vertical transverse dispersivity to the longitudinal dispersivity had a value of 0.01. A summary of the model parameters is shown in

Table 2.

MT3D assumes that retardation of contaminant transport is mainly due to sorption, which refers to the mass transfer process between the contaminants dissolved in groundwater (aqueous phase) and the contaminants sorbed on the porous medium (sorbed phase).

The functional relationship between sorbed and dissolved concentrations, called a sorption isotherm, is classified in MT3D as three types: linear, Freundlich and Langmuir. Linear sorption was used in this simulation, as it is often a good model for the relatively low concentrations typically encountered in groundwater. Linear sorption assumes that there is a linear relationship between the sorbed concentration and the dissolved concentration.

The retardation of a chemical front in groundwater relative to the bulk mass transfer in groundwater is characterized by the retardation factor (R), as given in the following equation:

$$R = 1 + \frac{\rho}{\eta} K_d$$

Where:

R = Retardation factor (dimensionless)

ρ = Bulk density of the aquifer material (M/L^3)

η = Effective porosity of the aquifer (dimensionless)

K_d = Soil-water partition coefficient (L^3/M)

This approach is based on the assumption that the organic carbon content of the porous medium controls the sorption process. The values of the chemical parameters used in the MT3D simulation, including K_d and R, for PCE, TCE and cis-1,2-DCE are shown in Table 3.

Finally, biodegradation is a process through which the contaminant mass in the groundwater is diminished. During the degradation process, the indigenous bacteria that exist in the subsurface consume electron acceptors such as DO. After the DO is consumed, anaerobic microorganisms typically use alternative electron acceptors in the following order of preference: nitrate, ferric iron, oxyhydroxide, sulfate, and finally, carbon dioxide. Evaluating the distribution of these electron acceptors can provide evidence of where and to what extent chlorinated and aliphatic hydrocarbon biodegradation is occurring. The by-products of the biodegradation processes are nitrite, ferrous iron, alkalinity, sulfide, methane, and carbon dioxide.

To simulate the impact of the above-mentioned processes on contaminants fate and transport two different models were used. The first model was BIOPLUME III, while the second model was MT-3D. The following is a description of these models.

3.2.1 BIOATTENUATION MODEL

The bioattenuation model is a combination of the groundwater flow, chemical transport, and biodegradation models. With the exception of the model domain and the bioattenuation components, the groundwater flow and chemical transport parameters and assumptions used in this model are identical to those used in MODFLOW and MT3D, as shown in Tables 2 and 3.

BIOPLUME III is a two-dimensional, finite difference model developed primarily to simulate the natural attenuation of organic contaminants in groundwater due to the processes of advection, dispersion, sorption and biodegradation using a number of aerobic and anaerobic electron acceptors. This model solves the transport equation six times to determine the fate and transport of the hydrocarbons, the electron acceptors and reaction by-products. BIOPLUME III is based on the U.S. Geological Survey Method of Characteristics Model (dated

July 1989) and was developed through collaboration between the U.S. Environmental Protection Agency and the U.S. Air Force.

3.2.2 MT-3D Model

MT3D, a modular three-dimensional transport model for simulation of advection, dispersion, sorption and chemical decay of contaminants in groundwater systems, developed by S.S. Papadopulos & Associates, Inc. (Zheng 1998), was also utilized. MT3D is a finite-difference transport model that uses a mixed Eulerian-Lagrangian approach to the solution of three-dimensional advective-dispersive-reactive equations in the method of characteristics, the modified method of characteristics, and a hybrid of the two methods, making it uniquely suitable for a wide range of field problems. For simulating the degradation of chemicals in the groundwater, MT-3D uses the decay rate of each chemical. By definition the decay rate is:

$$DecayRate = \frac{\ln 2}{T_{1/2}}$$

Where, $T_{1/2}$ is the half-life of the chemical.

MT3D can be used in conjunction with any block-centered finite-difference flow model, such as MODFLOW, and is based on the assumption that the flow field is not measurably affected by any change in the concentration field, allowing separate conceptualization and calibration of a flow model.

Water quality simulations were accomplished in two steps. In the first step, MODFLOW was run to generate the potentiometric head distribution for the single-layer system. The simulated hydraulic heads and other related flow terms were saved to a data file. In the second step, MT3D was run to simulate the chemical transport. MT3D retrieved the hydraulic heads and the flow and sink/source terms saved by the flow model, automatically incorporating the specified boundary conditions and the operations of any groundwater extraction system, such as wells, drains, etc.

The transport models were used to simulate future chemical concentration distributions in the groundwater for 30 years (assuming that no new sources of chemicals were released). The average concentrations of PCE, TCE and cis-1,2-DCE of the Third Quarter 1999 through the Third Quarter 2002 groundwater monitoring events (as shown in Table 4) were used as the initial conditions in the simulations.

The model was then used to simulate chemical transport under steady-state groundwater flow conditions for a period of 30 years, based on the previously stated assumptions.

In using the BIOPLUME III model, the average concentrations of electron acceptors were calculated and used as an initial condition. The average concentration of DO for aerobic biodegradation, and other electron acceptors for anaerobic biodegradation are presented in Table 4. The calculated degradation rates for PCE, TCE and cis-1,2-DCE used in the bioattenuation simulation are shown in Table 5.

BIOPLUME III was then used to simulate chemical transport and bioattenuation under steady-state groundwater flow conditions for 30 years, based on the previously stated assumptions.

4.0 RESULTS

The main objective of this study was to predict the groundwater chemical concentrations down-gradient from the Site, beneath the nearest residential neighboring property, in order to assess the Site's regulatory status and restore groundwater quality conditions to an acceptable level per RBCA recommendations. The following section presents the results of the groundwater flow, chemical transport and bioattenuation models.

4.1 Bioattenuation Model

Figures 5 through 14 illustrate the simulated PCE concentrations from year one through year 10 on a yearly basis using the BIOPLUME III model. As time elapses, the PCE plume dramatically decreases in concentration as it spreads in size. After only one year, the maximum PCE concentration in the residential area drops to less than 481 µg/L. After six years, the maximum PCE concentration drops to less than 319 µg/L, and its length is approximately limited within the northwest corner of Manila Avenue and 38th Street. After ten years, no PCE concentration is detectable underneath the Site or in the neighboring residential area. Land use information of the Site and its surrounding area can be found in Figure 4.

Figures 15 through 17 depict TCE concentrations in the next three years on a yearly basis. As the results of the simulation indicates, the TCE plume will biodegrade faster than the PCE plume, so that in three years it would dissipate after only traveling about 75 feet in the groundwater flow direction. The highest TCE concentration detected under the residential area would be about 144 µg/L after two years, as shown in Figure 16. However, after three years TCE concentration will disappear completely.

Figures 18 through 21 display cis-1,2-DCE concentrations in the next four years on a yearly basis. As shown in Figures 18 through 21, the cis-1,2-DCE plume would travel as far as the northwestern corner of Manila Avenue and 38th Street before being completely biodegraded in less than four years.

4.2 Groundwater Flow and Chemical Transport Models

Figures 22 through 28 depict the simulated PCE plumes after one to seven years under the no biodegradation scenario. Similar to the results with BIOPLUME III, the PCE plume migrates in a southwest direction toward the residential area, while natural degradation removes PCE from groundwater. The maximum simulated PCE concentration in the residential area was 544 µg/L. According to MODFLOW and MT3D, PCE will drop to non-detectable levels after only seven years.

Figures 29 through 37 depict the simulated TCE plume yearly, for the next 9 years. The maximum simulated TCE concentration within the residential area was about 445µg/L. Based on these results, after nine years TCE concentrations would be non-detectable, whereas it would drop to non-detectable levels in less than three years with BIOPLUME III.

Figures 38 through 50 depict the simulated cis-1,2-DCE plume in the groundwater over the next thirteen years on a yearly basis. The maximum simulated 1,2-DCE concentration in the groundwater within the residential area, down-gradient of the Site was 1,838 µg/L. Based on these results the 1,2-DCE plume in the groundwater would biodegrade in 13 years, as shown in Figure 50. In comparison, using BIOPLUME III, cis-1,2-DCE levels would persist underneath the Site for only 9 years.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Results of the BIOPLUME III model indicated that bioattenuation processes would remove the PCE plume in the groundwater underneath the Site within about 10 years , TCE in less than about three years and cis-1,2-DCE in less than about four years. SOMA has PCE, TCE and cis-1,2-DCE data dating back to the first quarter of 2000, which confirm the concentrations have indeed decreased. However, they have not decreased at the rate predicted by the model. Therefore, the results from BIOPLUME III may be too optimistic.

The MODFLOW and MT3D models only take into account advection, dispersion, sorption, and the decay processes for the chlorinated hydrocarbons. These two models do not account for the complex aerobic and anaerobic biodegradation of the contaminants by bacteria. Therefore, the results of the MODFLOW and MT3D models are more conservative than those of BIOPLUME III

The most realistic interpretation of the results from these models and the Site's data is that the contamination in the groundwater will be removed, but at rates less than predicted by BIOPLUME III. Therefore, contamination would most likely decrease at a rate somewhere between that predicted by BIOPLUME III, which is too optimistic, apparently due to a bug[1] in the electron acceptor routine, and the rate predicted by the other models.

In light of the groundwater modeling results, which confirm that biodegradation is occurring, SOMA believes that the Site should likely be characterized as a "Low" risk site according to the California Regional Water Quality Control Board's Interim Guidance Document dated December 8, 1995. In order to do so, however, the Interim Guidance document requires conducting a human health risk assessment to evaluate the impact of the Site's contaminant in soil and groundwater on the current and future Site's workers and the nearby residents. Accordingly, SOMA recommends conducting a human health risk assessment

---

[1] The U.S. EPA is supporting BIOPLUME III. As such, the EPA has a website which is offering technical help for interested individuals. Based on the discussion we had with Dr. Mingyu Wang of the U.S. EPA Kerr Environmental Research Center, apparently there is a bug in the BIOPLUME III routine, which over-estimates the dissipation of contaminants in the groundwater. The nature of the error and degree of over-estimation is not known at this time.

and continuing groundwater monitoring in order to validate the conclusions of the chemical fate and transport modeling.

Since 2000, groundwater monitoring data has been collected on a quarterly basis. This data has been sufficient to completely define the extent of the groundwater contamination and occurrence of biodegradation at the Site. Therefore, rather than conducting quarterly groundwater monitoring events, SOMA recommends that the future groundwater monitoring events be conducted on a semi-annual basis.

6.0 REFERENCES

Borden, R.C., 1998. “Hand book of Bioremediation” Section 9 Natural Bioremediation of Hydrocarbon-Contaminated Ground Water, pp 177-199.

EPA 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, EPA/600/R-98/128. September.

Helley, E.J., K.R. Lajoie, and D.B. Burke. 1972. Geologic Map of Late Cenozoic Deposits, Alameda County, California.

Howard, P.H., Boethling, R.S., Jarvis, W.F., Meylan, W.M., Michalenko, E.M. 1991. Handbook of Environmental Degradation Rates. Lewis Publishers, Inc.

LFR. 1999. Results of Utility Survey and Work Plan for Soil and Grab Groundwater Investigation. May 6.

LFR. 2000a. Soil and Groundwater Investigation Report. March 20.

LFR. 2000b. Work Plan for Installation of Groundwater Monitoring Wells, Former Glovatorium, 3815 Broadway, Oakland, California. June 14.

LFR. 2000c. Groundwater Monitoring Report, Second Quarter 2000, Former Glovatorium, 3815 Broadway, Oakland, California. July 7.

LFR. 2000d. Groundwater Monitoring Report, Third Quarter 2000, Former Glovatorium, 3815 Broadway, Oakland, California. November 2.

LFR. 2001. Groundwater Monitoring Report, Fourth Quarter 2000, Former Glovatorium, 3815 Broadway, Oakland, California. November 2.

Microseeps. 2000. Monitored Natural Attenuation As a Remedial Alternative In Groundwater Contamination. Lecture at LFR Levine - Fricke (LFR) Emeryville office by Robert J. Pirkle, Ph.D. of Microseeps. May 31.

Sepehr, M., 1999. "Methanogenesis and Anaerobic Biodegradation of Petroleum Hydrocarbons in Soil and Groundwater" a Paper Presented in 4th IAA Annual Conference at Petrochemical, Energy and Environment, September 1999, New York.

SOMA Environmental Engineering, Inc. 2001. First Quarter 2001 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, May 7, 2001.

SOMA Environmental Engineering, Inc. 2001. Second Quarter 2001 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, May 7, 2001.

SOMA Environmental Engineering, Inc. 2001. Third Quarter 2001 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, May 7.

SOMA Environmental Engineering, Inc. 2001. Fourth Quarter 2001 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, December 11.

SOMA Environmental Engineering, Inc. 2002. Report on Conducting Field Investigation to Evaluate the Site's Conceptual Model, Former Glovatorium Facility, 3815 Broadway, Oakland, California, January 11.

SOMA Environmental Engineering, Inc. 2002. First Quarter 2002 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, March 27.

SOMA Environmental Engineering, Inc. 2002. Second Quarter 2002 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, May 16.

SOMA Environmental Engineering, Inc. 2002. Third Quarter 2002 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, September 10.

SOMA Environmental Engineering, Inc. 2002. Fourth Quarter 2002 Groundwater Monitoring Report, Former Glovatorium Facility, 3815 Broadway, Oakland, California, December 3.

U.S. Geological Survey. Quaternary Geology of Alameda County, and Parts of Contra Costa, Santa Clara, San Mateo, San Francisco, Stanislaus, and San Joaquin Counties, CA: A Digital Database. U.S. Dept of the Interior.

TABLES

Table 1

Differences Between Measured and Simulated Water Levels
3815 Broadway, Oakland, California

Well Name	Measured (ft)	Simulated (ft)	Difference (ft)
GW-2	68.61	69.68	1.07
GW-3	67.78	68.41	0.63
GW-6	67.95	69.64	1.69
LFR-1	70.18	70.70	0.52
LFR-2	70.98	70.23	-0.75
LFR-3	67.67	67.66	-0.01
LFR-4	68.33	70.11	1.78
MW-08	77.27	75.84	-1.43
MW-09	77.12	75.43	-1.69
MW-11	73.90	73.61	-0.29
SOMA-2	70.40	71.12	0.72

The average difference is 0.96 foot.

Table 2

Summary of Model Parameters
3815 Broadway, Oakland, California

Model Parameters	Values
Hydraulic Conductivity	1.145 ft/day
Storage Coefficient	0.006
Effective porosity	0.32
Bulk Density	113.14 lb/ft^3
Longitudinal Dispersivity	6.50 ft
Dispersivity Ratio	0.1
Vertical Dispersivity	0.01

Table 3

Calculation of Retardation Coefficients
3815 Broadway, Oakland, California

Chemical	K_d (ft^3/lb)	F_{oc}	R
Tetrachlorethene	4.62E-03	0.0011	2.63
Trochloroethene	3.20E-04	0.0011	1.11
Cis-1,2-Dichloroethene	4.16E-04	0.0011	1.15

Table 4
Average Concentrations Used for Modeling
3815 Broadway, Oakland, California

	Third Quarter 1999 to Third Quarter 2002			Third Quarter 2000 to Third Quarter 2002			
Well Name	**PCE (µg/L)**	**TCE (µg/L)**	**Cis-1,2-DCE (µg/L)**	**Dissolved Oxygen (µg/L)**	**Nitrate (µg/L)**	**Sulfate (µg/L)**	**Ferric Iron (µg/L)**
B-2	< 1.3	< 1.3	270				
B-3	< 2.0	< 2.0	610				
B-7	4.7	5.9	928	763	756	3,600	2,690
B-8	< 0.5	< 0.5	35	450			
B-9	< 0.5	0.6	3.2				
B-10	1,862	1,618	8,017	1,844	42	1,008	453
B-13	20	29	130				
GW-2	34	5.8	3.6	2,323	3,300	56,000	535
GW-3	135	2.8	5.5	5,016	2,114	41,557	170
GW-4	2.5	< 0.5	3.8	1,352	3,140	5,000	3,078
GW-5	< 0.5	< 0.5	< 0.5				
GW-6A	< 0.5	< 0.5	< 0.5				
GW-8	111	124	34				
LFR-1	797	41	16	2,688	11,313	32,154	103
LFR-2	2.6	2.5	39	1,049	1,103	4,213	622
LFR-3	2.6	< 0.5	< 0.5	1,477	1,877	49,917	79
LFR-4	< 0.5	< 0.5	2.3	1,718	1,733	1,588	124
MW-11	2.2	2.2	2.7	4,239	8,275	76,000	19
SOMA-1	5.4	< 0.5	11	1,148	650	27,500	90
SOMA-2	416	154	2,825	318	325	0	18,800
SOMA-3	28	29	405	1,473	650	38,000	537
SOMA-4	< 130	< 130	2,600	830	22,000	17,000	220

Table 5
Calculation of Degradation Rates
3815 Broadway, Oakland, California

Chemical	Half Life (d)	1st Order Reaction Rate (ˉd)
PCE	730.0	9.50E-04
TCE	1642.5	4.22E-04
cis-1,2-DCE	2875.0	2.41E-04

FIGURES

Figure 1: Site vicinity map.

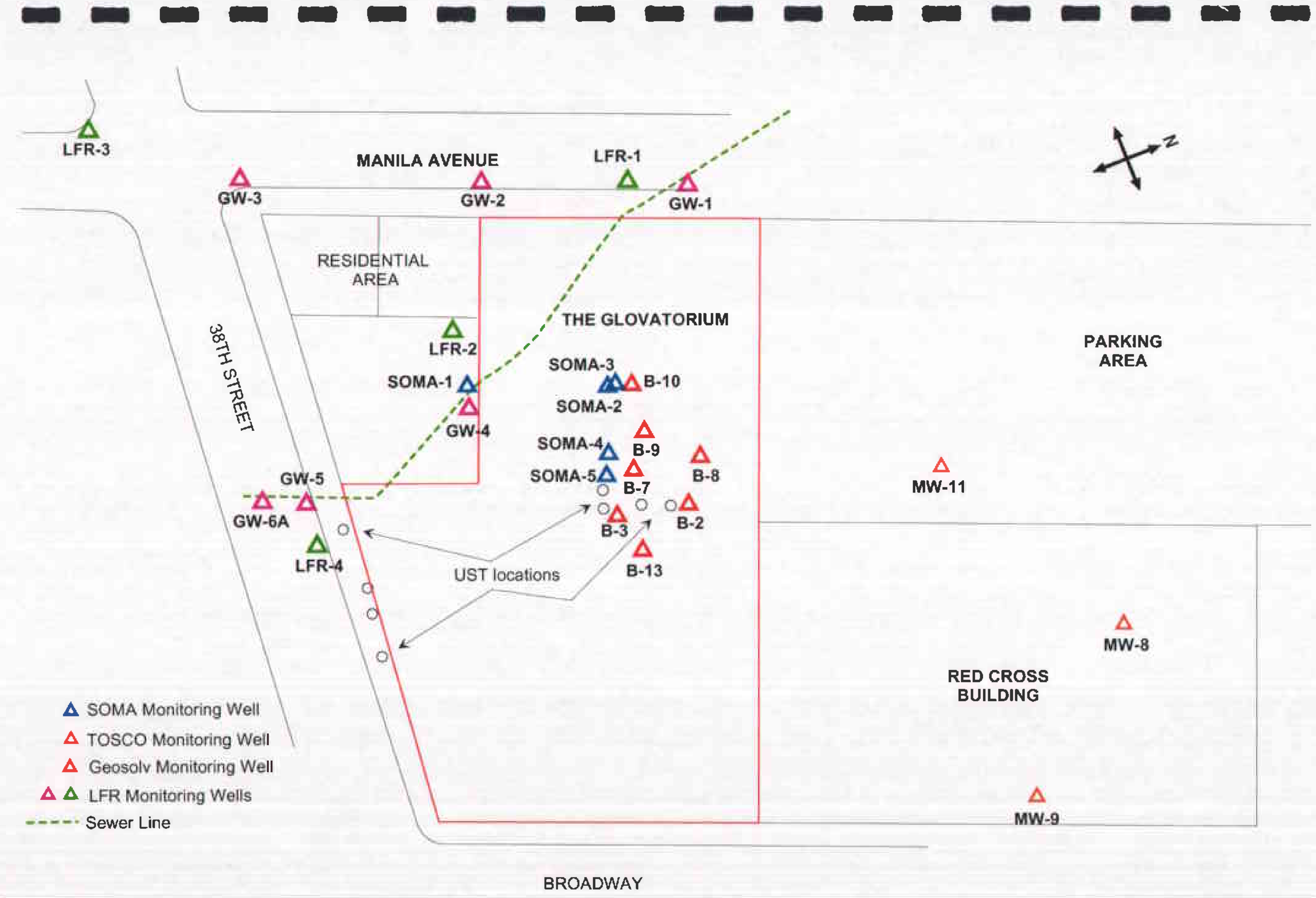


Figure 2: Map showing the locations of groundwater monitoring wells and USTs.

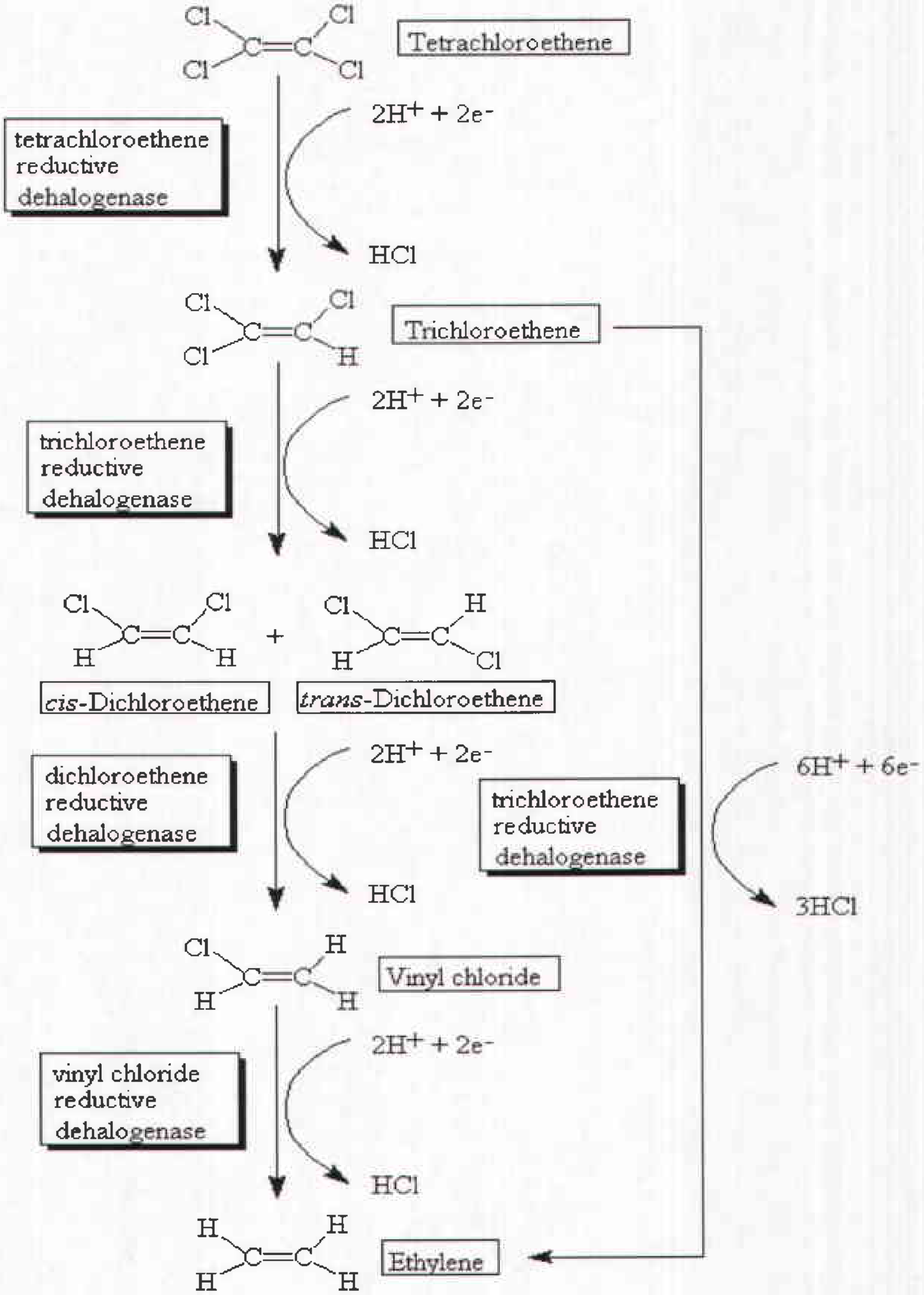


Figure 3. Anaerobic biodegradation pathway of tetrachloroethene.

