Protecting Our Water Environment

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MONITORING AND RESEARCH DEPARTMENT

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MONITORING THE EFFECTIVENESS OF URBAN STORMWATER BEST MANAGEMENT PRACTICES IN THE CERMAK-BLUE ISLAND STREETSCAPES CORRIDOR IN CHICAGO, ILLINOIS

July 2017

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GLOSSARY

Best management practice: Methods or techniques found to be most effective and practical means in achieving an objective (such as preventing or minimizing pollution) while making the optimum use of resources.

Catch basin: A receptacle or reservoir that receives surface water runoff or drainage. Typically made of precast concrete, brick, or concrete masonry units, with a cast-iron frame and grate on top.

Green infrastructure: An adaptable term used to describe an array of products, technologies, and practices that use natural systems - or engineered systems that mimic natural processes - to enhance overall environmental quality and provide utility services. Generally, Green Infrastructure techniques use soils and vegetation to infiltrate, evapotranspire, and/or recycle stormwater runoff.

Piezometer: An instrument for measuring the pressure of a liquid or gas, or something related to pressure (such as the compressibility of liquid). Piezometers are often placed in boreholes to monitor the pressure or depth of groundwater.

LIST OF ABBREVIATIONS/ACRONYMS

Abbreviation/Acronym	Definition
ASTM C1701	American Society for Testing and Materials C1701 Method
bgs	below ground surface
CDOT	Chicago Department of Transportation
District	Metropolitan Water Reclamation District of Greater Chicago
ISWS	Illinois State Water Survey
L-BI	Leavitt-Blue Island
BMP	Best Management Practices
P-BI	Paulina-Blue Island
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey

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EXECUTIVE SUMMARY

One of the primary motivations for "green infrastructure" is to reduce stormwater runoff which may contribute to combined sewer overflow (CSO) volume. Overflow occurs in cities with combined sewer systems where sanitary sewage water, stormwater, and urban runoff water are collected in the same pipe network. If the capacity of a treatment system cannot handle the amount of water collected, excess water is discharged directly to rivers, bays, and oceans as CSO. Green infrastructure is an approach that communities can choose to manage stormwater, provide multiple environmental benefits, and support sustainable communities. Unlike single-purpose gray stormwater infrastructure, which uses pipes to convey rainwater, green infrastructure uses vegetation and soil to manage rainwater where it falls. By weaving natural processes into the built environment, green infrastructure provides stormwater management for flood mitigation, mitigates urban heat island effect, reduces energy use for pumping and treatment, improves air quality, and much more.

The Chicago Department of Transportation (CDOT) is integrating complete streets and placemaking strategies with sustainable best management practices to achieve increased environmental performance from investments in transportation infrastructure. The CDOT Cermak Road/Blue Island Avenue Sustainable Streetscape Project is located on a two-mile reach of roadway in Chicago's Pilsen neighborhood on the southwest side of the city. The project spans two streets, Cermak Road between Halsted Street and Ashland Avenue, and Blue Island Avenue between Ashland Avenue and Western Avenue. The corridor is a busy four-lane roadway bordered on the north by dense urban housing, parks, schools, and businesses and along the south by industrial warehouses and former factory sites, which in turn line the South Branch of the Chicago River. The roadways are designated truck routes and are thoroughfares for cars, trucks, and buses.

The project was mainly designed to focus on stormwater management using green infrastructure best management practices (BMPs); however, many other sustainability goals were incorporated in the design and implementation of the project. These goals included:

i. Divert 80 percent of the typical annual average rainfall and at least two-thirds of rainwater falling within the catchment area into stormwater BMPs.

ii. Eliminate use of potable water for irrigation by using native, climate adapted, or drought and salt tolerant plants on the BMPs.

iii. Improve bus stops with signage, shelters, and lighting where possible, promote cycling with new bike lanes, and improve pedestrian mobility with accessible sidewalks.

iv. Reduce energy use by a minimum of 40 percent below a typical streetscape baseline by using reflective surfaces on roads/sidewalks and dark sky-friendly fixtures.

v. A minimum of 40 percent of the total materials at the site will be extracted, harvested, recovered, and/or manufactured within 500 miles of the project site.

vi. Recycle at least 90 percent of construction waste based on Leadership in Energy and Environment – New Construction (LEED NC) criteria; i.e. post/pre-consumer recycled content must be minimum 10 percent of total materials value.

vii. Reduce ambient summer temperatures on streets and sidewalks through the use of high albedo pavement, roadway coatings, landscaping, and permeable pavements.

viii. Provide public outreach materials/self-guided tour brochure to highlight innovative, sustainable design features of streetscape.

ix. Create places that celebrate community, provide a gathering space, and allow for interaction and observation of people and the natural world.

The CDOT requested that the Metropolitan Water Reclamation District of Greater Chicago (District) and the United States Geological Survey (USGS) monitor the hydrologic and water quality conditions of the Streetscape Project both pre- and post-BMP construction phases to determine the effectiveness of the BMPs in reducing the stormwater and pollutant loads to the local combined sewer. The data were also used to assess the maintenance needs.

The BMPs consisted of continuous bioswale on the south side of Cermak Road from Ashland Avenue to Halsted Street and planters and tree boxes on the north side of Cermak Road. On the Blue Island Avenue corridor, BMPs consisted of permeable pavers in parking and bike lanes and planter boxes on both sides of the road.

Periodic monitoring of BMPs showed that performance of BMPs declined with time and, maintenance of BMPs was required to retain their effectiveness in managing stormwater. The infiltration rate of permeable pavers declined with time; the decline was related to intensity of use. The infiltration rate of pavers recovered after cleaning. Manual cleaning with complete replacement of aggregate fill material was much more effective than mechanical cleaning. Similarly, the infiltration rate of soil in the bioswale also declined with time; greater amounts of sediments deposited close to the curb cut, as compared to the center of the bioswale, and hence, a greater decline in infiltration rates of the soil near the curb cut was observed.

Soil and plant characteristics in the bioswale and planter boxes were evaluated over time to assess the effectiveness of bioswale soils in removing pollutants from the stormwater runoff. Consistent trends of increasing soil pH and electrical conductivity (EC), since the BMP installations, were observed in bioswale and planter boxes. These changes were related to the amount of sediments and runoff that was routed through these BMPs. The analysis of elemental composition of five plant species grown in bioswale and planter boxes showed elevated levels of zinc (Zn), copper, and manganese (Mn); however, concentrations of these elements were very low compared to the range of concentrations reported for terrestrial plants in the literature.

Water quality results showed that large amounts of pollutants entered the BMPs and were retained in the BMPs, which would have otherwise entered the sewers directly.

All BMPs were designed to infiltrate stormwater to shallow groundwater. Groundwater levels, as observed from five shallow groundwater wells, responded to the control of stormwater infiltration provided by BMPs after every rainstorm. Such water elevation variations were also observed in the monitoring well installed in the bioswale, where groundwater levels responded to the storm events. On one occasion, the groundwater level reached the land surface in the bioswale in the vicinity of the monitoring well, almost reaching the full storage capacity of the bioswale, thus, indicating that significant volumes of water were infiltrating into the native soil and eventually to groundwater from the BMPs. The analysis of data from the catch basin and the catchment area showed that almost 100 percent of the stormwater infiltrated into the BMPs during the study period. The BMPs were designed to infiltrate 80 percent of rainfall for a two-year 30-minute storm equivalent to approximately 1.12 inches of rainfall. The catchment area received rainfall at much higher intensities, but the BMPs were still able to infiltrate almost 100 percent of runoff.

Field observations indicated the need of periodic maintenance of the curb cutouts in the roadway adjacent to the bioswales for sediment buildup and blockage from other debris. Also, periodic cleaning of permeable pavers was required to maintain the permeability, emphasizing that a maintenance protocol is required for these BMPs to function effectively.

The results of this study highlight how layering stormwater BMPs with traditional sewer systems can greatly increase the capacity of these existing systems in absorbing stormwater and provide a wide range of synergistic benefits at a reasonable cost.

INTRODUCTION

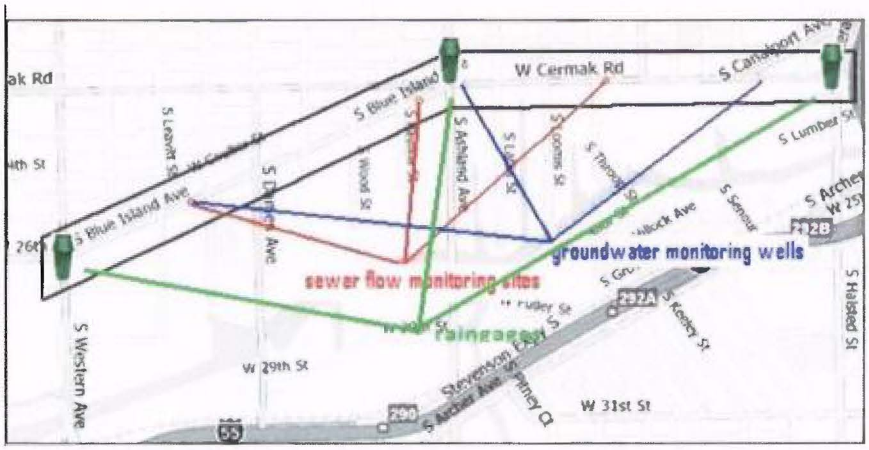
Urban stormwater green infrastructure BMPs are being used in many cities across the United States as a means of reducing the stormwater runoff and pollutant loads to local combined sewer systems. In most cases, these BMPs function to increase the infiltration of stormwater runoff to shallow groundwater instead of draining directly to the local combined sewer, providing volume control of stormwater. They also provide temporary storage, rate control, and reduce peak flows (Drake et al., 2014; Kumar et al., 2016). The performance of the BMPs is primarily determined by the volume of available storage provided and the infiltration rate of the soils. There are other contributing factors that include uptake and evapo-transpiration by vegetation growing in BMPs. Conceptually, the BMPs should function to capture and infiltrate at least an initial volume, or "first flush," of runoff, up to the point where the available storage and infiltration rates are surpassed. However, limited information exists on the effectiveness of these BMPs, how best to maintain them to keep them functioning over time, and the impact of pollutants, salts, and weather on their long-term functionality. Data collected during this study were used to obtain these types of information and to show how, on the Cermak Road/Blue Island Avenue Sustainable Streetscape, a system's approach of integrated stormwater BMPs in an urban setting can leverage a wealth of potential benefits.

Background

The CDOT is integrating complete streets and placemaking strategies with sustainable design BMPs to achieve increased environmental performance from investments in transportation infrastructure. The objectives of these projects are to create flourishing public places and vibrant livable streets while improving the functionality of infrastructure to support dense urban living. These improvements make cities more resilient and adaptable to changing weather conditions. There are numerous projects utilizing urban stormwater BMPs, but there is little information available about the effectiveness of the BMPs in reducing the stormwater runoff and pollutant loads to local combined sewer systems.

The CDOT Cermak Road/Blue Island Avenue Sustainable Streetscape Project, also known as the Pilsen Sustainable Street Project, is located on a two-mile reach of roadway in Chicago's Pilsen neighborhood on the near southwest side of the city. The project spans two streets, Cermak Road between Halsted Street and Ashland Avenue, and Blue Island Avenue between Ashland Avenue and Western Avenue (Figure 1). The corridor is a busy four-lane roadway bordered on the north by dense urban housing, parks, schools, and businesses and along the south by industrial warehouses and former factory sites which line the South Branch of the Chicago River. The roadways are designated truck routes and thoroughfares for a mix of traffic that includes cars, trucks, and buses. Until very recently, there was a coal-fired power plant and an active railroad line along the south side of Cermak Road.

FIGURE 1: LOCATION OF MONITORING STATIONS IN THE STUDY AREA



Purpose and Scope

The purpose of this study is to determine the effectiveness of several urban stormwater BMPs implemented along a reach of the Cermak Road/Blue Island Avenue Sustainable Streetscapes corridor (Figure 1). Many other sustainability goals were also incorporated to improve the functionality of new infrastructure to support dense urban living and are listed in the project goals. The hydrologic and water quality conditions in the CDOT Cermak Road/Blue Island Avenue corridor in both pre- and post-BMP construction phases were monitored to determine the effectiveness of the BMPs in reducing the stormwater and pollutant loads to the local combined sewer. The data were also used to evaluate the changes in the BMP effectiveness over time and assess the maintenance needs of urban stormwater BMPs.

PROJECT GOALS

The project was mainly designed to focus on stormwater management using green infrastructure BMPs; however, many other sustainability goals were incorporated in the design and implementation of the project and are listed below:

i. Stormwater Management: Divert 80 percent of the typical annual average rainfall and at least two thirds of rainwater falling within catchment area into stormwater BMPs.

ii. Water Efficiency: Eliminate use of potable water for irrigation by selecting native or climate-adapted, or drought and salt-tolerant plants to be grown in BMPs.

iii. Transportation: Improve bus stops with signage, shelters, and lighting, where possible; promote cycling with new bike lanes; and improve pedestrian mobility with accessible sidewalks.

iv. Energy Efficiency: Reduce energy use by a minimum 40 percent below a typical streetscape baseline, use reflective surfaces on roads/sidewalks, and use dark, sky-friendly fixtures. A minimum of 40 percent of the total materials will be extracted, harvested, recovered, and/or manufactured within 500 miles of the project site.

v. Recycling: Recycle at least 90 percent of construction waste based on LEED NC criteria; Post/Pre-consumer recycled content must be a minimum of 10 percent of total materials value.

vi. Urban Heat Island and Air Quality: Reduce ambient summer temperatures on streets and sidewalks through the use of high albedo pavement, roadway coatings, landscaping, and permeable pavements.

vii. Education, Beauty and Community: Provide public outreach materials/self-guided tour brochure to highlight innovative, sustainable design features of streetscape. Create places that celebrate community, provide gathering space, and allow for interaction and observation of people and the natural world.

viii. Commissioning: Model Stormwater BMPs in Infoworks Model (a city-wide hydraulics and hydrology model of trunk sewers; http://www.innovyze.com/products/infoworks_icm/) to analyze and refine design. Monitor stormwater BMPs to ensure predicted performance and determine maintenance practices.

ix. Create places that celebrate community, provide a gathering space, and allow for interaction and observation of people and the natural world.

EXISTING LANDSCAPE CONDITIONS

An example of the existing landscape condition is shown in Figure 2. The landscape condition on the south side of Cermak Avenue towards the rail line consisted of compacted soil and gravel mix with very sparse weeds and invasive grasses. The surface drainage of the area was very poor, and even small rain events can cause ponding of water on the surface or overflow to the streets to the sewer inlets on the road. Similarly, on Blue Island Avenue, the landscape was degraded with hardly any green space. Almost 100 percent of the landscape was impervious; sidewalks were degraded with potholes and very poor surface drainage.

FIGURE 2: TWO STREET-LEVEL PHOTOGRAPHS SHOWING EXISTING CONDITIONS IN THE STUDY AREA ALONG CERMAK ROAD PRIOR TO THE START OF THE PROJECT

INSTALLED BEST MANAGEMENT PRACTICES

The CDOT construction plans progressed in two phases, with the Phase 1 BMP construction, beginning in 2010 on the east end of the corridor at Halsted Street and ending at Wolcott Street (~1.2 miles), completed in the summer of 2012. Phase 2 BMP construction, beginning the summer of 2016, starts at Wolcott Street and ends at Western Avenue (~0.8 miles), and presently there are no plans to monitor the Phase 2 program.

Three types of BMPs were installed at the project site during Phase 1 (Figure 3, from Wolcott/Blue Island Avenue to Halsted/Cermak Road). Features of the landscape before, during, and after construction are shown in Figure 4. The following is a brief description of green infrastructure BMPs installed at the project corridor:

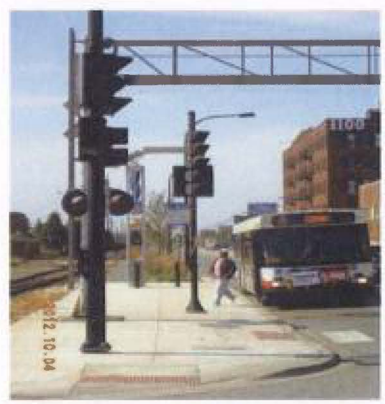
i. Permeable Pavers: Permeable pavers that covered the parking and biking lanes were installed on both sides of the road on Blue Island Avenue (Figure 3). Rainwater falling directly on these areas and the runoff from the road and adjoining impervious areas soak through the spaces in between these pavers and are stored temporarily in the stone storage area below the pavers before the water infiltrates into the native soil below. The stone layer underneath the pavers, infiltration boxes, and the sidewalks were connected to provide large storage volumes for infiltrated water. The permeable pavers were also installed in the nearby Juarez Academy High School plaza and the sidewalks along the school up to Loomis Avenue. The overflow from the pavers at the school plaza and sidewalks was directed to bioswales through a water feature. This water feature also delivered the runoff from the school's roof in the form of channeled fountains to the bioswale. The water feature directed the water to aesthetically enhanced stone formations on the west side of the bioswale (Figure 5).

ii. Infiltration Boxes: A total of 43 infiltration planter boxes were installed on both sides of Blue Island Avenue which received the runoff from road surface and sidewalks. Infiltration planter boxes had mixed vegetation, which included native grasses, perennial shrubs, and forbes. The stone sub-layer below the planter boxes, sidewalks, and below permeable pavers were connected to provide large storage volumes for infiltrating water. On the north side of Cermak Road, there were 19 infiltration boxes and 41 tree boxes. The typical infiltration planter box and tree box installed in this corridor are shown in Figure 5.

iii. Bioswales: There was a continuous bioswale on the south side of Cermak Road between Ashland Avenue and Halsted Avenue (Figure 3 and 5). The bioswale received the runoff water from the road surface and some surrounding impervious areas. The bioswale was landscaped to maximize the benefits of the micro-environments – with most drought-resistant plants on the drier upper edges of the bioswale and water-loving plants at the bottom of bioswale. Another bioswale was located on the west side of Loomis Avenue in front of the high-school plaza (see Figure 5).

FIGURE 3: GENERAL LAYOUT GRAPHICS SHOWING SALIENT FEATURES OF THE PROJECT SITE

FIGURE 4: PHOTOGRAPHS OF THE SITE BEFORE, DURING, AND AFTER CONSTRUCTION



South side of Cermak Road at Racine Road, looking west, before (left) and after (right) construction

North side of Blue Island Ave., looking west, during (left) and after (right) construction.

FIGURE 5: PHOTOGRAPHS OF BEST MANAGEMENT PRACTICES AFTER CONSTRUCTION AT THE PROJECT SITE

Planter Box Alongside Permeable Pavers in Bike and Parking Lane on Blue Island Ave.

Tree Box on Cermak Rd.

Bioswale - School

Bioswale on Cermak – Roadside view

Bioswale on Cermak – Railroad Side View

Water Feature: Arrows Indicating Overflow from Permeable Pavers in School Plaza to Bioswale

Water Feature: Runoff From School Roof Entering Bioswale After Falling on Aesthetic Rocks

This bioswale received the overflow water from the permeable pavers installed on the school plaza but also runoff water from the school's roof via a water feature (see Figure 5).

MONITORING PLAN

A project monitoring plan was developed to guide the collection of hydrologic, water quality, soil, and plant data before and after BMP construction. These data were used to evaluate the effectiveness of the BMPs in reducing the stormwater and pollutant loadings to local combined sewers. The data were also used to determine BMP integrity over the course of the study, which will be helpful to CDOT for developing maintenance protocol. Project staff (USGS and the District) met on numerous occasions to discuss monitoring plans, construction schedules, and permit applications. The project staff also met with consulting engineers who had previously modeled the impacts of urban stormwater BMPs in the study reach using InfoWorks CS (a city-wide hydraulics and hydrology model of trunk sewers). A detailed hydrologic and hydraulic model was developed for the corridor, building on the city's trunk sewer model with the goal of optimizing design elements to meet the performance goal of the project, which was to divert 80 percent of the average annual rainfall. The model characterized the existing system performance, refined design solutions to meet the desired level of service, and examined the impact of the design to reduce the stormwater load to the collection system. A future goal for the monitoring data is to use the data to both calibrate the model and perform a sensitivity analysis. Data were collected from 2008 - 2015 at the project site from three precipitation gages, three sewer flow monitoring stations, two catch basins, and five shallow groundwater wells for the analysis (Figure 1).

Precipitation

Rainfall data within the study area were obtained from three tipping bucket rain gages (RGs) installed within the study corridor (Figure 1). The RGs were installed on street-light poles approximately 20 ft above the ground surface. Rainfall data from two weighing bucket RGs (Numbers 9 and 10), located in close proximity to the study area that are part of the Illinois State Water Survey (ISWS) Cook County Precipitation Network (Figure 6), were also used.

Sewer

Three sewer flow monitoring stations were established along the Cermak Road/Blue Island Avenue corridor (Figure 1). The monitoring stations were located on Blue Island Avenue near Leavitt Street, and near Paulina Street, and on Cermak Road near Throop Street. The locations were chosen to provide full coverage from east to west in the study area.

The contributing drainage area, or "sewershed," for each of the sewer flow monitoring stations were determined by first examining the City of Chicago Sewer Atlas and then by field verification (Figure 7). Field verification consisted of walking the sewer line and confirming flow direction at manholes in the delineated sewershed.

FIGURE 6: LOCATION OF THE ILLINOIS STATE WATER SURVEY COOK COUNTY PRECIPITATION NETWORK GAGES 9 AND 10 IN RELATION TO THE STUDY AREA

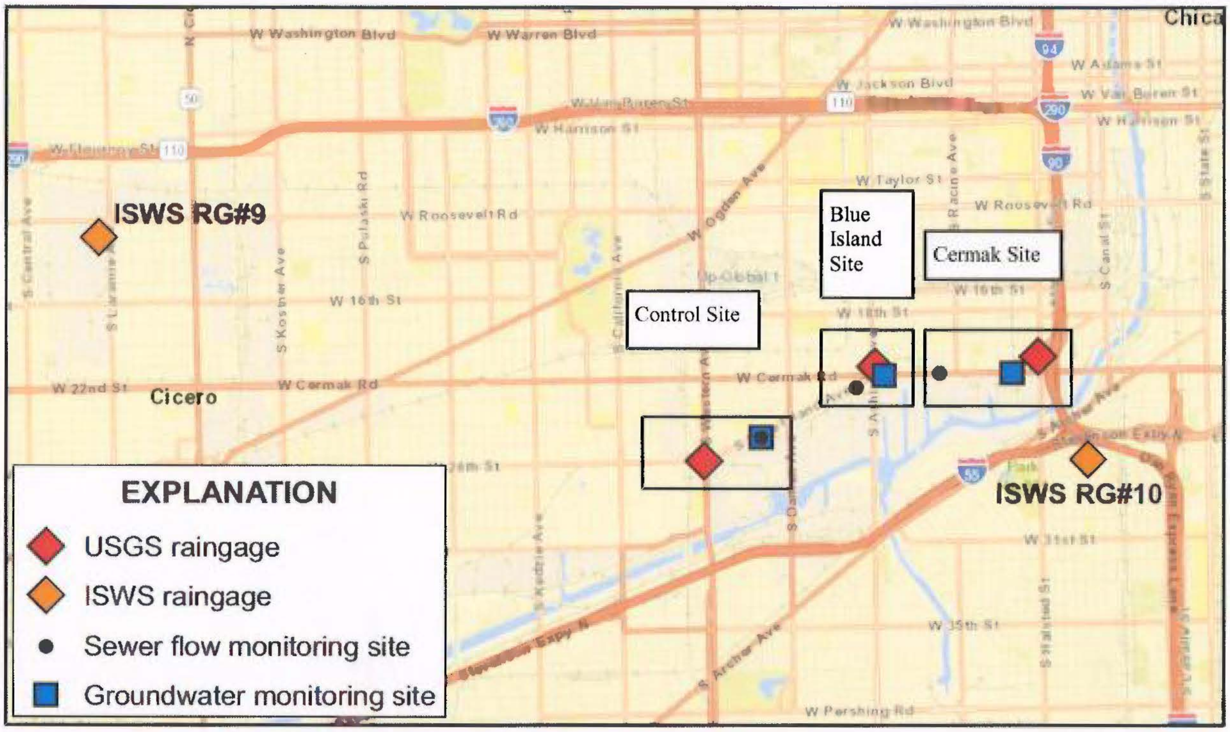


FIGURE 7: APPROXIMATE SEWERSHED FOR EACH OF THE THREE SEWER FLOW MONITORING STATIONS IN THE STUDY AREA

Control Site | Cermak Site | Blue Island Site

The sewer flow monitoring stations consisted of an area-velocity flow meter and an auxiliary water level sensor (submersible pressure transducer) installed in the local combined sewer beneath the roadway at a manhole location. A water quality autosampler intake was co-located at the same manhole locations to facilitate the collection of water quality samples.

Water quality samples were collected from the local combined sewer initially using a manual bucket sample and an automatic sampler at the Leavitt Street and Paulina Street monitoring stations. The manual bucket samples were collected early in the study during dry weather to document water quality during dry-weather conditions. The automatic samplers were installed in June 2011 in small huts located adjacent to the roadway. At each location, a narrow trench was excavated from the manhole location near the center of the roadway to the small huts to accommodate the autosampler tubing. Dry- and wet-weather water quality samples were collected for analysis. The data from the Leavitt Street and Paulina Street locations provide for a pre- and post-BMP construction comparison. Due to high variability in flows and other issues with functioning of autosamplers, the data were inconsistent. From 2013 to 2015, manual grab samples were collected from the Leavitt-Blue Island (L-BI) control site, Paulina-Blue Island (P-BI), and Throop-Cermak (T-CE) sites. At the T-CE site, grab samples were collected for first flush runoff water entering the bioswale at the curb cut; and at the P-BI site, a grab sample was collected from the catch basin during a rain storm. However, at the control L-BI site, grab samples were collected to capture first flush and also after one to two hours into the rain storm.