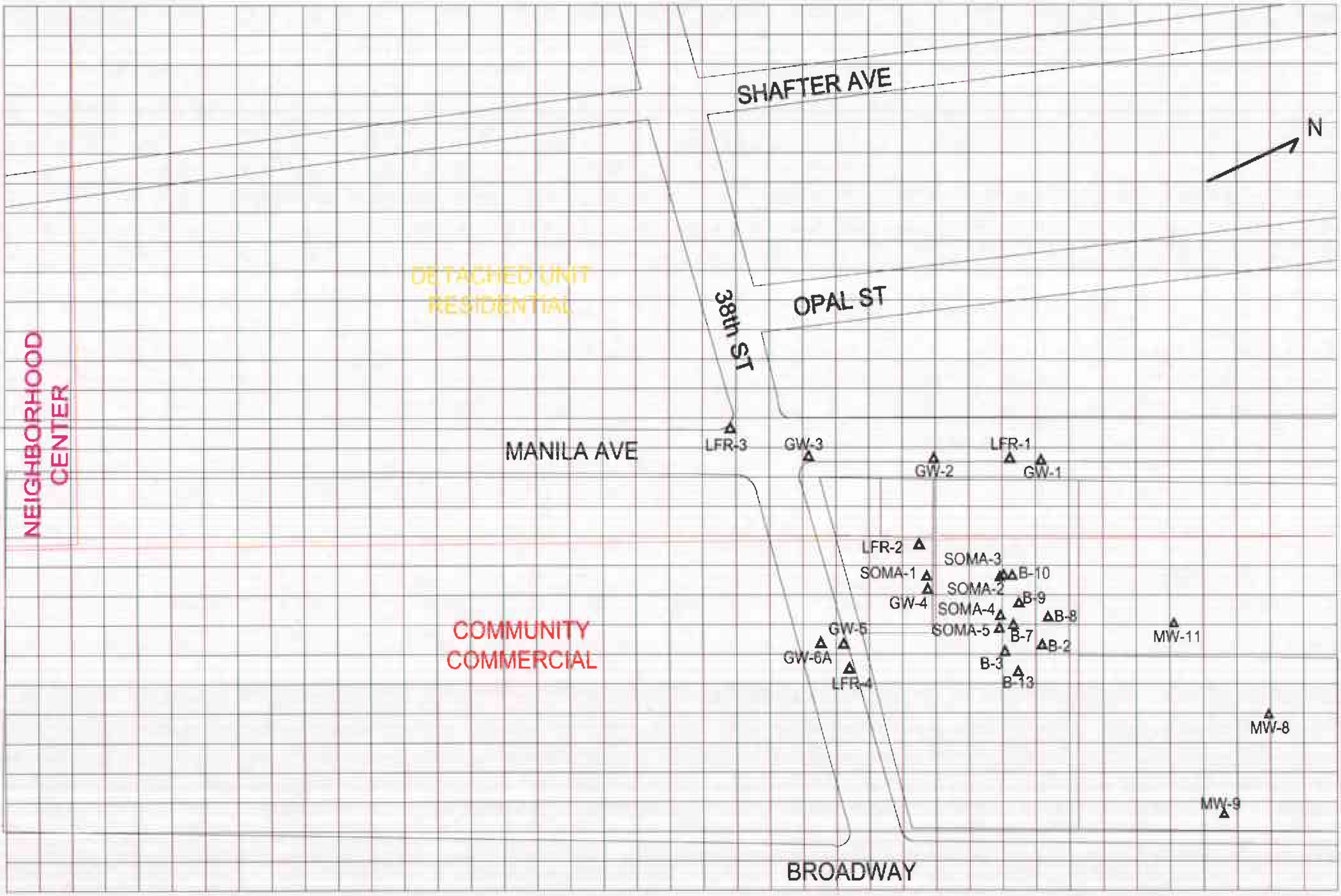
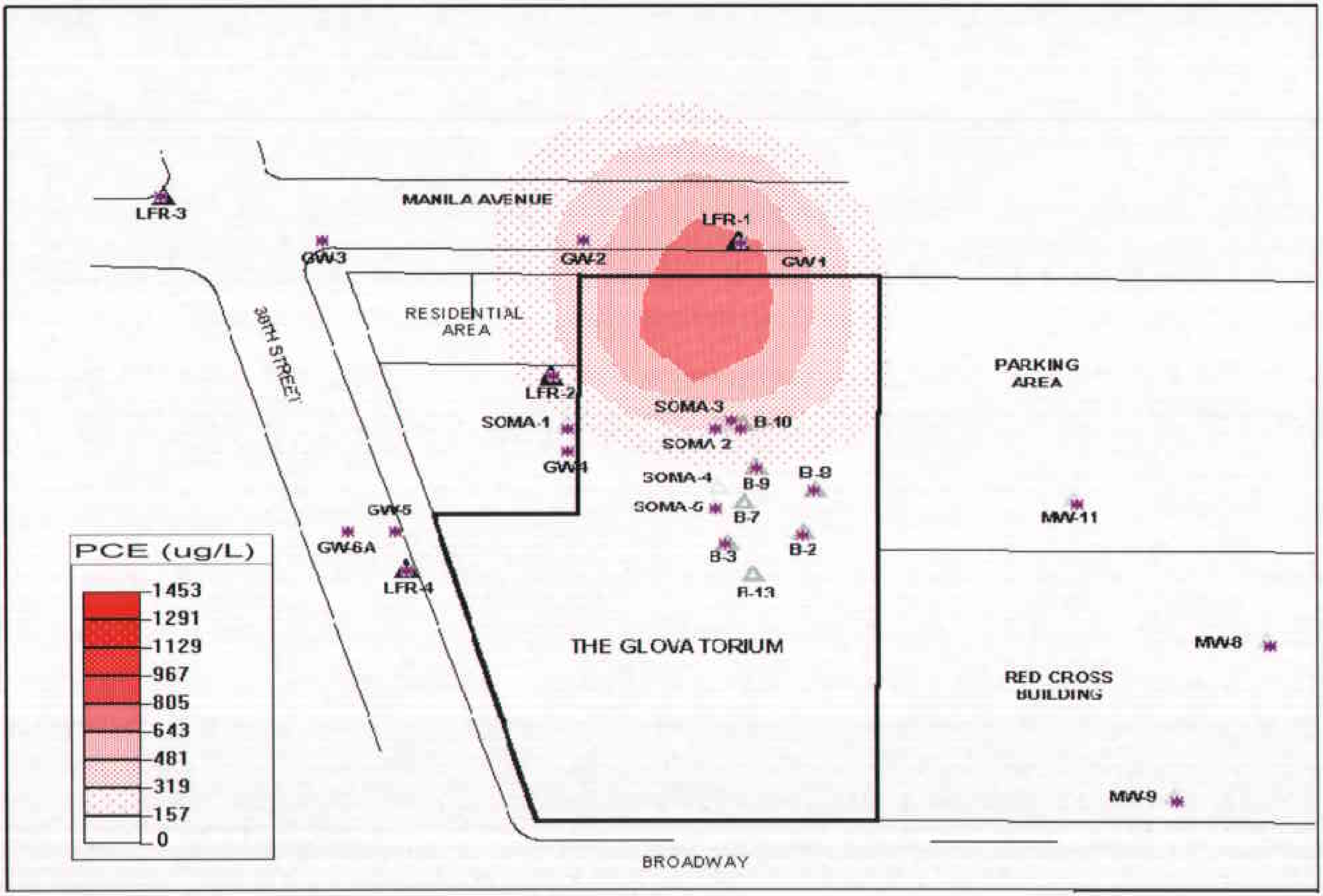


Figure 4. Groundwater flow model domain.

SOMA ENVIRONMENTAL ENGINEERING, INC.

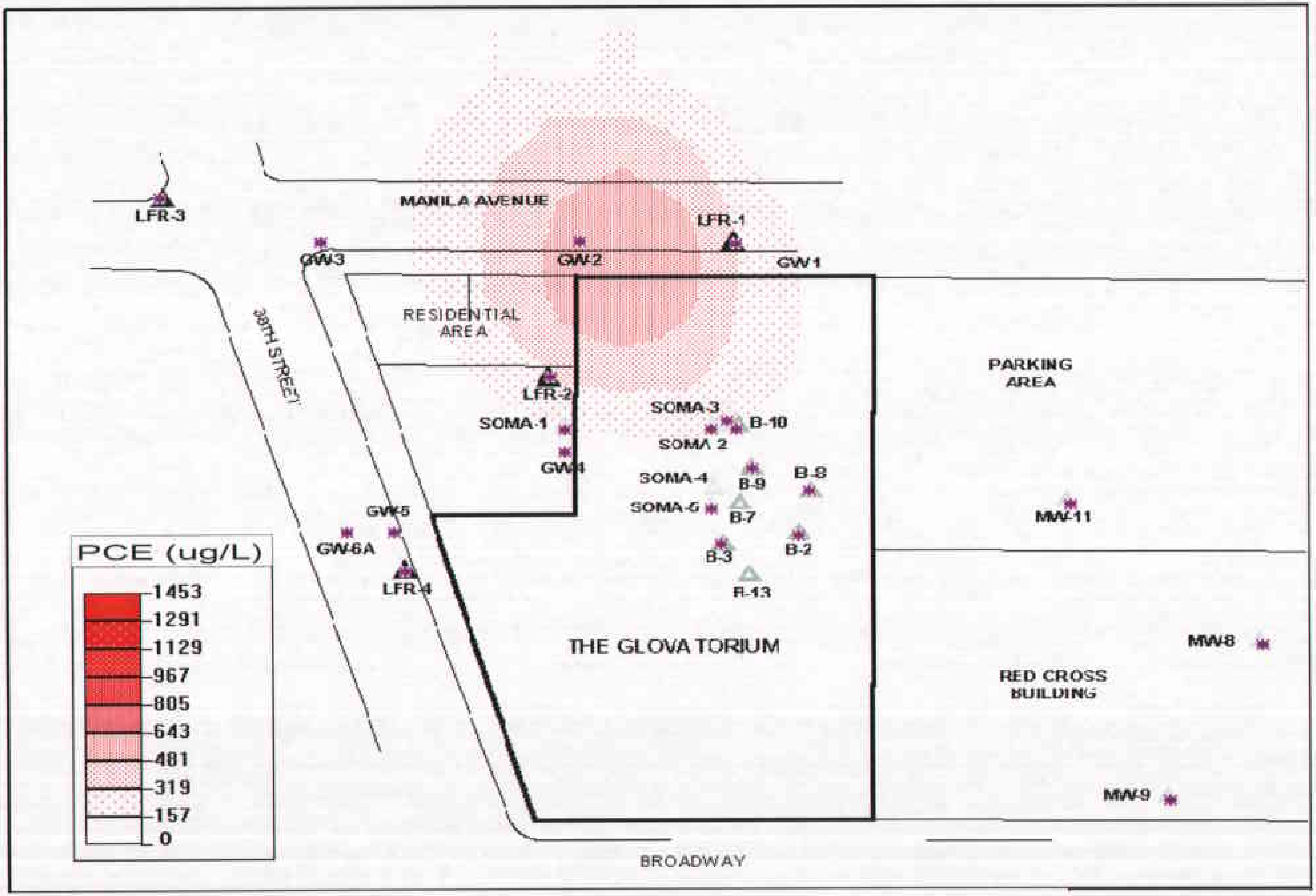


approximate scale in feet

0 50

Figure 5. BIOPLUME III simulation of PCE concentrations after 1 year.

SOMA ENVIRONMENTAL ENGINEERING, INC.

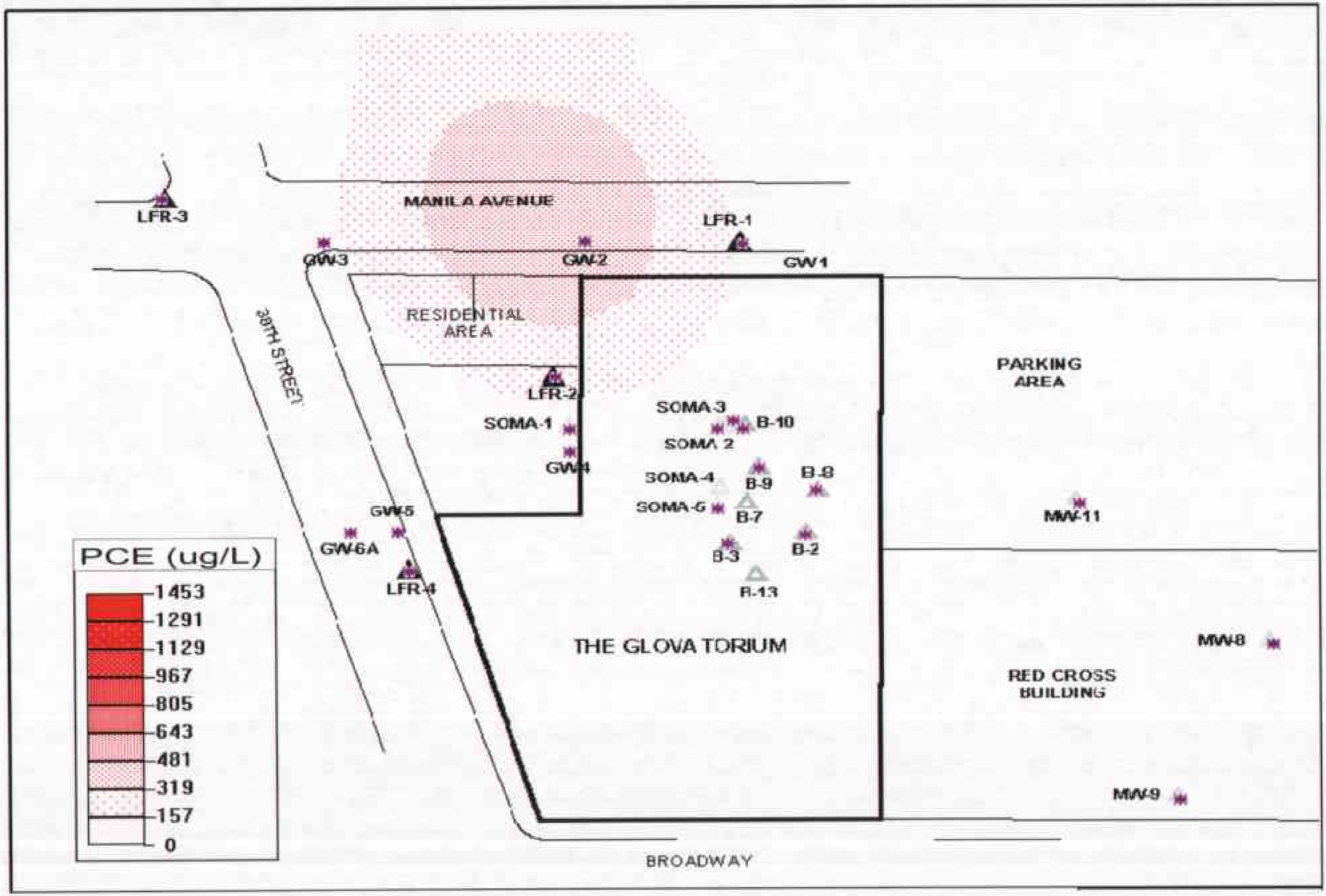


approximate scale in feet

0 50

Figure 6. BIOPLUME III simulation of PCE concentrations after 2 year.

SOMA ENVIRONMENTAL ENGINEERING, INC.

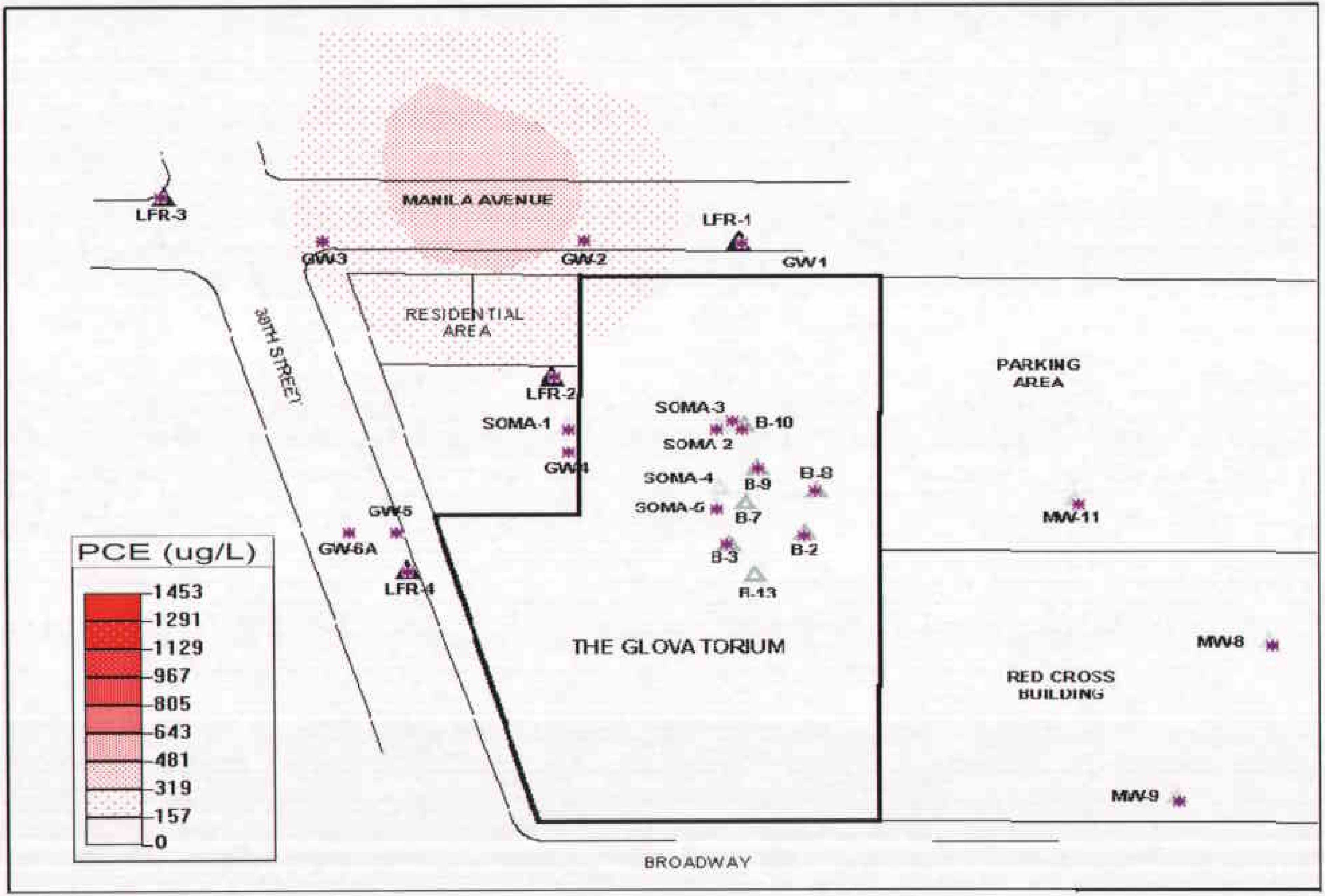


approximate scale in feet

0 50

Figure 7. BIOPLUME III simulation of PCE concentrations after 3 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet

0 50

Figure 8. BIOPLUME III simulation of PCE concentrations after 4 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

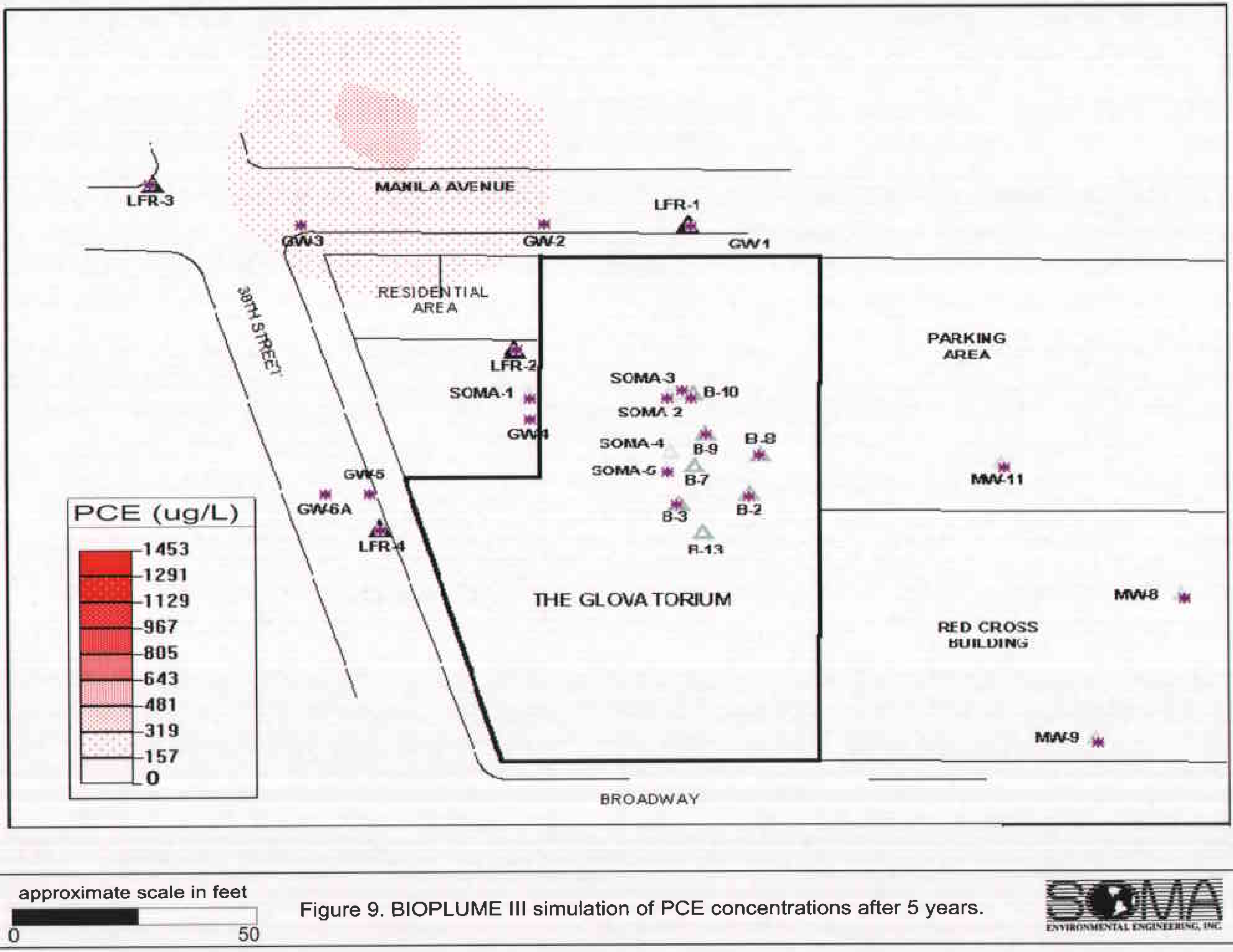
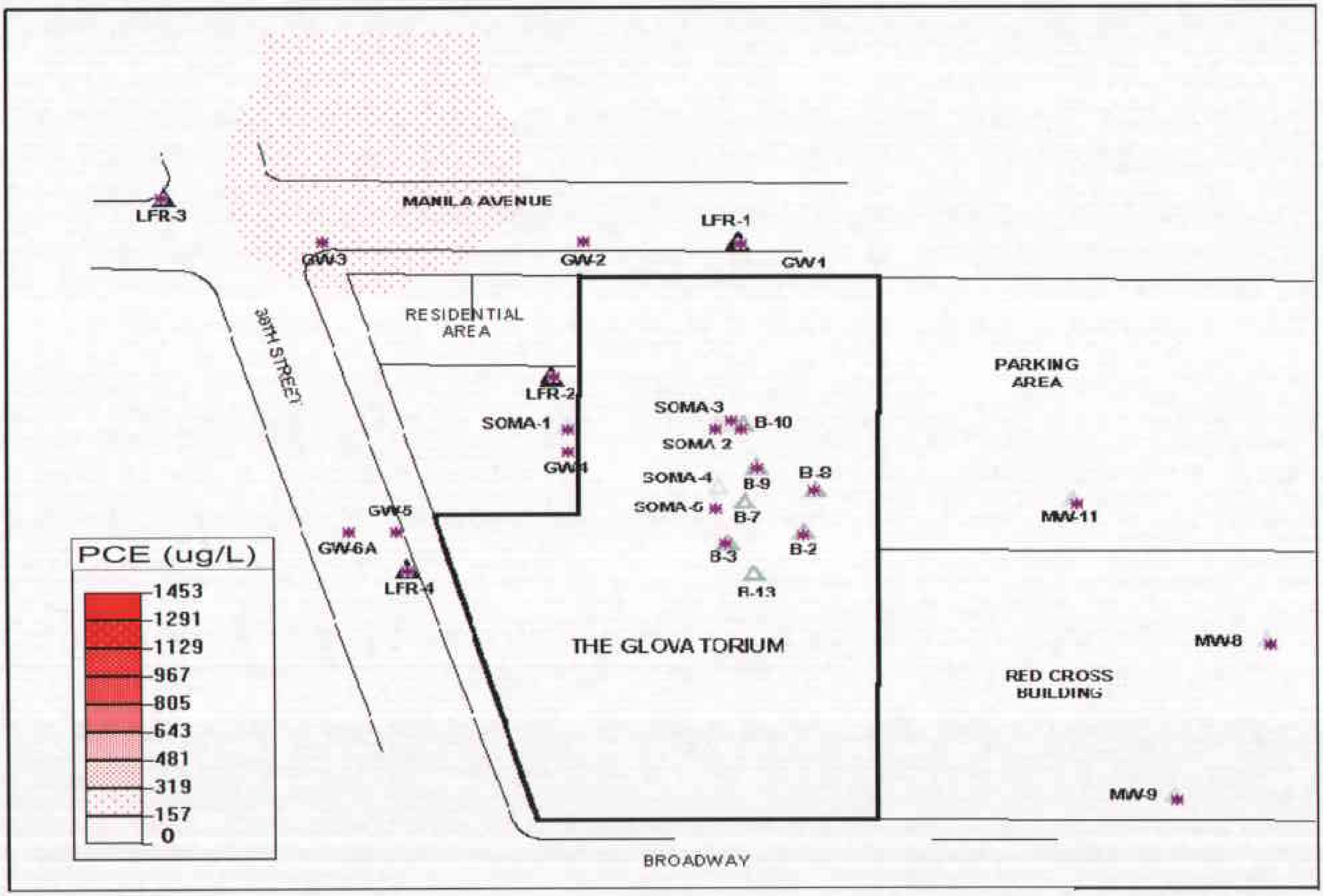


Figure 9. BIOPLUME III simulation of PCE concentrations after 5 years.

SOMA ENVIRONMENTAL ENGINEERING, INC

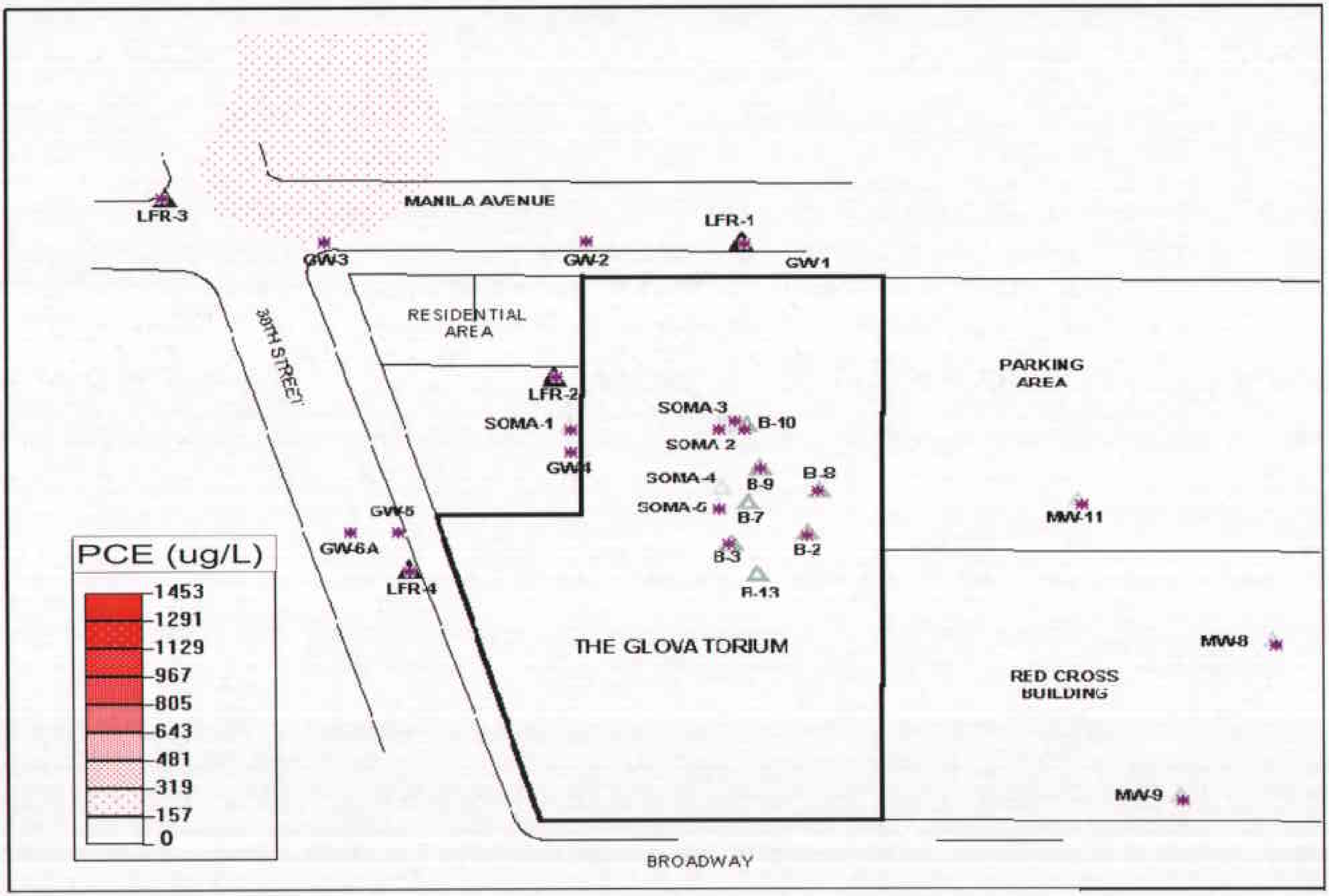


approximate scale in feet

0 50

Figure 10. BIOPLUME III simulation of PCE concentrations after 6 years.

SOMA
ENVIRONMENTAL ENGINEERING, INC.

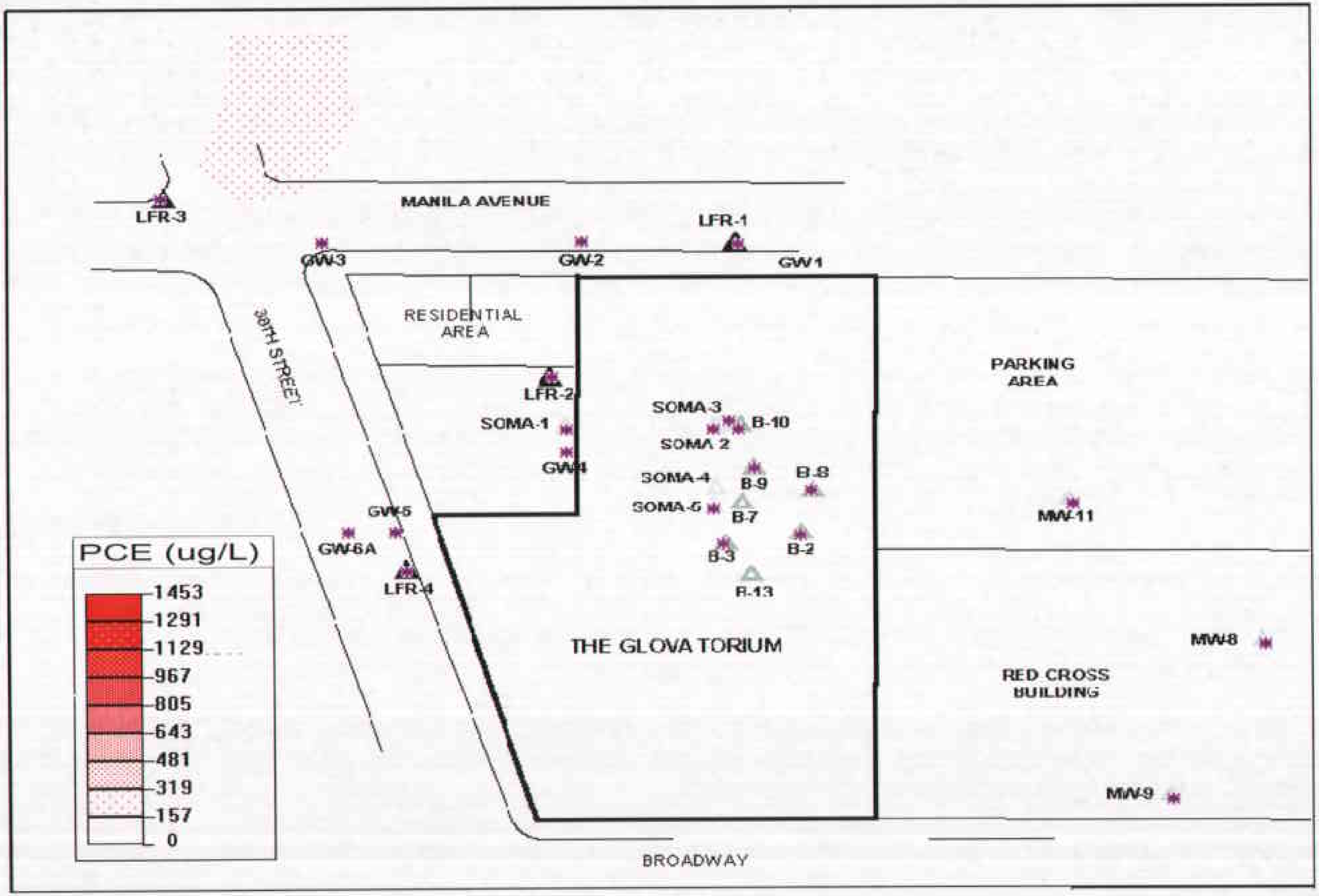


approximate scale in feet

0 50

Figure 11. BIOPLUME III simulation of PCE concentrations after 7 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

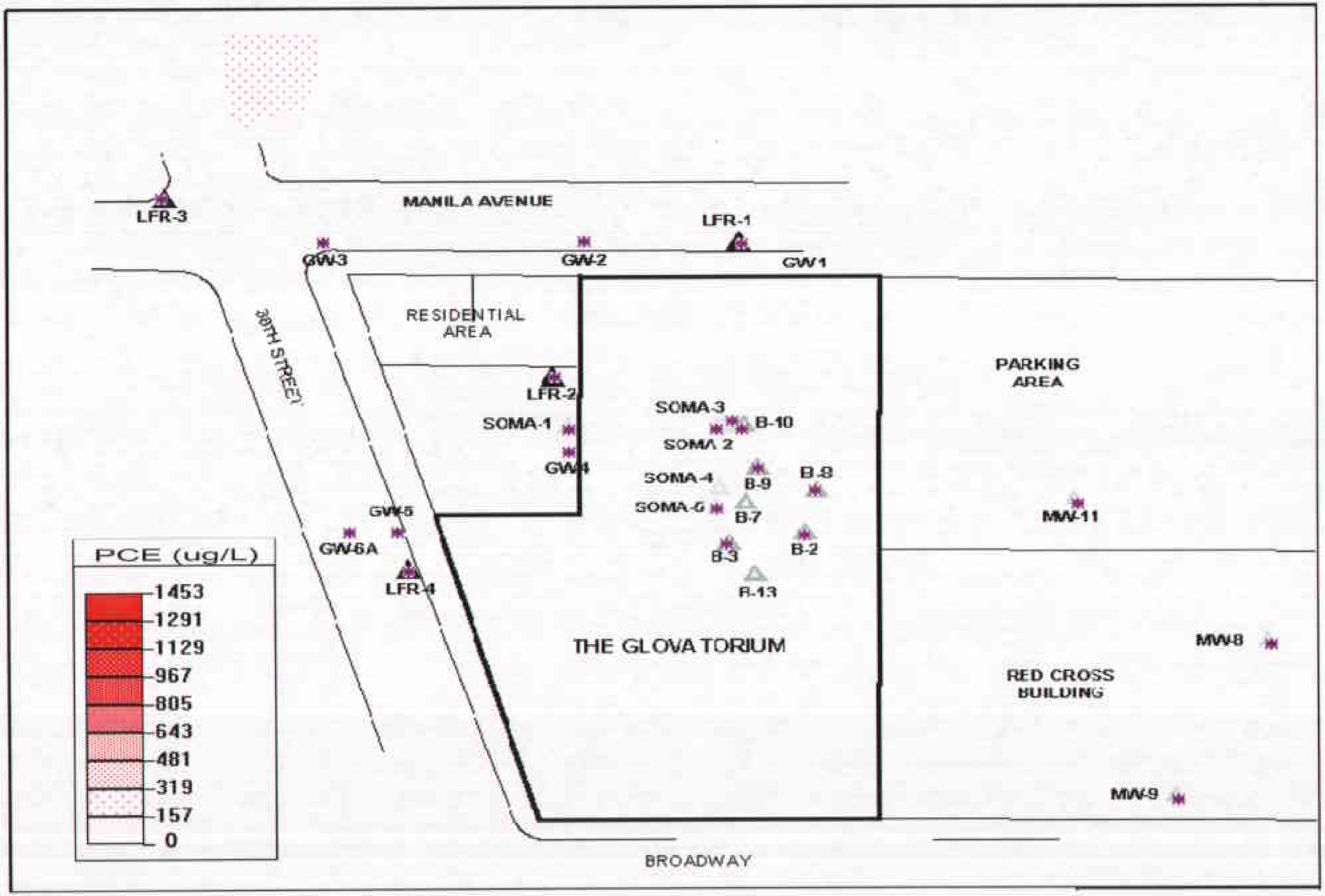


approximate scale in feet

0 50

Figure 12. BIOPLUME III simulation of PCE concentrations after 8 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

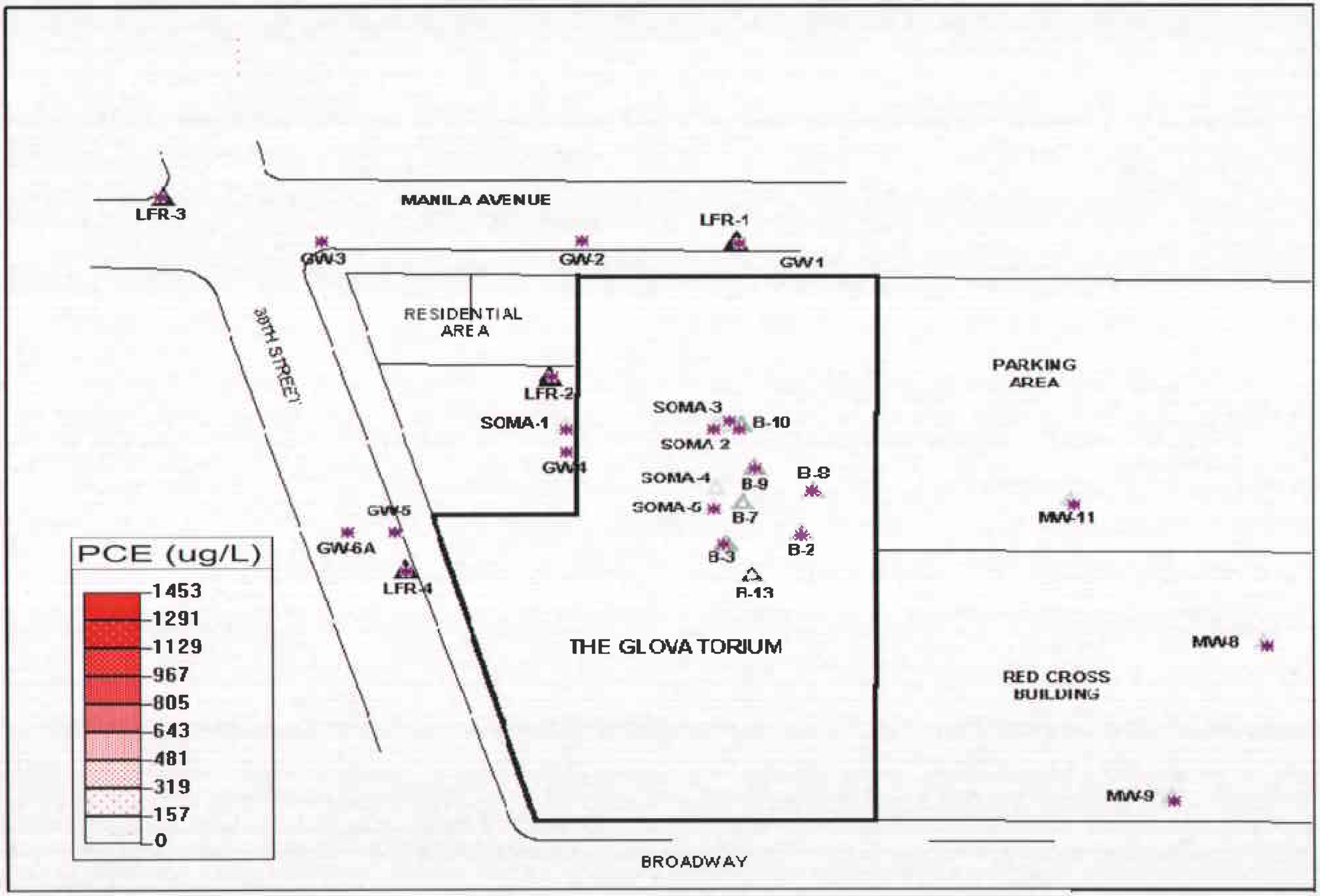


approximate scale in feet

0 50

Figure 13. BIOPLUME III simulation of PCE concentrations after 9 years.

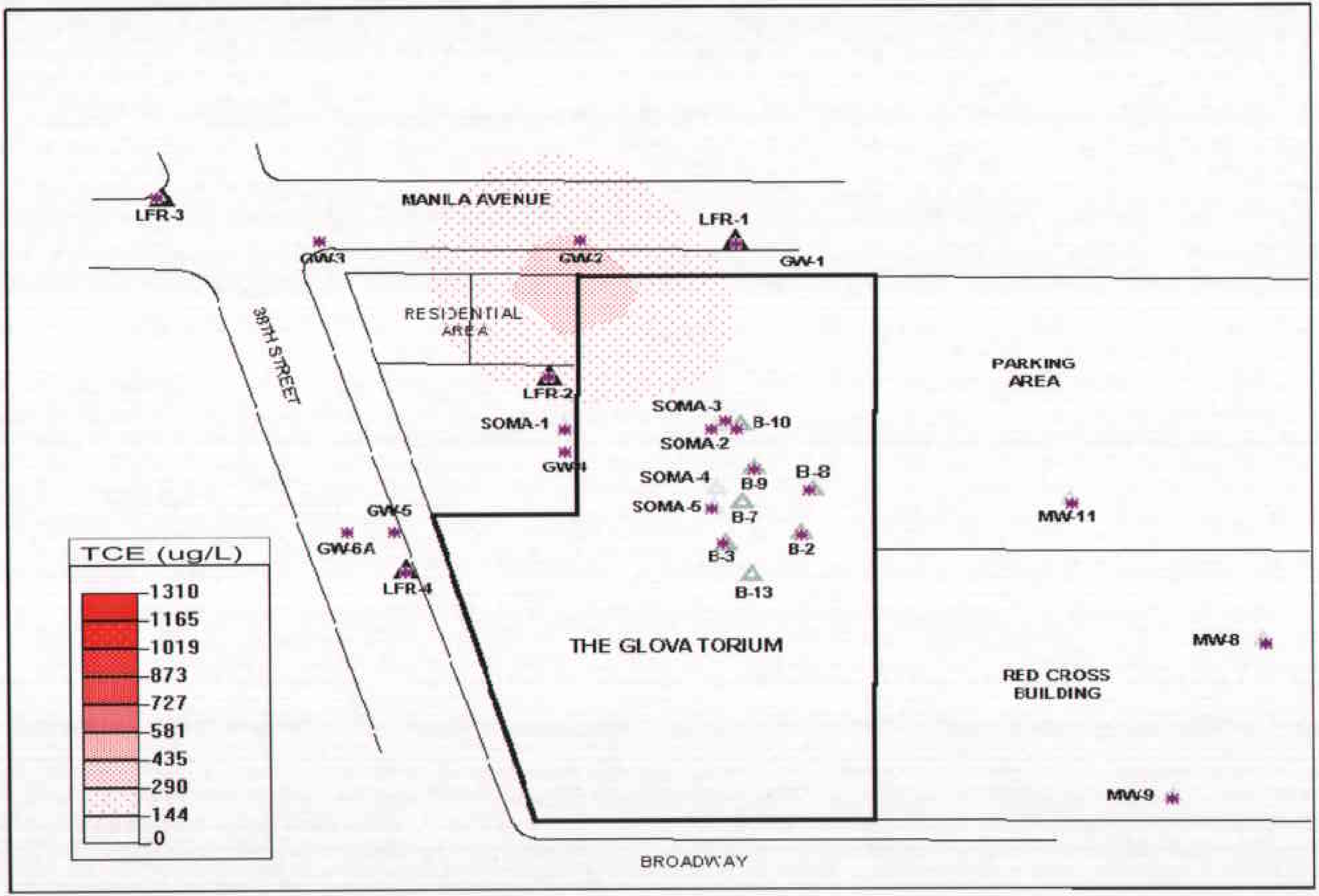
SOMA ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet

0 50

Figure 14. BIOPLUME III simulation of PCE concentrations after 10 years.



approximate scale in feet

0 50

Figure 15. BIOPLUME III simulation of TCE concentrations after 1 year.

SOMA ENVIRONMENTAL ENGINEERING, INC.

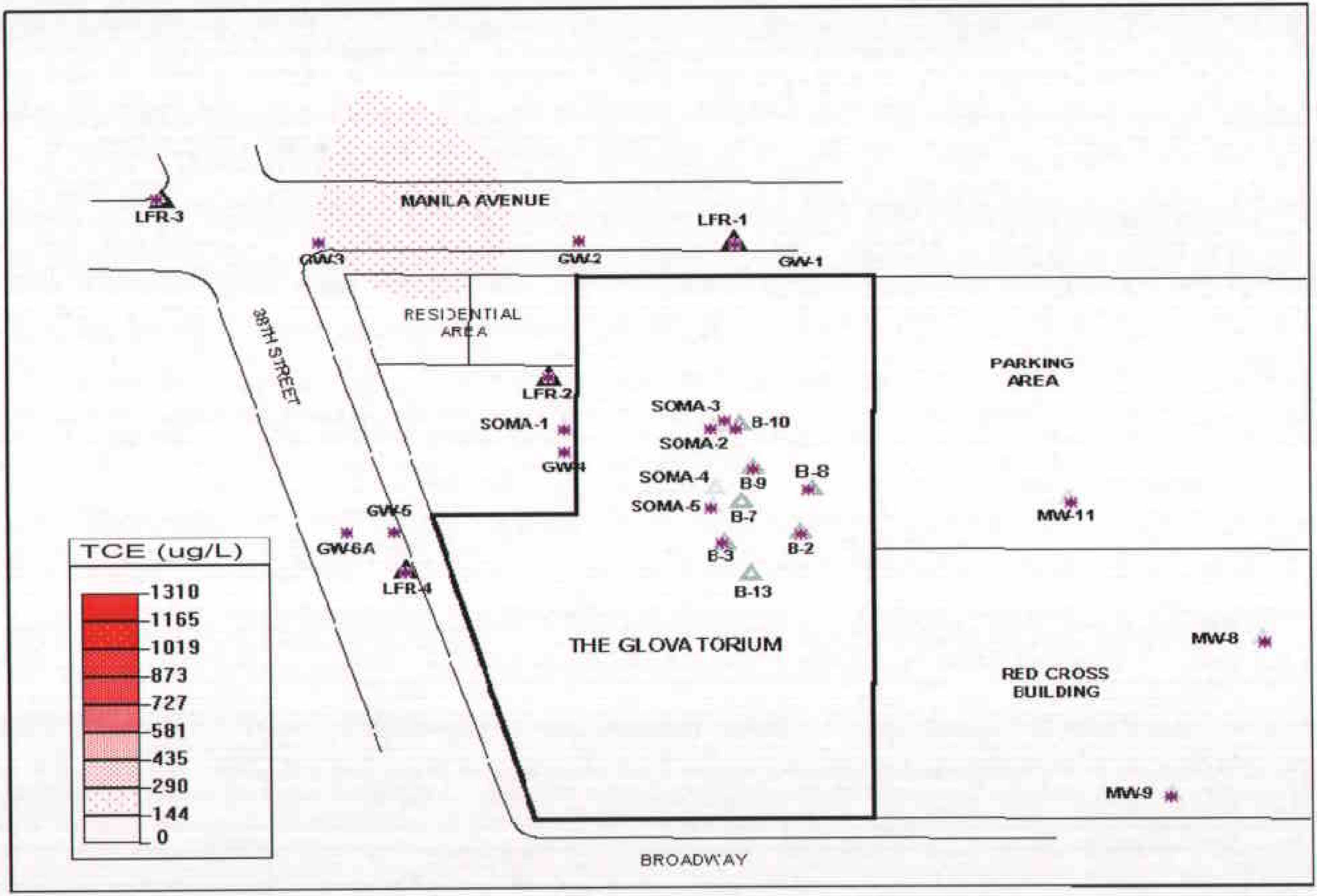
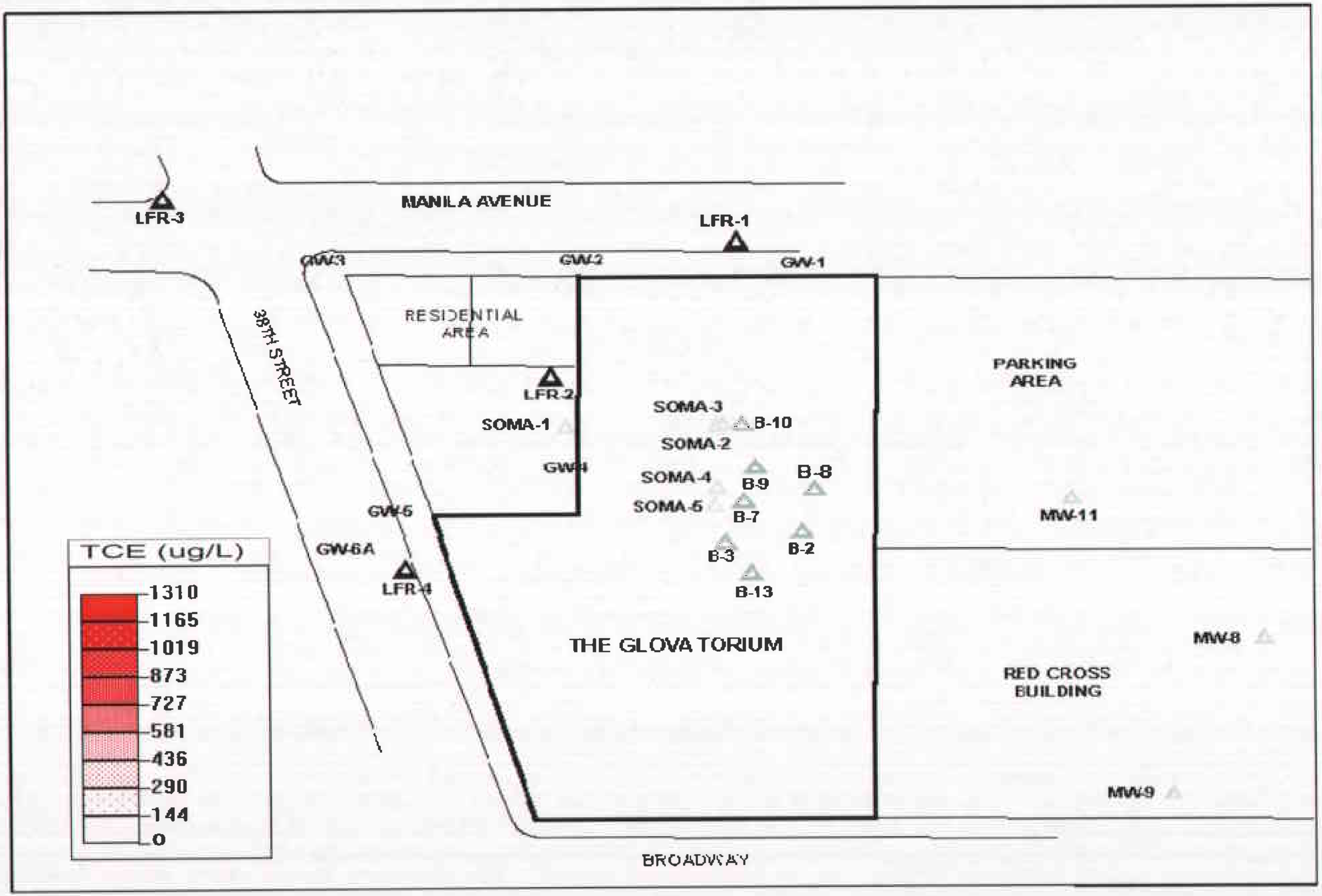


Figure 16. BIOPLUME III simulation of TCE concentrations after 2 years.