Catch Basins

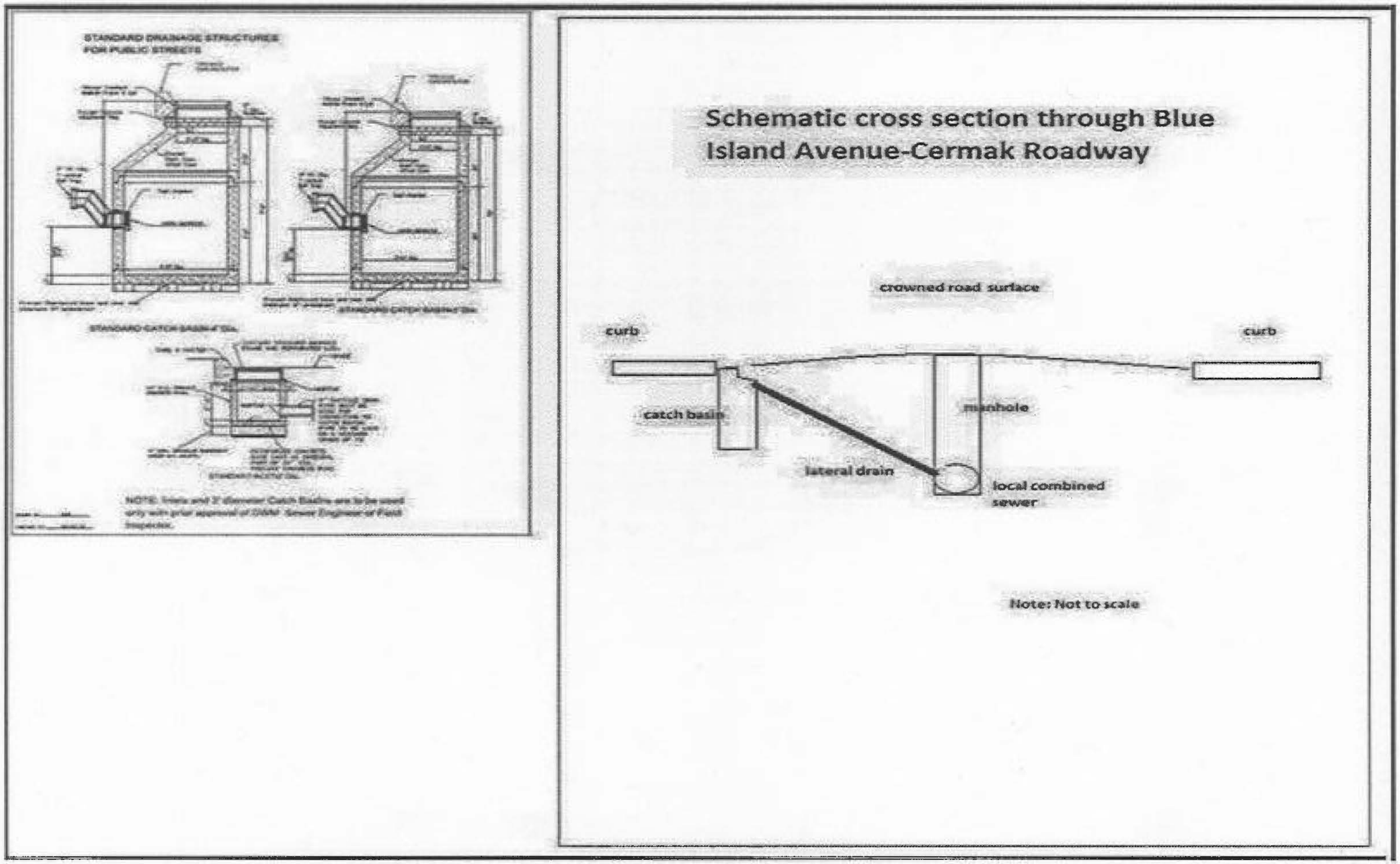
Water level sensors (submersible pressure transducers) were installed in curb-side catch basins at the Leavitt Street and Paulina Street locations (Figure 1). The catch basins' function was to collect stormwater runoff from the roadway and drain through a lateral pipe directly to the local combined sewer (Figure 8). During the study period, permeable pavers were installed at the Paulina Street location as part of the Phase 1 construction. However, BMP construction at the Leavitt Street location near the western end of the study corridor will be done in Phase 2, which is scheduled for completion in 2017.

Groundwater

Groundwater level and quality were monitored at four locations within the study area (Figure 1). A total of five monitoring piezometer type wells were installed at these four locations. The locations of the monitoring wells were chosen to represent shallow groundwater across the study reach.

Piezometer Descriptions. PZ2-CE is the most eastern piezometer located on the south side of Cermak Road approximately 300 ft east of Canal Port Avenue (Figure 1). The flush-mount piezometer depth is 12 ft with a 5-ft screen. Water level depths vary approximately 4 - 7 ft below ground surface (bgs). The geology comprises fill to 5.5 ft and silt (clayey to sandy silt) to 12.0 ft. Continuous 15-minute data collection started on June 11, 2009.

FIGURE 8: SCHEMATIC DIAGRAM OF CATCH BASIN SHOWING THE TYPICAL CATCH BASIN DIMENSIONS, CURBSIDE LOCATION, AND THE LATERAL CONNECTION TO THE LOCAL COMBINED SEWER



PZ4-CC is a piezometer located in the middle of the bioswale located on the south side of Cermak Road approximately 200 ft east of Throop Street. The piezometer top of casing is 2.1 ft above ground surface. The piezometer depth is 8.7 ft deep with a 2.5 ft screen. Water levels vary from approximately 1 to 5.5 ft bgs. The geology comprises fill to 8.7 ft. Continuous 15-minute data collection started on December 18, 2012.

PZ3S-JH is a piezometer centrally located on the north side of Cermak Road approximately 230 ft east of Ashland Avenue. The flush-mount piezometer depth is 10.2 ft deep with a 5-ft screen. Water levels vary between approximately 2 - 8.5 ft bgs. The geology comprises fill to 8 ft and silt and clay to 10.2 ft. Continuous 15-minute data collection started on May 4, 2009.

PZ3D-JH is a piezometer centrally located on the north side of Cermak Road approximately 230 ft east of Ashland Avenue. The piezometer is located approximately 6 ft northwest of PZ3S-JH, but the deeper piezometer is considered "nested" with PZ3S-JH. The flush-mount piezometer depth is 19.5 ft deep with a 10-ft screen. Water levels vary between approximately 2 - 8.5 ft bgs. The geology comprises fill to 8 ft, silt and clay to 12 ft, and clayey silt to 19.5 ft. Continuous 15-minute data collection started on January 10, 2009.

PZ1-BI is the most western piezometer located on the south side of Blue Island Avenue approximately 400 ft east of Oakley Avenue. The flush-mount piezometer depth is 16.8 ft deep with a 5-ft screen. Water-level depths vary between approximately 7 - 9 ft bgs. The geology comprises fill to 10 ft, silty clay and clayey silt to 12 ft, then silt and fine sand to 16.8 ft. Continuous 15-minute data collection started on June 11, 2009.

Soils and Plants in Best Management Practices

The BMPs were designed with selected soil and plant materials in the planters and bioswales that work together to enhance infiltration of stormwater runoff and reduce pollutant loads while also providing an aesthetic value along the corridor.

Soil Properties

All the BMPs (planter boxes and bioswales) were constructed with imported soil with sandy loam texture to a depth of 2 ft with a 6-in layer of mulch on the top. The physico-chemical properties of soil in the BMPs at two surface layers (0 to 2 inches and 0 to 6 inches) were measured periodically. In the case of bioswales, these properties were measured at two locations near the curb cut and middle of the bioswales.

Plant Performance and Elemental Composition. Plant tissue samples from different BMPs were collected periodically and analyzed for elemental concentration, mainly to evaluate heavy metals accumulation in tissue with time. Rugosa Rose (new growth), Daylily (two inside leaves), Prairie Dropseed (above ground biomass), Joe Pye Weed (above ground biomass), Western Sunflower (top five leaves), and Pennsylvania Sedge (above ground biomass) from various BMPs and locations were sampled as representative plants for this evaluation. The plant biomass was dried at 60 °C to a constant weight and analyzed for Ca, Mg, N, K, and heavy metal concentrations.

Infiltration Performance of Permeable Pavers and Soil in the Planter Boxes and Bioswales

The ASTM C1701 method was used to measure the infiltration rate of permeable pavers installed at Juarez Academy High School and the Blue Island Avenue corridor. The test protocols are described in detail in Kumar et al., (2016). The tests were repeated at random spots twice a year or before and after pavers were cleaned. On Blue Island Avenue, tests were performed on both the north and south sides of the street. These surface inundation tests do not prevent horizontal migration of the water once it enters the pervious surface. However, it is assumed that most of the water drained directly downward into the pavement and underlying aggregate fill. The water infiltration rate of soil in the planter boxes and bioswales was also measured periodically using the standard double-ring infiltrometer ASTM 3385 method.

Maintenance of Best Management Practices

Permeable pavers were cleaned during July of 2013 and 2014 using pressurized air to remove all fill aggregates and replaced with new aggregates. In May 2015, mechanical cleaning was conducted utilizing a vacuum truck and rotary wet brushing; only one-half inch surface aggregate fill material was removed and replaced with new aggregates. Permeable pavers at the school plaza and sidewalks in front of the school received no maintenance during the study period. Infiltration planter boxes and bioswale maintenance involved removing trash and debris twice a year, in early spring and fall.

DATA AND ANALYSIS

The data collected during the study were used to evaluate the effectiveness of the BMPs. Data collected from monitoring precipitation, sewer level and flow, catch basin levels, infiltration rates, shallow groundwater, soil and plant chemistry, and water quality provided for a more complete analysis of the local hydrology and a means of evaluating the effectiveness of the BMPs for reducing the loading of stormwater and pollutants to the local combined sewer system on a larger scale.

Precipitation

The study utilized rainfall data from two ISWS weighing-bucket RGs located just outside the study corridor (Figures 1 and 6) and three District tipping-bucket RGs located within the study corridor. The ISWS RGs provided a more complete, continuous record of rainfall and were used for most of the data analysis. The District's RGs located at Western Avenue, Ashland Avenue, and Halsted Street were used to confirm rainfall totals and temporal distribution of selected storm events.

The ISWS precipitation gage data provided continuous precipitation data during the 2008 - 2015 study. Monthly total precipitation data from the two ISWS precipitation gages (RG Nos. 9 and 10) located in close proximity to the study area show the spatial variability of precipitation over relatively small distances (Figure 9). The annual total precipitation from the ISWS gages near the study corridor ranged from a low of 32.36 inches (RG No. 9 in 2012) to 50.69 inches (RG No. 10 in 2010). The mean annual total precipitation for the 2008 - 2015 water years from the ISWS precipitation gages Nos. 9 and 10 were 41.10 inches and 42.39 inches, respectively (Table 1).

Rainfall data from the ISWS precipitation gage network for the period of this study were evaluated in terms of magnitude and recurrence intervals. The ISWS Bulletin 71 (Table 2) shows the recurrence intervals (range two months to 100 years) for storms of a fixed duration (five minutes to ten days).

FIGURE 9: MONTHLY PRECIPITATION HYETOGRAPH FROM THE ILLINOIS STATE WATER SURVEY COOK COUNTY PRECIPITATION NETWORK GAGE, GAGE NUMBERS 9 AND 10, DURING THE STUDY PERIOD

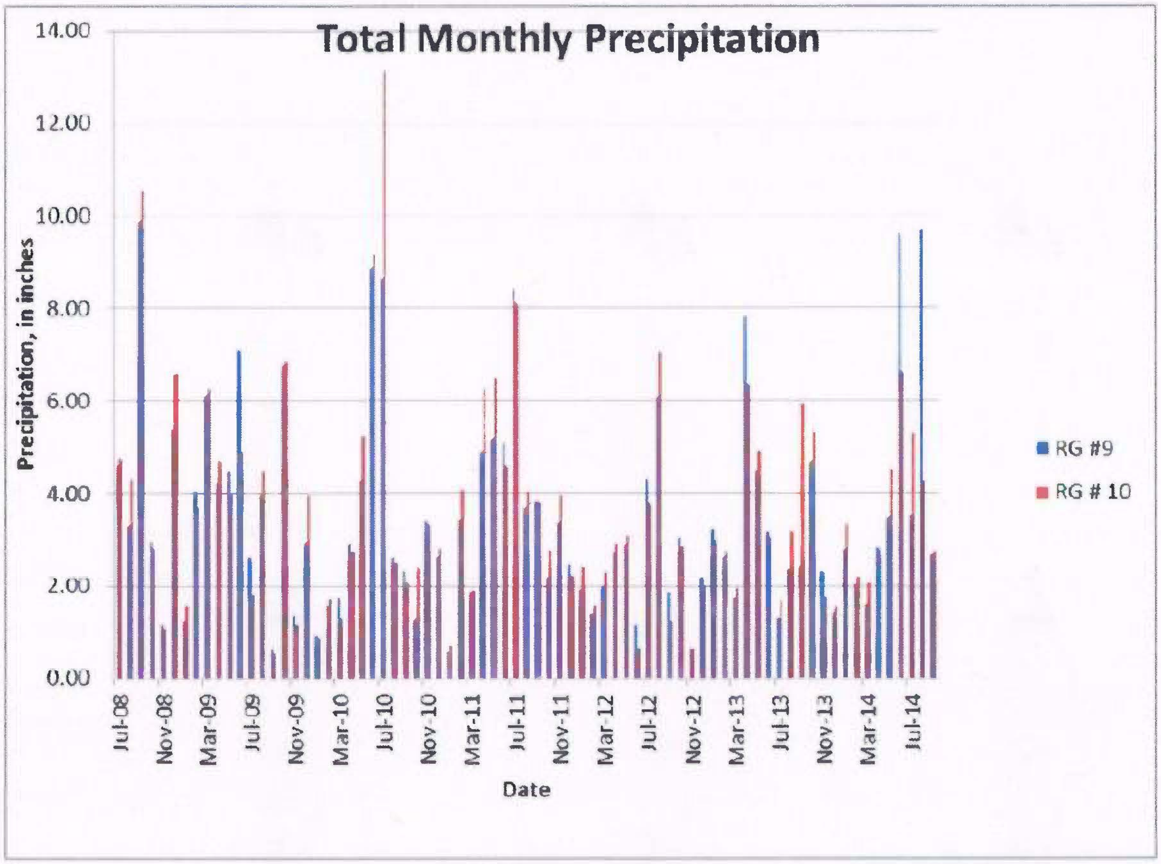


TABLE 1: ANNUAL TOTAL PRECIPITATION FROM THE ILLINOIS STATE WATER SURVEY COOK COUNTY PRECIPITATION NETWORK GAGES NUMBERS 9 AND 10 DURING THE 2008 - 2015 WATER YEARS

Water Year	Gage # 9	Gage # 10
2008	43.27	47.25
2009	43.95	42.32
2010	44.91	50.69
2011	44.25	48.42
2012	32.36	33.96
2013	35.01	38.32
2014	46.62	42.41
2015	38.42	35.76

TABLE 2: RAINFALL RECURRENCE INTERVALS FOR TWO-MONTHS TO 100-YEAR STORM LASTING BETWEEN FIVE MINUTES TO TEN DAYS DURATION[1]

Duration	Rainfall in Inches for a Given Recurrence Interval											
	2 Month	3 Month	4 Month	6 Month	9 Month	1 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
10 day	2.02	2.48	2.80	3.30	3.79	4.12	4.95	6.04	6.89	8.18	9.38	11.14
5 day	1.66	1.98	2.24	2.60	2.99	3.25	3.93	4.91	5.70	6.93	8.04	9.96
72 hour	1.53	1.83	2.02	2.34	2.70	2.93	3.55	4.44	5.18	6.32	7.41	8.78
48 hour	1.44	1.70	1.90	2.18	2.49	2.70	3.30	4.09	4.81	5.88	6.84	8.16
24 hour	1.38	1.61	1.76	2.03	2.31	2.51	3.04	3.80	4.47	5.51	6.46	7.58
18 hour	1.26	1.47	1.61	1.86	2.12	2.30	2.79	3.50	4.11	5.06	5.95	6.97
12 hour	1.20	1.40	1.53	1.77	2.01	2.18	2.64	3.31	3.89	4.79	5.62	6.59
6 hour	1.03	1.21	1.32	1.52	1.74	1.88	2.28	2.85	3.35	4.13	4.85	5.68
3 hour	0.88	1.02	1.13	1.30	1.47	1.60	1.94	2.43	2.86	3.53	4.14	4.85
2 hour	0.81	0.95	1.05	1.20	1.36	1.48	1.79	2.24	2.64	3.25	3.82	4.47
1 hour	0.65	0.76	0.84	0.96	1.09	1.18	1.43	1.79	2.10	2.59	3.04	3.56
30 minutes	0.51	0.60	0.65	0.75	0.86	0.93	1.12	1.41	1.65	2.04	2.39	2.80
15 minute	0.37	0.44	0.48	0.55	0.63	0.68	0.82	1.03	1.21	1.49	1.75	2.05
10 minute	0.30	0.35	0.39	0.45	0.51	0.55	0.67	0.84	0.98	1.20	1.42	1.20
5 minute	0.17	0.19	0.21	0.24	0.28	0.30	0.36	0.46	0.54	0.66	0.78	0.91

[1]From Illinois State Water Survey Bulletin 71.

RESULTS AND DISCUSSION

Infiltration Performance of Permeable Pavers and Soil in the Planter Boxes and Bioswales

Changes in the average infiltration rate of permeable pavements in the Streetscape project corridor with time are presented in Table 3. In general, the infiltration rate of pavers declined with time. The decline was greater on the pavers located on Blue Island north as compared to Blue Island south. This was most likely due to higher traffic intensity on the north side of the road as compared to the south side where daily commuters parked their cars during the daytime. This decline is most likely linked to the clogging of the aggregate fill material between the pavers. This clogging not only reduces the total pore space volume but may also block the pores, which reduce their connectivity and ultimately hinder the flow of water. The main causes of clogging may be (i) particulate matter from dry deposition, particles from tire wear, or vehicle exhaust entering the pores; (ii) waterborne particulate matter which drains into porous pavement and clogs the pavers, (iii) shear stress on the surface caused by vehicle traffic, resulting in the collapse of bigger voids; (iv) deterioration of pores of surfaces by freeze-thaw; and (v) oil leaks from vehicles which make the pores hydrophobic and thus impede water movement.

The infiltration rates of pavers recovered after cleaning: Manual cleaning with complete replacement of aggregate fill material was much more effective than mechanical cleaning (Table 3). The results show the importance of maintenance of pavers to maintain their performance. The pavers at the school plaza were never cleaned and thus, show significant deterioration in terms of infiltration performance and often ponding of water was observed at the depression areas in the school plaza and sidewalks in front of the school.

Periodic measurements of soil infiltration rates were done at two locations within the bioswale: near the curb cut where stormwater runoff enters the bioswale and at the center of the bioswale (Table 4). The infiltration data show a trend of decreasing infiltration rates for the soil in the bioswale over time. These results are as expected because the soil compacts after the initial installation, and also fine-grain sediments in the stormwater runoff from the street are deposited in the bioswale and thereby clog soil pores. Greater amounts of sediments deposited close to the curb cut as compared to the center of the bioswale and hence, a greater decline in infiltration rates of soil near the curb cut.

Changes in Soil Characteristics in Infiltration Planter Boxes and Bioswales

The effectiveness of the bioswale as a stormwater BMP was evaluated on the basis of stormwater volume reduction and the capacity of bioswale soils and plants to reduce pollutant loads. Stormwater runoff in urban areas is widely recognized as a major source of environmental contaminants (USEPA, 1983; Walker et al., 1999). The soils and vegetation within the bioswale were selected to remove pollutants from stormwater runoff. Soil characteristics in the bioswale and planter boxes were evaluated over time to assess the effectiveness of bioswale soils in removing pollutants from the stormwater runoff.

TABLE 3: CHANGES IN AVERAGE PERCOLATION RATE OF PERMEABLE PAVEMENTS OVER TIME IN THE STREETSCAPE PROJECT CORRIDOR

Test Date	Juarez Academy	Blue Island North[1]	Blue Island South[1]
	----------	inches/hr	----------
October 2012	9.0 ± 1.2	18.2 ± 3.4	20.1 ± 2.2
June 2013	3.9 ± 0.9	4.1 ± 1.8	8.3 ± 1.9
August 2013	2.7 ± 0.6	44.7 ± 6.9	169.5 ± 22.4
May 2014	2.4 ± 0.6	21.0 ± 6.0	63.0 ± 14.4
August 2014	2.4 ± 0.6	43.2 ± 10.8	140.4 ± 22.2
May 2015	1.9 ± 0.9	2.35 ± 0.79	2.63 ± 1.0
June 2015	1.6 ± 0.5	20.6 ± 11.8	7.17 ± 4.3

[1]Cleaning of pavers done manually in July 2013 and July 2014 and mechanically in May 2015. Manual cleaning with pressurized air; all fill aggregates removed and replaced with new aggregates. Mechanical cleaning conducted utilizing a vacuum truck and rotary wet brushing; only ½-inch aggregates removed and replaced with new aggregates.

TABLE 4: CHANGES IN AVERAGE PERCOLATION RATE OF SOIL OVER TIME IN THE BIOSWALE AND PLANTER BOXES IN THE STREETSCAPE PROJECT CORRIDOR

	Bioswale		Planter Boxes	
Test Done	Near Curb-Cut	Center	Without Curb-Cut	With Curb-Cut
	------ inches/hr ------			
October 2012	11.4 ± 3.7	61.2 ± 18.3	65.9 ± 15.2	60.5 + 14.9
June 2013	9.2 ± 3.2	55.3 ± 15.4	62.7 ± 13.5	45.9 + 10.6
August 2013	7.5 ± 3.6	50.4 ± 11.8	55.6 ± 12.1	43.4 + 8.9
May 2014	5.5 ± 2.3	20.6 + 7.2	52.4 ± 10.5	35.8 ± 9.6
August 2014	5.2 ± 2.1	18.4 + 7.1	48.6 ± 9.2	30.5 ± 8.8
May 2015	3.3 ± 1.4	10.5 + 5.6	39.7 ± 8.7	20.9 ± 7.4
June 2015	3.1 ± 1.6	8.6 + 4.7	35.7 ± 7.4	18.9 ± 6.6

Figures 10 and 11 show the results of biannual measurements of pH and EC of bioswale and planter soils. Consistent trends of increasing soil pH and EC for the bioswale and planter soils between fall 2012 and fall 2015 were observed. Similar trends were observed in both the surface-to-5 cm and the surface-to-30 cm layers of soil. In general, increases in soil pH and EC were of a higher magnitude in the bioswale on Cermak Road, as compared to the school bioswale, and also in infiltration planter boxes with a curb cut than without a curb cut. These trends are due to changes in the bioswale and planter soils as stormwater runoff is routed into the BMPs and infiltrated through the soils but also the source of that runoff water. For example, the school bioswale received runoff from the school roof top and overflow from the permeable pavement plaza, but the bioswale on Cermak Road received the runoff from the Cermak Road catchment area, which is expected to carry more sediments and pollutants than the school roof or plaza. Similarly, the infiltration planter boxes with curb cut showed a greater increase in pH and EC as compared to planter boxes without-curb cut. Infiltration planter boxes with curb cut received runoff from both the road pavement and also the sidewalks and without curb cut received runoff only from sidewalks. The soil pH and EC were significantly higher near the curb cut of Cermak Road bioswale as compared to the middle of the bioswale, likely due to the greater deposition of sediments and the infiltration of concentrated first flush runoff closer to the curb cut. These results indicate that soil in the infiltration planter boxes and bioswales not only retain sediments and pollutants from runoff, which would otherwise end up in combined sewers, but also retard their transport to the surface or ground water.

Elemental Composition of Different Plant Species Grown in Bioswales and Infiltration Planter Boxes

Five species of plants (Rugosa rose, Daylily, Prairie dropseed, Joe Pye Weed, Western Sunflower, and Pennsylvania sedge) utilized in the bioswales and infiltration planters were analyzed for fifteen metal elements: Zn, cadmium, Cu, nickel (Ni), lead, Mn, molybdenum (Mo), arsenic, selenium, calcium, phosphorus, sodium, magnesium, iron (Fe), and aluminum (Al). Metals, such as Cu, Zn, Fe, Mn, Mo, and Ni are essential micronutrients (Reeves and Baker, 2000). All five species of plants show elevated levels of Zn, Cu, and Mn. In general, the concentrations of these metals, especially heavy metals, were very low as compared to the range of concentrations reported for terrestrial plants (Nagajyoti et al., 2010). Plant uptake of these elements not only depends on the species but also soil properties like organic carbon and pH.