SOMA ENVIRONMENTAL ENGINEERING, INC

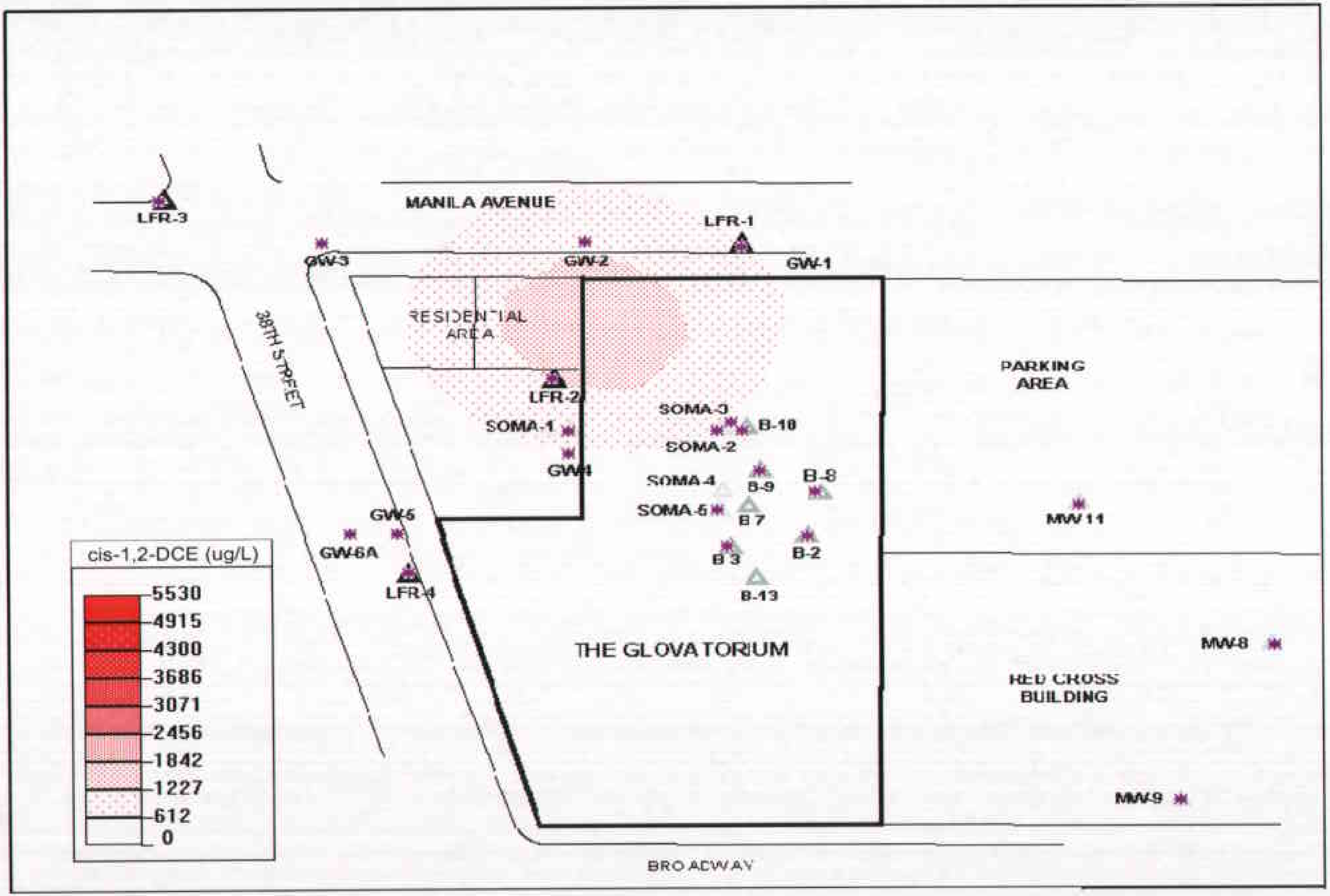


approximate scale in feet

0 50

Figure 17. BIOPLUME III simulation of TCE concentrations after 3 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

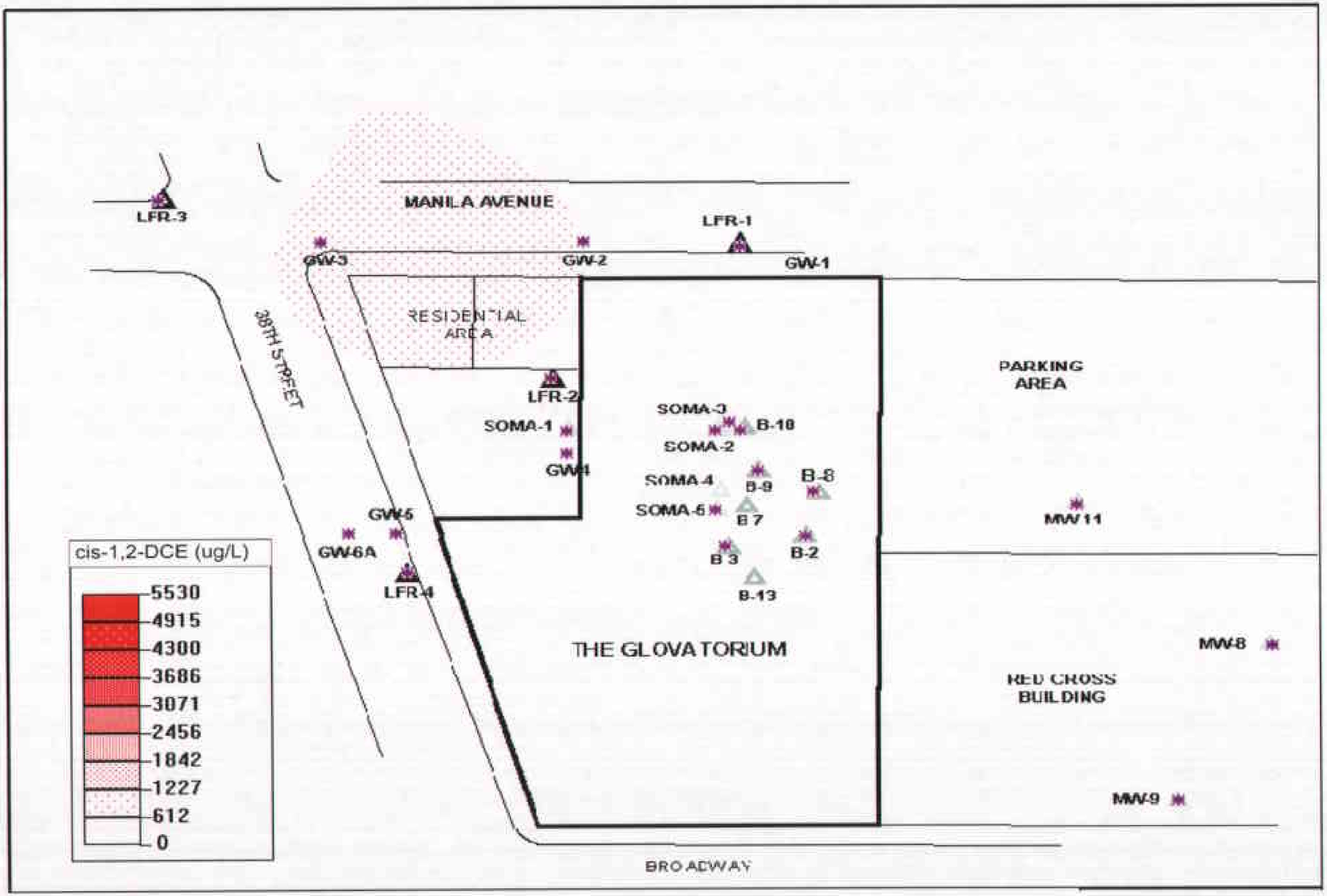


approximate scale in feet

0 50

Figure 18. BIOPLUME III simulation of cis-1,2-DCE concentrations after 1 year.

SOMA ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet

0 50

Figure 19. BIOPLUME III simulation of cis-1,2-DCE concentrations after 2 years.

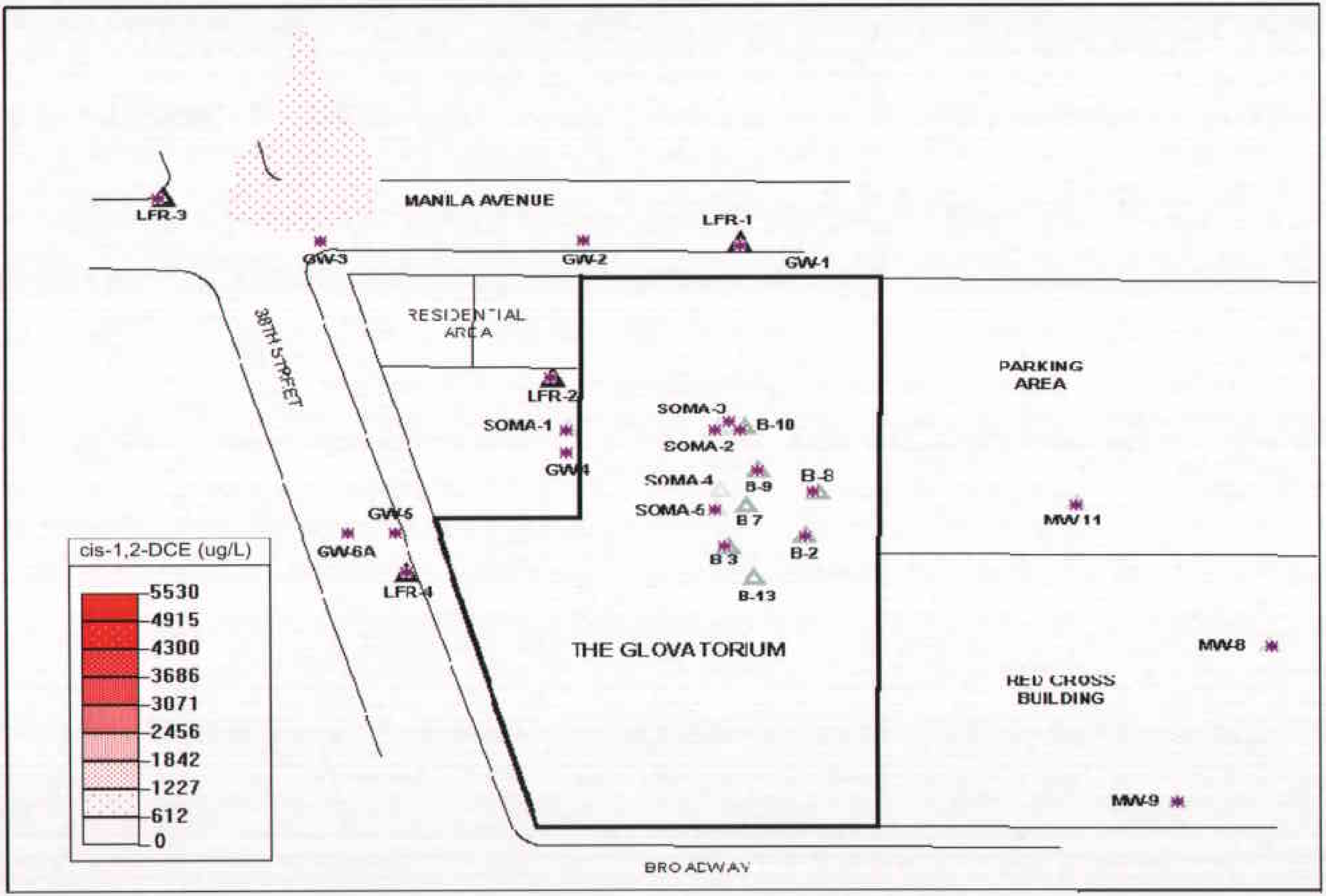
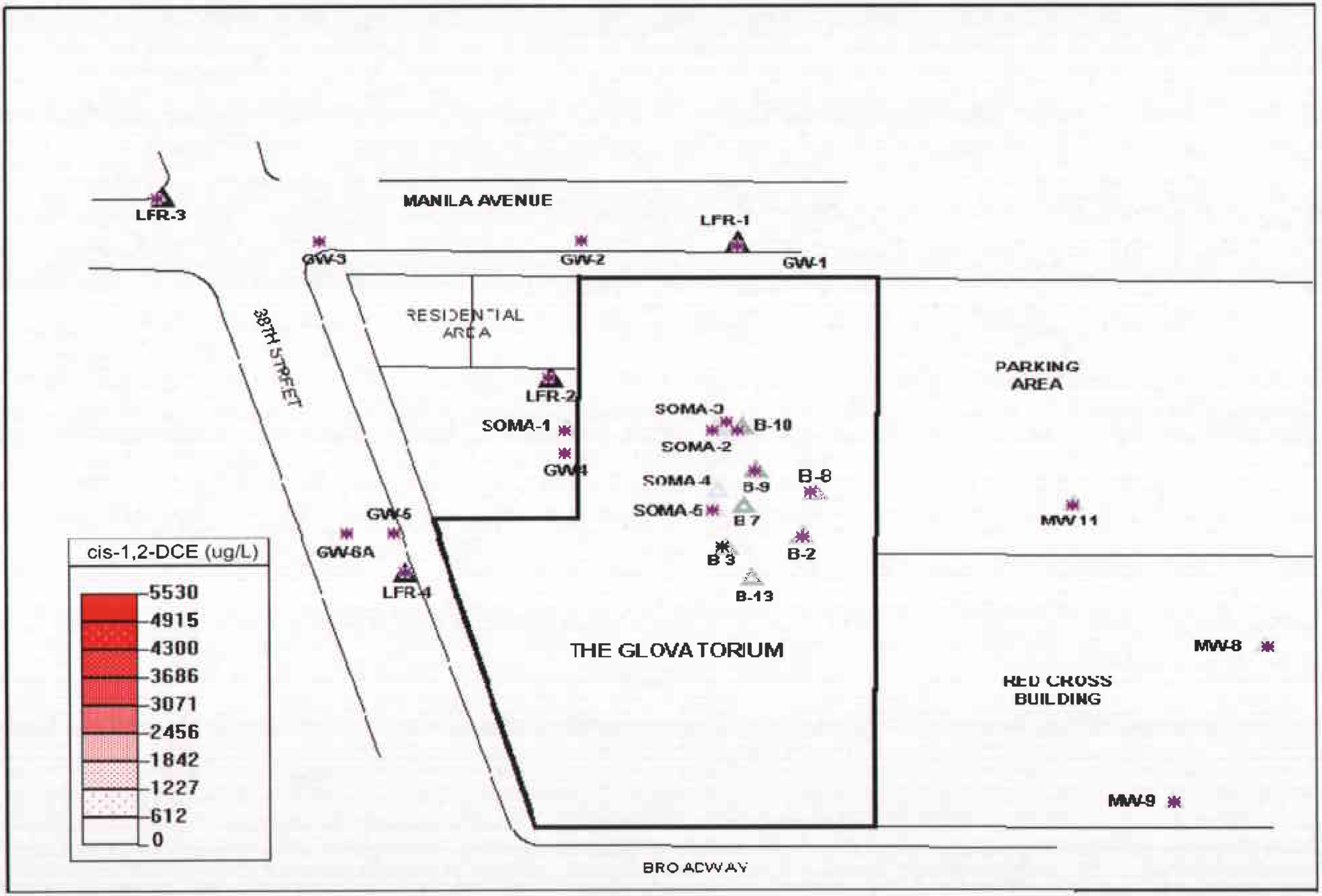


Figure 20. BIOPLUME III simulation of cis-1,2-DCE concentrations after 3 years.



approximate scale in feet

0 50

Figure 21. BIOPLUME III simulation of cis-1,2-DCE concentrations after 4 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

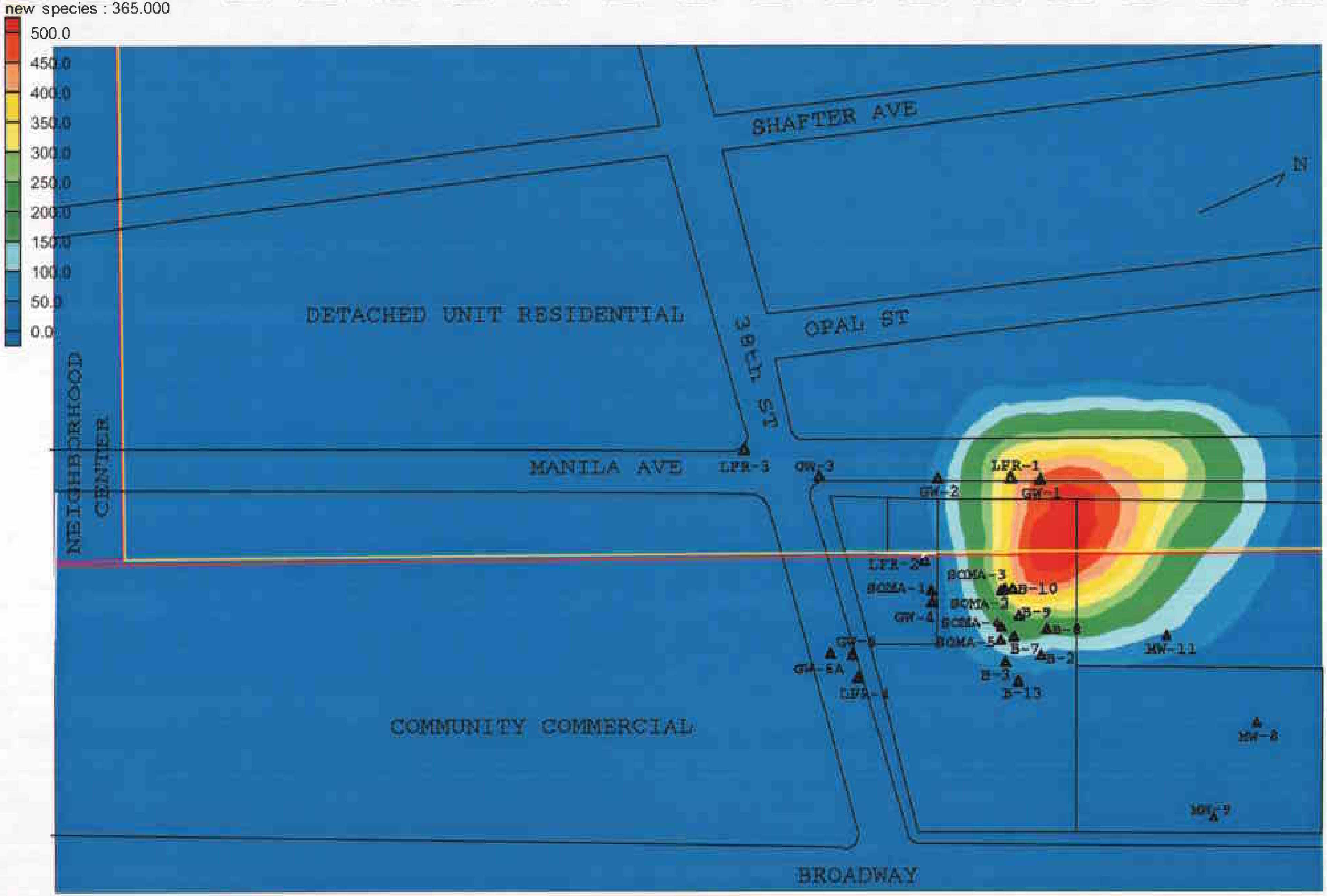
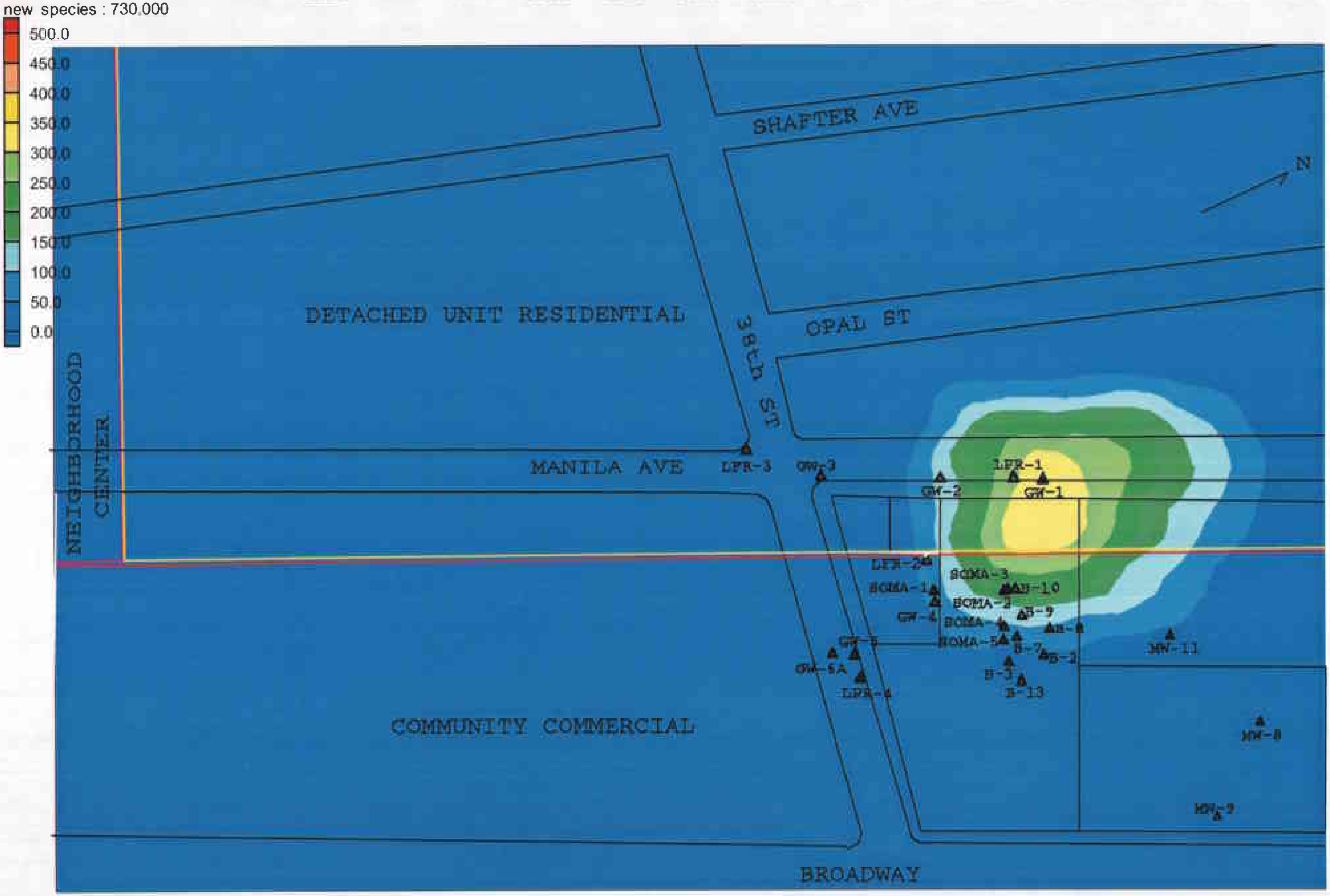


Figure 22. MODFLOW and MT3D simulation of PCE concentrations after 1 year.