The results on the elemental concentration of three plant species growing close to the curb cut and middle of the roadside bioswale (Figure 12) show that in general, concentrations of all heavy metals were lower close to the curb cut as compared to the middle of the bioswale, except in the case of Daylily. Similarly, the concentrations of all metal elements in the three plant species compared were low in the school bioswale as compared to those grown in roadside bioswale and did not show any trend between plants grown near the inlet or middle of the school bioswale (Figure 13). Comparison of heavy metals accumulation in Prairie dropseed plants between the roadside and school bioswale showed a significantly higher concentration of Zn, Mn and Al in roadside bioswale, which may be expected as runoff from the road may be enriched in these metals as compared to runoff from the roof of the school (Figure 14). Comparison of daylily grown in roadside bioswale on Cermak Road and infiltration planter boxes at Blue Island

FIGURE 10: CHANGES IN SOIL pH AND ELECTRICAL CONDUCTIVITY OF SURFACE 0 TO 30 cm LAYER IN BIOSWALES AND PLANTER BOXES WITH TIME

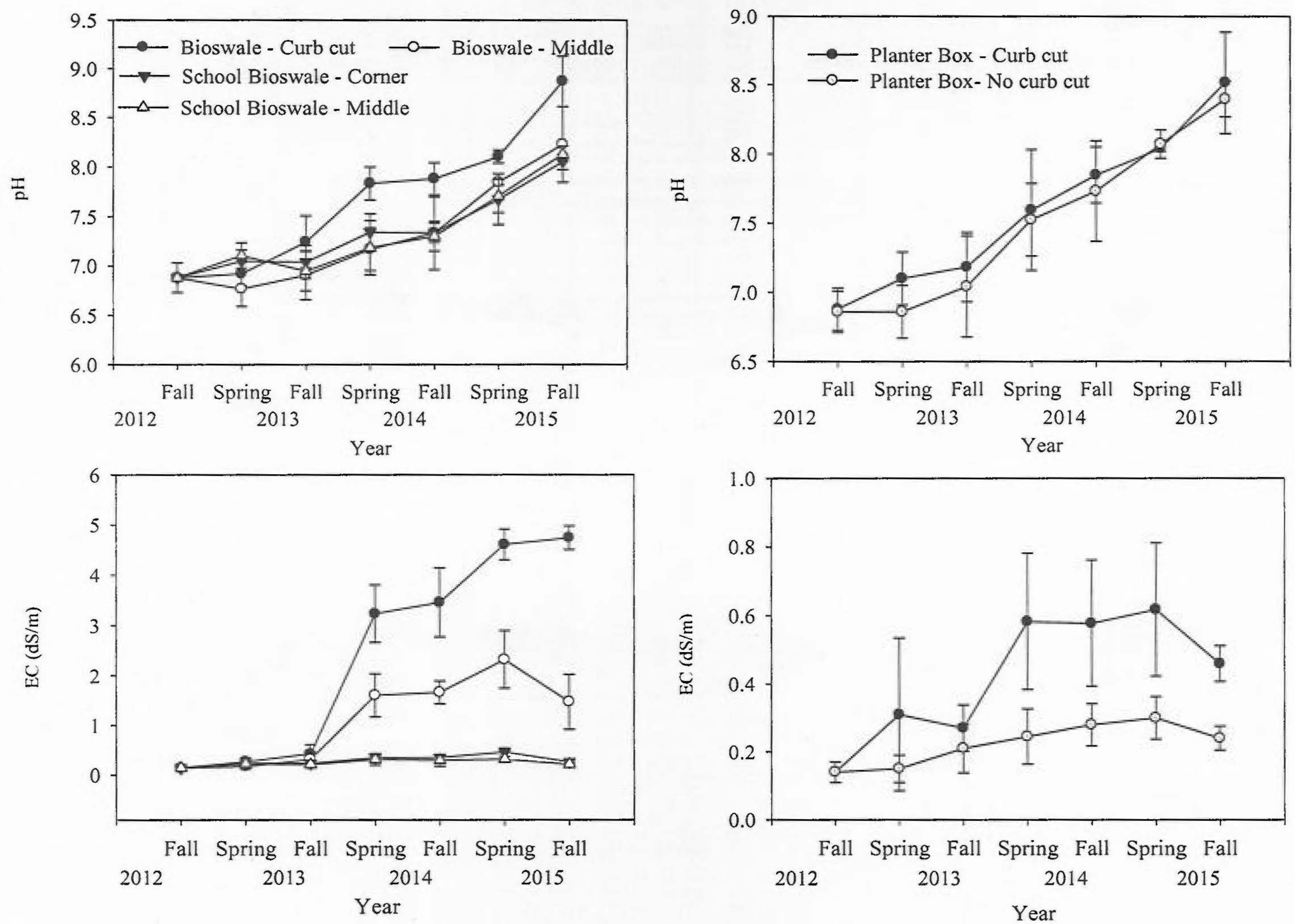


FIGURE 11: CHANGES IN SOIL pH AND ELECTRICAL CONDUCTIVITY OF SURFACE 0 TO 5 cm LAYER IN BIOSWALES AND PLANTER BOXES WITH TIME

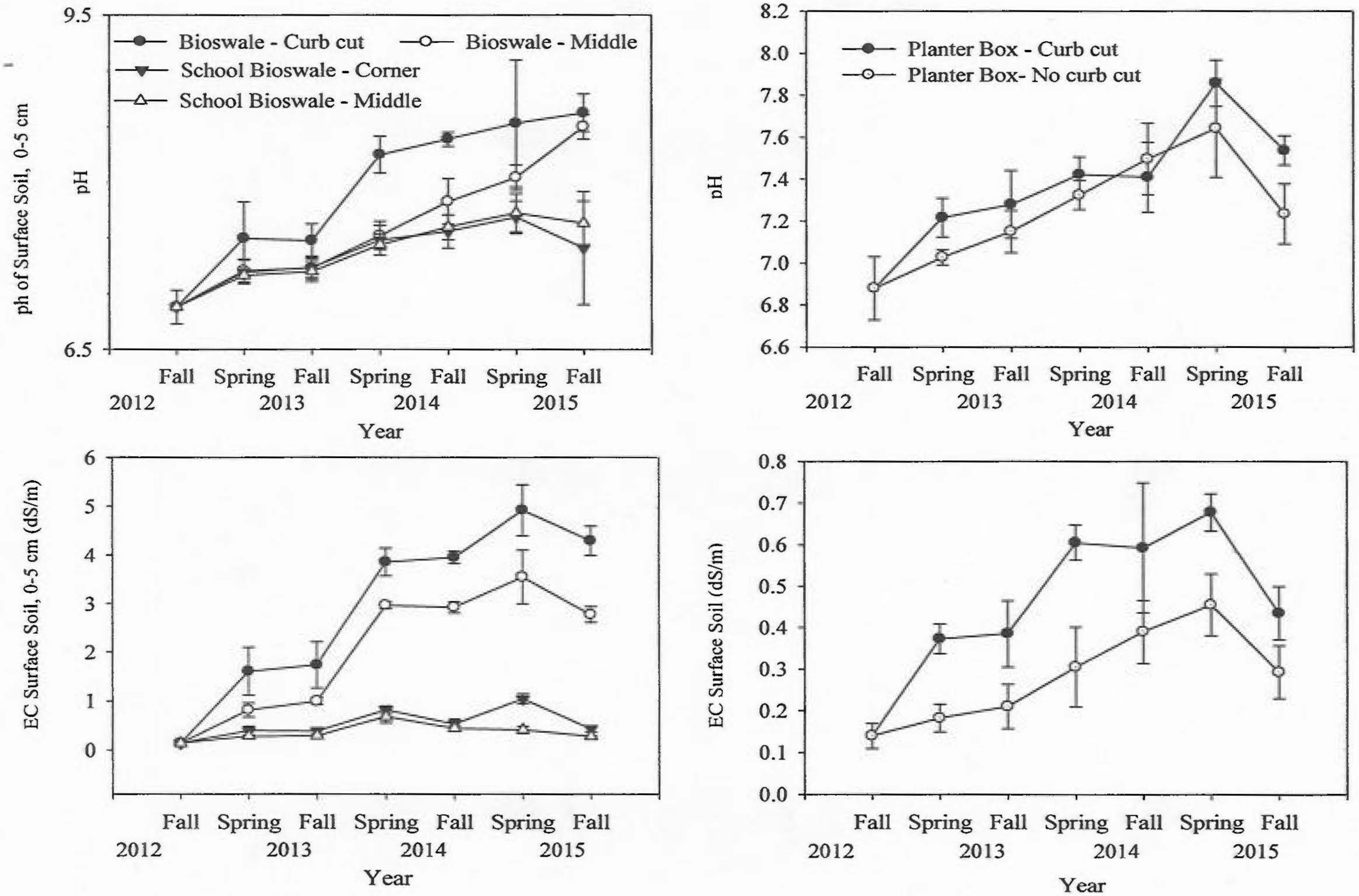


FIGURE 12: ELEMENTAL CONCENTRATION IN PLANT TISSUE GROWN NEAR CURB-CUT AND MIDDLE OF A ROADSIDE BIOSWALE IN STREETSCAPE CORRIDOR

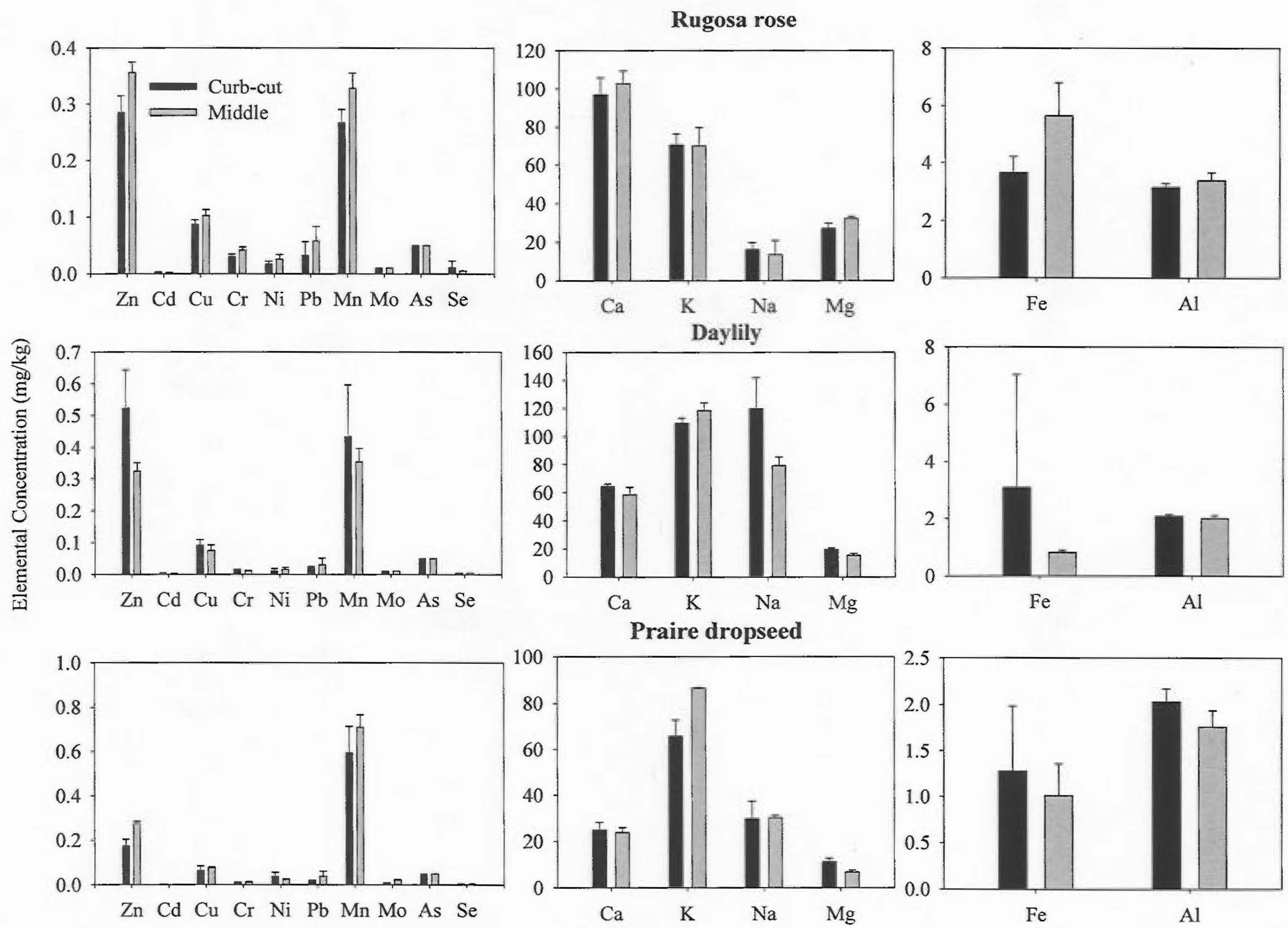


FIGURE 13: ELEMENTAL CONCENTRATION IN PLANT TISSUE GROWN NEAR INLET AND MIDDLE OF SCHOOL BIOSWALE IN STREETSCAPE CORRIDOR

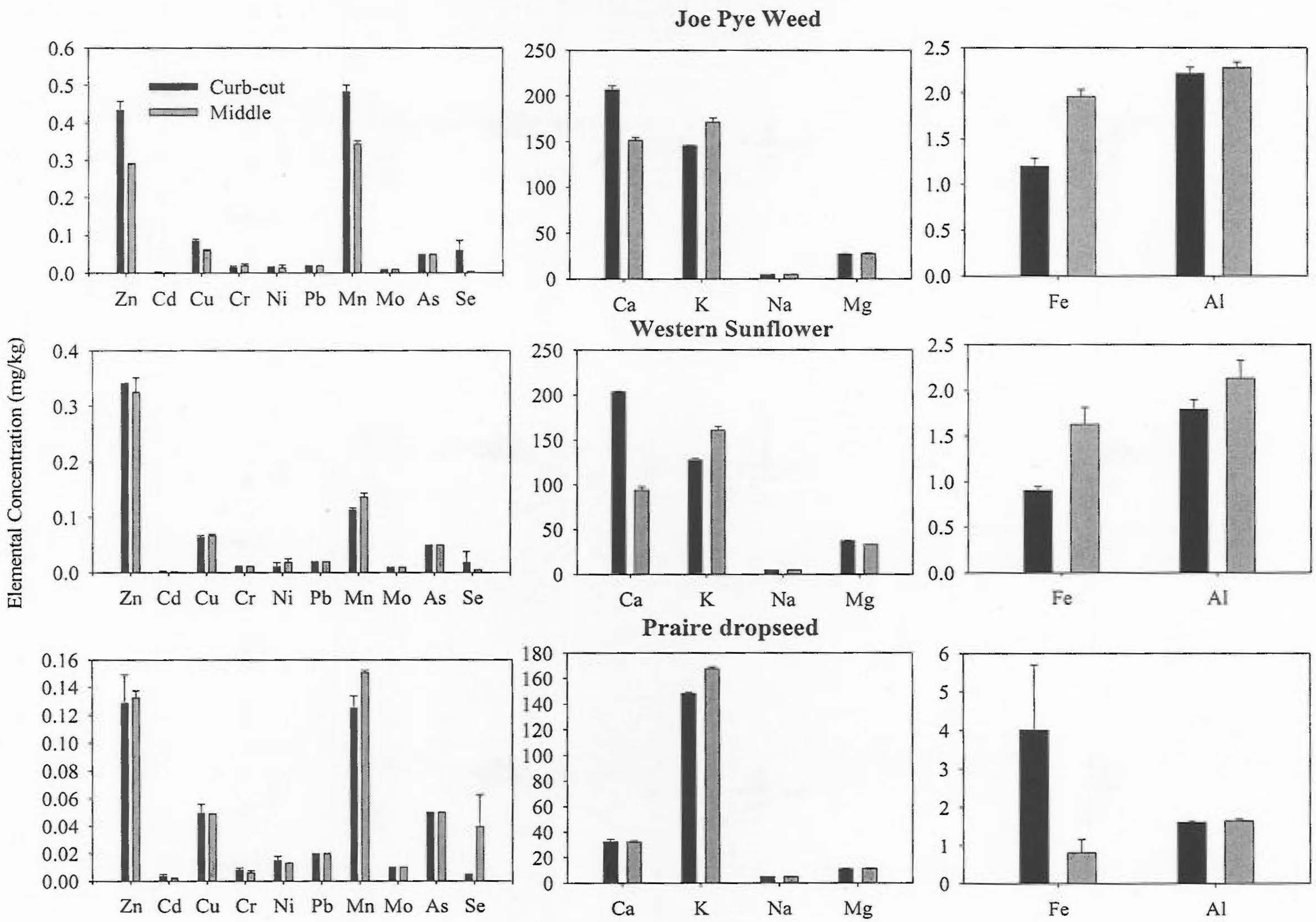
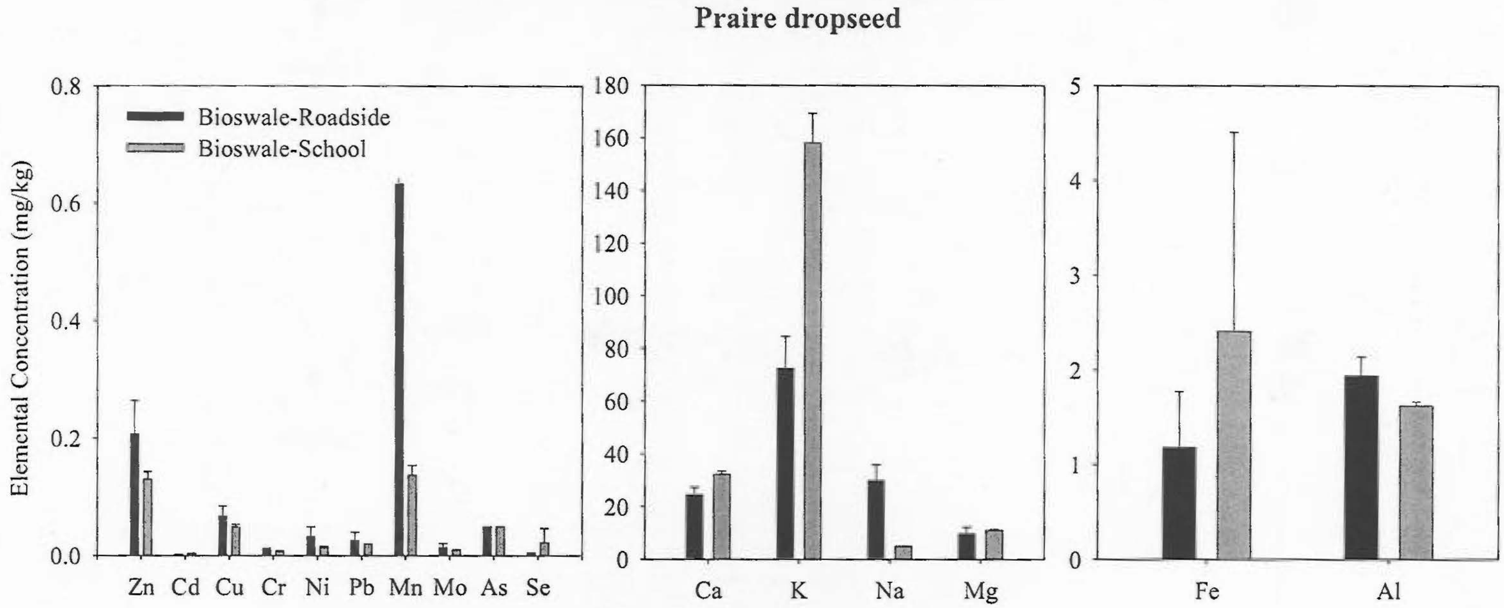


FIGURE 14: ELEMENTAL CONCENTRATION IN PRAIRE DROPSEED TISSUE GROWN IN ROADSIDE BIOSWALE AND SCHOOL BIOSWALE IN THE STREETSCAPE CORRIDOR



Avenue showed only significantly higher accumulation of Mn when grown in roadside bioswale. The reason for higher Mn in roadside bioswale may be linked to industrial activity, as a metal recycling facility was located in the vicinity of this bioswale (Figure 15). On Blue Island Avenue, Pennsylvania sedge growing in the infiltration planter boxes on the north side of the roadway had significantly higher concentrations of Zn and Mn as compared to those plants growing in the infiltration boxes on the south side of the roadway, while the results for Fe and Al were the opposite (Figure 16).

Overall, the concentrations of heavy metals in plants grown in bioswale or infiltration planter boxes were towards the lower side of the range of concentrations reported in the literature (Table 5).

Water Quality

Water quality results from grab samples for four major rain storms between 2013 and 2015 for the control site L-BI, the site with infiltration planter boxes and permeable pavers at the Blue Island Avenue location (P-BI), and the site with the bioswale as a BMP at the Cermak Road location (T-CE), are presented in Table 6. In general, concentrations of pollutants in runoff during the first flush at the control site, L-BI, and first flush runoff entering the bioswale, T-CE, site were similar. This result shows that a large amount of pollutants was retained in the bioswale, which would have otherwise entered the local combined sewers (Table 6). Similarly, comparisons of pollutant concentrations in runoff from first flush and during the middle of the storm between control L-BI site and BMP's P-BI site showed that significant pollutants were retained in permeable pavers and planter boxes. Most of the first flush storm water from the road surface entered the permeable pavers and, therefore, did not result in runoff reaching the catch basin. Overall, the results showed that there may be a large amount of pollutants in the storm water, which would either enter storm/combined sewers and end up in water reclamation plants or end up in surface waters. Green infrastructure BMPs are capable of retaining and thus reducing this pollutant load from entering waterways either directly or via storm/combined sewers.

Sewer Level and Flow

The initial monitoring plan and study approach outlined the collection of sewer flow data in both the pre- and post BMP construction phases to document changes in stormwater runoff loads to the local combined sewers. While the BMPs are installed along the Blue Island Avenue/Cermak Road corridor, examination of the sewer atlas revealed that the service area for each of the sewer flow monitoring stations included portions of the neighborhoods to the north of the road corridor (Figure 7 A-C). Analysis of the first few months of sewer flow data showed that the uncertainty in sewer flow data was relatively high (estimated at greater than 10 percent). The relatively high uncertainty is not unusual for the type of meters and the difficult measurement conditions found in small combined sewers (Waite et al., 2002; Ribeiro et al., 2009; World Meteorological Organization, 2016). Computed flow volumes and relatively small changes in flow volumes that might be attributable to BMPs were difficult to determine due to the small flow volume and relative uncertainty in the flowmeter data. Rainfall-runoff coefficients were determined for a range of storm events and were found to be inconsistent. This can

FIGURE 15: ELEMENTAL CONCENTRATION IN DAYLILY PLANT TISSUE GROWN IN ROADSIDE BIOSWALE AND PLANTER BOXES ON BLUE ISLAND ROAD IN THE STREETSCAPE CORRIDOR

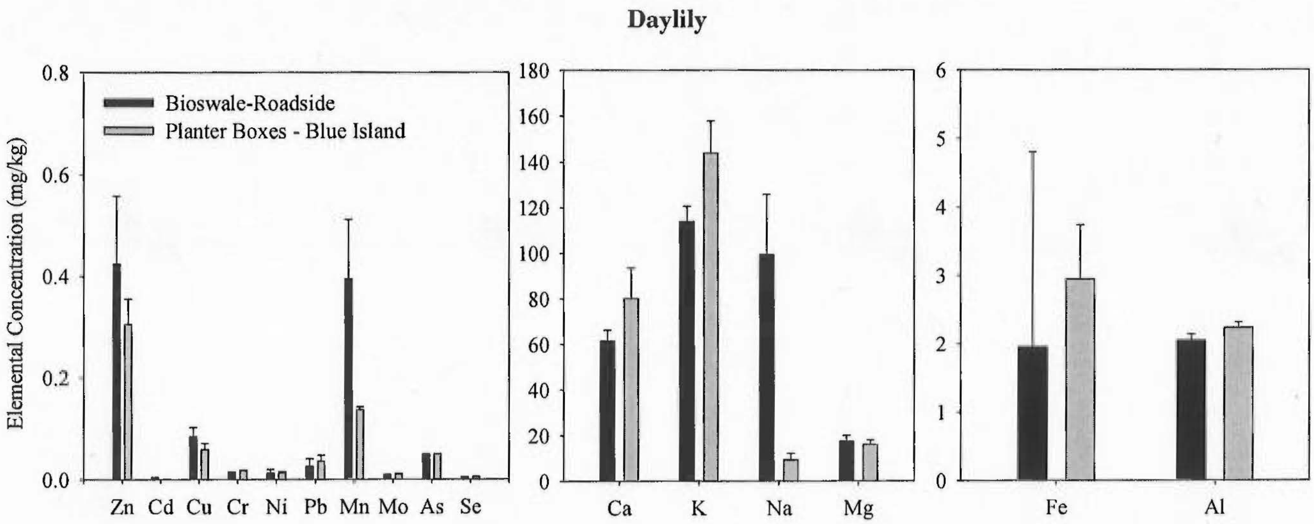


FIGURE 16: ELEMENTAL CONCENTRATION IN PENNSYLVANIA SEDGE PLANT TISSUE GROWN IN PLANTER BOXES ON NORTH AND SOUTH SIDE OF BLUE ISLAND ROAD IN THE STREETSCAPE CORRIDOR

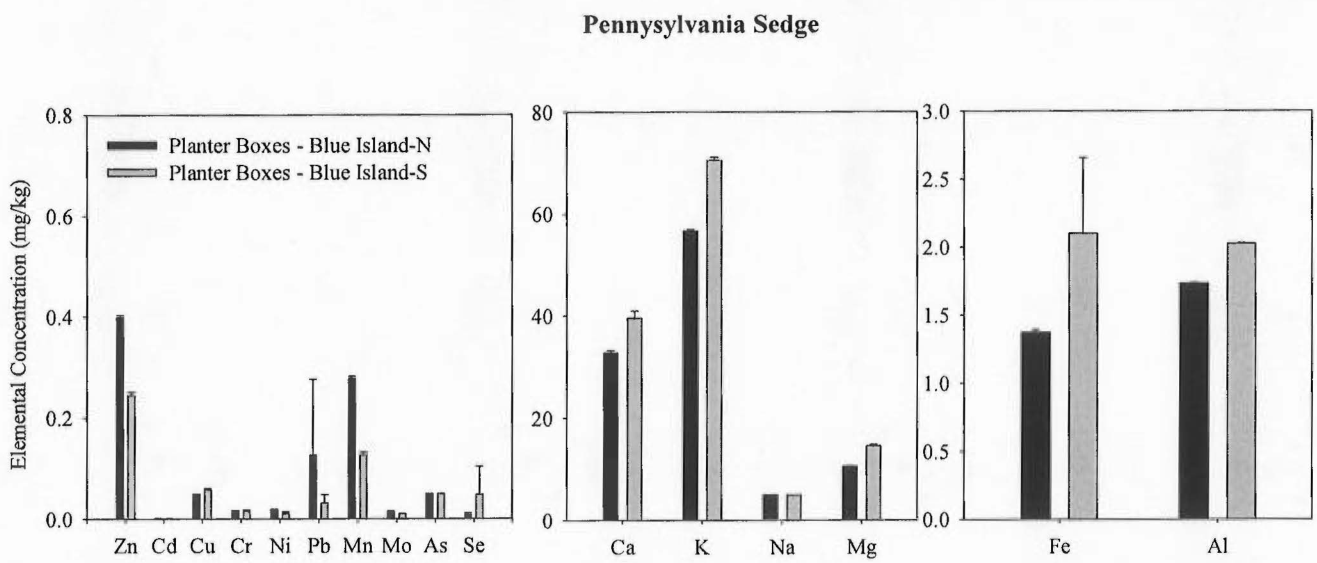


TABLE 5: HIGHEST CONCENTRATIONS OF ENVIRONMENTALLY IMPORTANT HEAVY METALS IN PLANTS GROWN IN VARIOUS BEST MANAGEMENT PRACTICES AT STREETSCAPE CORRIDOR COMPARED TO RANGE REPORTED IN TERRESTRIAL PLANTS

Elements	Highest Concentration in Plants Grown in BMPs mg/kg	Concentration Range Reported in Literature[1] mg/kg
As	< 0.05	0.02 – 7
Cd	< 0.02	0.1 – 2.4
Hg	–	0.005 – 0.02
Pb	< 0.1	1 – 13
Cr	< 0.05	0.2 – 1
Cu	< 0.1	4 – 15
Fe	< 6	1 – 140
Mn	< 0.7	15 – 100
Ni	< 0.05	0.1 – 1
Se	< 0.05	–
Zn	< 0.6	8 – 100

[1] Nagajyoti et al., (2010).