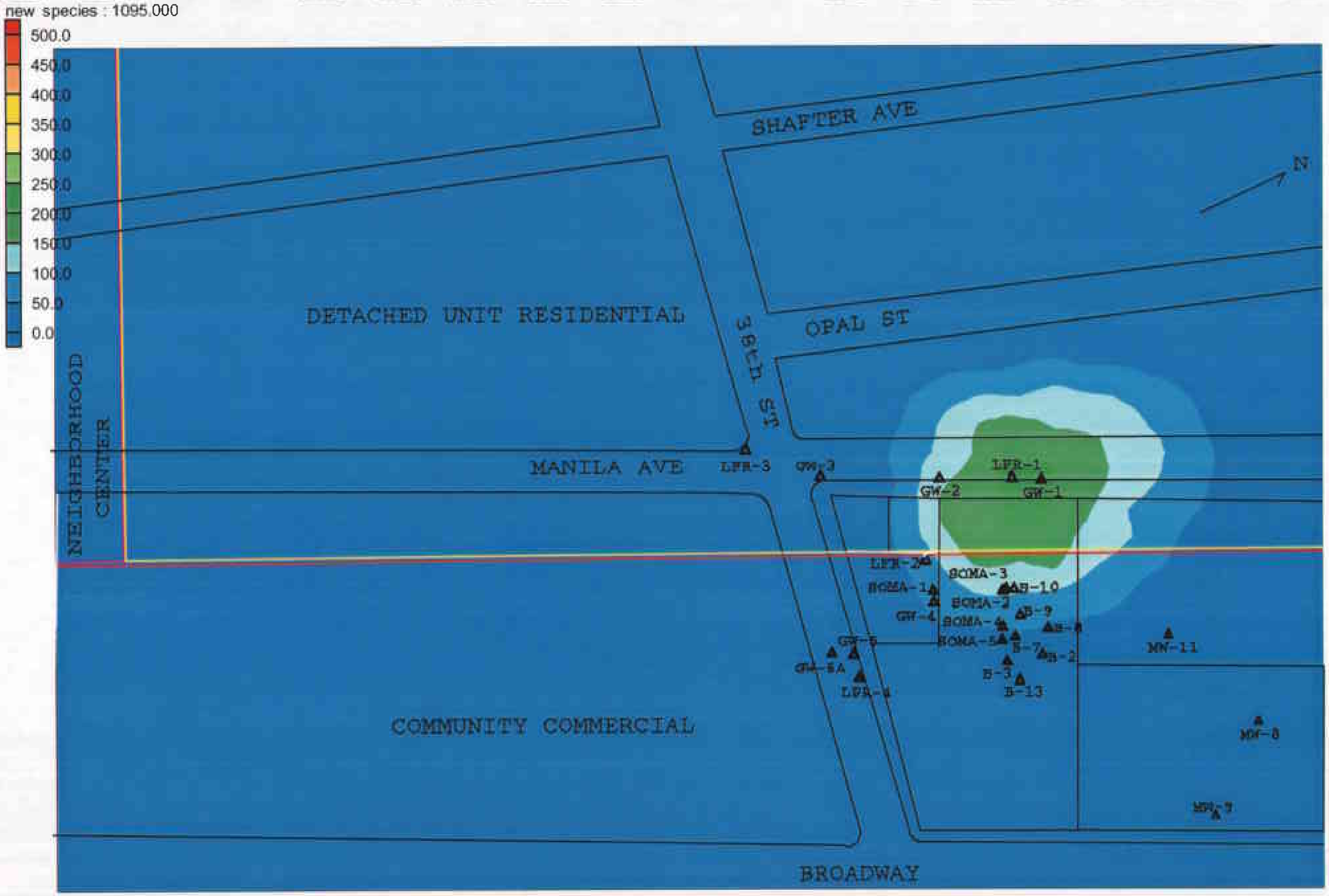
SOMA
ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet

0 100

Figure 23. MODFLOW and MT3D simulation of PCE concentrations after 2 years.

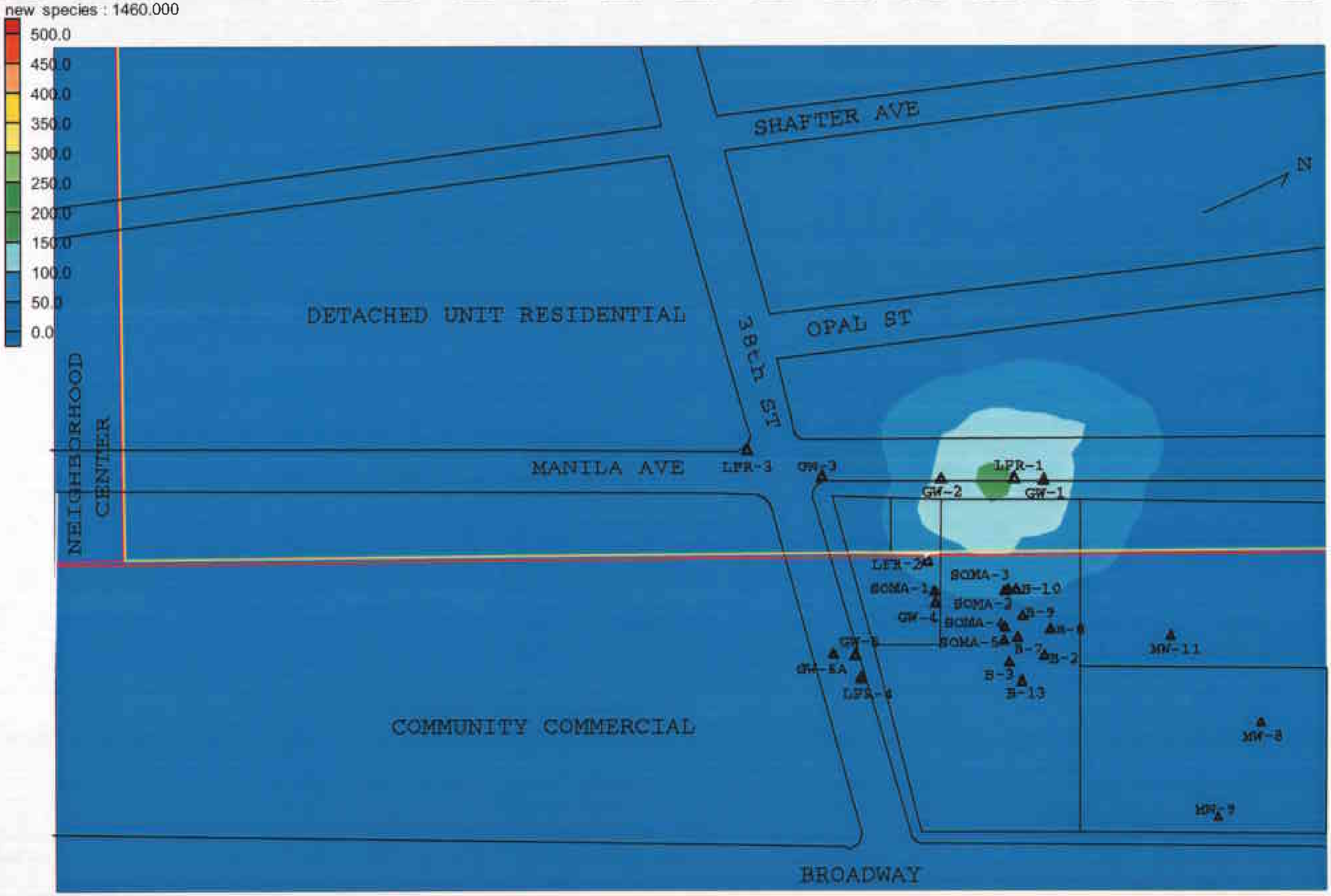


approximate scale in feet

0 100

Figure 24. MODFLOW and MT3D simulation of PCE concentrations after 3 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

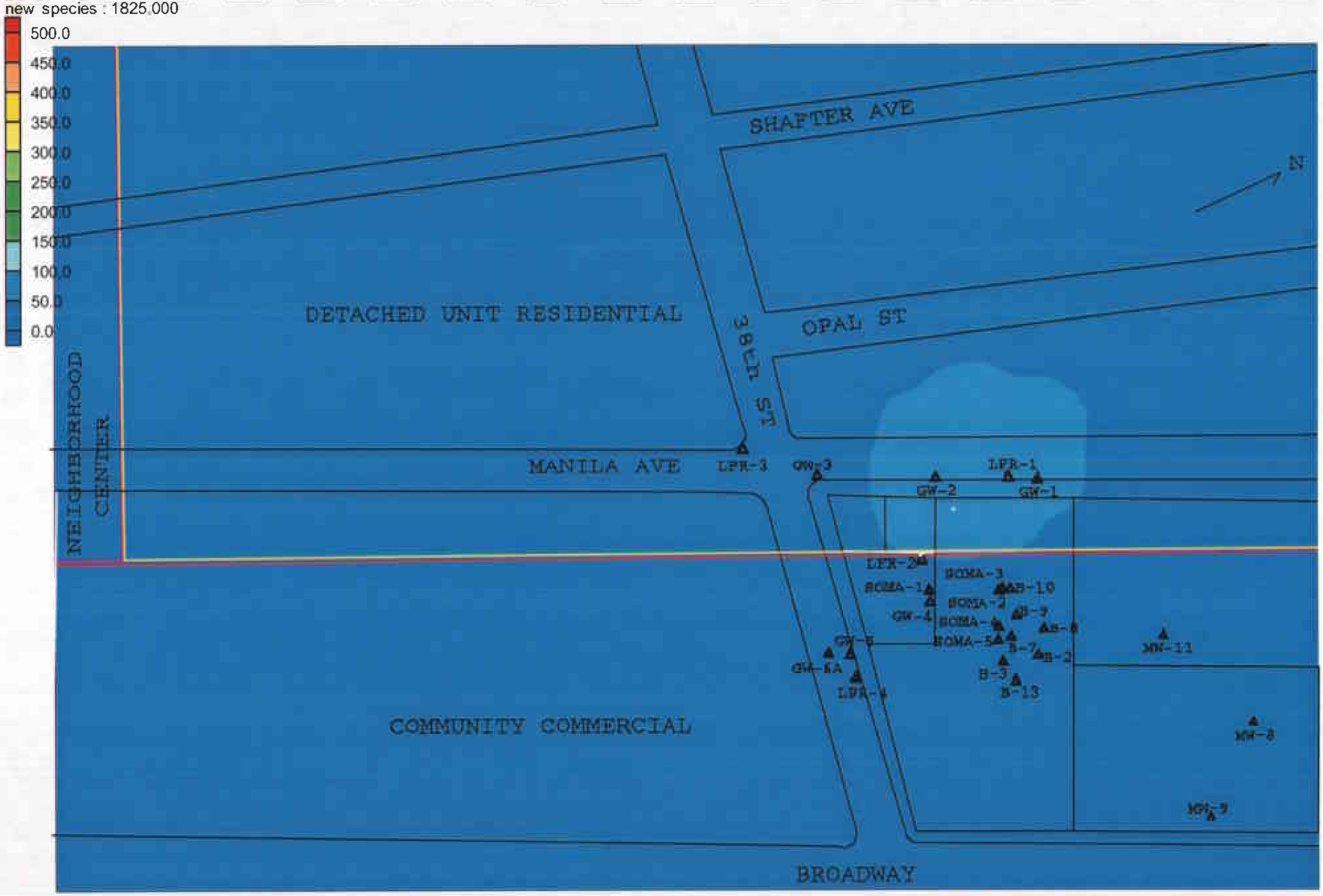


approximate scale in feet

0 100

Figure 25. MODFLOW and MT3D simulation of PCE concentrations after 4 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

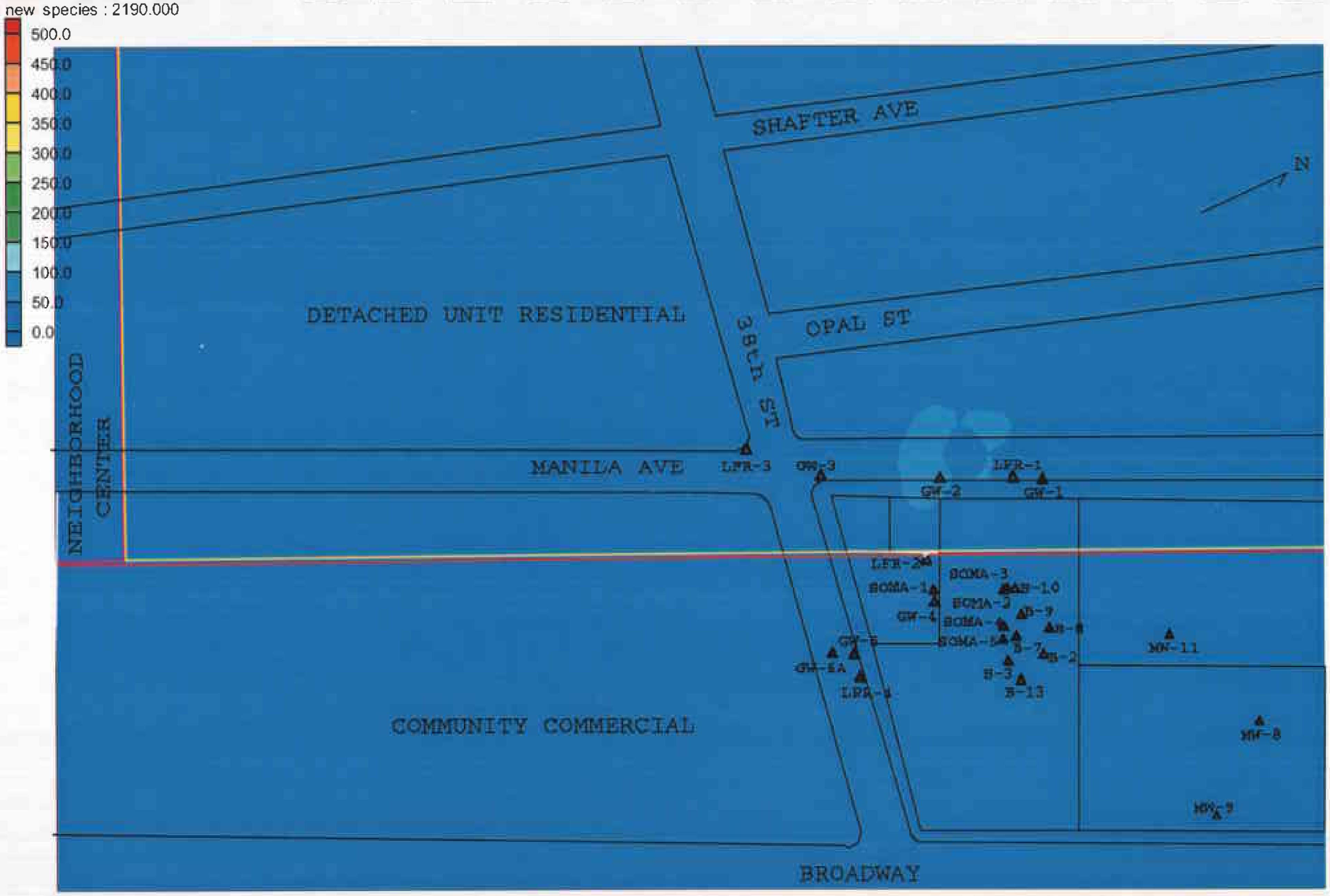


approximate scale in feet

0 100

Figure 26. MODFLOW and MT3D simulation of PCE concentrations after 5 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

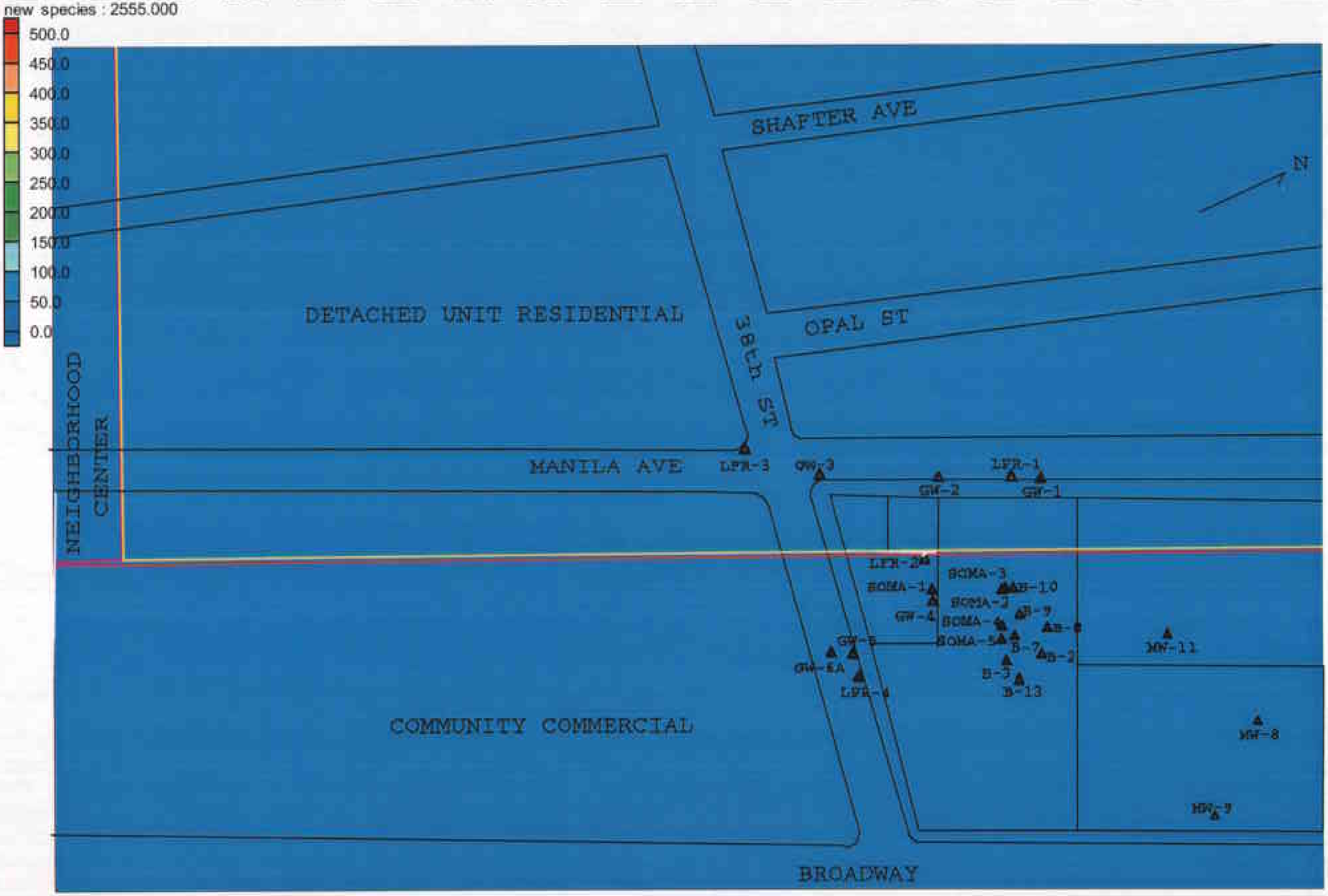


approximate scale in feet

0 100

Figure 27. MODFLOW and MT3D simulation of PCE concentrations after 6 years.

SOMA
ENVIRONMENTAL ENGINEERING, INC.

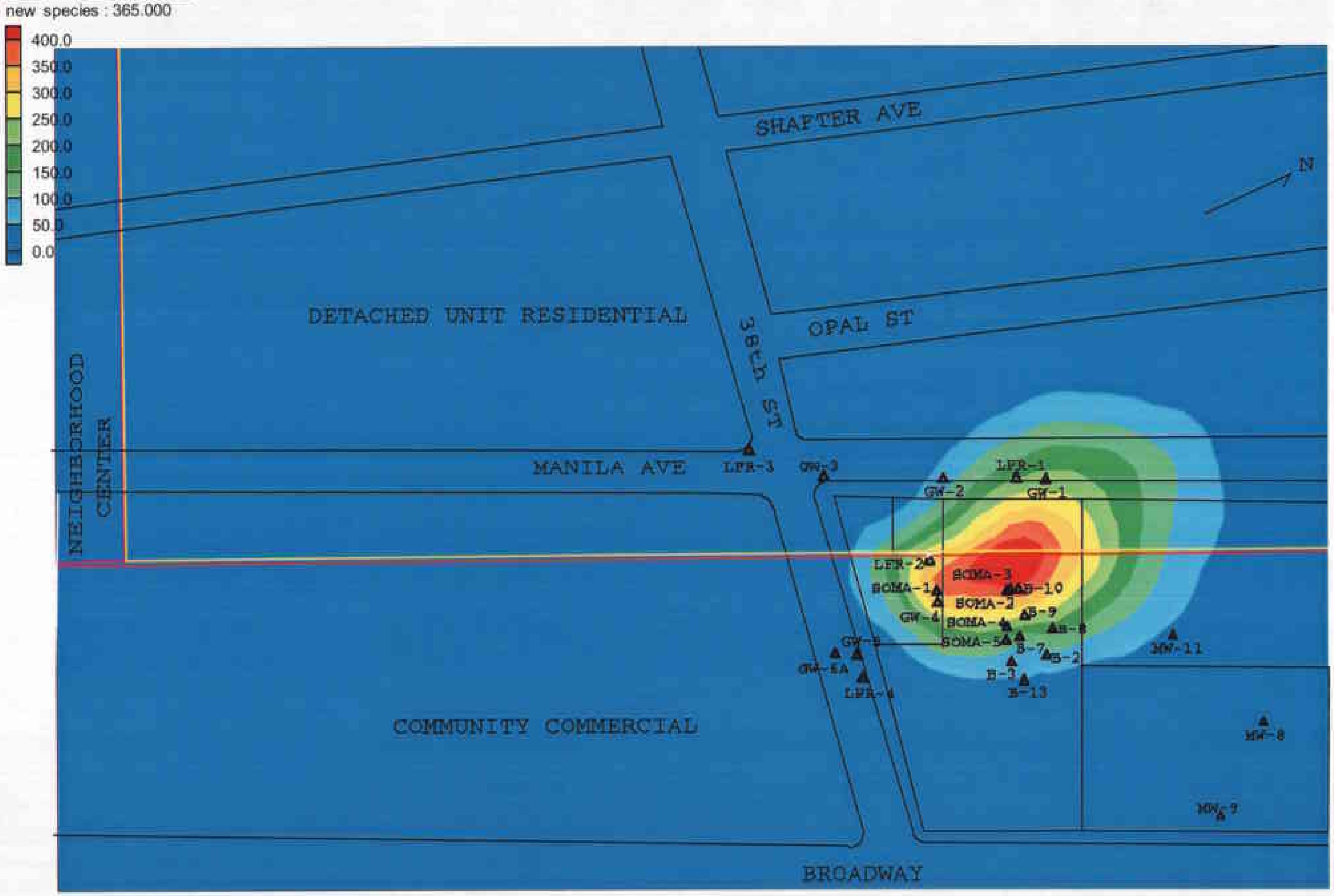


approximate scale in feet

0 100

Figure 28. MODFLOW and MT3D simulation of PCE concentrations after 7 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

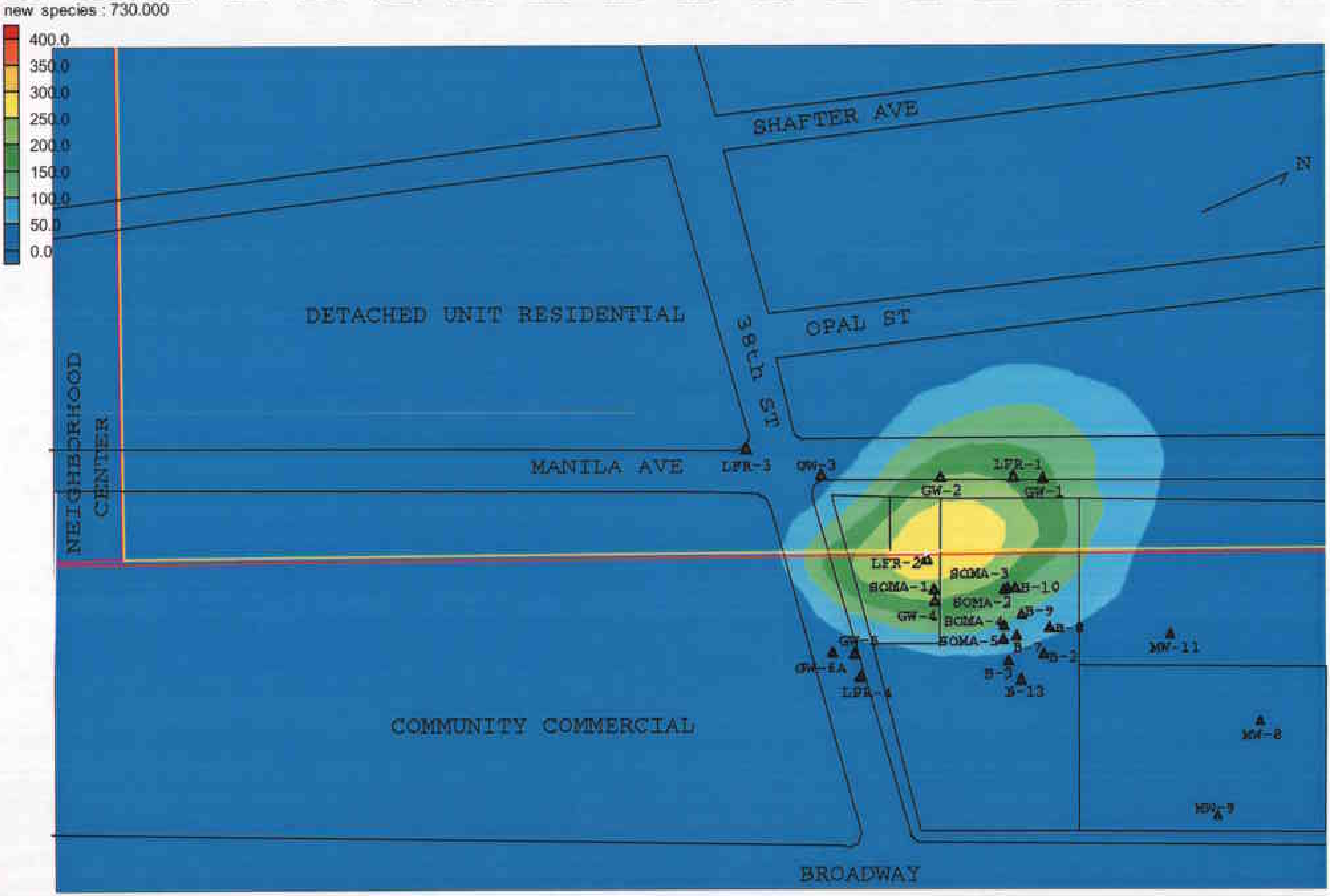


approximate scale in feet

0 100

Figure 29. MODFLOW and MT3D simulation of TCE concentrations after 1 year.