TABLE 6: POLLUTANTS OF CONCERN IN SURFACE RUNOFF AT THE LEAVITT-BLUE ISLAND CONTROL SITE AND THE PAULINA-BLUE ISLAND AND THROOP-CERMAK CORRIDOR OF STREETSCAPE PROJECT

	April 18, 2013				August 21 – 22, 2014				April 18, 2015				June 12, 2015			
	FF	MS	MS	FF	FF	MS	MS	FF	FF	MS	MS	FF	FF	MS	MS	FF
Analyte	L-BI	L-BI	P-BI	T-CE	L-BI	L-BI	P-BI	T-CE	L-BI	L-BI	P-BI	T-CE	L-BI	L-BI	P-BI	T-CE
pH	6.85	7.02	7.08	6.75	7.02	7.29	7.20	7.05	7.04	7.45	7.30	7.10	7.25	7.56	7.45	7.33
	µS/cm															
EC	231	117	145	289	165	125	146	182	245	156	187	292	189	126	152	204
	mg/L															
TS	2,509	255	458	2,007	2,208	208	512	2,496	3,245	706	1,906	2,555	2,709	666	2,054	2,712
BOD_5	17	5	7	9	12	5	5	9	9.00	5.00	6.00	11.00	7.00	4.00	5.00	10.00
COD	52	27	29	61	39	22	27	41	39.0	22.0	20.0	45.0	32.0	28.0	24.0	40.0
FOG	19.8	7.7	8.2	15.6	18.9	10.2	9.4	17.8	22.9	8.1	13.5	10.6	19.7	6.4	5.9	9.8
Cl	1,105	109	525	925	89	76	92	80	946	243	700	812	956	201	858	712
NH_3-N	2.44	0.28	0.78	1.99	1.04	0.19	0.38	0.78	0.97	0.83	0.69	1.04	2.56	2.16	1.78	3.01
NO_2+NO_3	1.87	0.56	0.99	1.91	2.56	0.45	1.01	3.06	1.28	0.34	1.03	2.04	1.56	0.27	0.72	1.44
TKN	6.58	1.89	2.01	4.95	5.86	1.89	2.81	4.88	3.21	2.01	2.53	3.99	6.02	5.61	4.38	6.56
TP	1.49	0.33	0.48	1.02	0.99	0.27	0.39	0.84	0.79	0.29	0.48	0.82	1.02	0.53	0.62	1.24
Ca	189.9	56.5	75.2	165.8	140.2	36.9	70.2	136.8	155	49.2	94.8	167	137	49.3	85.1	127
Mg	62.8	20.4	37.9	67.8	47.8	13.5	24.9	42.9	57.0	15.6	42.7	62.4	50.3	16.7	35.1	65.7
Na	1,088	89	457	877	78	82	87	74	901	151	453	987	945	130	676	723
K	27.6	18.9	21.2	29.9	40.3	10.8	15.6	36.7	36.0	2.30	15.6	27.8	31.2	4.39	14.61	25.6
Al	4.23	2.21	1.89	3.79	5.55	2.89	1.56	6.02	4.63	2.64	3.92	5.66	4.89	1.13	2.04	3.02
Fe	45.2	10.1	9.8	37.5	67.9	12.5	14.3	70.2	78.6	6.80	17.1	85.9	56.4	3.29	6.73	47.8
As	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cd	0.10	0.002	0.002	0.008	0.008	0.002	0.002	0.007	0.009	0.002	0.005	0.007	0.009	0.001	0.004	0.009

TABLE 6 (Continued): POLLUTANTS OF CONCERN IN SURFACE RUNOFF AT THE LEAVITT-BLUE ISLAND CONTROL SITE AND THE PAULINA-BLUE ISLAND AND THROOP-CERMAK CORRIDOR OF STREETSCAPE. ALL UNITS IN mg/L EXCEPT FOR pH AND ELECTRICAL CONDUCTIVITY

	April 18, 2013				August 21 – 22, 2014				April 18, 2015				June 12, 2015			
Analyte	FF L-BI	MS L-BI	MS P-BI	FF T-CE	FF L-BI	MS L-BI	MS P-BI	FF T-CE	FF L-BI	MS L-BI	MS P-BI	FF T-CE	FF L-BI	MS L-BI	MS P-BI	FF T-CE
	mg/L															
Cr	0.10	0.04	0.04	0.09	0.07	0.01	0.03	0.08	0.08	0.02	0.05	0.09	0.07	0.01	0.02	0.07
Cu	0.40	0.12	0.10	0.29	0.35	0.18	0.20	0.45	0.31	0.05	0.20	0.34	0.38	0.06	0.11	0.21
Mn	0.43	0.22	0.18	0.37	0.55	0.23	0.22	0.60	0.64	0.14	0.43	0.57	0.39	0.08	0.22	0.27
Mo	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ni	0.12	0.03	0.04	0.09	0.17	0.06	0.08	0.19	0.11	0.01	0.06	0.12	0.10	0.01	0.03	0.12
Pb	0.24	0.04	0.06	0.27	0.21	0.07	0.06	0.18	0.31	0.04	0.18	0.27	0.17	0.04	0.10	0.22
Se	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Zn	2.05	0.78	0.82	1.85	2.45	0.99	1.05	2.02	1.78	0.26	0.72	2.01	1.45	0.18	0.51	1.89

FF = first flush; MS = middle of storm; L-BI = Leavitt Blue Island control site; P-BI = Paulina Blue Island site; T-CE = Throop Cermak site.

be the result of natural variability in the precipitation coverage over the contributing watershed (sewershed) or error in the computed flow volumes. Due to the relatively large uncertainty in sewer flow meter data, rainfall-runoff coefficients were not utilized for the evaluation of BMP effectiveness.

The water level data for the Leavitt and Paulina sewer flow monitoring stations were analyzed to determine if the level data provided a relative indication of the effectiveness of the BMPs. Hydrographic comparison of the water level records (Figure 17 and Appendix 2) did not show any effect on sewer water level. A comparison of the annual frequency of surcharging also did not show any effect of BMPs. Spatial and temporal variability in storm volume and intensity and periods of missing stage records between the two sites complicated the analysis.

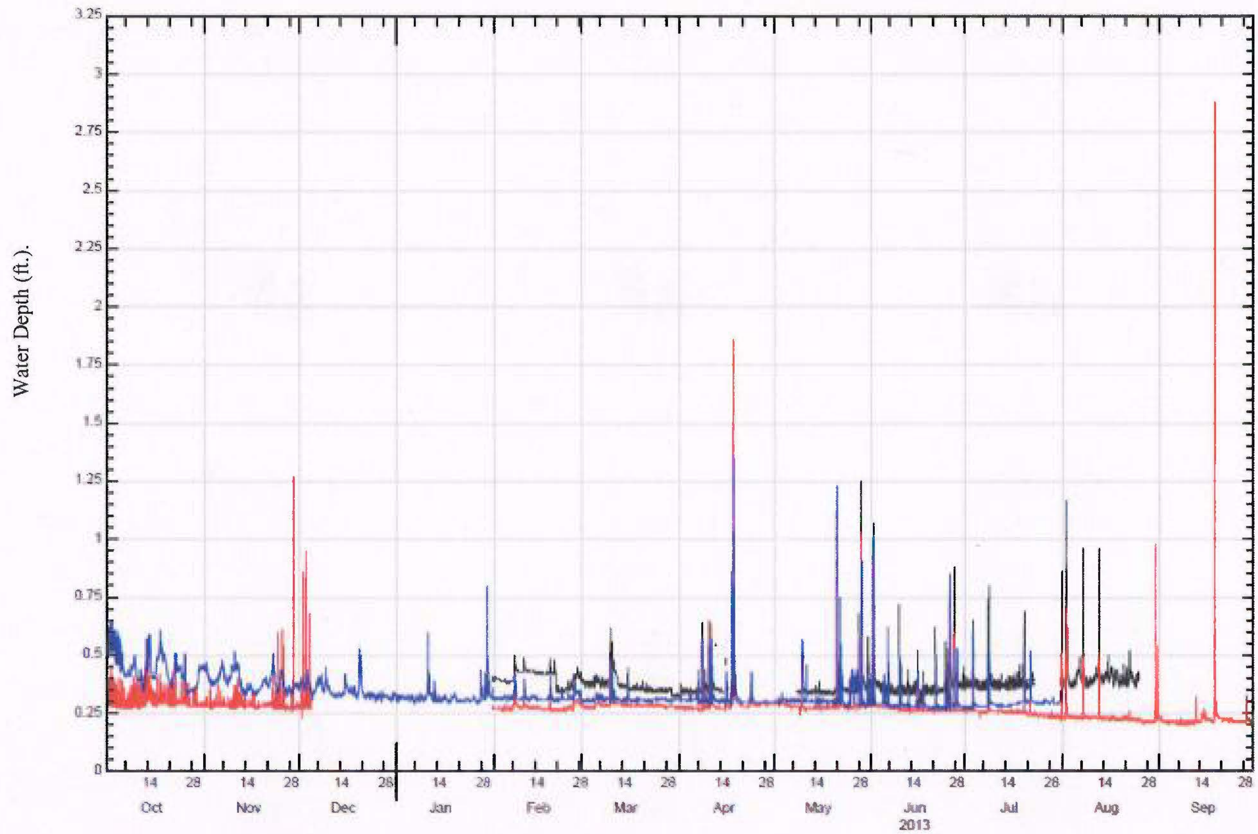
Catch Basins

Catch basin water levels were analyzed to determine the volume of water infiltrated by the permeable pavers. The catch basins at the Paulina Street (with permeable pavers) and Leavitt Street (without permeable pavers) locations (Figure 18) provided comparisons of pre- and post-BMP construction catch basin water levels from which stormwater runoff volumes and stormwater infiltrated were determined.

Figure 19 (A and B) shows sketch diagrams of roadways with and without permeable pavers and the general flow path of stormwater in both settings. Precipitation falling on the crowned pavement of the roadway at both sites initially drains towards the curb. At the Leavitt Street location (without permeable pavers), the water drains off the roadway to the curb and runs along the curb until it reaches the catch basin. Water levels in the catch basin increase until the level reaches the lateral drain pipe to the local combined sewer. Precipitation falling on the impermeable road pavement is routed quickly to the catch basin, and when the catch basin fills to the level of the lateral drain pipe, it overflows to the local combined sewer. At the Paulina Street location (with permeable pavers), the water drains off the roadway towards the curb, but before it reaches the curb, it flows over the section of permeable pavers. The interstitial space between pavers consists of gravel, and the stormwater infiltrates into the subsurface before it reaches the curb.

Figure 20 shows catch basin water levels at the Leavitt Street and Paulina Street locations for a 32-month period (August 2012 – April 2015). Changes in the catch basin water level hydrograph were used to calculate the volume of outflow from the catch basin to the local combined sewer for selected storm events. The catch basins in the study corridor were relatively consistent in dimension. The catch basin dimensions (diameter and area) and recorded catch basin water level data were used to compute the volume of stormwater that drained from the roadway to the catch basin (Table 7). The general differences in the recorded catch basin water level hydrographs between the Leavitt Street and Paulina Street locations are the result of the permeable pavers infiltrating stormwater runoff before it reached the curb at the Paulina Street location.

FIGURE 17: WATER LEVEL HYDROGRAPH FROM THE SEWER FLOW MONITORING STATION NEAR PAULINA STREET



Black Line = SMH-1-Blue Island Avenue near Leavitt Street
Red Line = SMH-2-Blue Island Avenue near Paulina Street
Blue Line = SMH3-Cermak Road near Throop Street

FIGURE 18: LOCATION OF CATCH BASINS IN THE SECTION OF BLUE ISLAND AVENUE BETWEEN OAKLEY AVENUE AND LEAVITT STREET

The Catch Basins

FIGURE 19: SKETCH DIAGRAMS OF ROADWAY WITH AND WITHOUT PERMEABLE PAVERS AND THE GENERAL FLOW PATH OF STORMWATER IN BOTH SETTINGS

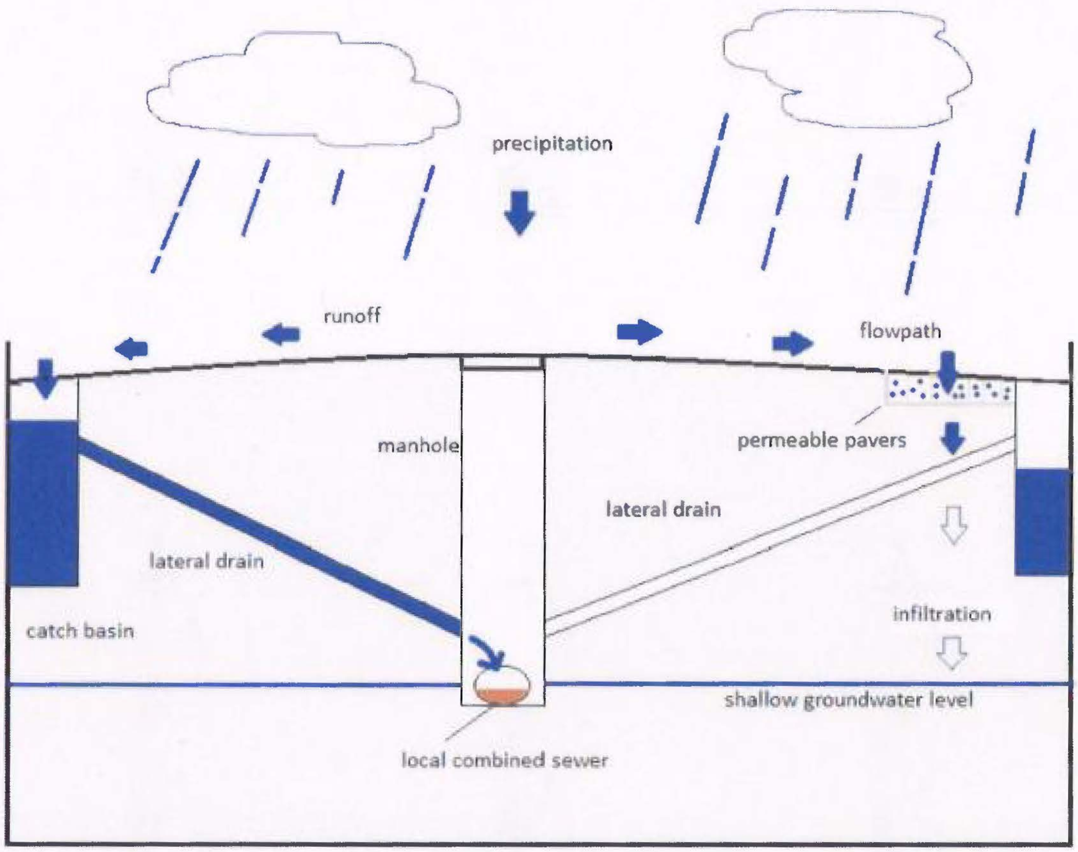
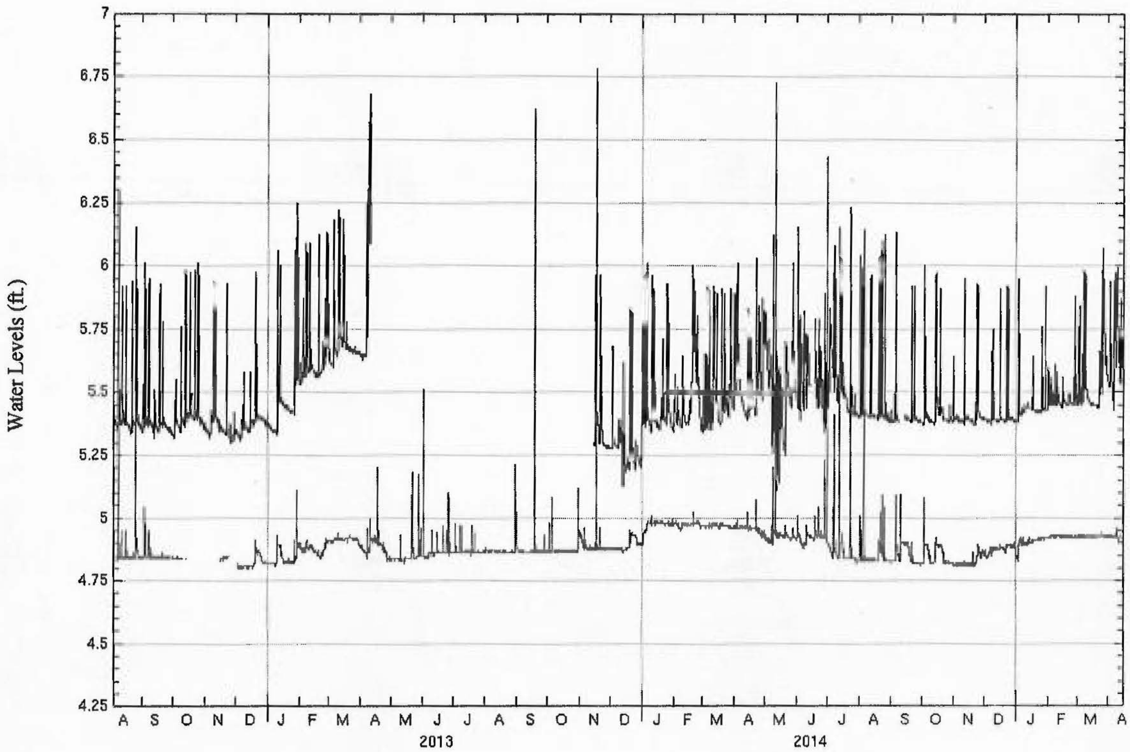


FIGURE 20: HYDROGRAPH OF CATCH BASIN WATER LEVELS AT THE LEAVITT STREET, WITHOUT PERMEABLE PAVERS, AND PAULINA STREET, WITH PERMEABLE PAVERS, LOCATIONS FOR THE PERIOD AUGUST 2012 - APRIL 2015



Black Line = SMH-1-Paulina Street
Red Line = SMH-2-Leavitt Street

TABLE 7: ESTIMATED TOTAL STORMWATER RUNOFF VOLUME INFILTRATED THROUGH THE PERMEABLE PAVERS BY WATER YEAR CALCULATED USING ILLINOIS STATE WATER SURVEY RAINGAGES NUMBERS 9 AND 10

Water Year	Total Annual Rainfall Gage No. 9	Total Annual Rainfall Gage No. 10	Average Annual Rainfall	Estimated Total Stormwater Catchment Area Volume	Estimated Stormwater Runoff Volume	Percent Of Rainfall Infiltrated
	---------- inches	----------	----------	---------- gallons	----------	%
2013	35.01	38.32	36.66	171,117	1065	99.4
2014	46.62	42.41	44.52	208,146	1477	99.3
2015	38.42	35.76	37.09	173,361	1989	98.9

Groundwater

Groundwater levels were analyzed to determine the role of shallow groundwater on the hydrology of the study area and the effectiveness of BMPs in infiltrating stormwater runoff to shallow groundwater. The five monitoring wells were all completed/screened in the "native" soil/fill material at depths of 8.7 - 19.5 ft below land surface. Figure 21 shows the groundwater hydrographs for a ten-month period (December 2012 - September 2013) from the five monitoring locations in the study corridor. Each of the shallow monitoring wells shows the same general trends and fluctuations of shallow groundwater levels.

Groundwater levels at the five monitoring wells were analyzed in relation to sewer levels to determine if shallow groundwater drained to the local combined sewers. While not a formal evaluation of sewer infiltration, the groundwater levels in the study reach were higher at times than the water in the sewers (Figure 22). However, the sewer flow data did not show evidence for significant infiltration of groundwater. Shallow groundwater in the study corridor likely drains towards the closest reach of the Chicago Sanitary and Ship Canal/South Branch of the Chicago River/Bubbly Creek that interconnects to form the Chicago Area Waterway System.

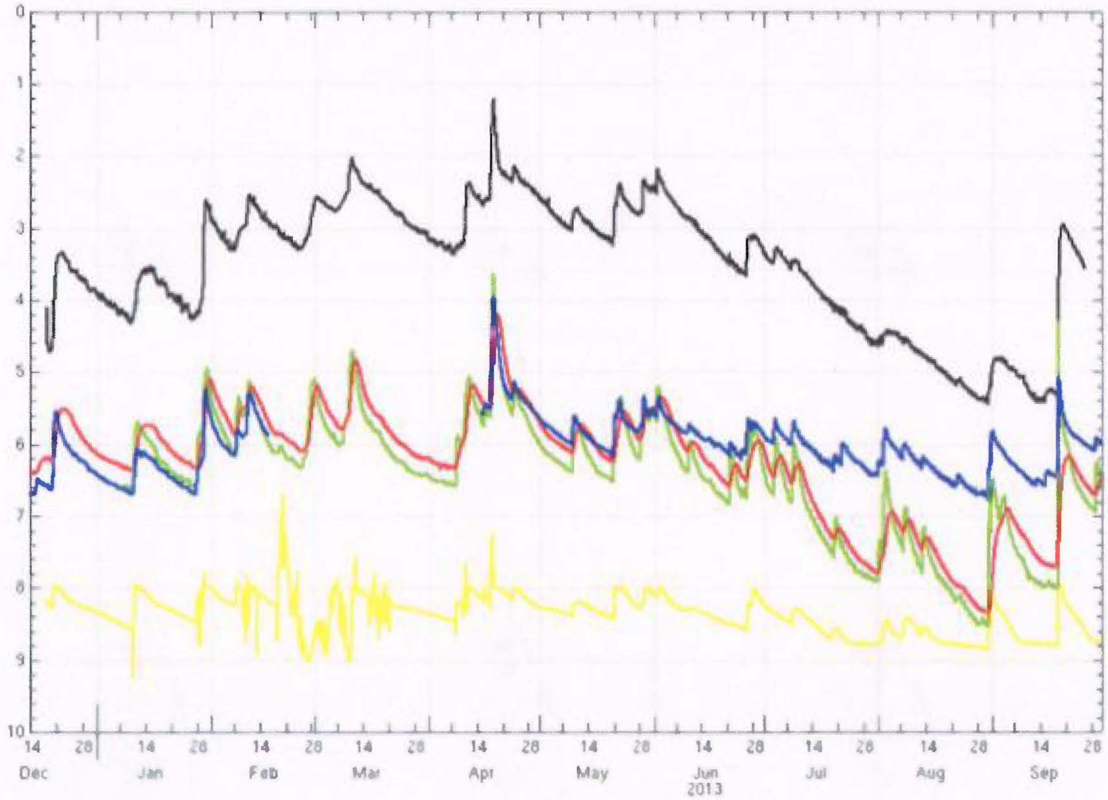
The hydraulic conductivity of the native soil/fill material was evaluated at the bioswale monitoring well (PZ4-CC). Seven slug tests were conducted on the monitoring well using a mechanical slug to produce an instantaneous change in head. The slug tests were conducted using standard USGS protocols and quality assurance/quality control practices.

The results of the slug test were presented in a USGS memorandum dated May 1, 2015 (written communication, Patrick C. Mills) as follows:

> "The fine-grained sand fill deposits of the study area, including the test location, are unconfined. In most area locations, these or similar deposits are present from about 9 ft below land surface to within 4 ft or less of land surface. Sandy silt to silt deposits generally overlie the fine-sand deposits. Within the infiltration basins, such as the one test basin described, the base of the basin is 1 - 2 ft below the existing land surface. The upper 1.5 ft or so of the basins consist of top soil and silt and are planted with vegetation that can survive periodic submergence in water and elevated saline levels from road salt. About 1 ft of gravel and cobbles up to 2 in. in diameter underlie the top soil and overlie the area's sandy silt and silt fill. The fine-sand fill is underlain by plastic clay, which for purposes of the test analysis, is considered to represent the base of the aquifer."

The slug test results show an average hydraulic conductivity of the native soil/fill material of 0.20 ft/day. The hydraulic conductivity value and the water level data from the bioswale monitoring well show that the bioswale functions are designed to infiltrate stormwater runoff from the roadway to shallow groundwater (Figure 23). Fluctuation in the level of shallow groundwater in response to storm events shows the bioswale filling with stormwater, but only on one occasion, reaching the level of the land surface in the vicinity of the monitoring well.

FIGURE 21: GROUNDWATER HYDROGRAPHS FOR THE PERIOD DECEMBER 2012 - SEPTEMBER 2013 FROM THE FIVE MONITORING WELLS IN THE STUDY



Black Line = Bioswale
Yellow Line = Leavitt
Green Line = Juarez High School, Shallow
Red Line = Juarez High School, Deep
Blue Line = Canalport

FIGURE 22: SCHEMATIC CROSS-SECTION OF SHALLOW GROUNDWATER LEVELS, WATER LEVEL IN THE LOCAL COMBINED SEWERS AND WATER LEVEL IN BUBBLY CREEK

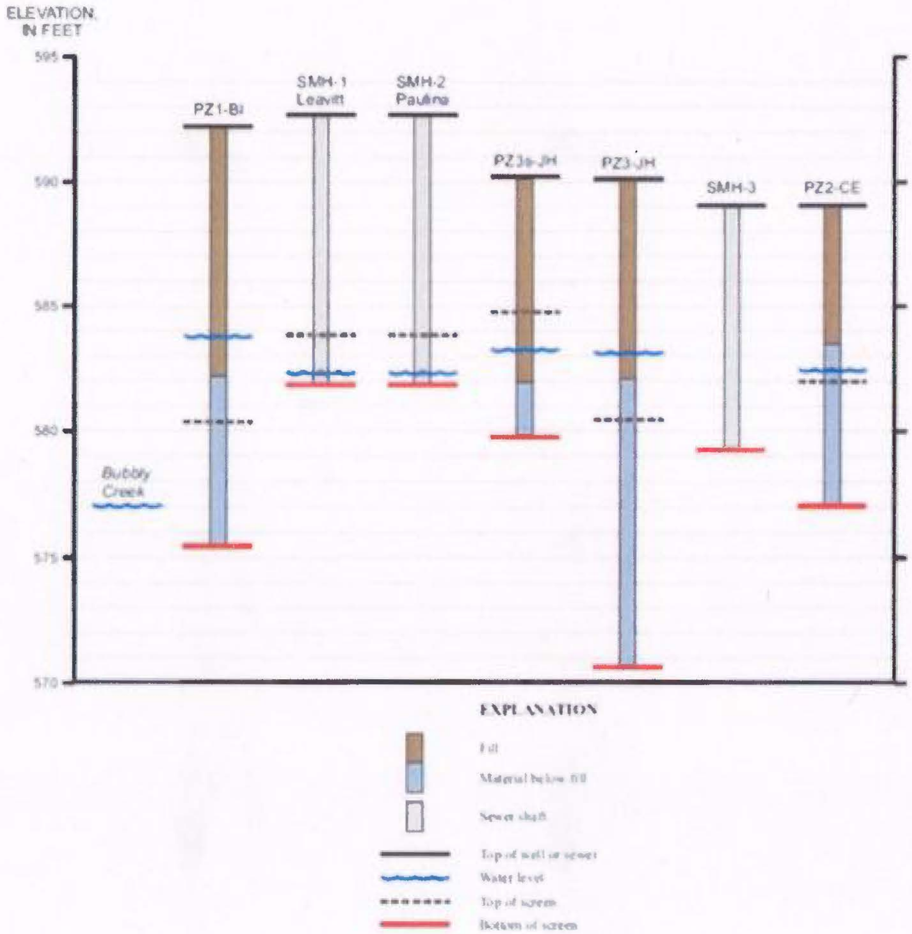
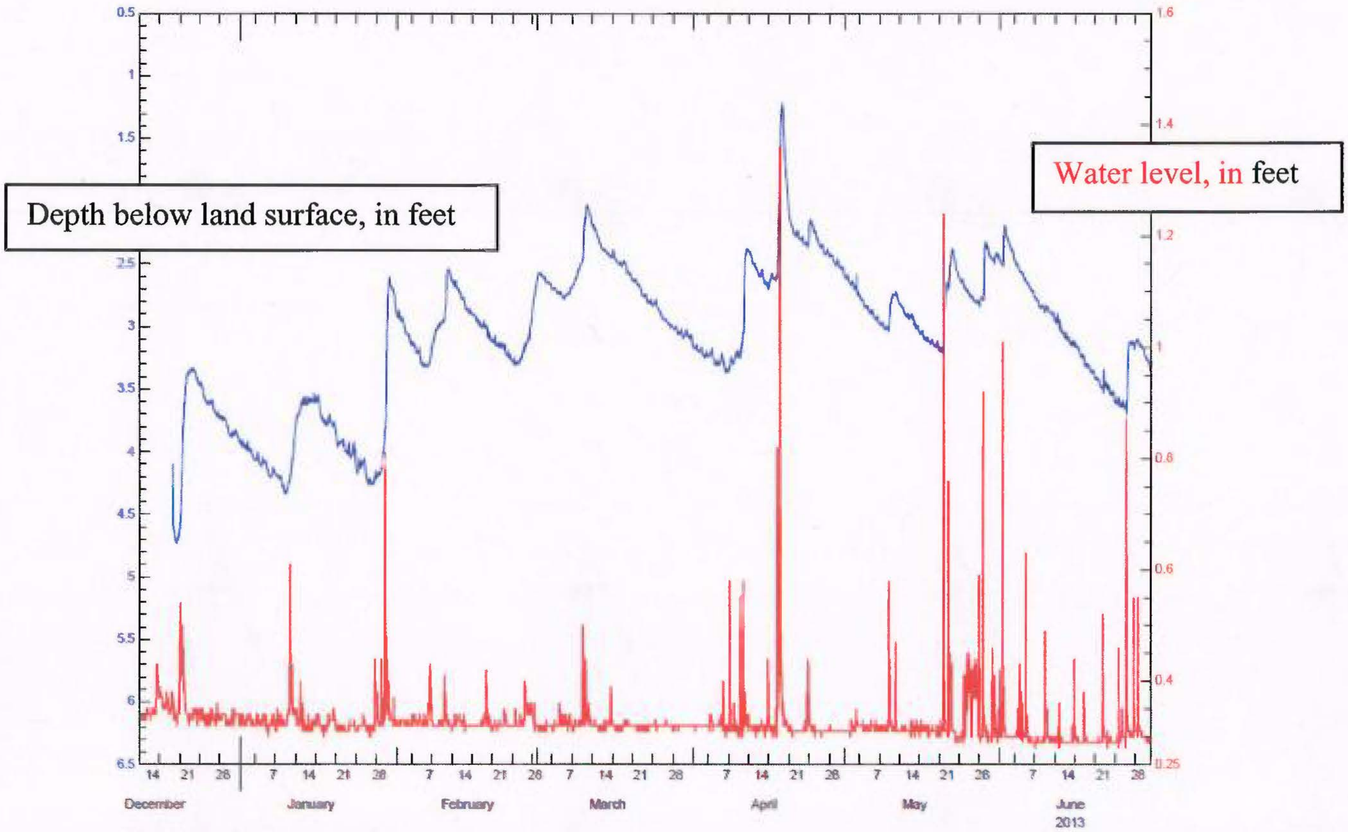


FIGURE 23: GROUNDWATER HYDROGRAPH FROM THE BIOSWALE MONITORING WELL AND WATER LEVEL IN THE LOCAL COMBINED SEWER SHOWING FLUCTUATIONS IN THE LEVEL OF SHALLOW GROUNDWATER IN RESPONSE TO STORM EVENTS



Blue Line = Bioswale
Red Line = Local Combined Sewer

EFFECTIVENESS OF URBAN STORMWATER BEST MANAGEMENT PRACTICES

The monitoring data show that the urban stormwater BMPs (permeable pavers and bioswale) in the Cermak Road-Blue Island Avenue Sustainable Streetscapes corridor function to infiltrate stormwater and reduce the stormwater loading of the local combined sewer system. More detailed analysis of the monitoring data provides a quantified measure of the effectiveness of the permeable paver and bioswale BMPs. These results can be used for cost/benefit analysis, economic evaluations, etc. For example, the infiltration of stormwater has the added benefit of being a subsequent equal reduction in stormwater that would have to be treated at the wastewater treatment plant. The District has calculated costs per gallon for wastewater treatment and can readily compute the savings for a set volume of stormwater runoff that was infiltrated by BMP instead of treated by the wastewater treatment plant.

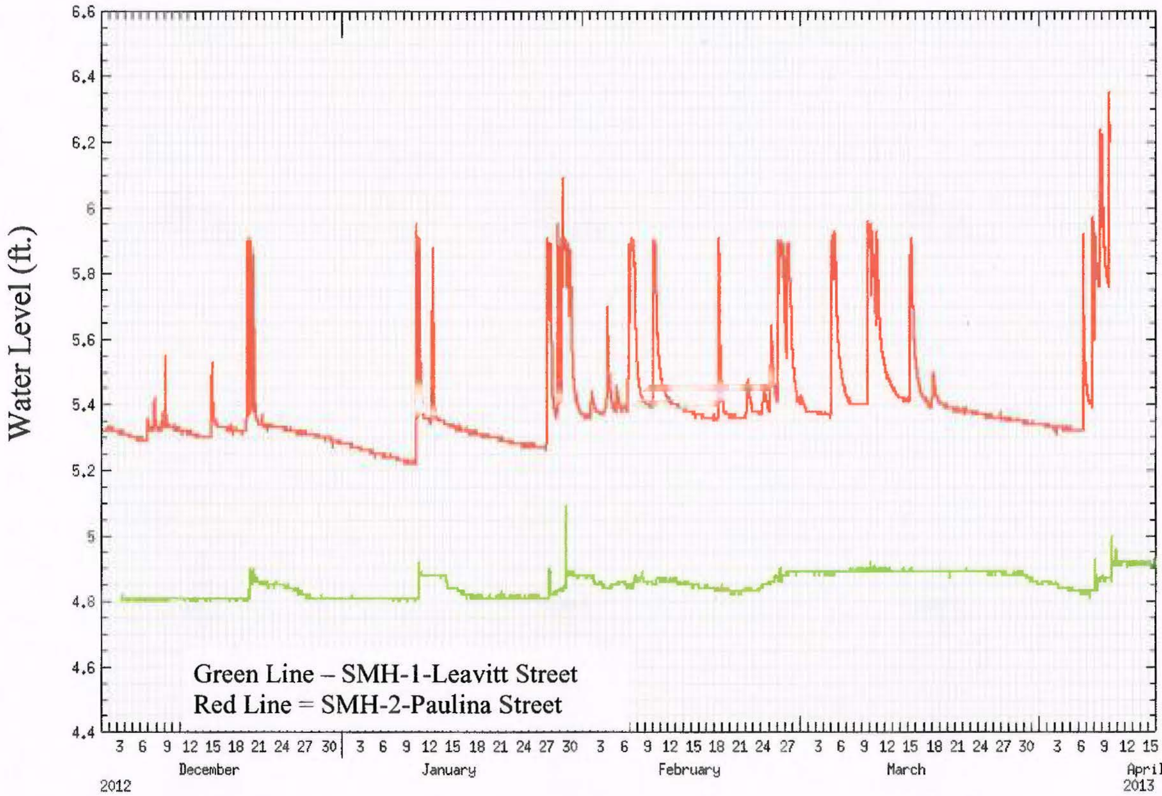
Permeable Pavers and Infiltration Boxes

The stormwater volume calculations at the Leavitt Street and Paulina Street locations were used to estimate the reduction in stormwater entering the local combined sewer system per mile of roadway. At the Leavitt Street location, there is approximately 735 ft (approximately one-seventh of a mile) of Blue Island Avenue between Oakley Avenue on the west and Leavitt Street on the east. Figure 18 shows that three catch basins are located (approximately equally spaced) on each side of Blue Island Avenue in this section of roadway. The stormwater runoff volume for a specific storm event that was captured by the monitored Leavitt Street catch basin was used to estimate the total stormwater runoff that was captured by the six catch basins in the section of Blue Island Avenue between Oakley Avenue and Leavitt Street for that same storm event. The calculations assumed a uniform and equal distribution of rainfall over the Oakley Avenue - Leavitt Street section of roadway. These same calculations can be used to estimate the stormwater runoff captured over larger scale sections of the study area.

Analysis of the catch basin data over time shows variability in the water level hydrographs (Figure 24). The Leavitt catch basin water levels respond to almost every rainfall, which is expected with the impermeable surface of the roadway and the relatively short flow paths for precipitation from road surface to catch basin. The Paulina Street catch basin, after permeable pavers were installed, produces a hydrograph that shows, in some cases, no response (change in water surface elevation within the catch basin) to rainfall or much less response to rainfall. This result is expected as precipitation infiltrates to the subsurface through the section of permeable pavers and never makes it to the catch basin. The Paulina Street catch basin hydrograph shows some "dampened" response to rainfall, which may be the result of either intense rainfall exceeding the infiltration rate of the permeable pavers, long duration storm events saturating the subsurface, or a reduction in the permeability of the paver sections over time as the interstitial spaces become clogged with road debris.

The Paulina catch basin water level data were also used to estimate the total stormwater runoff that was captured by the permeable pavers during the 2012 - 2015 water years. The

FIGURE 24: WATER LEVEL HYDROGRAPHS FOR THE LEAVITT STREET AND PAULINA STREET CATCH BASINS FOR THE PERIOD DECEMBER 2012 TO APRIL 2013



catchment area for the Paulina catch basin runs along Blue Island Avenue and is approximately 250 feet in length and 30 ft in width (half of the width of the crowned roadway). This results in a rectangular catch basin catchment area of approximately 7,500 square ft (Figure 25).

The estimated total stormwater runoff for the Paulina catch basin for 2013 - 2015 water years was determined by multiplying the average (ISWS raingages # 9 and 10) annual rainfall (in ft) by the catchment area (in square ft). This estimate assumes that 100 percent of the runoff drains from the roadway and then infiltrates through the permeable pavers (Table 7). The Paulina catch basin water level data show that this assumption is not true; however; it provides an estimate of the upper boundary of effectiveness for the permeable paver BMP. Recognized limits on the infiltration capacity and storms exceeding that capacity result in stormwater not infiltrating through the permeable pavers and draining to the catch basin. The Paulina catch basin water level data were used to compute the volume of stormwater runoff that drained into the catch basin and then flowed through the lateral drain to the local combined sewer (Table 7). The volume that flowed to the local combined sewer was subtracted from the estimated total stormwater runoff for each of the 2013 - 2015 water years. This calculation represents an estimate of the total stormwater runoff that infiltrated through the permeable pavers. During the 2015 water year, the Paulina catch basin recorded gage height levels continuously from October 1, 2014, to September 30, 2015, except for a period of missing records from April 22 - June 12, 2015.

The results shown in Table 7 exceed the stated project goals of infiltrating at least 80 percent of the rainfall falling on the catchment. The methodology assumes that all rainfall falling on the catchment either infiltrates through the permeable pavers or returns to the local sewer through the catch basin lateral drain. The assumption ignores the direct evaporation of rainfall from the pavement, which may be a significant volume during smaller storms in warmer summer temperatures. The catch basin data showed a slight decrease in the percent rainfall infiltrating over time. This may be the result of clogging of the interstitial spaces between pavers. It should be noted that the pavers in the Paulina section were installed in 2012 and then removed and reset in 2013 due to differential settling. This likely resulted in high overall infiltration after re-installation of the pavers.

Bioswale

Analysis of the bioswale monitoring well water level data in relation to the elevation of key drainage components of the bioswale, such as the elevation of the underdrain connection to the catch basin, shows that during the period from December 18, 2012, to April 2015, the water level in the bioswale never reached the underdrain elevation (Figure 26). This indicates that the stormwater runoff entering the bioswale infiltrated to shallow groundwater and did not return to the local combined sewer by way of the underdrain.

The bioswale functions as a linear stormwater storage feature that is approximately 2,400 ft in length (from near Ashland Avenue east along Cermak Road to just past Racine Avenue). The sections of bioswale between each cross street are hydraulically connected to the adjacent section of bioswale by pipes that run beneath the cross streets. Engineering drawings of the bioswale cross section (Figure 27) show that the bioswale has two adjacent rectangular

FIGURE 25: GOOGLE EARTH IMAGE SHOWING APPROXIMATE CATCH BASIN CATCHMENT AREA FOR THE PAULINA CATCH BASIN

FIGURE 26: SCHEMATIC CROSS SECTION OF CERMAK ROAD IN THE VICINITY OF THE BIOSWALE WITH KEY DRAINAGE ELEVATIONS NOTED

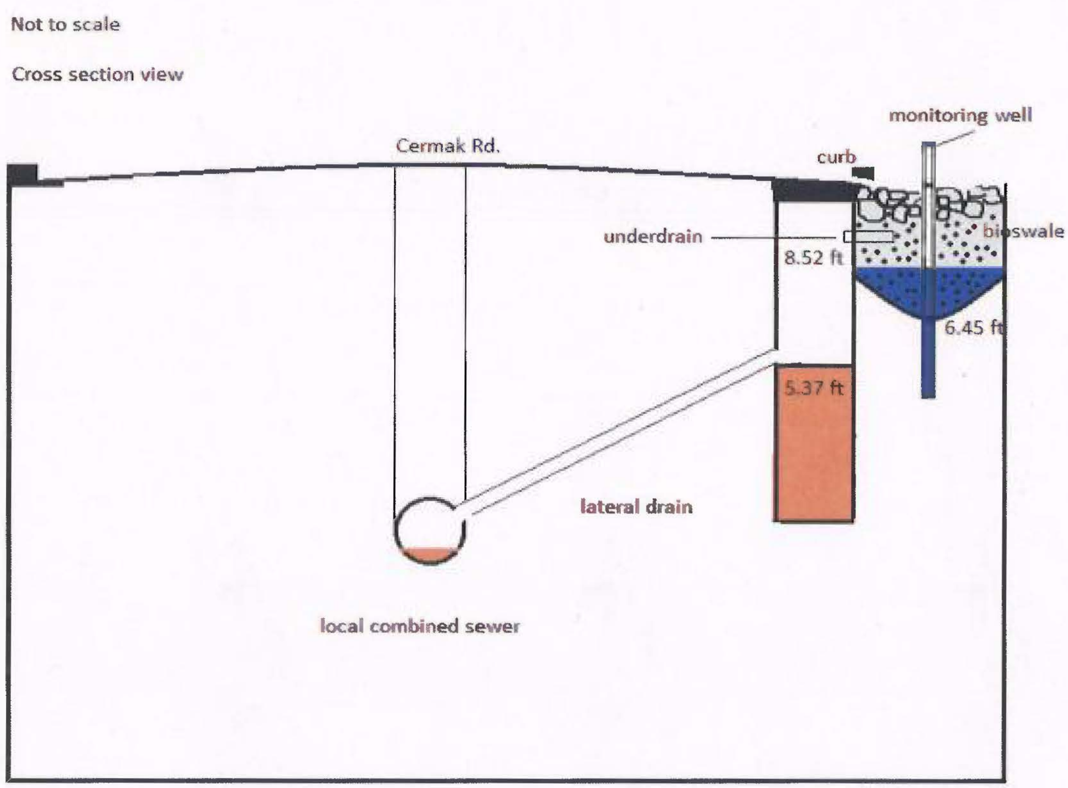
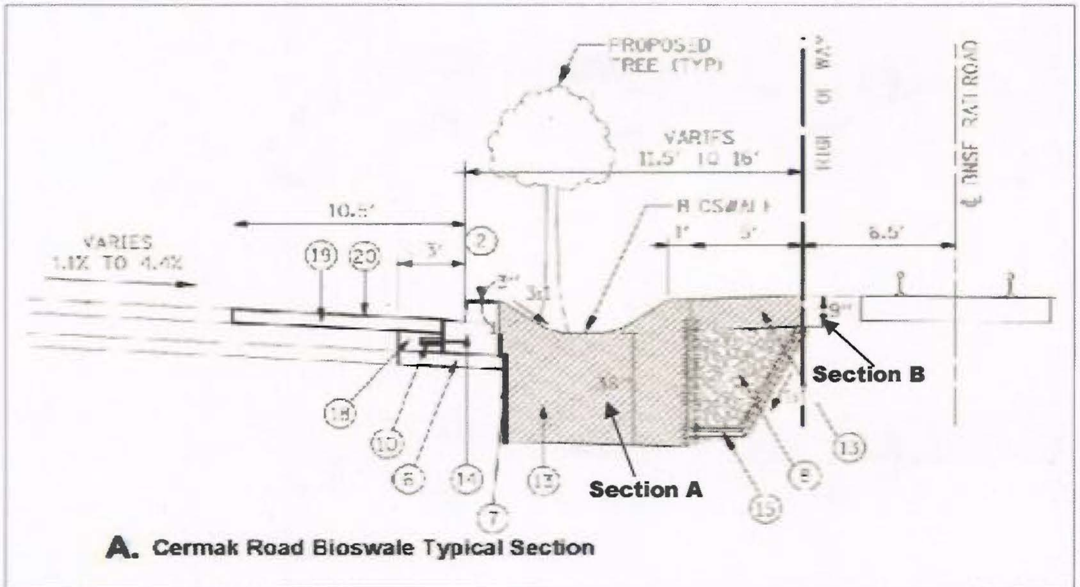


FIGURE 27: CROSS-SECTION DRAWING OF BIOSWALE (A) AND PHOTOGRAPH OF BIOSWALE (B)



A. Cermak Road Bioswale Typical Section

B.

sections (labeled A and B). A total storage volume was calculated based upon the dimensions of the bioswale sections A and B and the full length of the bioswale from Ashland to Racine. The storage volume of each section (A and B) of the bioswale was estimated based upon the design specifications and porosity of the bioswale material and best engineering judgment.

Volume bioswale section A = (2,400 ft) (8.4 ft) (3.0 ft) = 60,480 cubic ft assuming 20 percent porosity results in approximately 12,096 cubic ft

Volume bioswale section B = (2,400 ft) (5.0 ft) (1.6 ft) = 19,200 cubic ft assuming 30 percent porosity results in approximately 5,760 cubic ft

Total available storage volume bioswale (sections A and B) = 17,856 cubic ft = 133,572 gallons

This calculation represents the total available stormwater storage volume in the bioswale. The bioswale monitoring well water level data were then used to estimate the total volume of stormwater diverted from the roadway along the full length of the bioswale for selected storm events. The change in water level in the bioswale monitoring well for a selected storm event is a direct function of the stormwater runoff from the roadway into the bioswale.

The catchment area for the bioswale runs approximately 2,670 ft along Cermak Road, from the intersection with Ashland Avenue east to approximately Racine Avenue, where the width of the bioswale pinches out next to railroad tracks (Figure 28).

The roadway is 60 ft wide and crowned, so the catchment area is approximately 80,100 square ft. (2,670 ft x 30 ft). The total volume of stormwater runoff captured by the bioswale for the 2014 water year (October 1, 2013 - September 30, 2014) was estimated using the catchment area for the entire bioswale and the rainfall data from the ISWS Cook County Precipitation Network Gages numbers 9 and 10. The average of the annual total precipitation for Gages 9 and 10 for the 2014 water year is 44.52 inches (3.71 ft). Assuming all of the precipitation falling on the catchment area drained to the bioswale, the total volume captured by the bioswale for the 2014 water year is approximately 297,171 cubic ft or 2,222,993 gallons (Table 8). Based upon the underdrain elevation and the maximum water level in the bioswale monitoring well, this volume of stormwater was infiltrated to shallow groundwater and did not flow into the local combined sewer and thus did not flow to the wastewater treatment plant. These results indicate that almost 100 percent of runoff water infiltrates into the bioswale.

However, field observations have shown that during one intense storm event, stormwater was observed flowing out of one of the curb inlets to the bioswale. This was the result of debris and sediments in the immediate area of the curb cutout restricting the lateral flow of water within the bioswale, causing water to move alongside the roadway to the catch basin. This was resolved when sediments and debris were cleaned. Field observations have also shown stormwater runoff from the roadway bypassing a sediment-clogged curb inlet to the bioswale. This results in the stormwater runoff flowing directly into the catch basin and the local combined sewer. These field observations reinforce the need for periodic maintenance of the bioswale BMP.

FIGURE 28: APPROXIMATE CATCHMENT AREA FOR THE BIOSWALE

2,670 ft Catchment Area of Bioswale

TABLE 8: ESTIMATED TOTAL STORMWATER RUNOFF VOLUME INFILTRATED THROUGH THE BIOSWALE BY WATER YEAR CALCULATED USING ILLINOIS STATE WATER SURVEY RAINGAGES NUMBERS 9 AND 10

Water Year	Total Annual Rainfall Gage No. 9 (in.)	Total Annual Rainfall Gage No. 10 (in.)	Average Annual Rainfall (in.)	Estimated Stormwater Runoff Volume (Gallons)
2012	32.36	33.96	33.16	1,655,753
2013	35.01	38.32	36.66	1,830,528
2014	46.62	42.41	44.52	2,222,993
2015	38.42	35.76	37.09	1,851,496

SUMMARY

Hydrologic data were collected in the CDOT Blue Island - Cermak Road Sustainable Streetscapes Corridor between August 2009 and September 2015. The data were used to evaluate the effectiveness of urban stormwater BMPs in the project (permeable pavers and bioswales).

Field observations and analysis of catch basin water level data show that the BMP's pavers do function to infiltrate stormwater runoff and reduce the stormwater load to the local combined sewer system. The effectiveness of the permeable pavers to infiltrate stormwater runoff varies depending on the characteristics of the storm event (rainfall intensity and duration) and also varies with the frequency and level of BMP maintenance.

Permeability data from ring infiltrometer tests show a reduction in the permeability of the soil in the bioswale over time. Field observations document the need for periodic maintenance of curb cutouts in the roadway adjacent to the bioswale. Sediment build-up in the curb cutout has been observed on one occasion in one section of the bioswale to effectively isolate the bioswale from the curb drainage and direct the stormwater runoff directly to the curbside catch basin instead of the bioswale. After the sediment build up was cleaned, there was no overflow from the bioswale to the catch basin observed during the study period.

Soil chemistry and plant tissue analysis indicate that the planters and bioswales do function to remove pollutant loads from stormwater runoff.

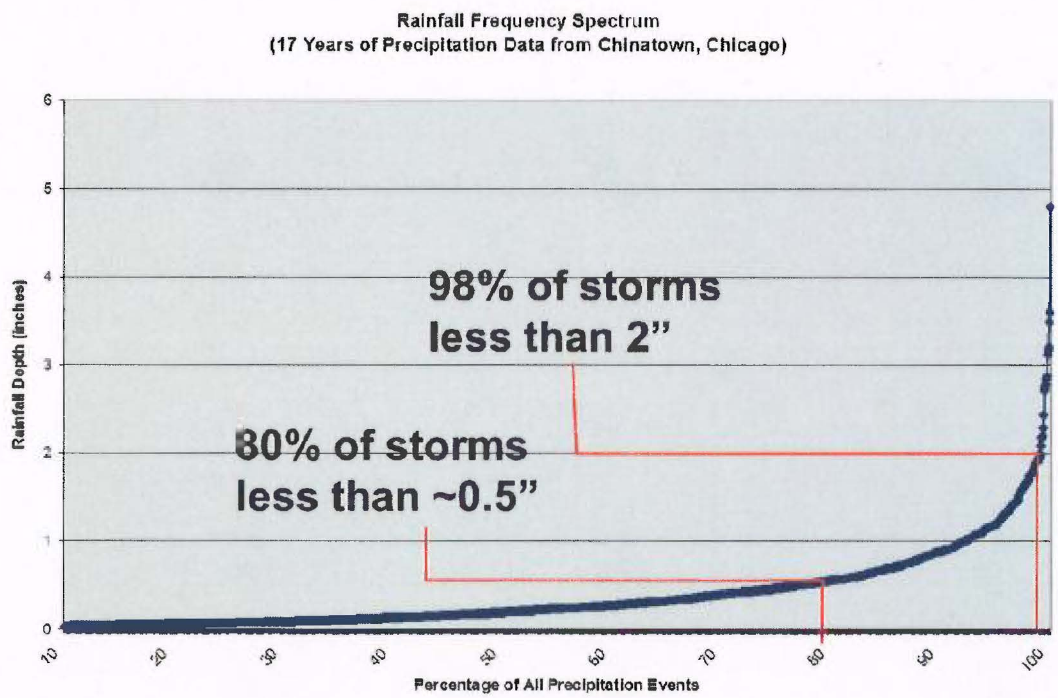
Field observations and analysis of shallow groundwater well data show that the bioswale functions to infiltrate stormwater runoff and reduce the stormwater load to the local combined sewer system. During the period of study, water level data from the monitoring well in the bioswale showed that stormwater runoff entering the bioswale did not return to the local sewer by way of the underdrain.