SOMA ENVIRONMENTAL ENGINEERING, INC.

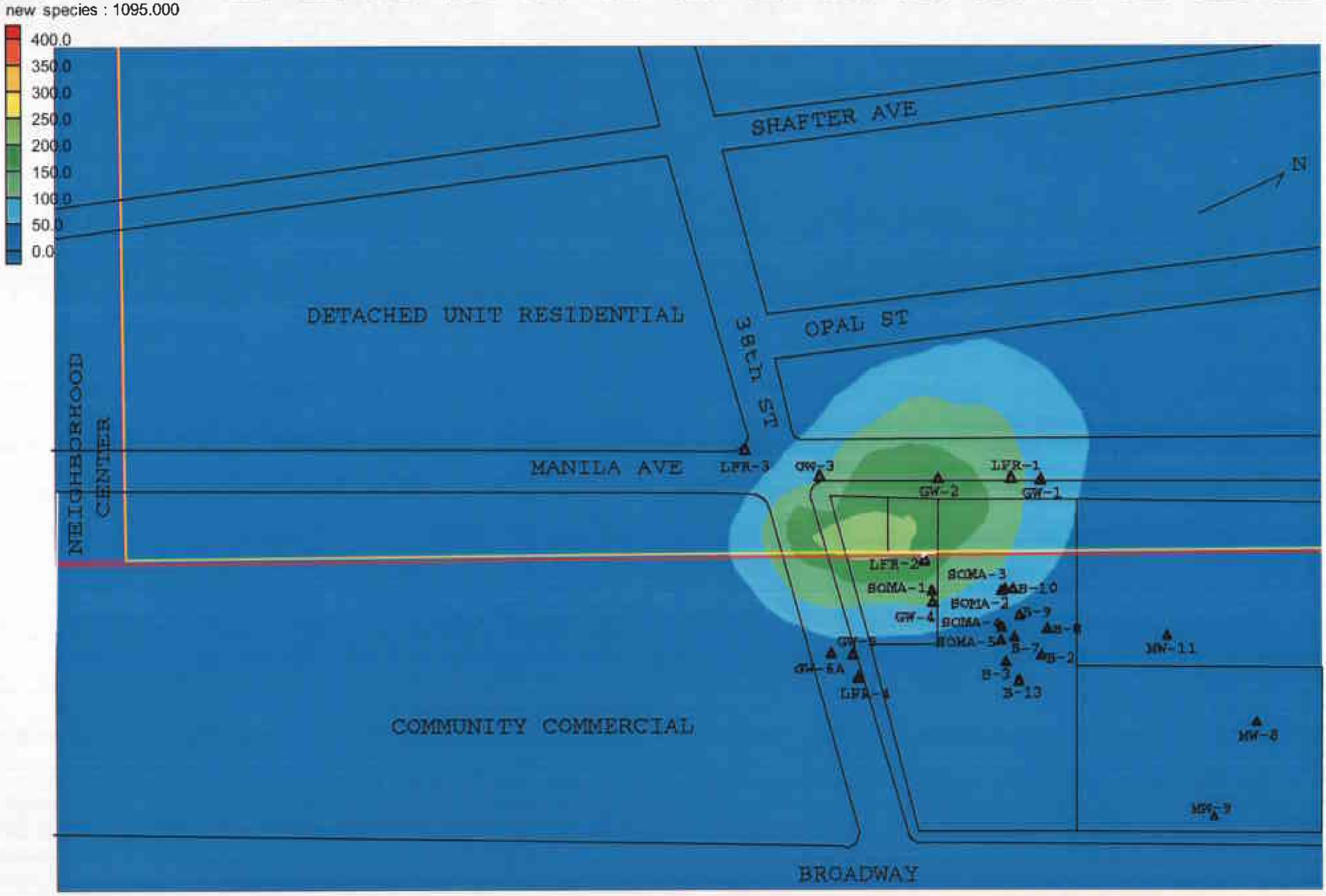


approximate scale in feet

0 100

Figure 30. MODFLOW and MT3D simulation of TCE concentrations after 2 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

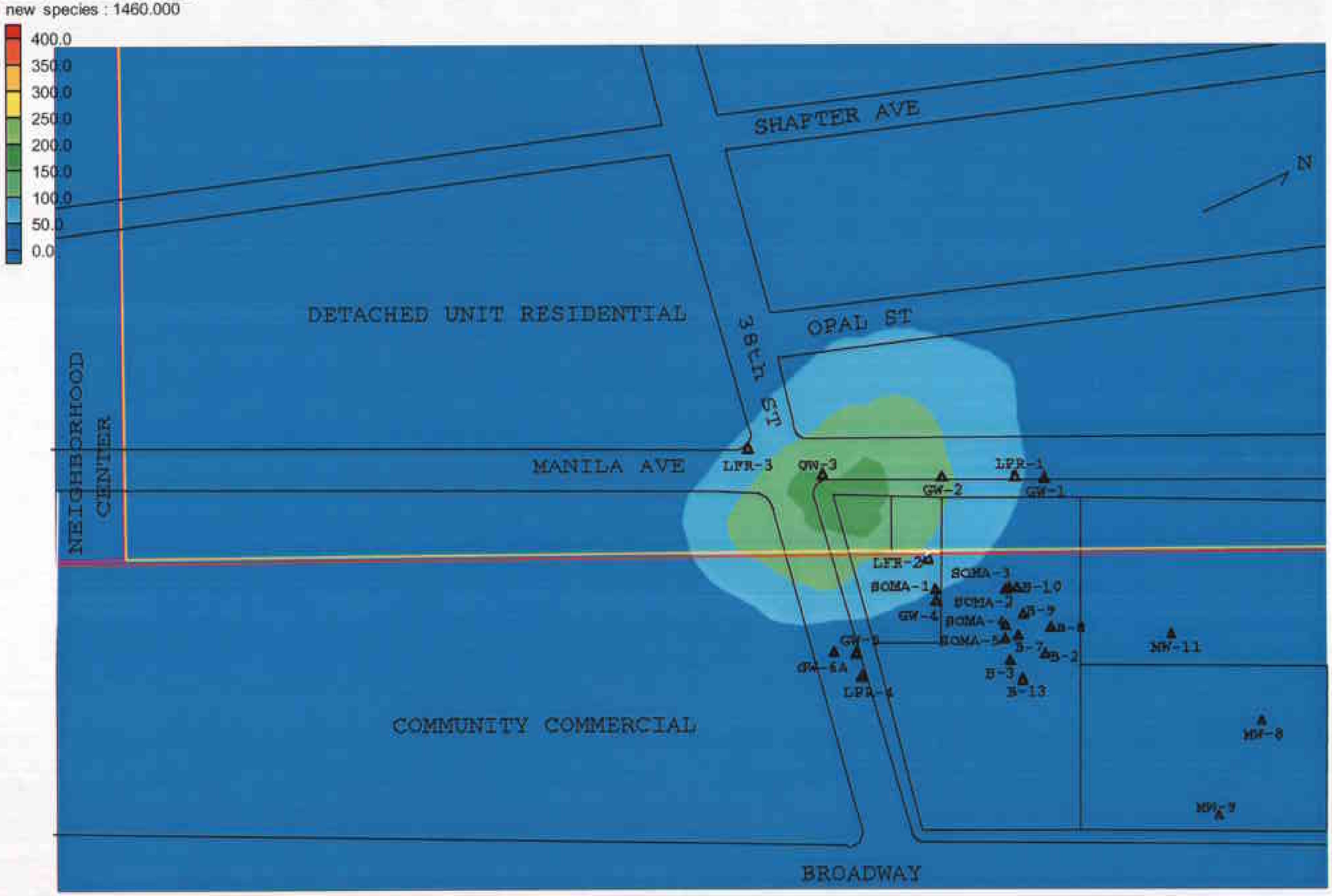


approximate scale in feet

0 100

Figure 31. MODFLOW and MT3D simulation of TCE concentrations after 3 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

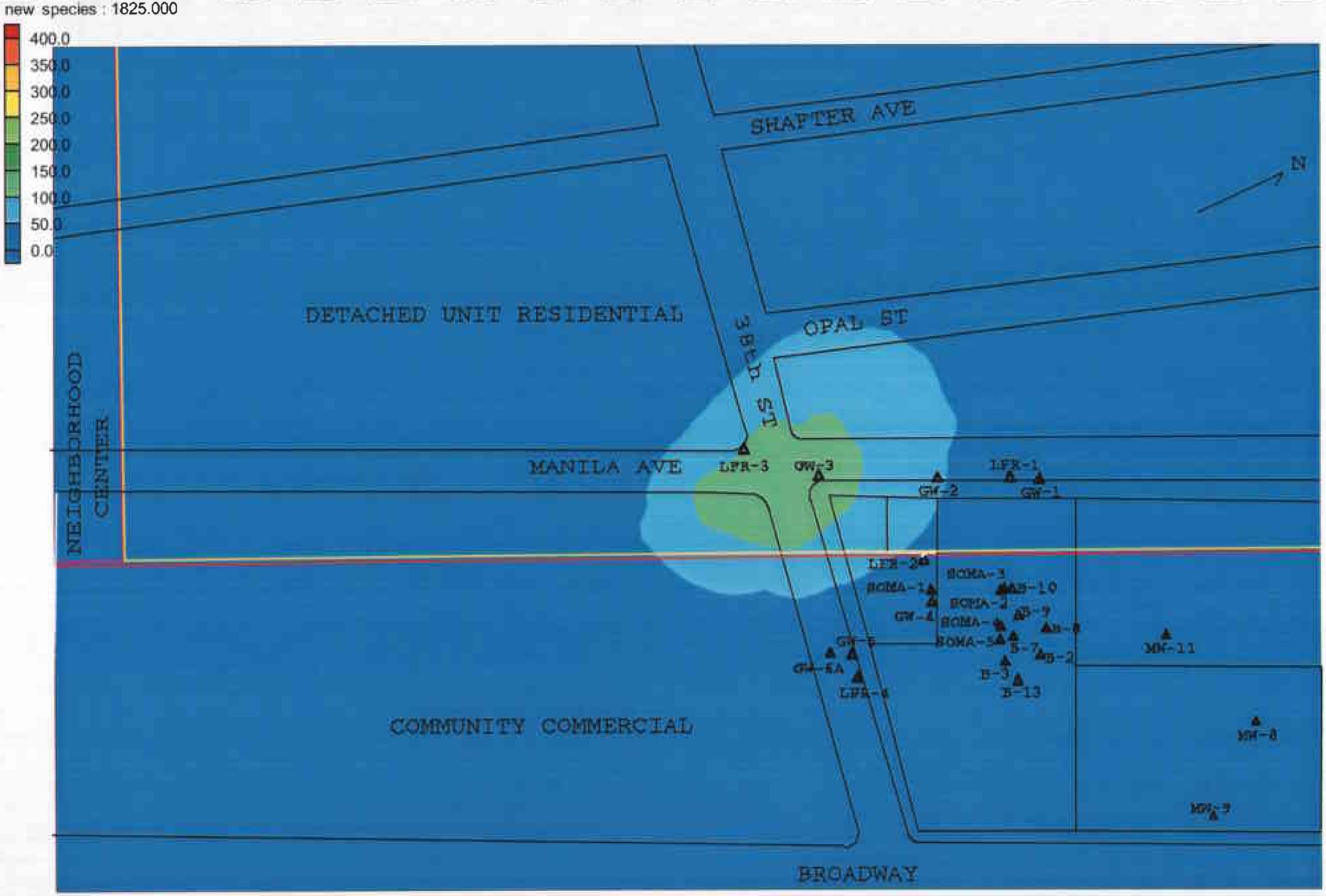


approximate scale in feet

0 100

Figure 32. MODFLOW and MT3D simulation of TCE concentrations after 4 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

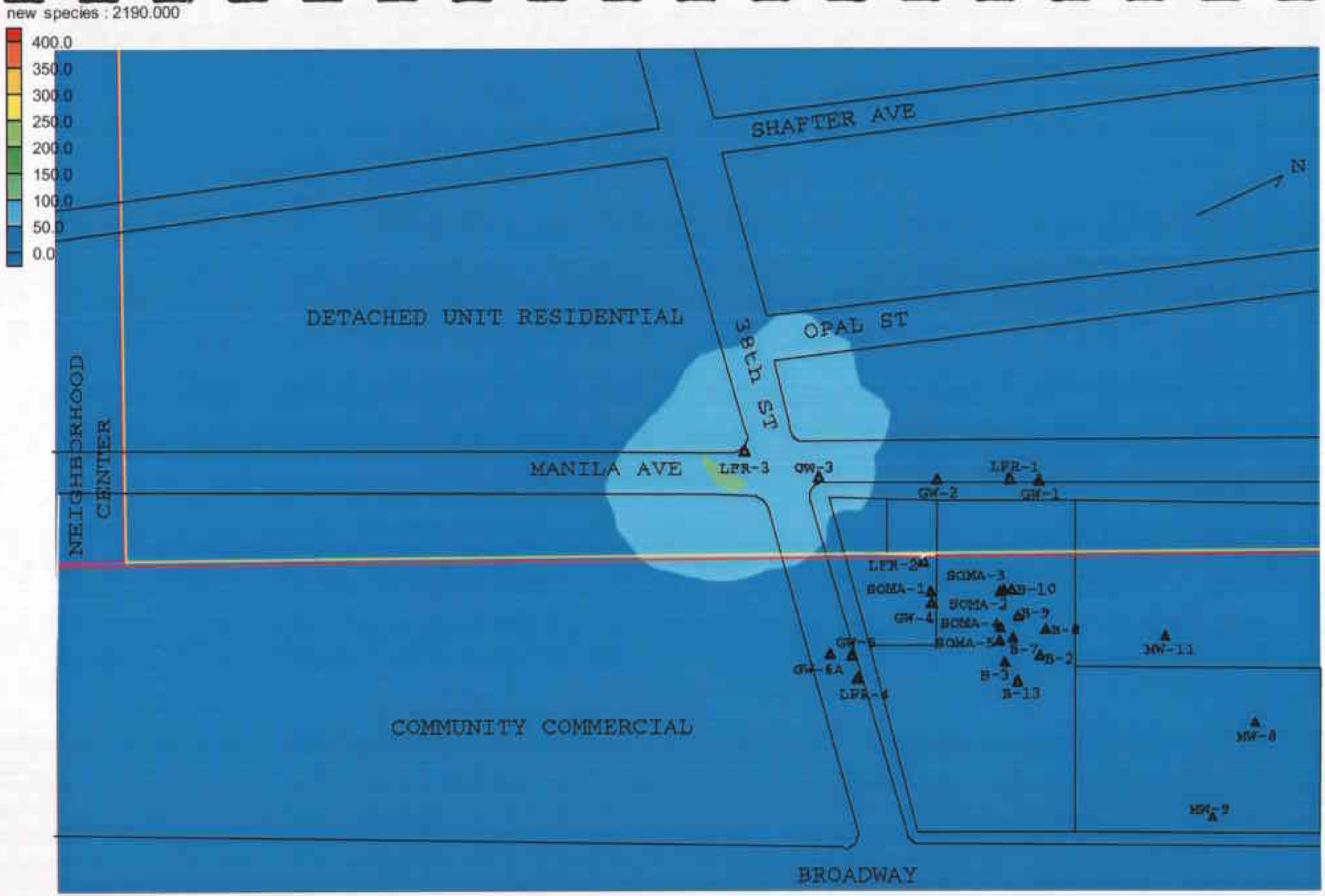


approximate scale in feet

0 100

Figure 33. MODFLOW and MT3D simulation of TCE concentrations after 5 years.

SOMA
ENVIRONMENTAL ENGINEERING, INC.

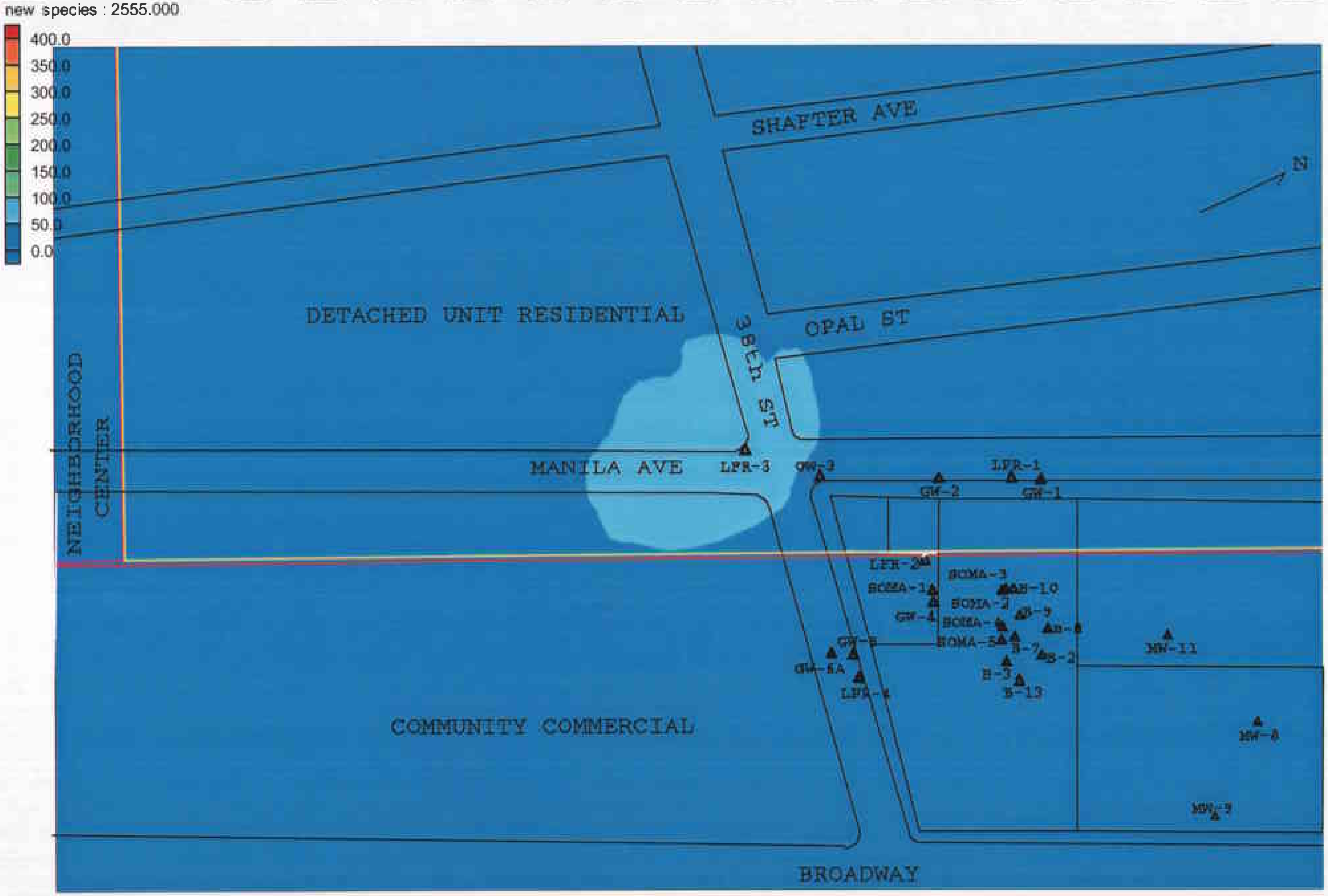


approximate scale in feet

0 100

Figure 34. MODFLOW and MT3D simulation of TCE concentrations after 6 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

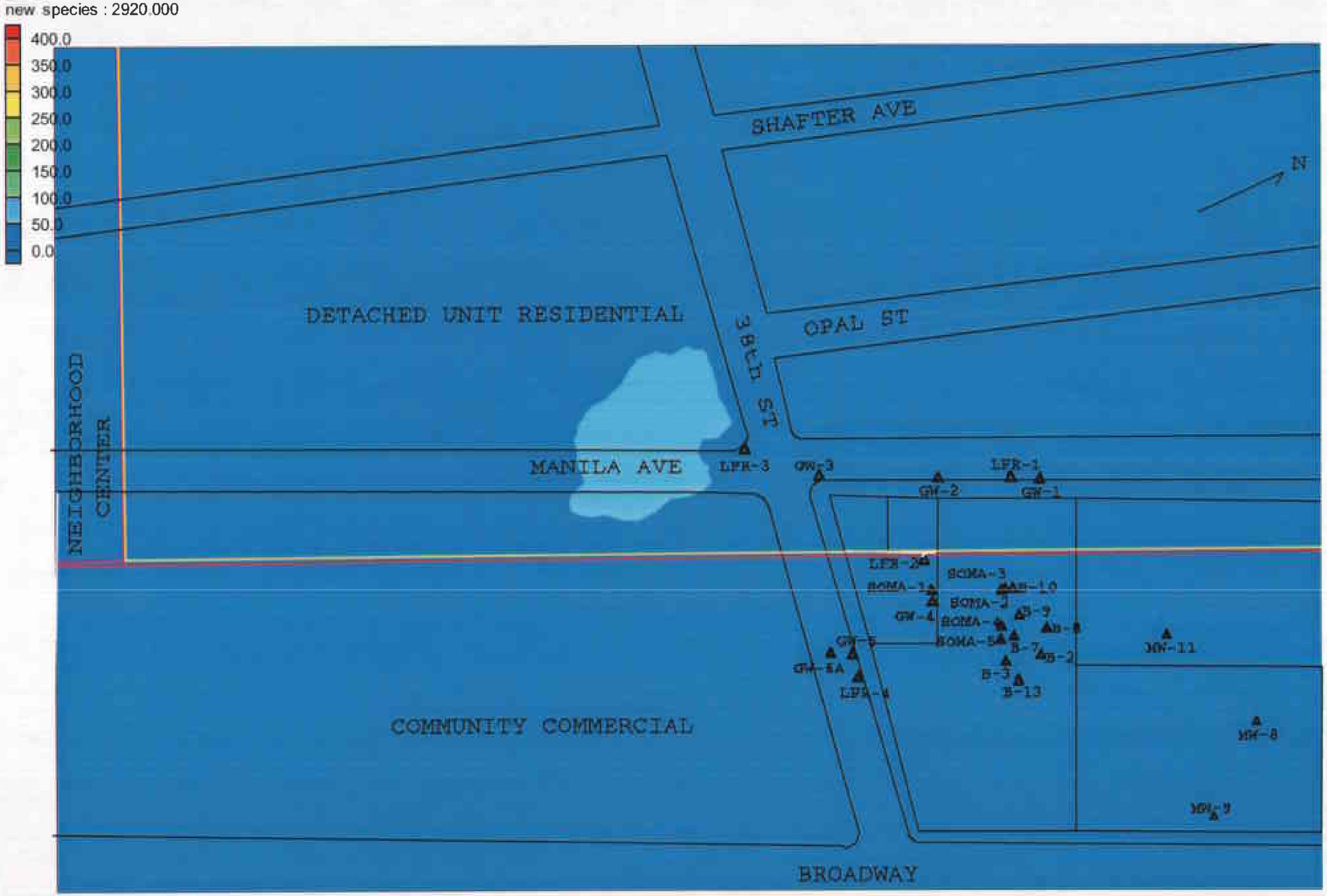


approximate scale in feet

0 100

Figure 35. MODFLOW and MT3D simulation of TCE concentrations after 7 years.