The BMPs were designed to infiltrate 80 percent of rainfall for a 2-year 30-minute storm, which is equivalent to approximately 1.12 inches of rainfall. However, during the study period, the area received rainfall at much higher intensities, and still the BMPs were able to infiltrate almost 100 percent of runoff.

Figure 29 indicates that 80 percent of the storms in the area are <0.5 inches and 98 percent are <2 inches. Thus, it may be concluded that the BMPs installed at the Streetscape corridor in the study area were able to infiltrate significantly large volumes of water which would have otherwise ended up in the combined sewers.

The monitoring data from this project, along with other early pilot projects implemented by the CDOT, including the original green alley pilot project in 2006 and the Maxwell Street Market project in 2008, have led to the implementation of over 200 capital transportation projects integrating stormwater best management projects by the CDOT. The results of this project showed that the monitoring approach and the effectiveness of the BMPs were able to

FIGURE 29: RAINFALL FREQUENCY SPECTRUM OF THE CHICAGO AREA



demonstrate how a layering of stormwater BMPs with traditional sewer systems can greatly increase the capacity of the existing system while providing a wide range of synergistic benefits at a reasonable cost.

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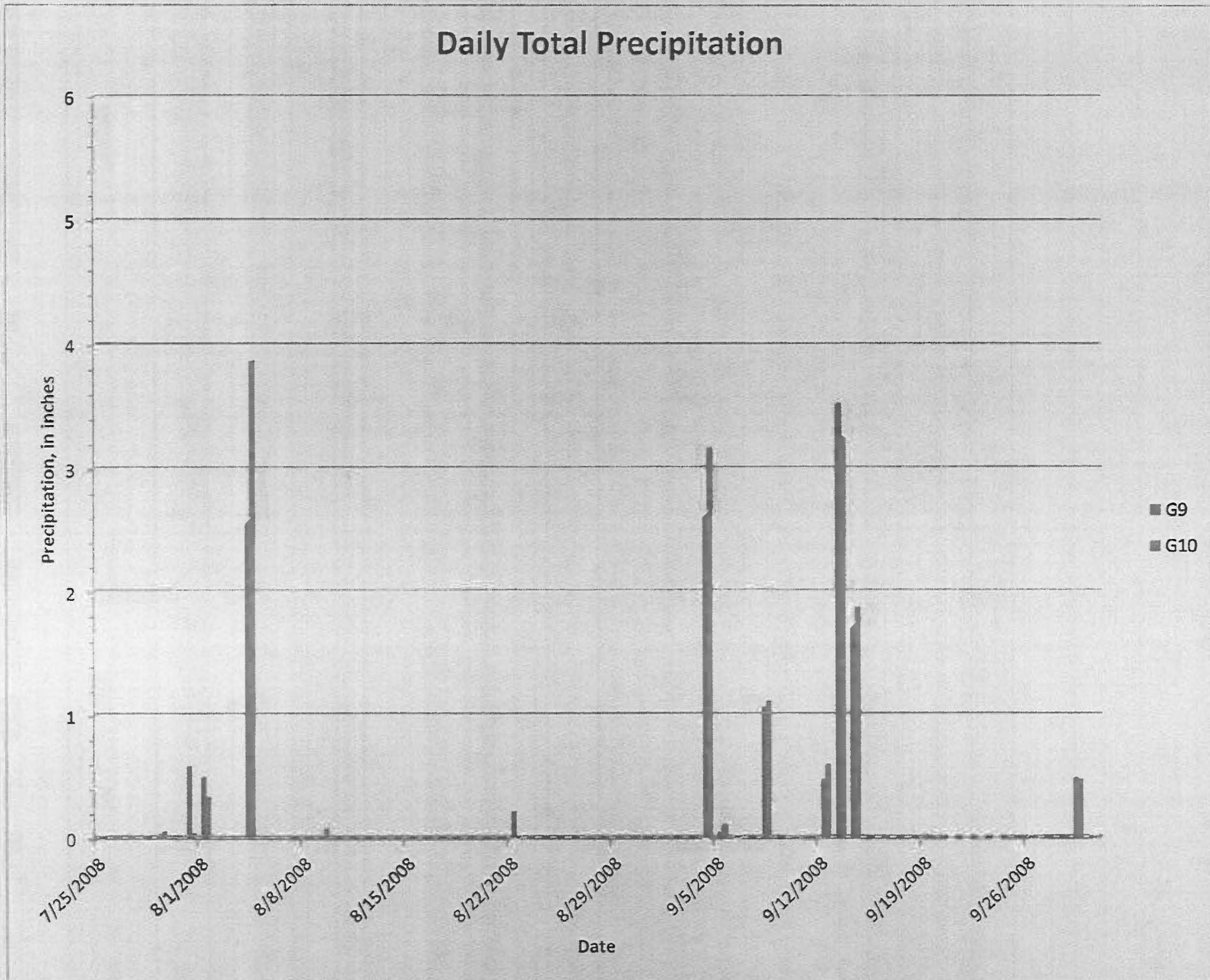
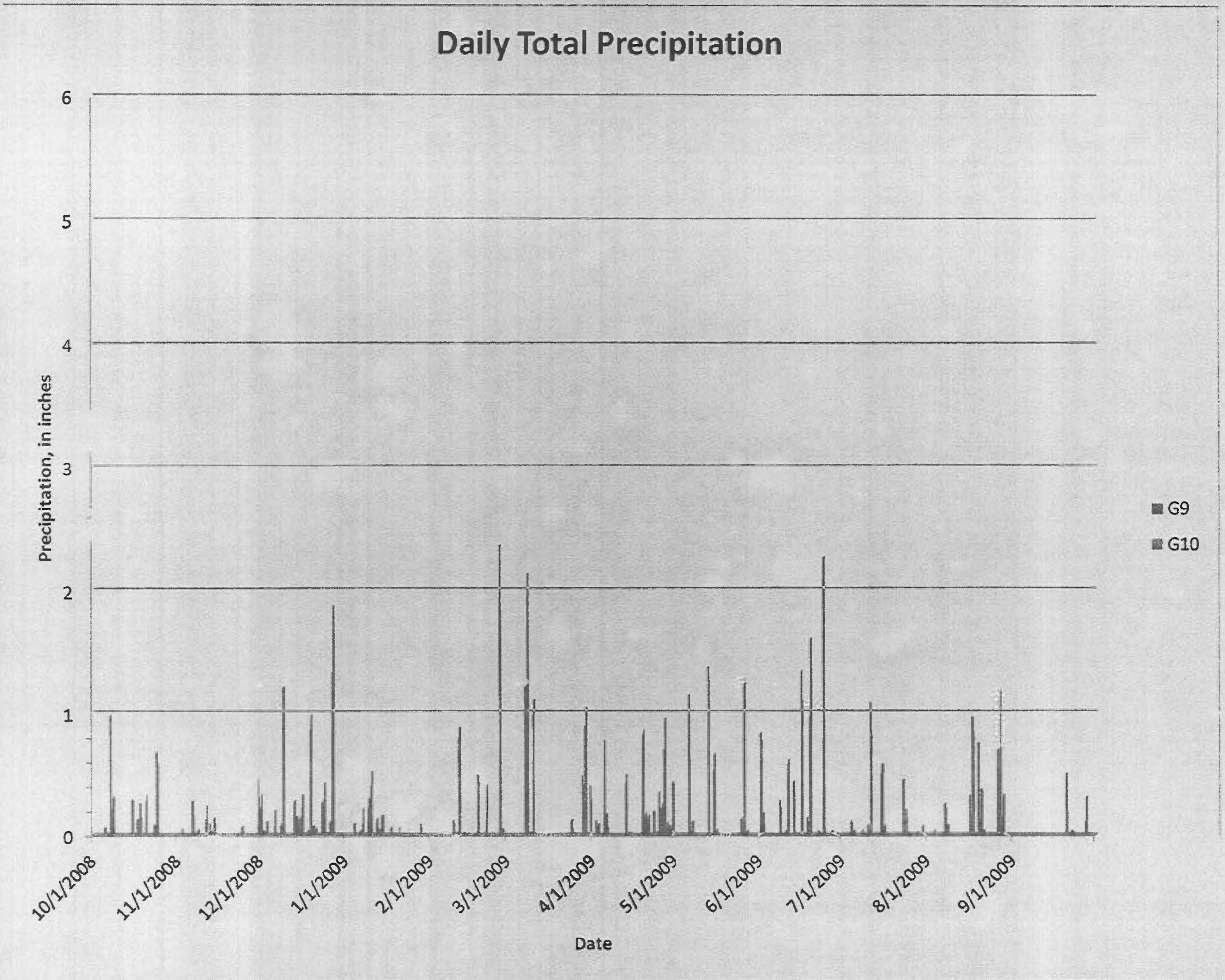
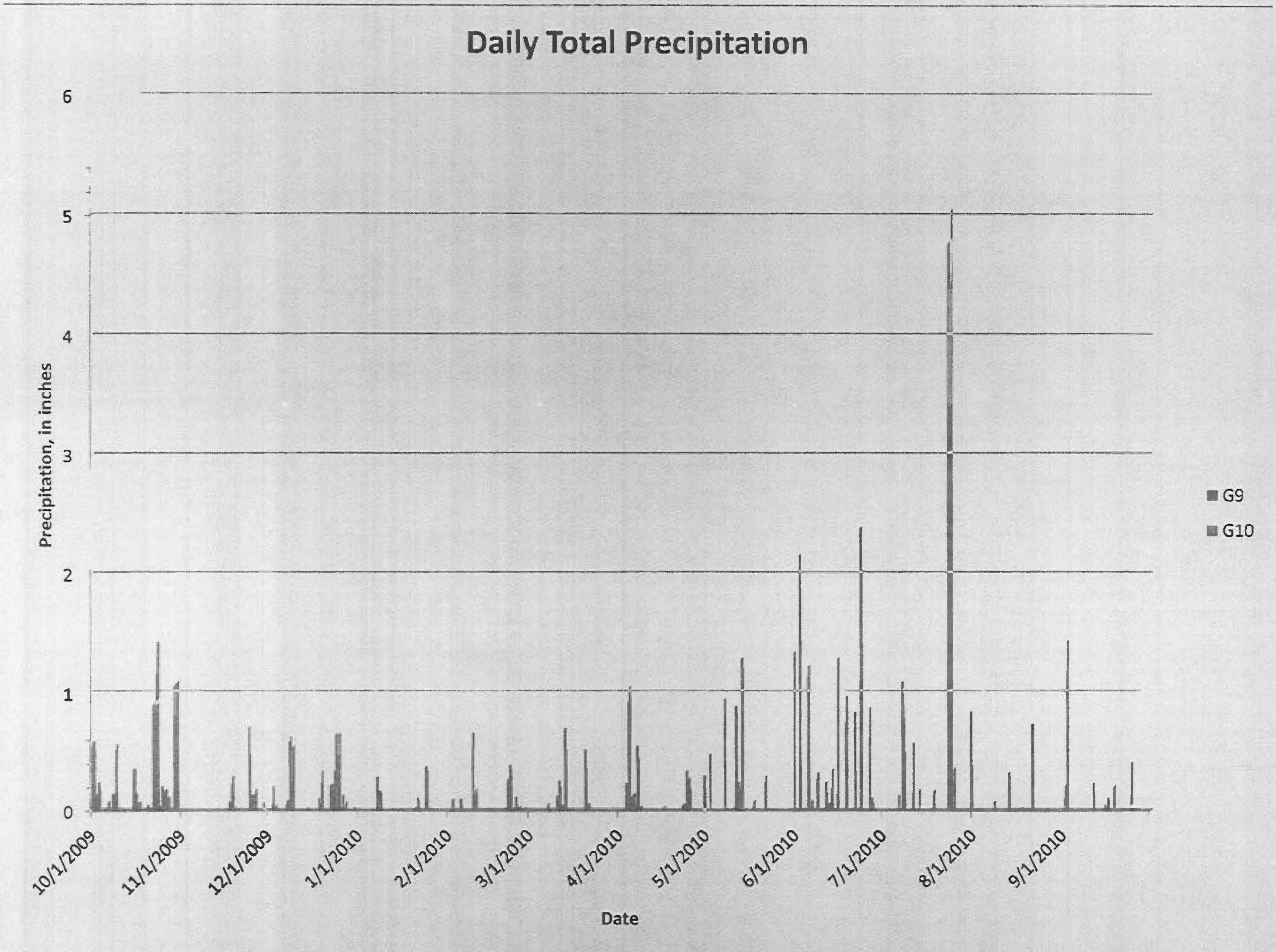
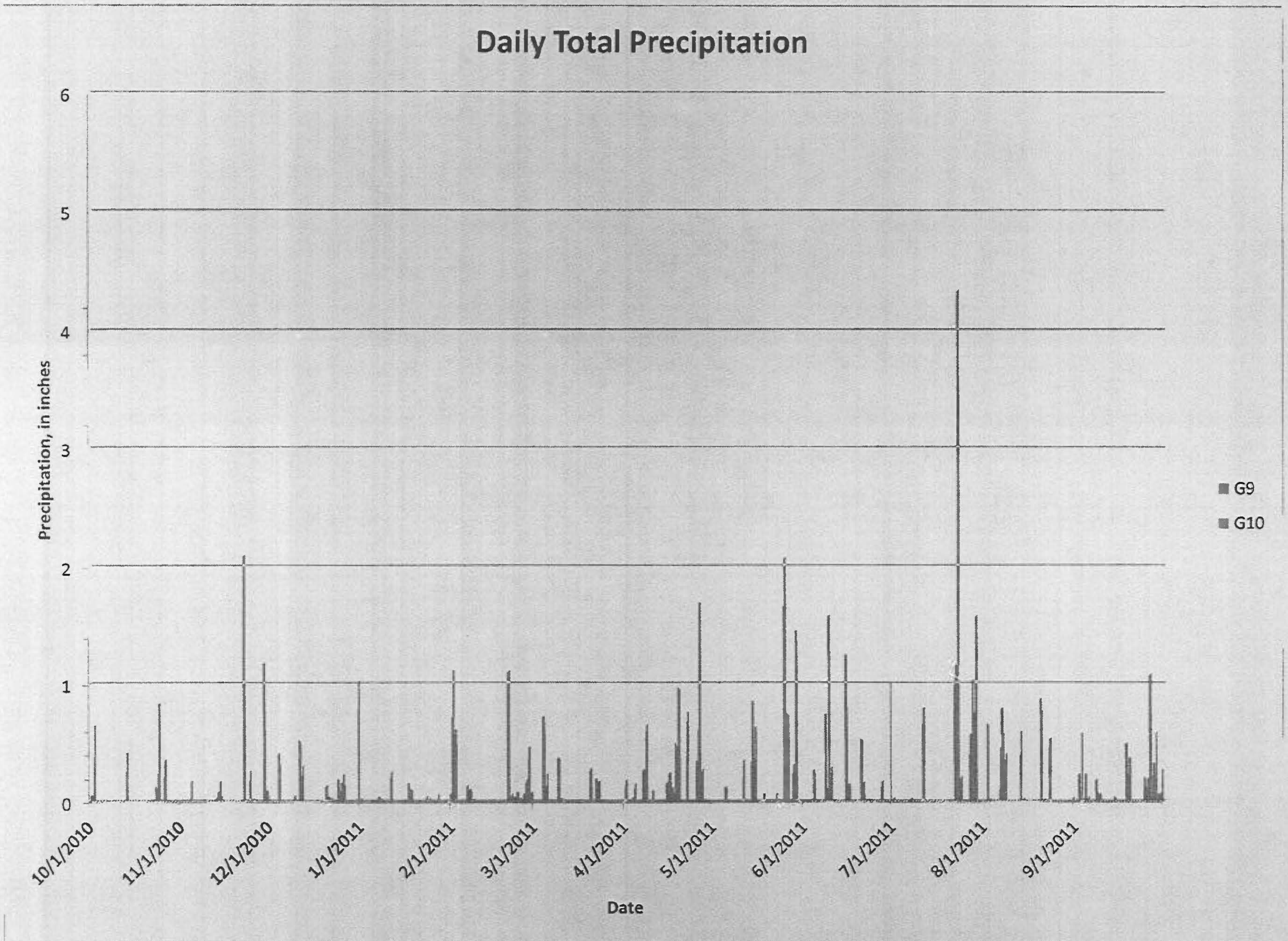
APPENDIX A: DAILY TOTAL PRECIPITATION FROM THE ILLINOIS STATE WATER SURVEY COOK COUNTY PRECIPITATION NETWORK GAGES G9 AND G10 LOCATED IN THE VICINITY OF STREETSCAPE PROJECT CORRIDOR FROM 2008 TO 2015.

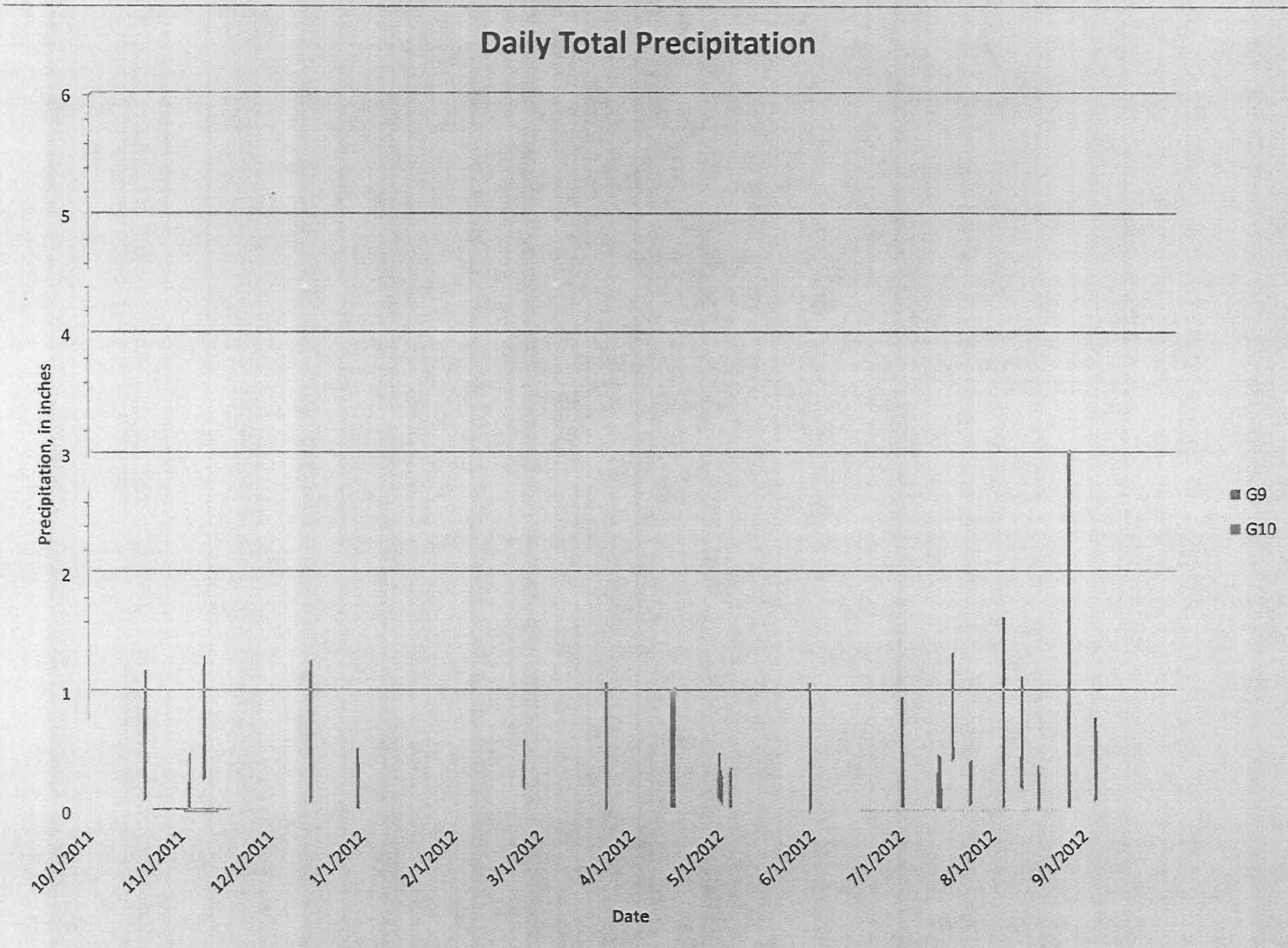


Daily Total Precipitation
Precipitation, in inches
6
5
4
3
2
1
0
7/25/2008
8/1/2008
8/8/2008
8/15/2008
8/22/2008
8/29/2008
9/5/2008
9/12/2008
9/19/2008
9/26/2008
Date
G9
G10

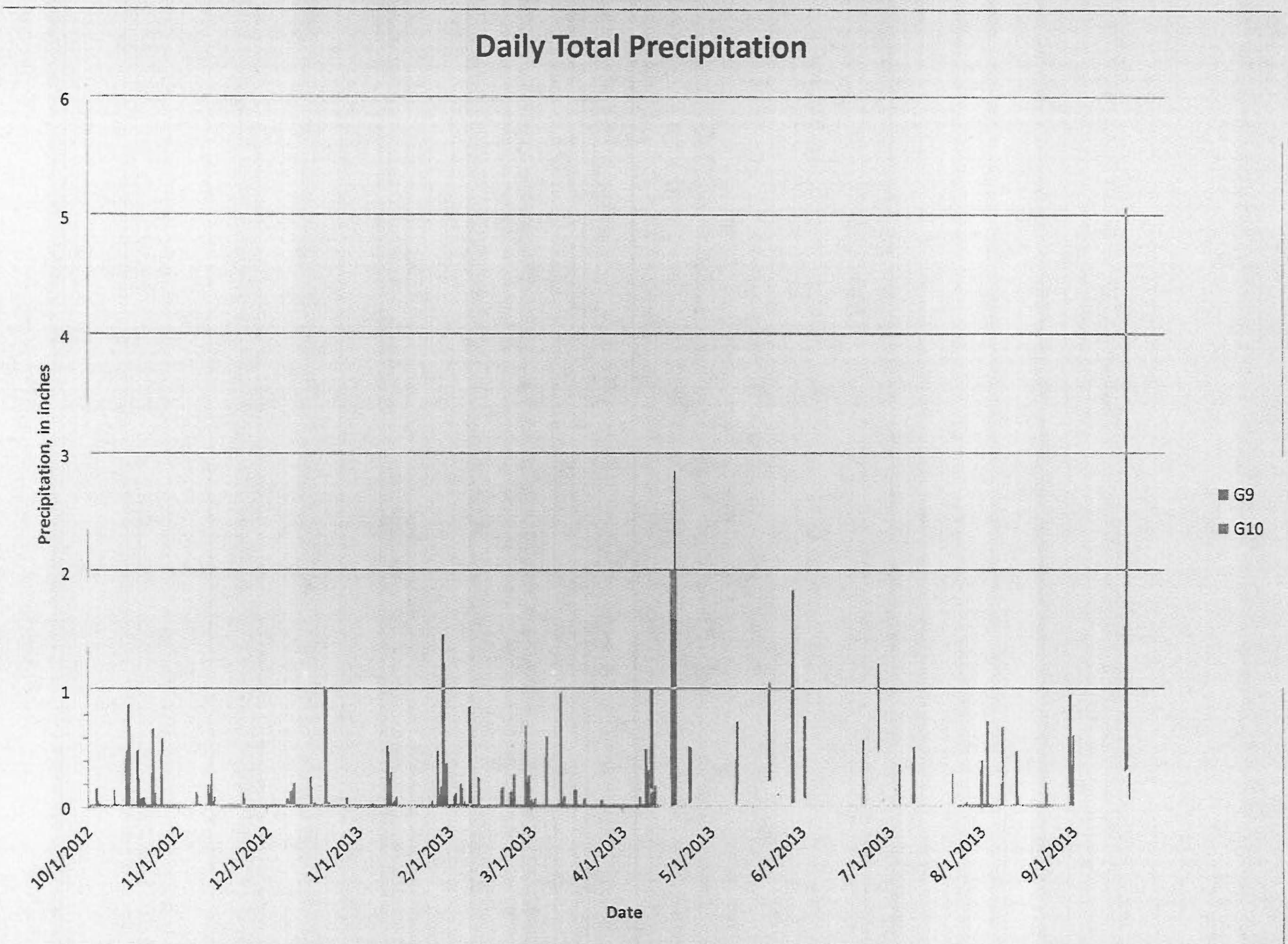

Daily Total Precipitation
Precipitation, in inches
0
1
2
3
4
5
6
10/1/2008
11/1/2008
12/1/2008
1/1/2009
2/1/2009
3/1/2009
4/1/2009
5/1/2009
6/1/2009
7/1/2009
8/1/2009
9/1/2009
Date
G9
G10