ENVIRONMENTAL ENGINEERING, INC.

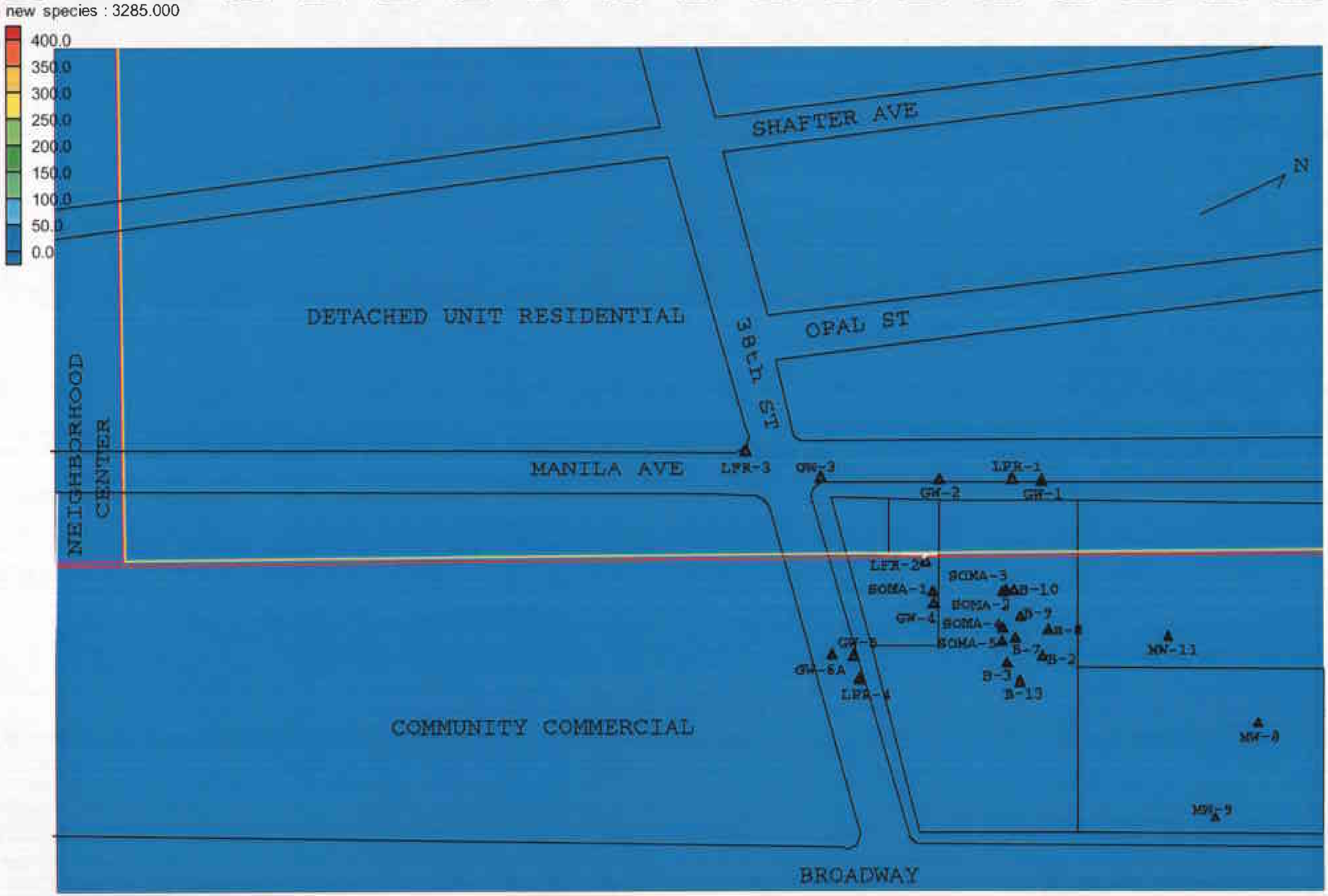


approximate scale in feet

0 100

Figure 36. MODFLOW and MT3D simulation of TCE concentrations after 8 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet

0 100

Figure 37. MODFLOW and MT3D simulation of TCE concentrations after 9 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

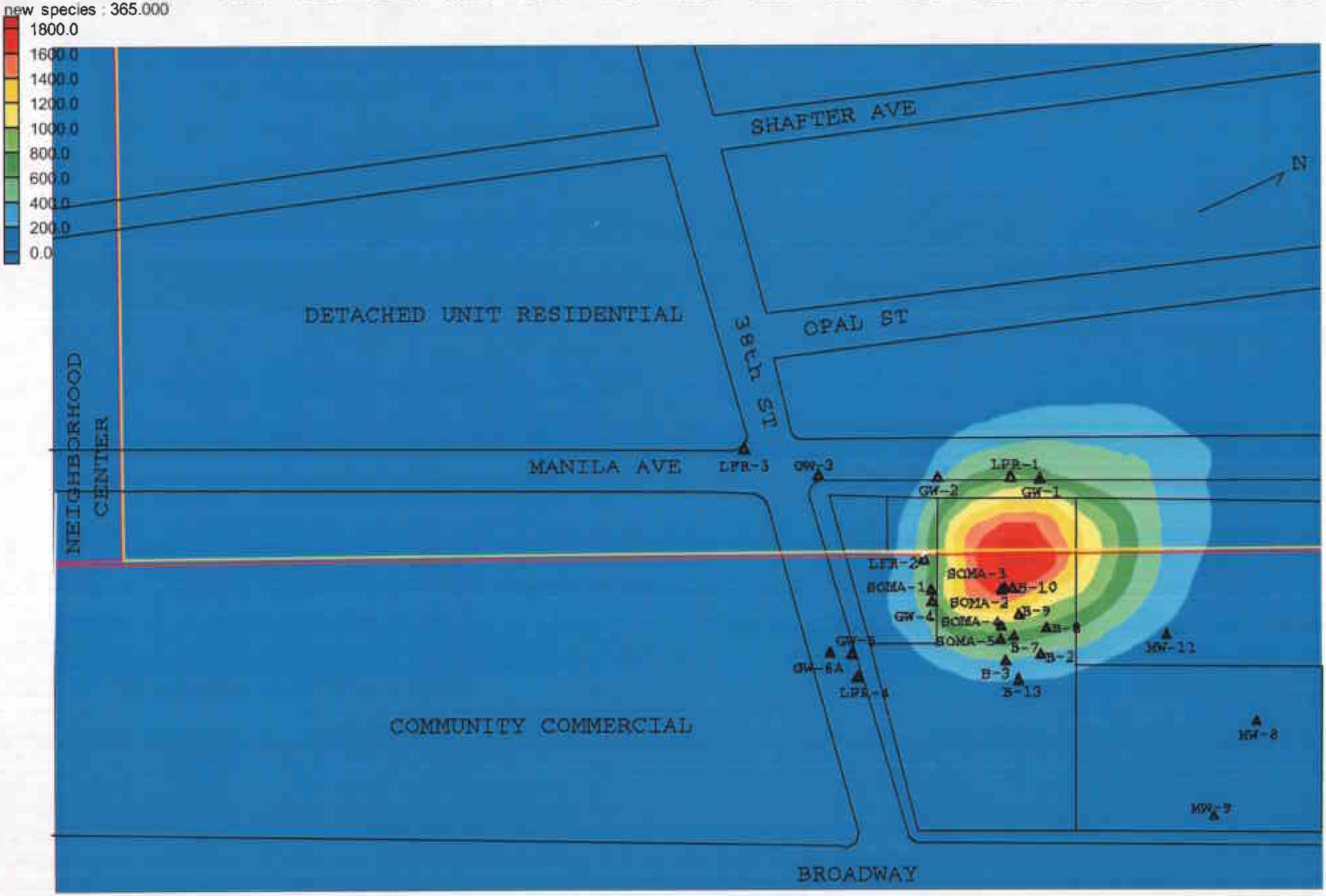
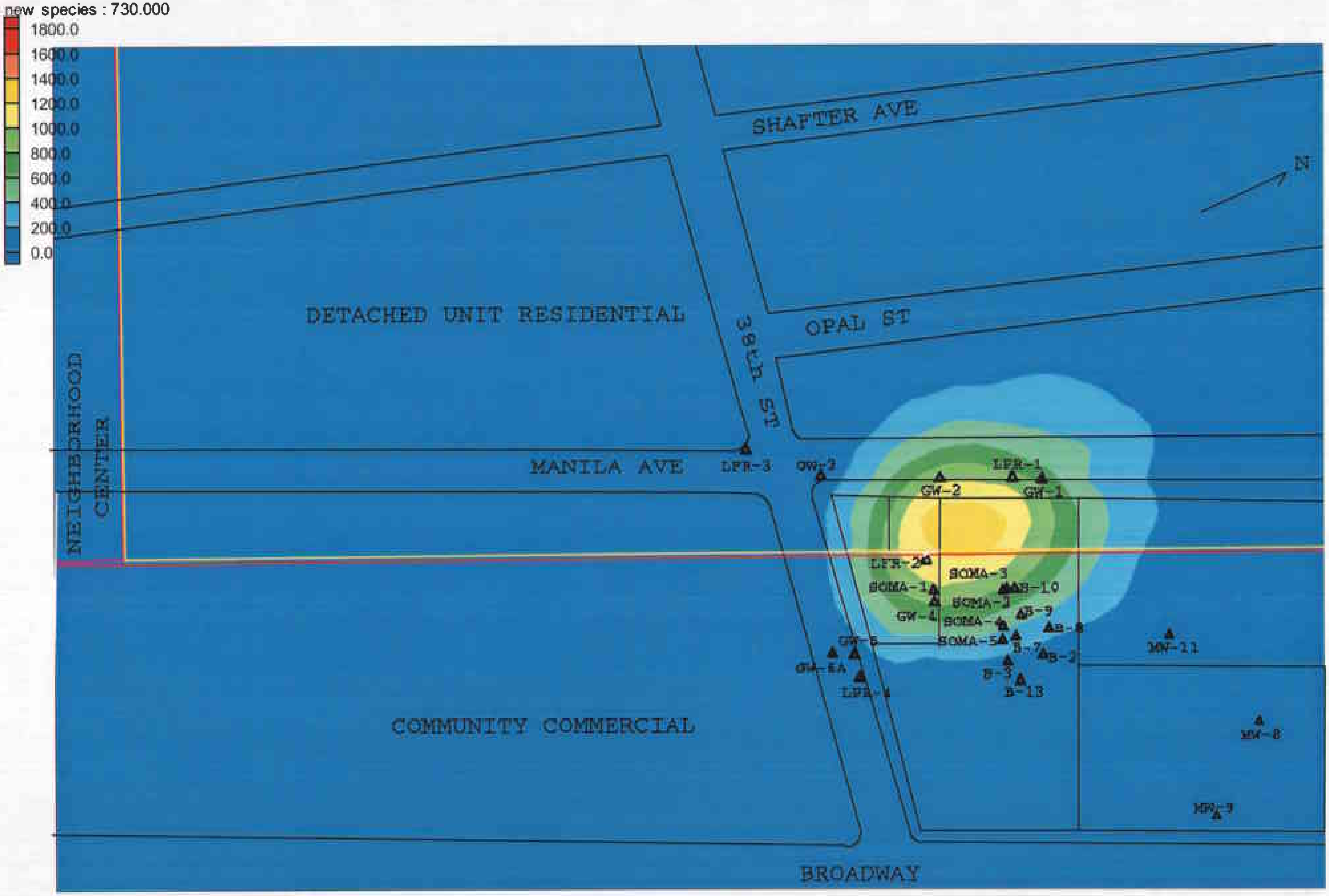


Figure 38. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 1 year.

SOMA
ENVIRONMENTAL ENGINEERING, INC.

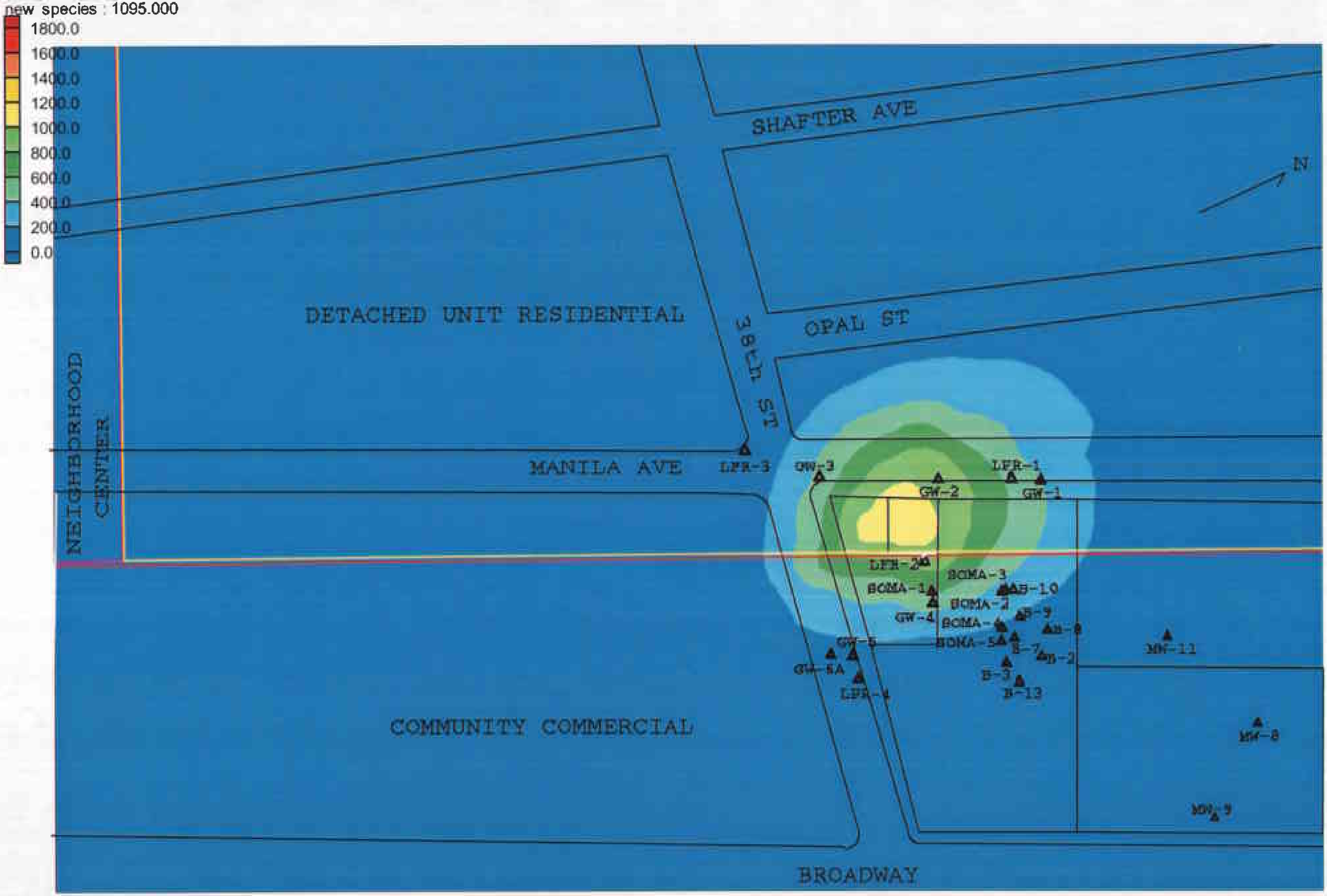


approximate scale in feet

0 100

Figure 39. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 2 years.

SOMA
ENVIRONMENTAL ENGINEERING, INC.

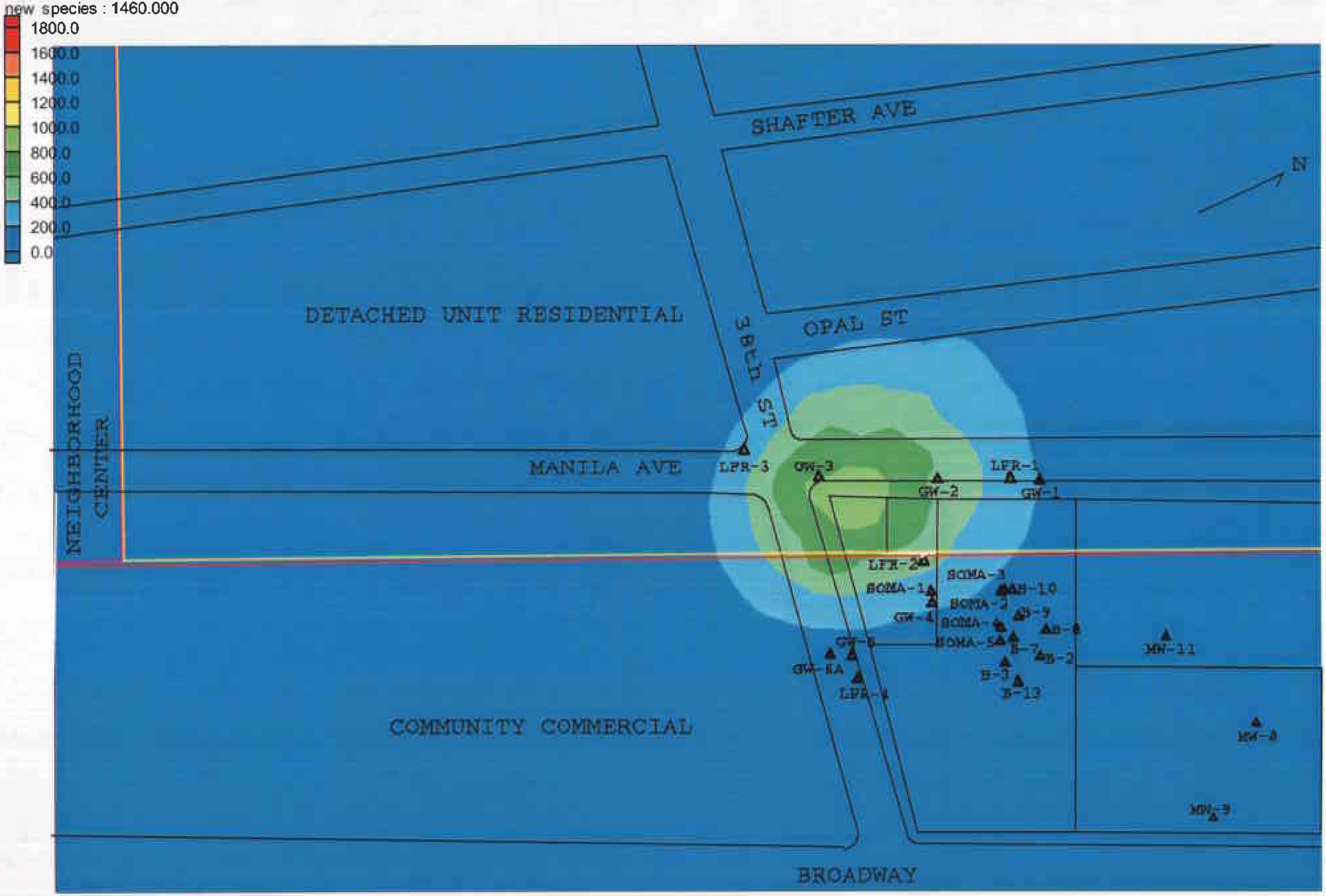


approximate scale in feet

0 100

Figure 40. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 3 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

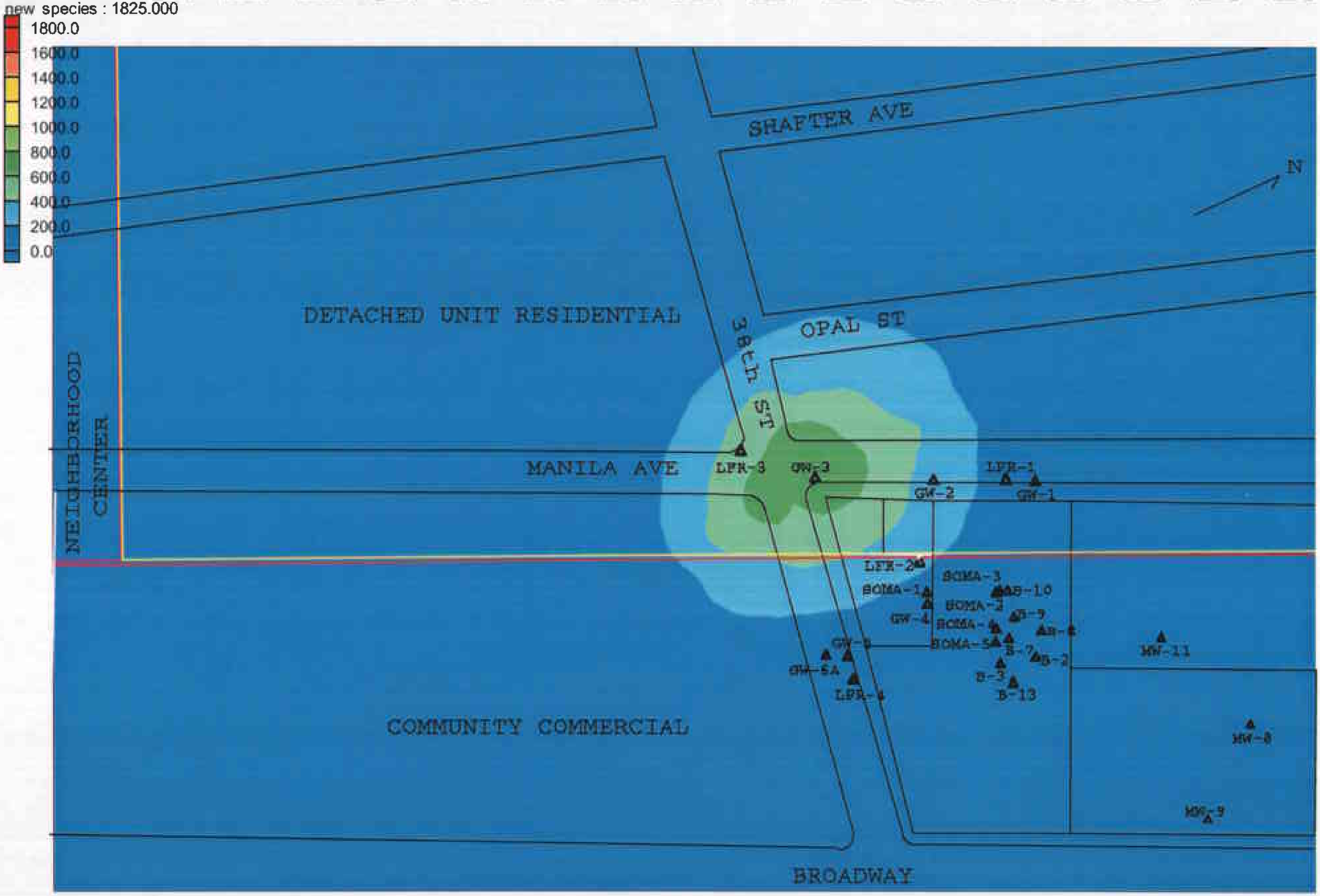


approximate scale in feet

0 100

Figure 41. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 4 years.

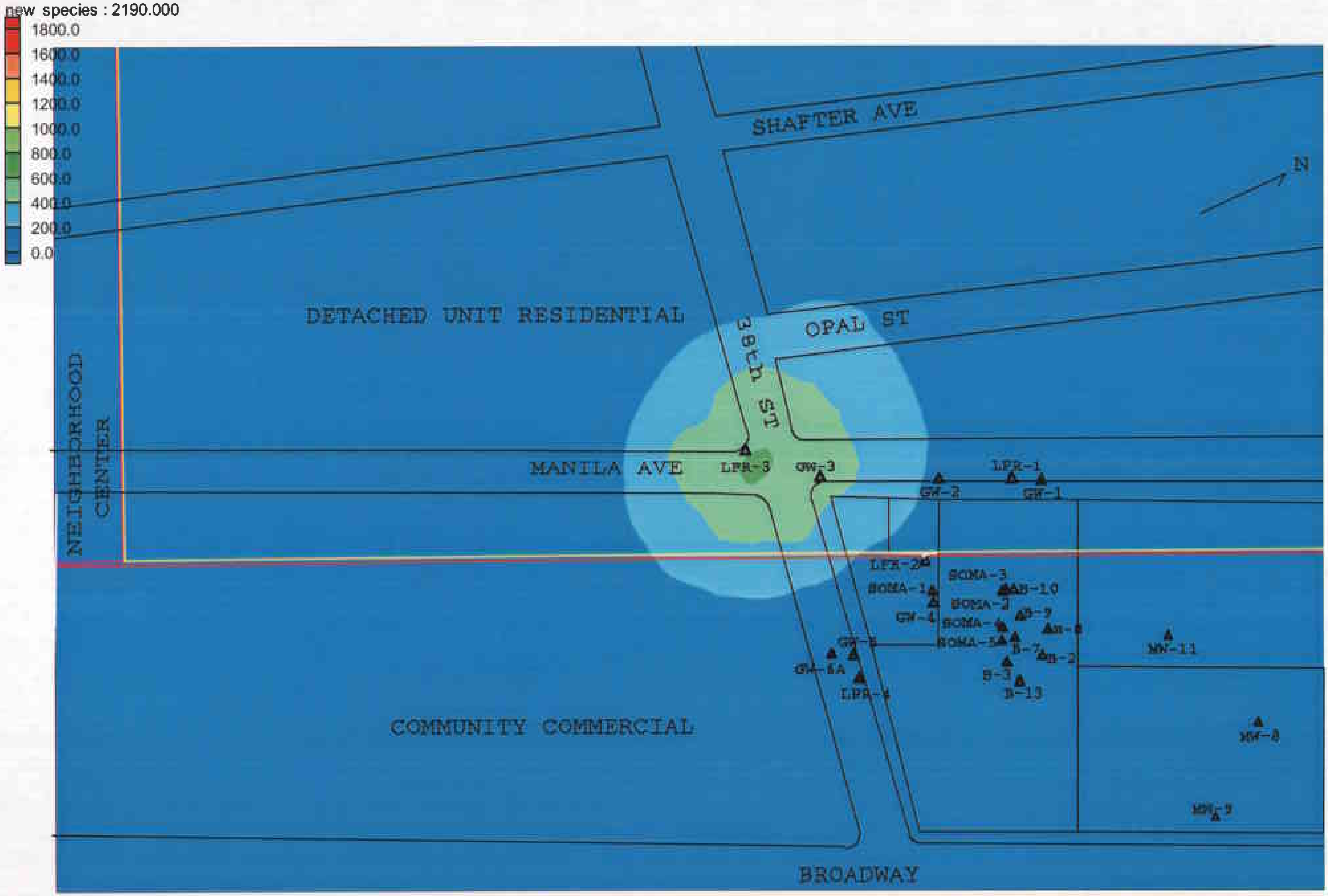
SOMA ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet
0 100

Figure 42. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 5 years.

SOMA
ENVIRONMENTAL ENGINEERING, INC.

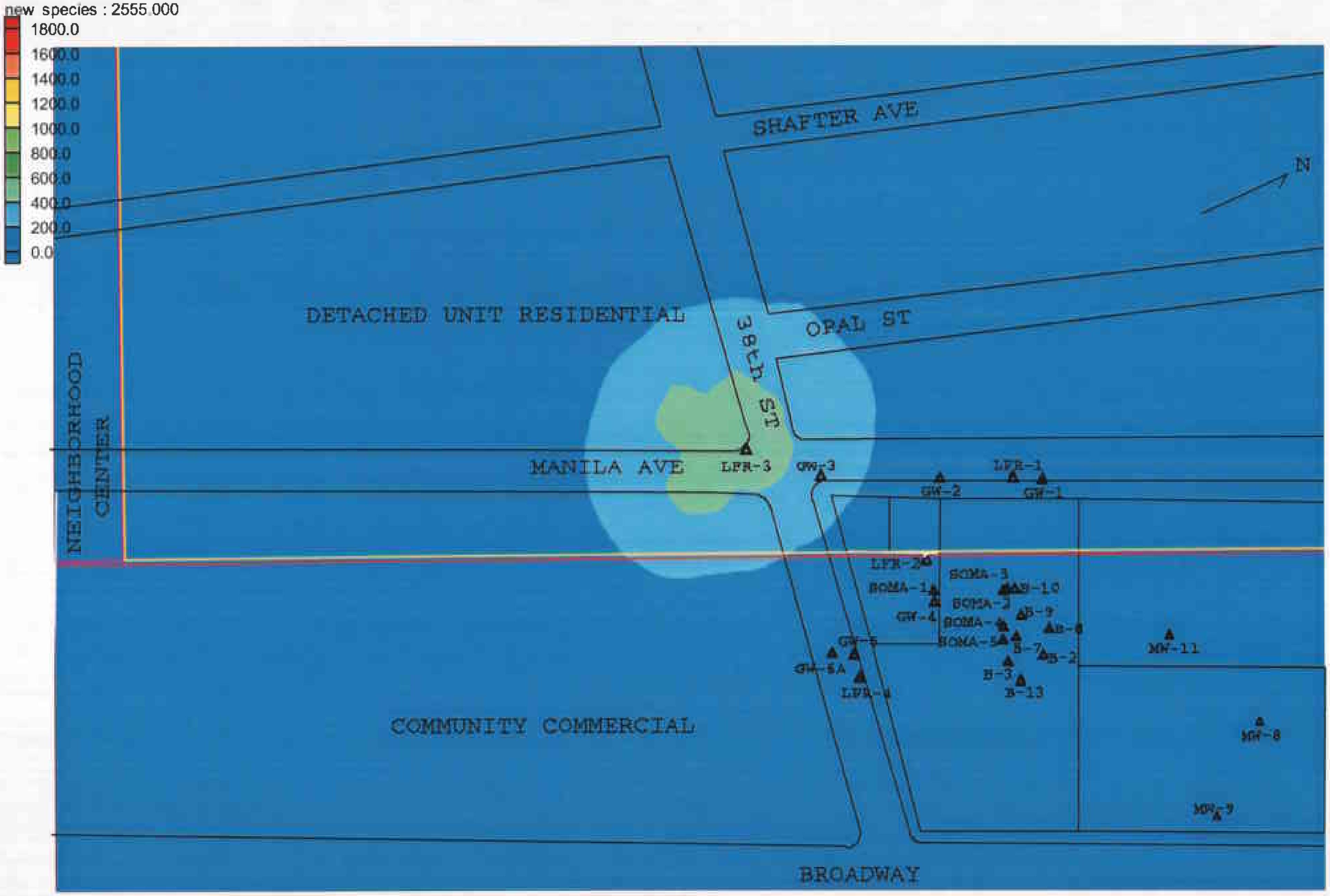


approximate scale in feet

0 100

Figure 43. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 6 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

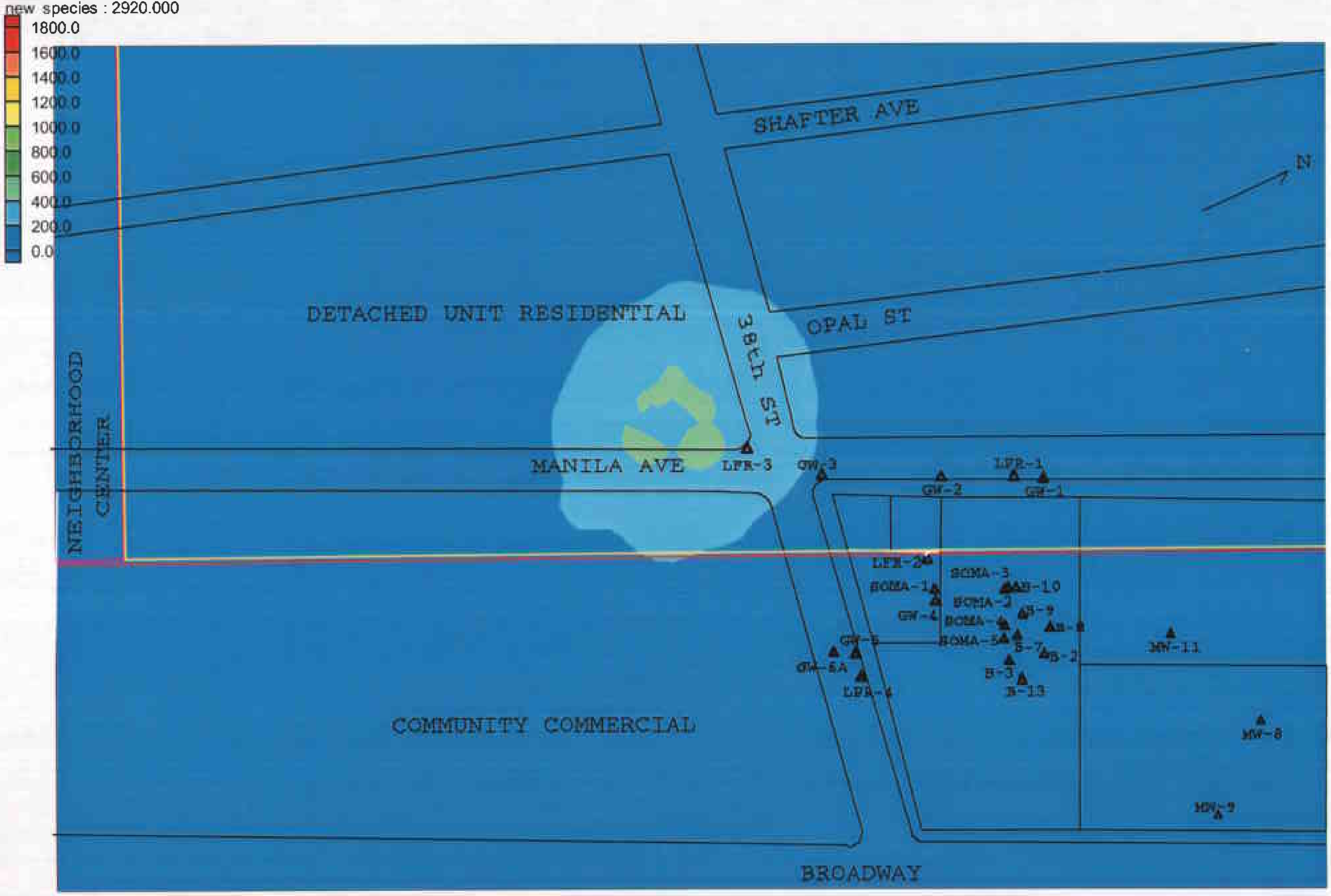


approximate scale in feet

0 100

Figure 44. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 7 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.

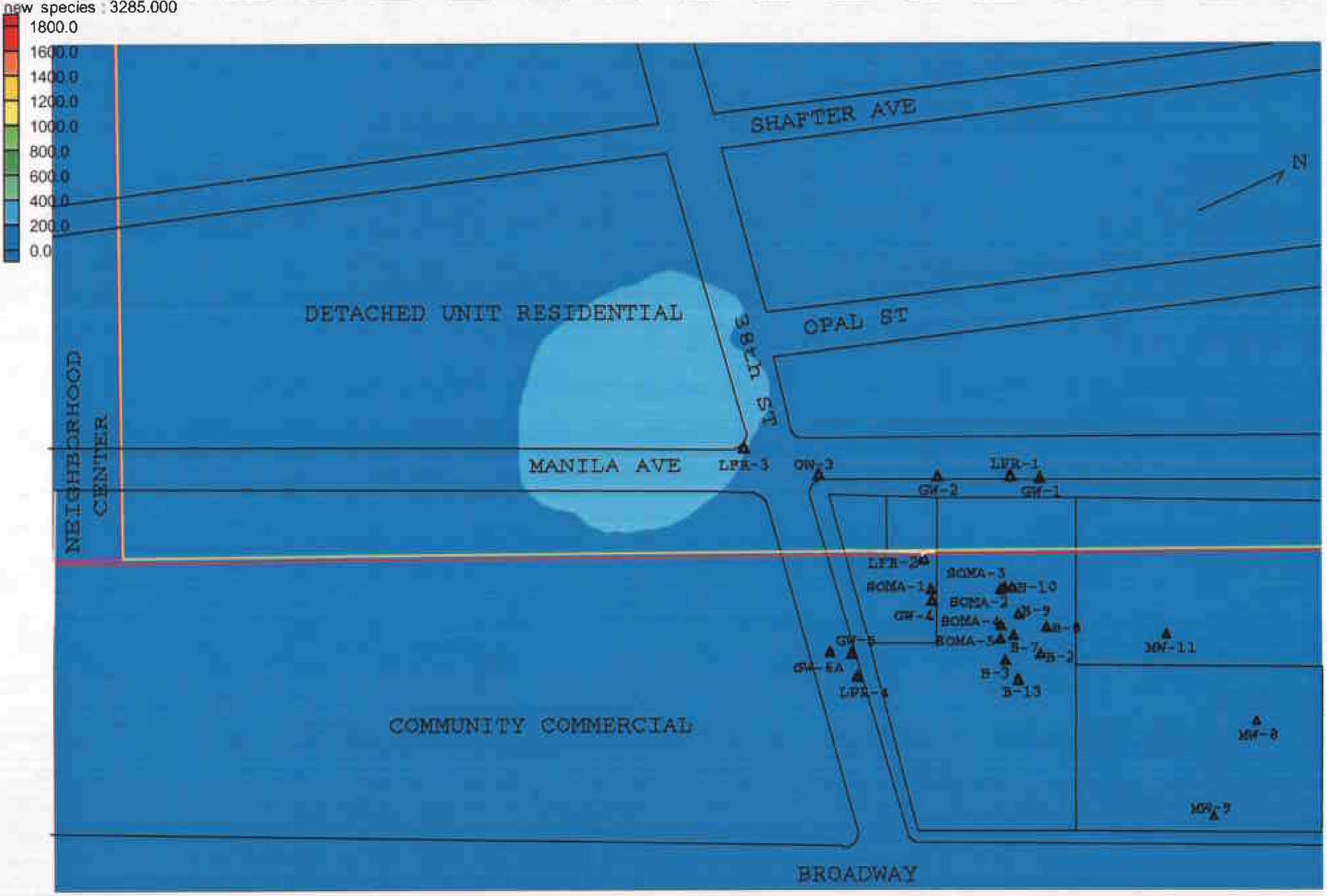


approximate scale in feet

0 100

Figure 45. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 8 years.

SOMA
ENVIRONMENTAL ENGINEERING, INC.

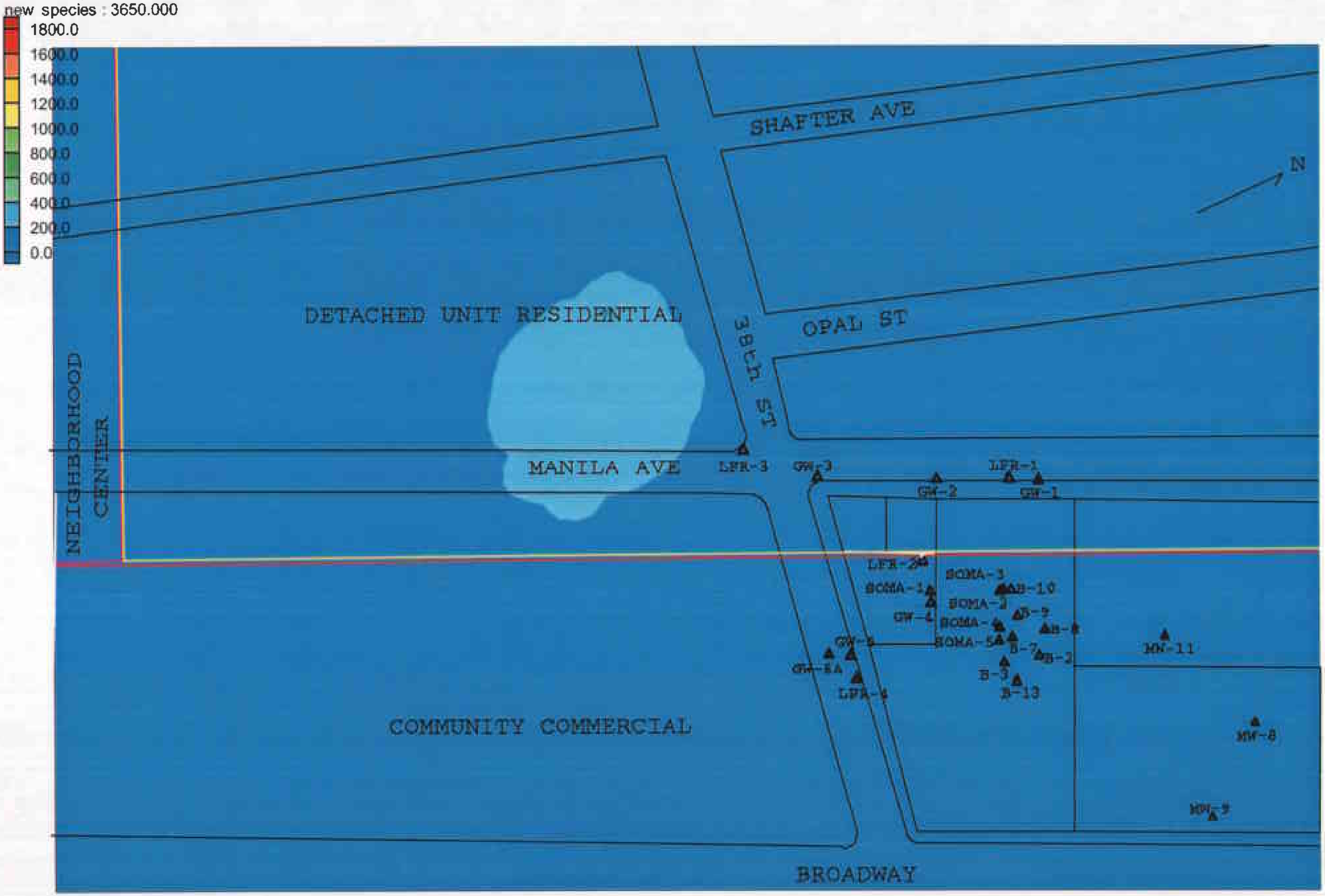


approximate scale in feet

0 100

Figure 46. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 9 years.

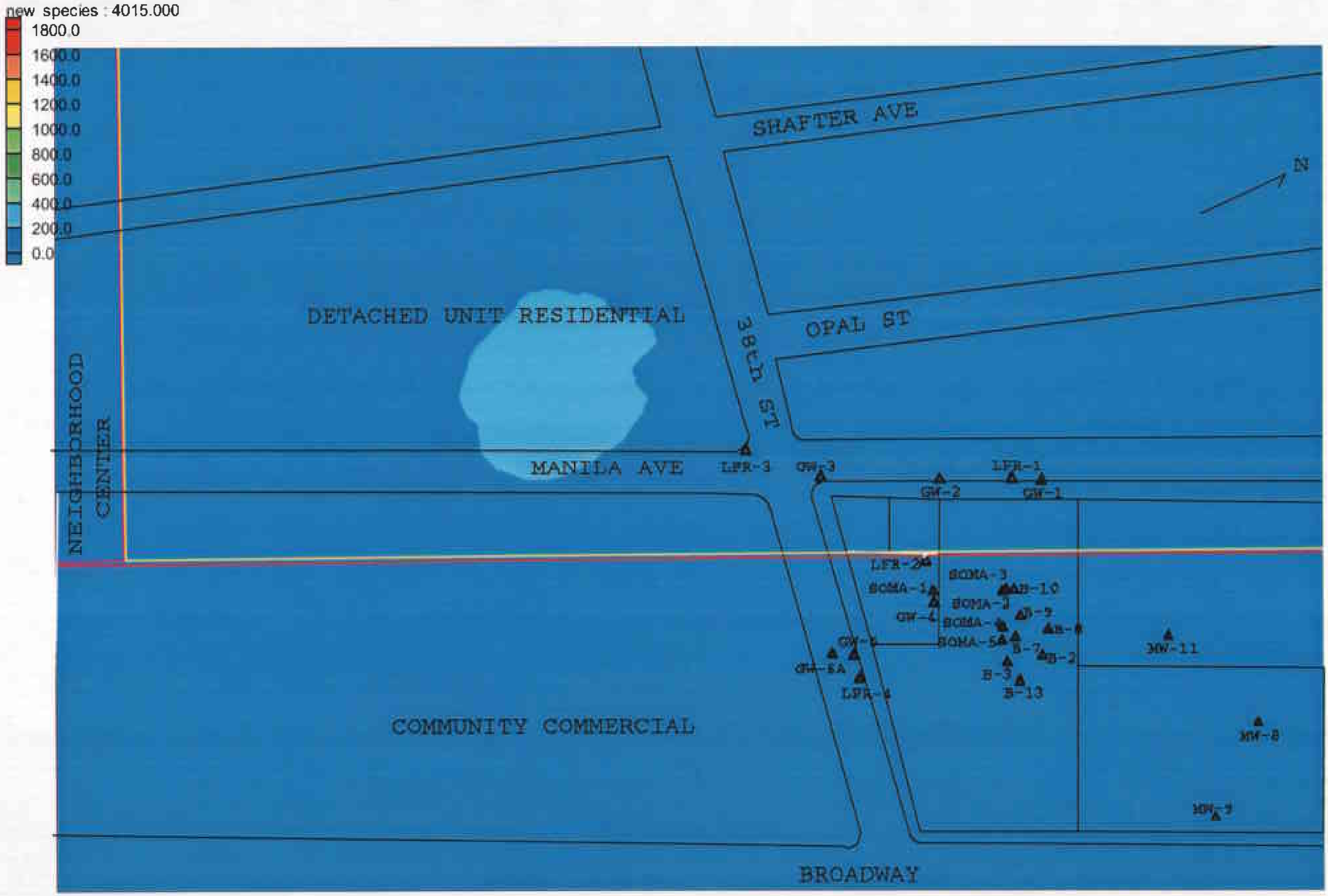
SOMA ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet

0 100

Figure 47. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 10 years.



approximate scale in feet

0 100

Figure 48. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 11 years.

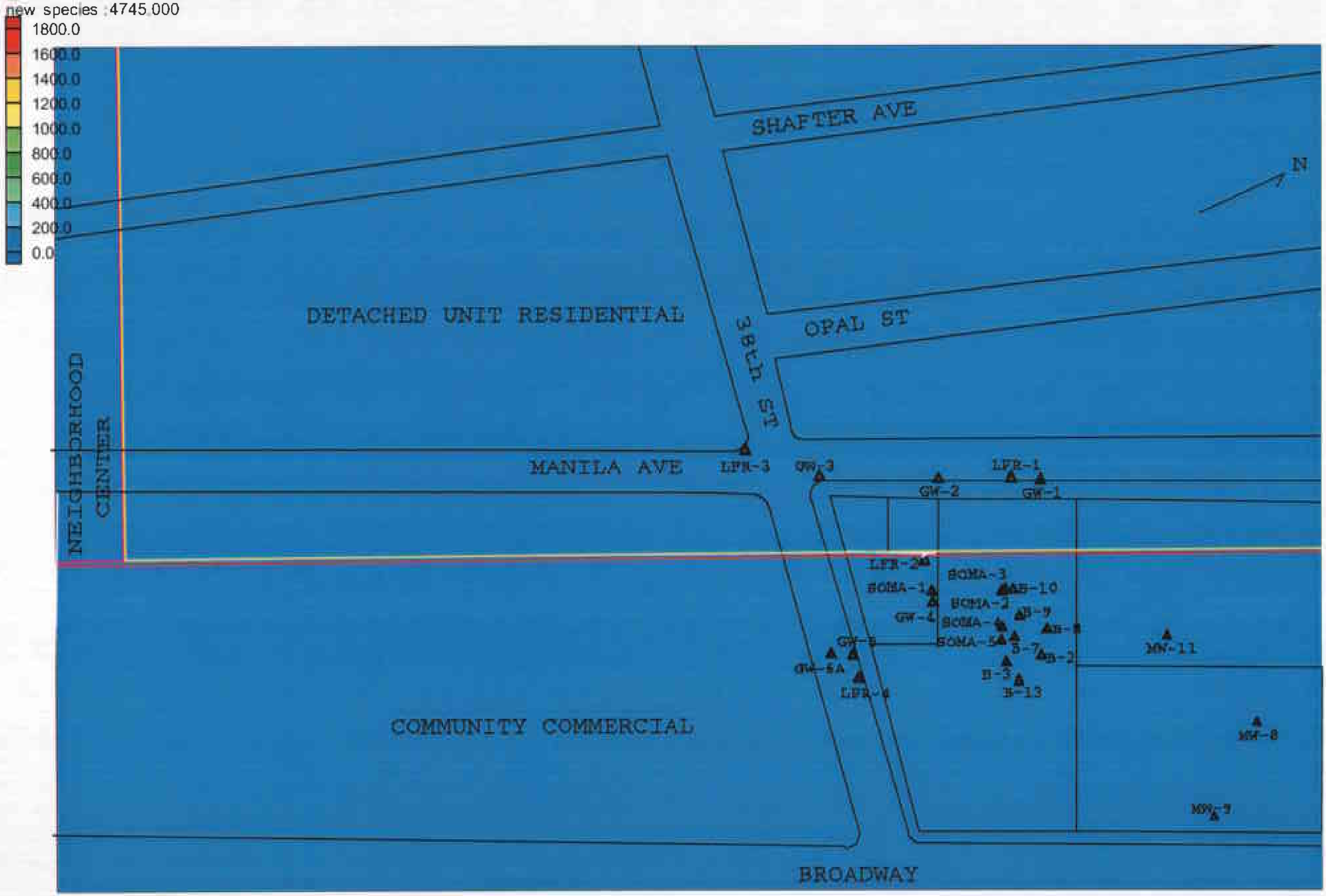
SOMA ENVIRONMENTAL ENGINEERING, INC.

approximate scale in feet

0 100

Figure 49. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 12 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.



approximate scale in feet

0 100

Figure 50. MODFLOW and MT3D simulation of cis-1,2-DCE concentrations after 13 years.

SOMA ENVIRONMENTAL ENGINEERING, INC.