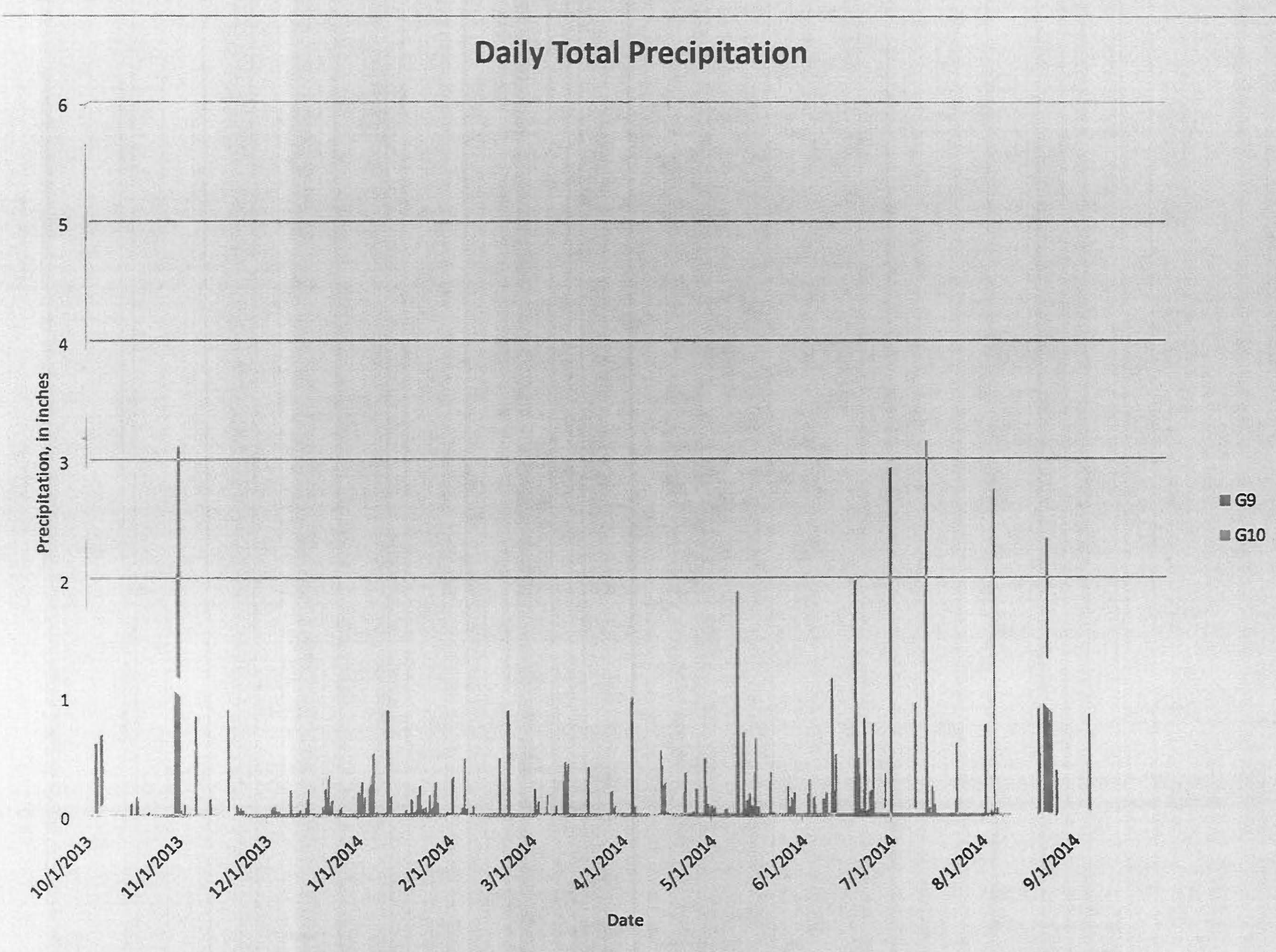

Daily Total Precipitation
Precipitation, in inches
0
1
2
3
4
5
6
10/1/2009
11/1/2009
12/1/2009
1/1/2010
2/1/2010
3/1/2010
4/1/2010
5/1/2010
6/1/2010
7/1/2010
8/1/2010
9/1/2010
Date
G9
G10


Daily Total Precipitation
Precipitation, in inches
0
1
2
3
4
5
6
10/1/2010
11/1/2010
12/1/2010
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
Date
G9
G10

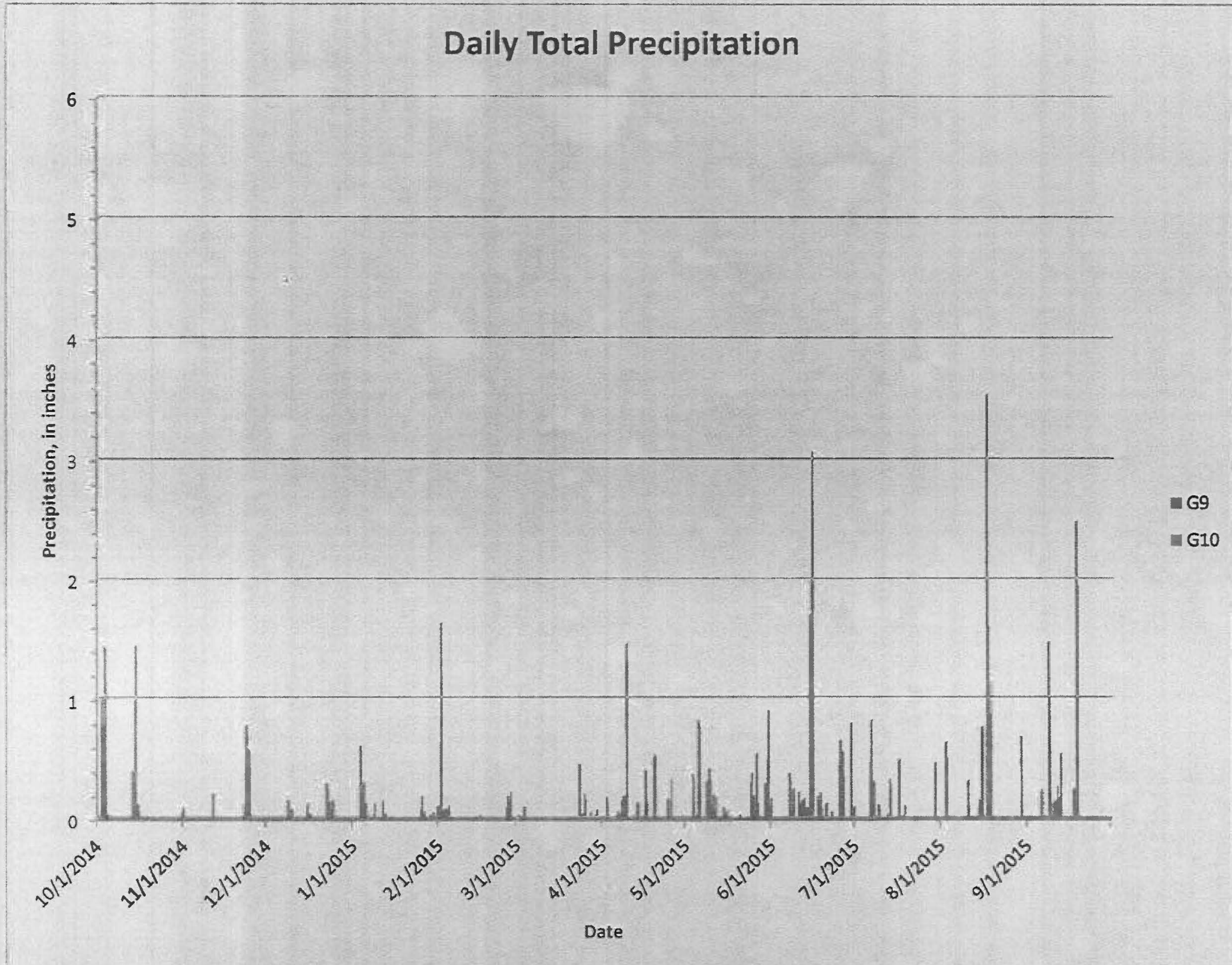


Daily Total Precipitation
Precipitation, in inches
0
1
2
3
4
5
6
10/1/2011
11/1/2011
12/1/2011
1/1/2012
2/1/2012
3/1/2012
4/1/2012
5/1/2012
6/1/2012
7/1/2012
8/1/2012
9/1/2012
Date
G9
G10


Daily Total Precipitation
Precipitation, in inches
0
1
2
3
4
5
6
10/1/2012
11/1/2012
12/1/2012
1/1/2013
2/1/2013
3/1/2013
4/1/2013
5/1/2013
6/1/2013
7/1/2013
8/1/2013
9/1/2013
Date
G9
G10

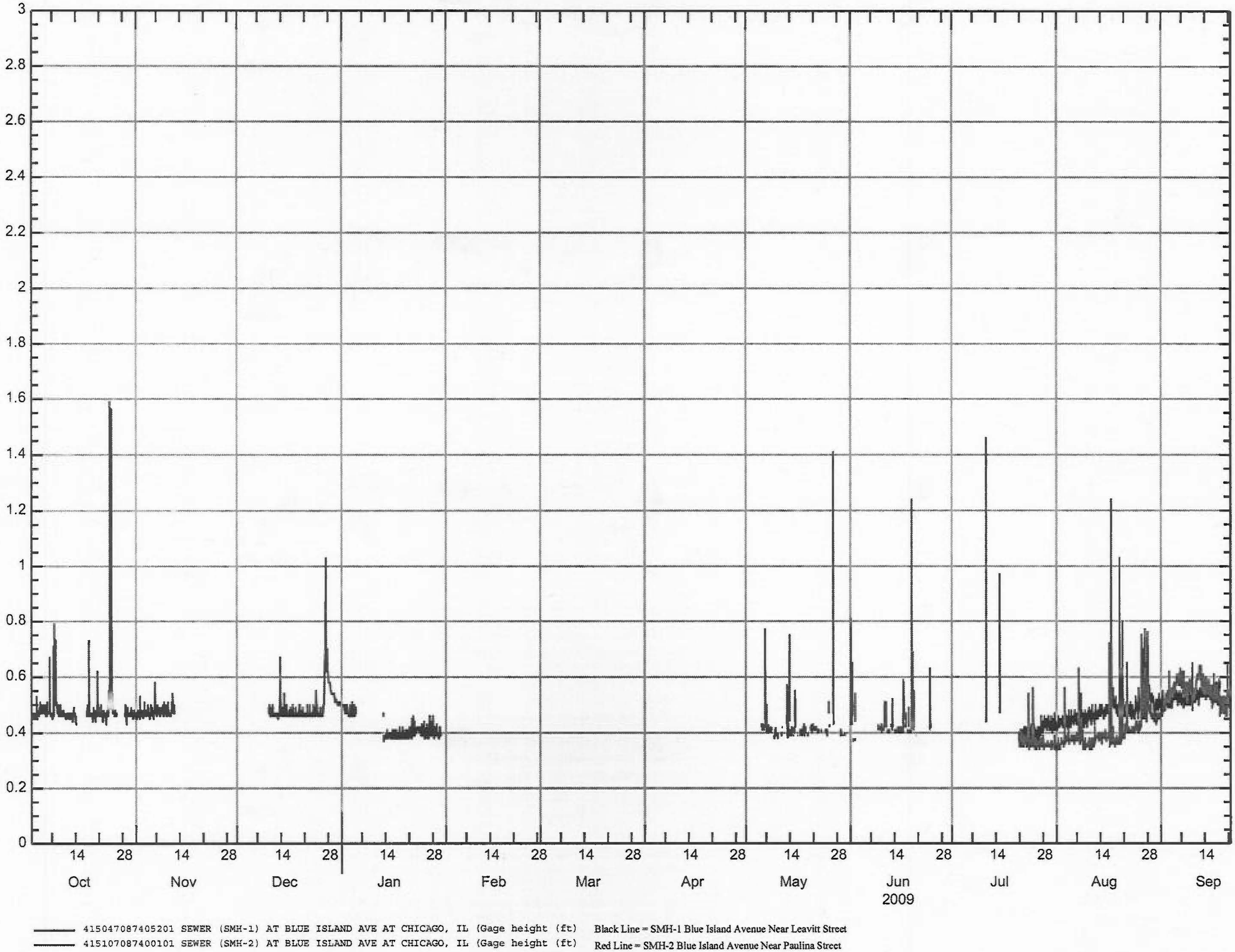


Daily Total Precipitation
Precipitation, in inches
6
5
4
3
2
1
0
10/1/2013
11/1/2013
12/1/2013
1/1/2014
2/1/2014
3/1/2014
4/1/2014
5/1/2014
6/1/2014
7/1/2014
8/1/2014
9/1/2014
Date
G9
G10


Daily Total Precipitation
Precipitation, in inches
0
1
2
3
4
5
6
10/1/2014
11/1/2014
12/1/2014
1/1/2015
2/1/2015
3/1/2015
4/1/2015
5/1/2015
6/1/2015
7/1/2015
8/1/2015
9/1/2015
Date
G9
G10

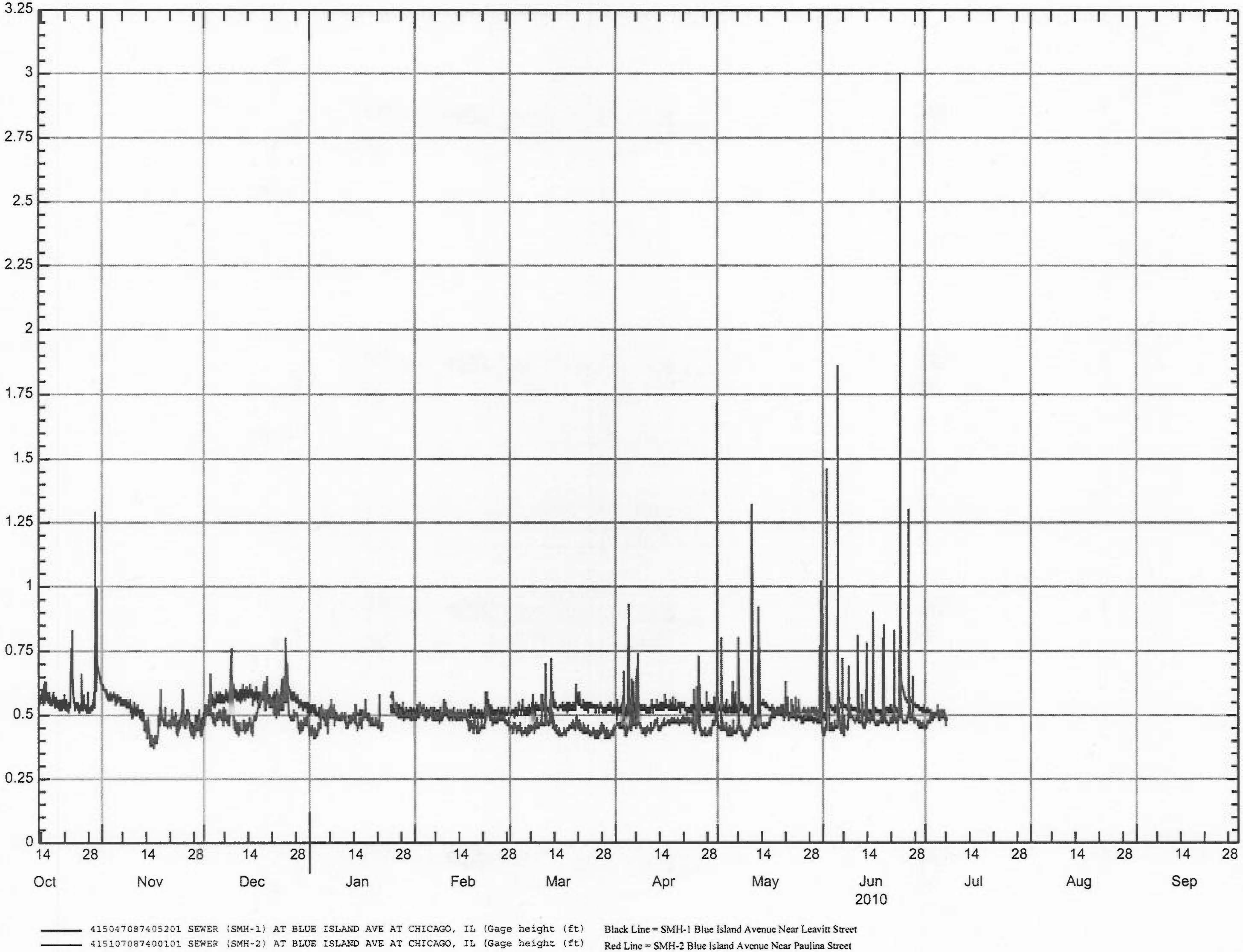
APPENDIX B: SEWER FLOW HYDROGRAPHS FOR THE STUDY LOCATIONS FROM 2009 TO 2015

B-1

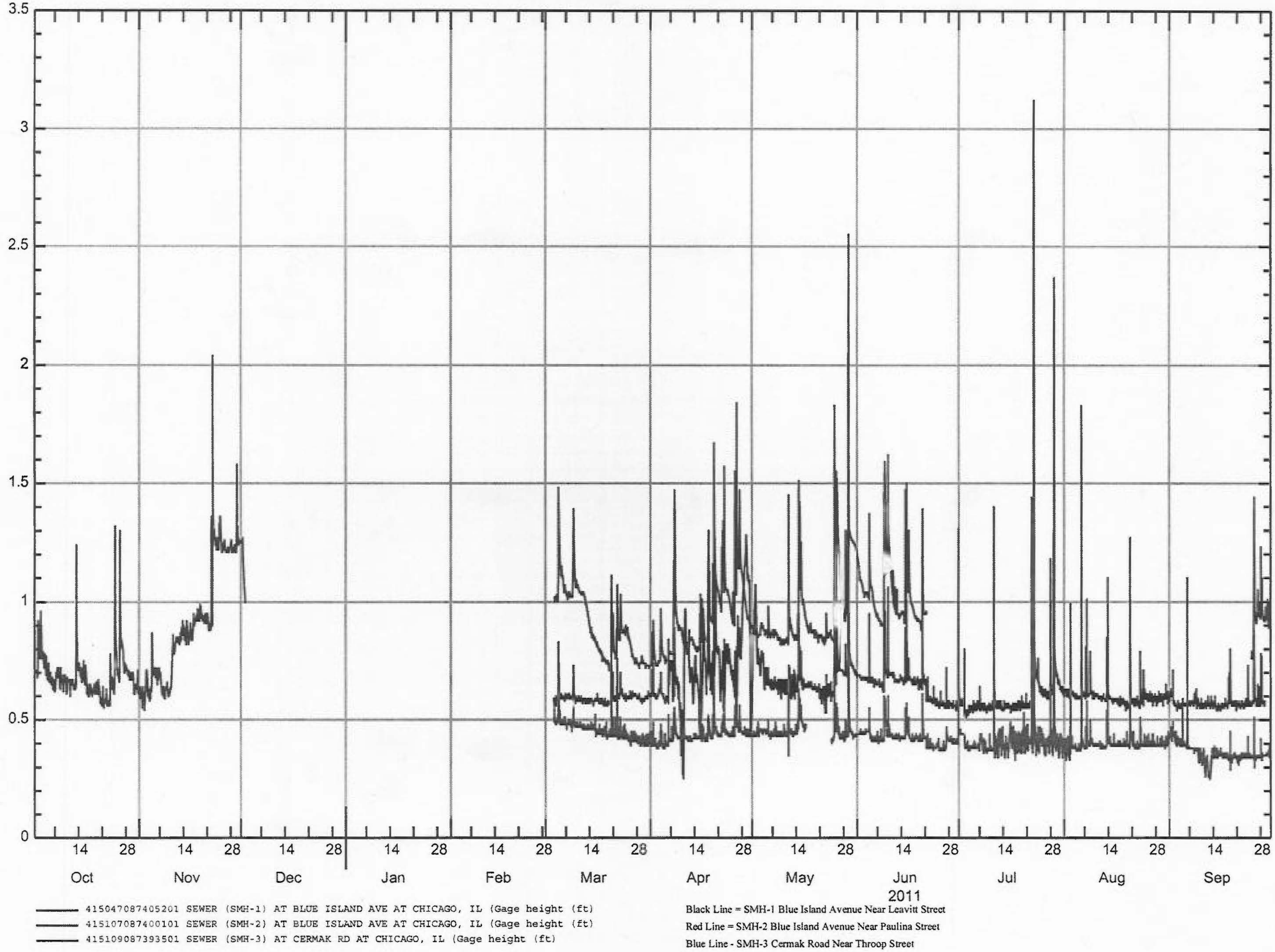


3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2009
Jul
Aug
Sep
415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
Black Line = SMH-1 Blue Island Avenue Near Leavitt Street
Red Line = SMH-2 Blue Island Avenue Near Paulina Street

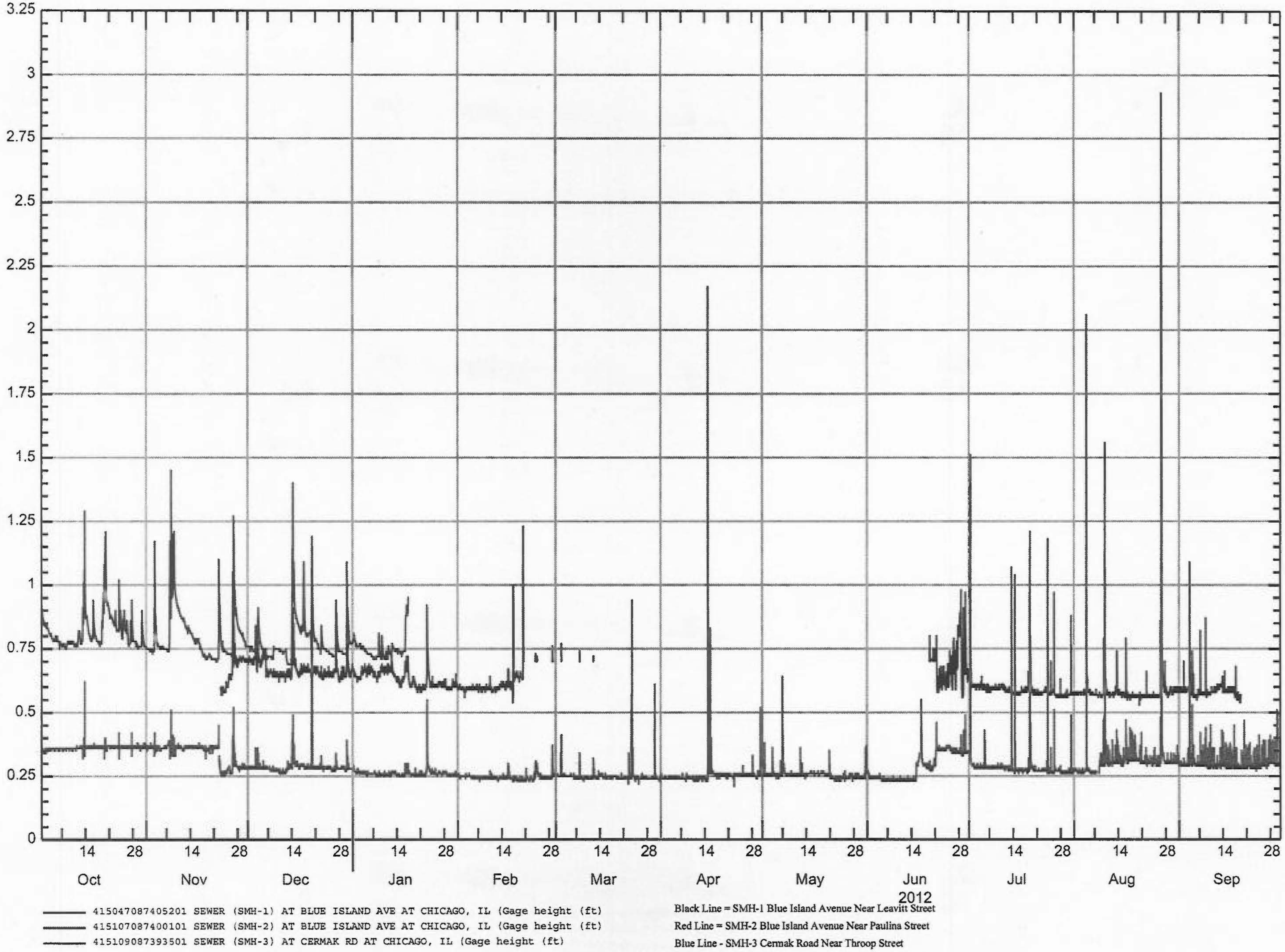
B-2

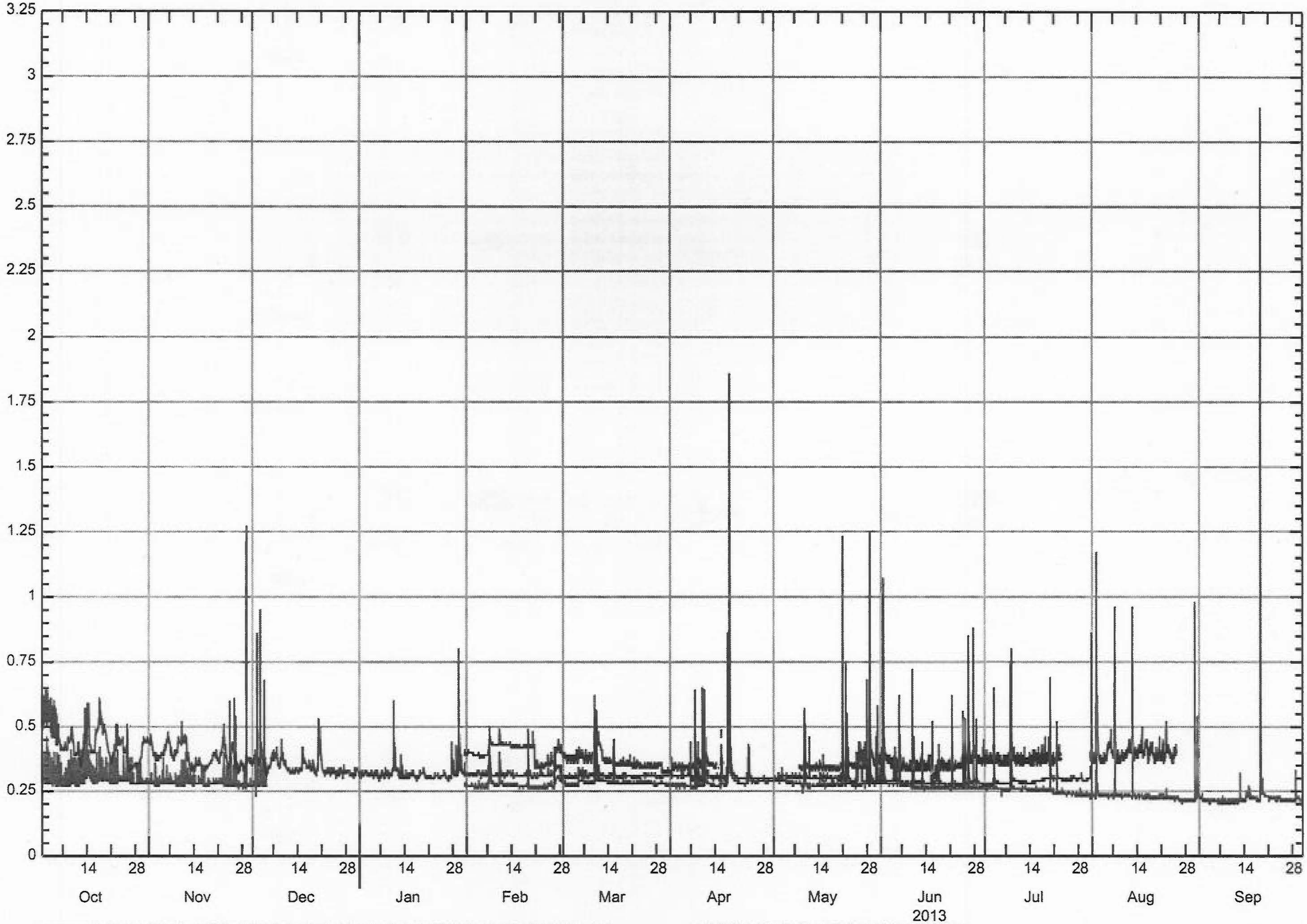


3.25
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
2010
415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
Black Line = SMH-1 Blue Island Avenue Near Leavitt Street
Red Line = SMH-2 Blue Island Avenue Near Paulina Street



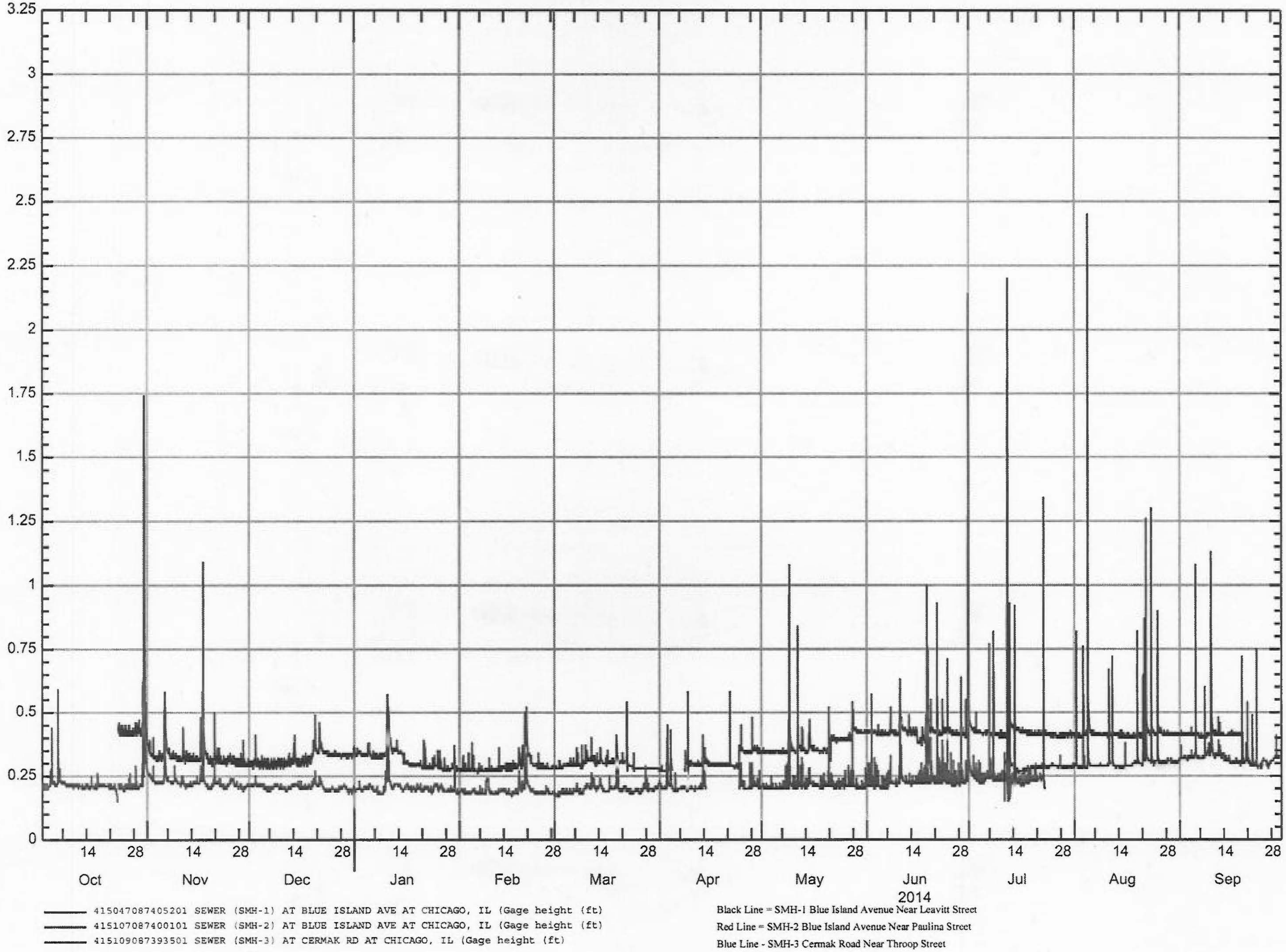
Black Line = SMH-1 Blue Island Avenue Near Leavitt Street
Red Line = SMH-2 Blue Island Avenue Near Paulina Street
Blue Line - SMH-3 Cermak Road Near Throop Street


3.25
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
2012
415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
415109087393501 SEWER (SMH-3) AT CERMAK RD AT CHICAGO, IL (Gage height (ft)
Black Line = SMH-1 Blue Island Avenue Near Leavitt Street
Red Line = SMH-2 Blue Island Avenue Near Paulina Street
Blue Line - SMH-3 Cermak Road Near Throop Street



415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (ft)
415109087393501 SEWER (SMH-3) AT CERMAK RD AT CHICAGO, IL (Gage height (ft)

Black Line = SMH-1 Blue Island Avenue Near Leavitt Street
Red Line = SMH-2 Blue Island Avenue Near Paulina Street
Blue Line - SMH-3 Cermak Road Near Throop Street

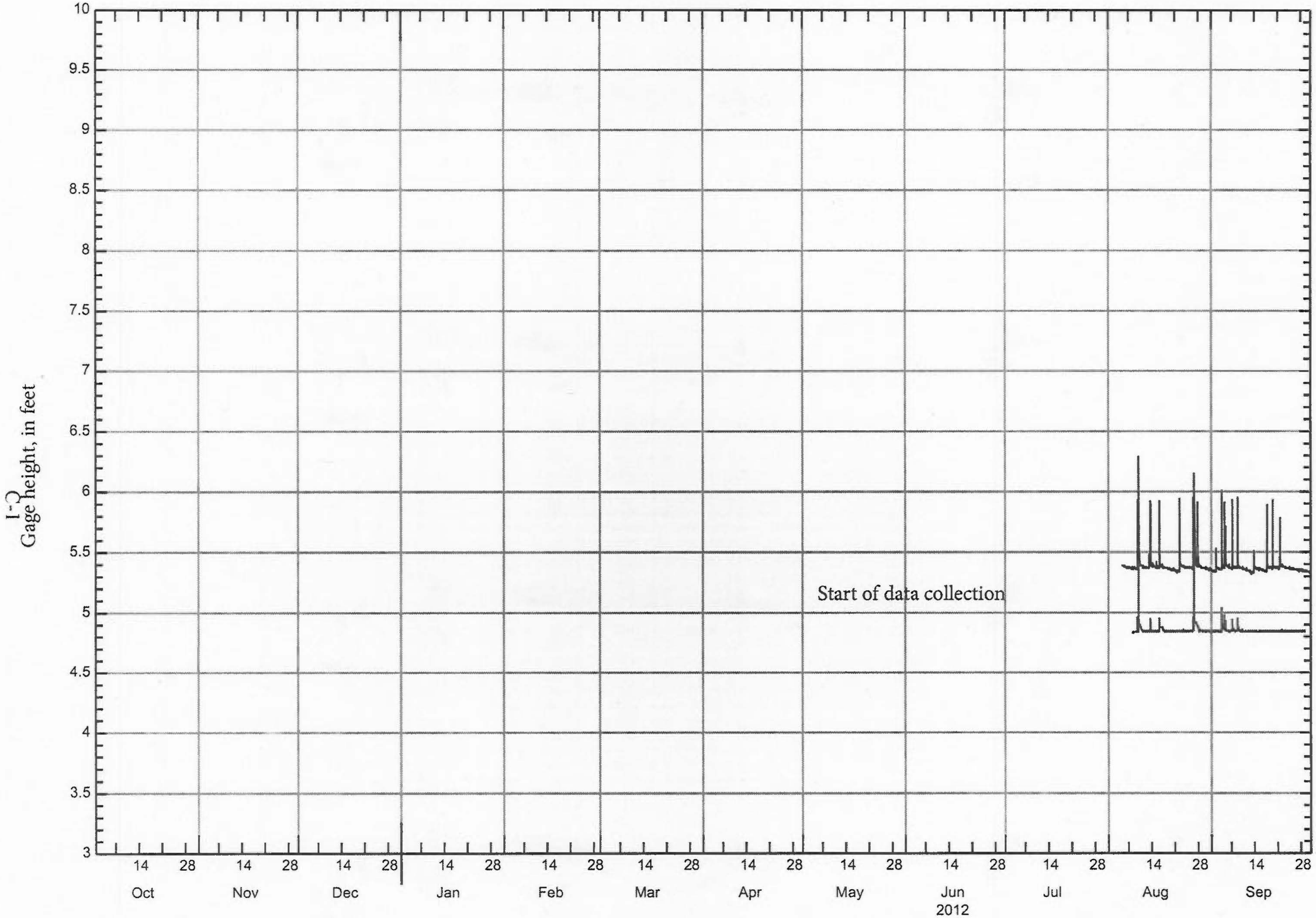


Black Line = SMH-1 Blue Island Avenue Near Leavitt Street

Red Line = SMH-2 Blue Island Avenue Near Paulina Street

Blue Line - SMH-3 Cermak Road Near Throop Street

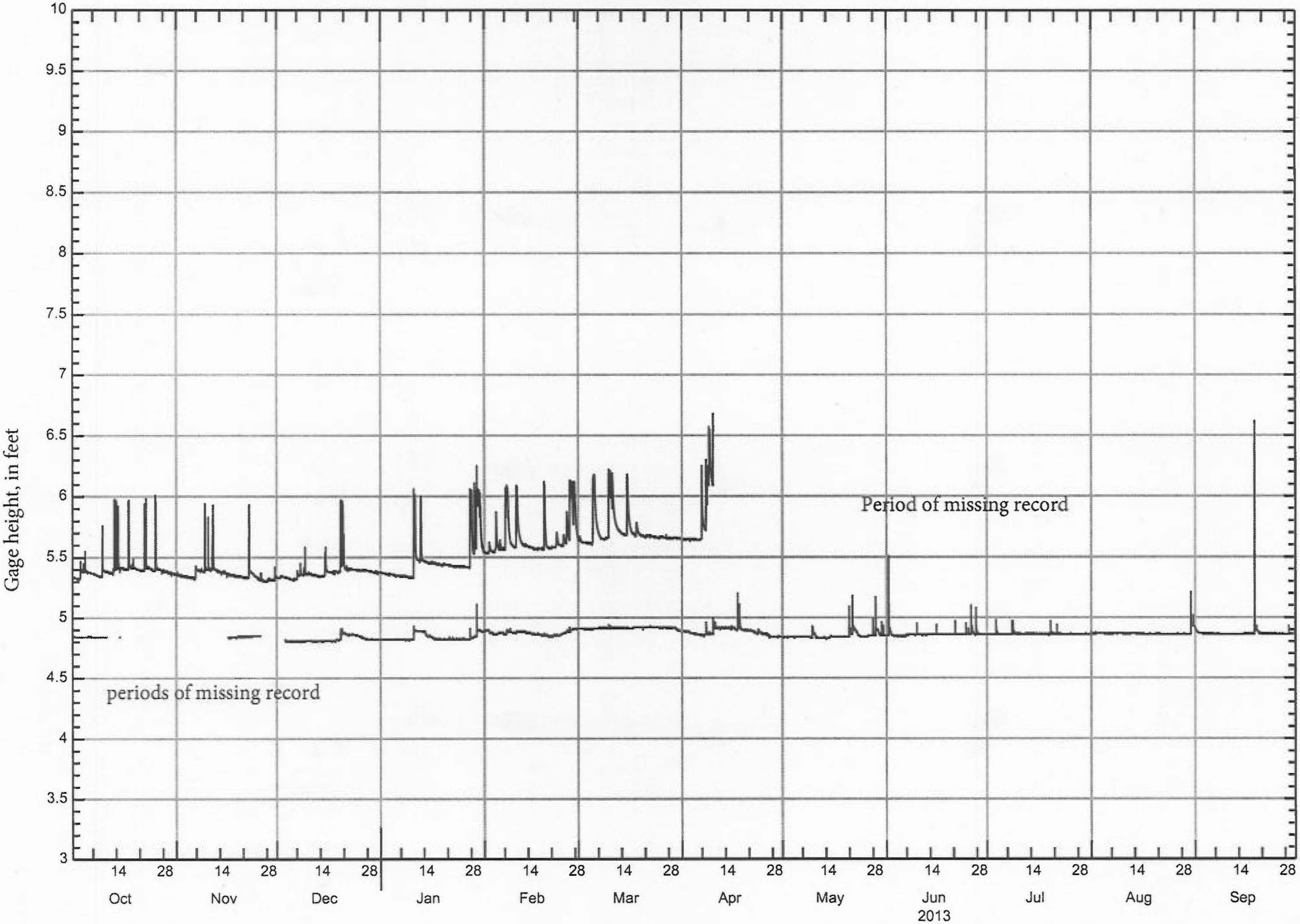
APPENDIX C: FLOW HYDROGRAPHS FOR CATCH BASINS LOCATED AT LEAVITT STREET AND PAULINA STREET ON BLUE ISLAND ROAD FROM 2012 TO 2015



415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)
415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)

Black Line = SMH-1 Paulina Street
Red Line = SMH-2 Leavitt Street

C-1

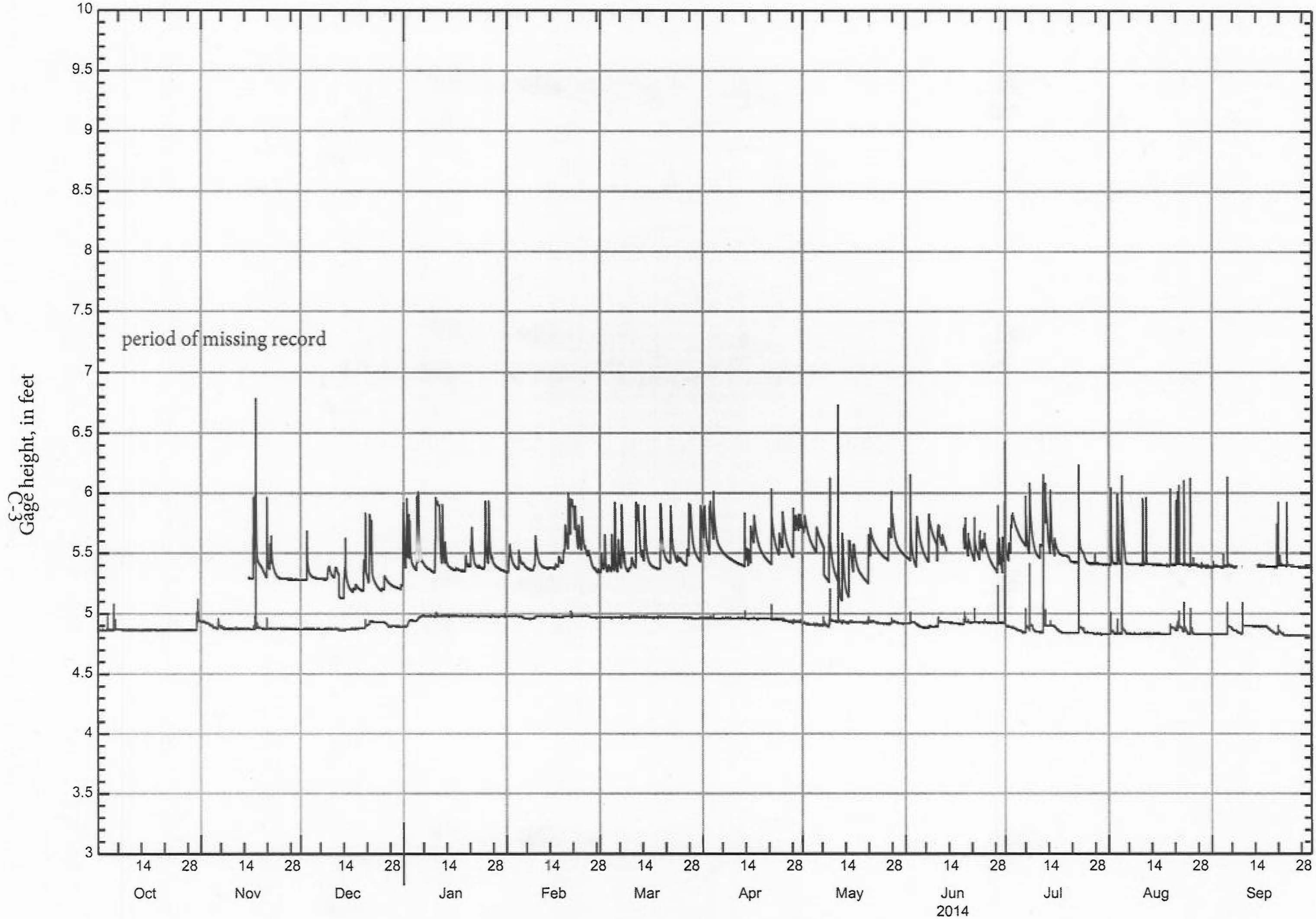


415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)

415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)

Black Line = SMH-1 Paulina Street

Red Line = SMH-2 Leavitt Street

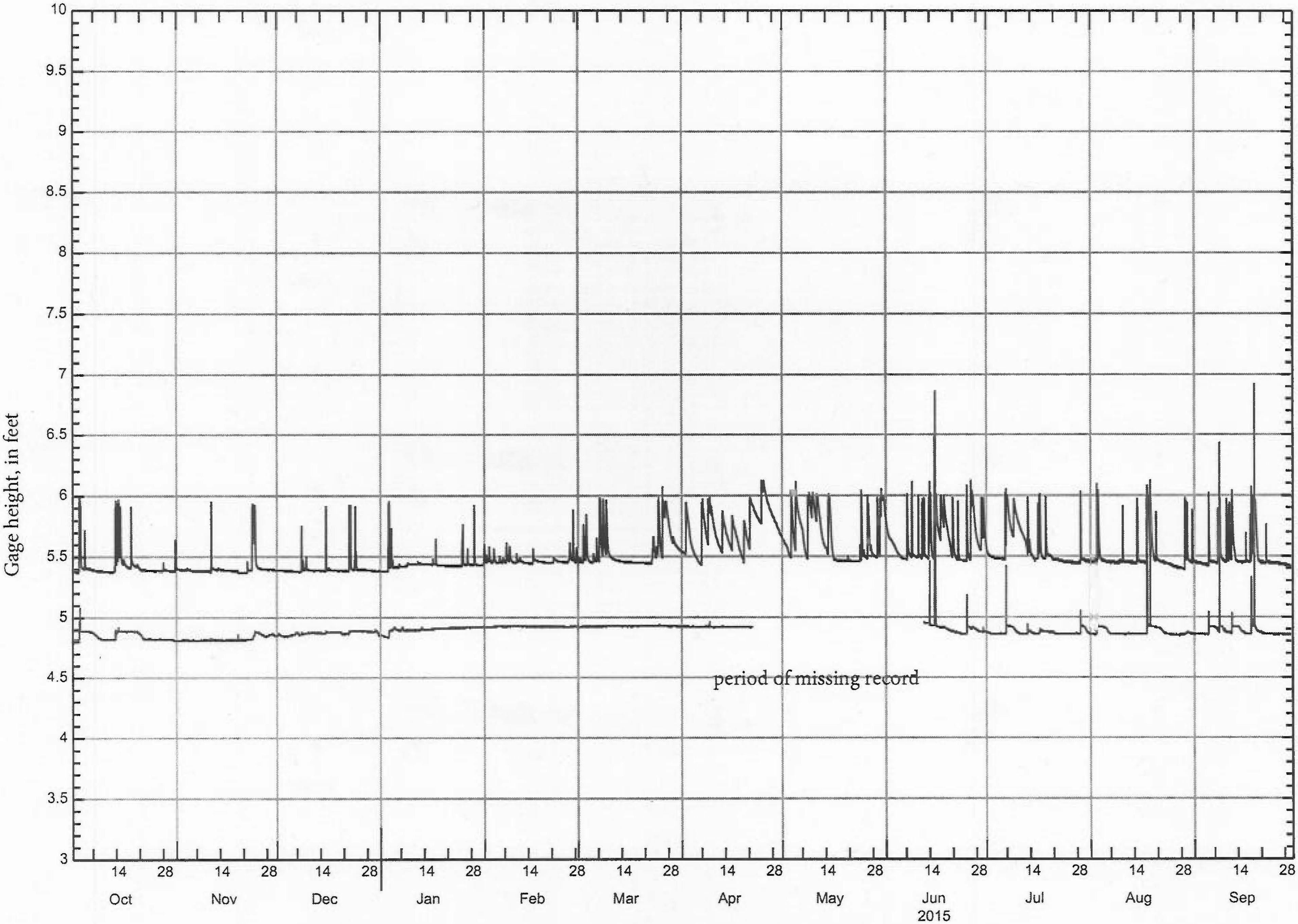


415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)

415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)

Black Line = SMH-1 Paulina Street

Red Line = SMH-2 Leavitt Street



415047087405201 SEWER (SMH-1) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)

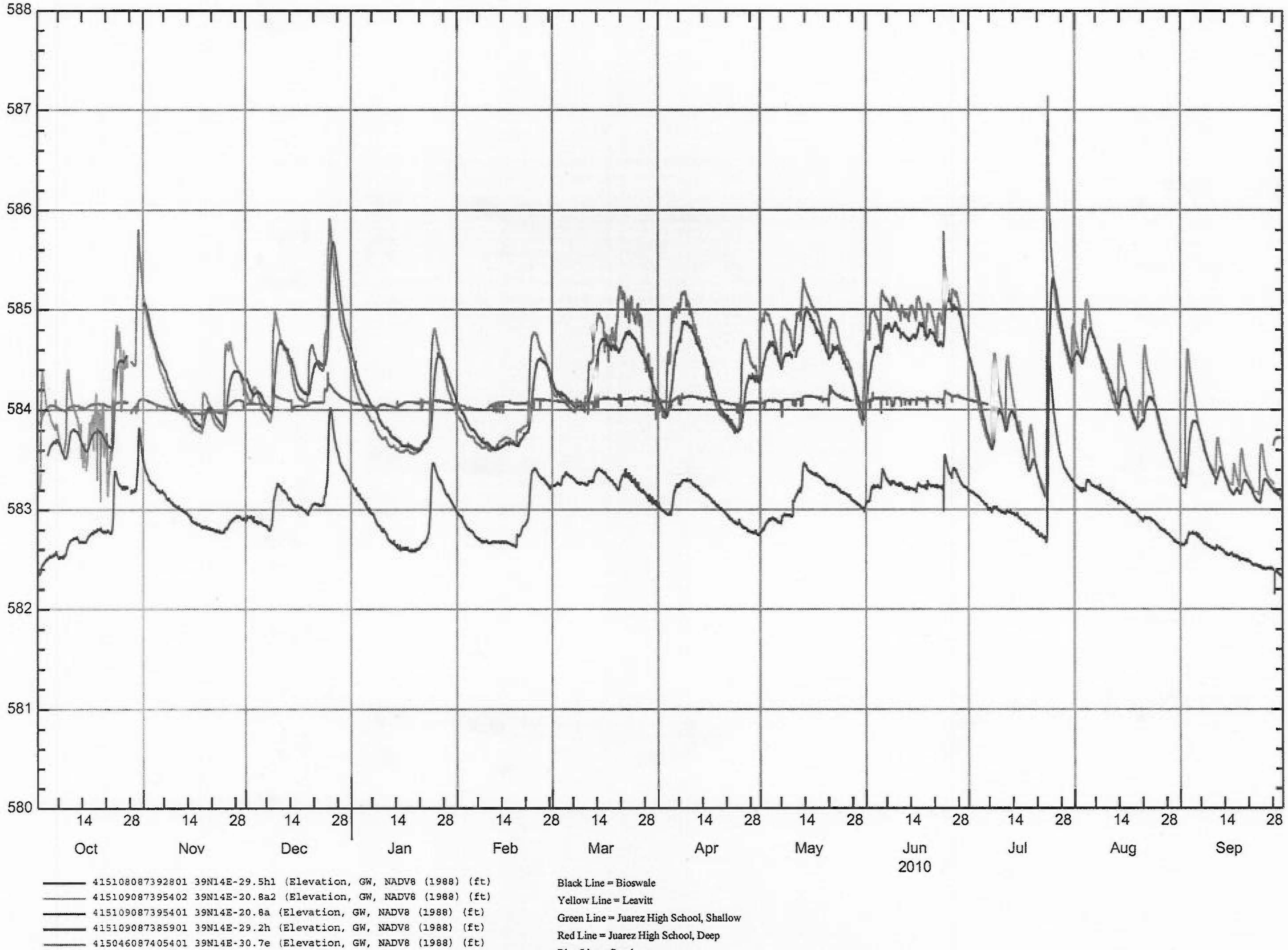
415107087400101 SEWER (SMH-2) AT BLUE ISLAND AVE AT CHICAGO, IL (Gage height (CATCH BASIN) (ft)

Black Line = SMH-1 Paulina Street

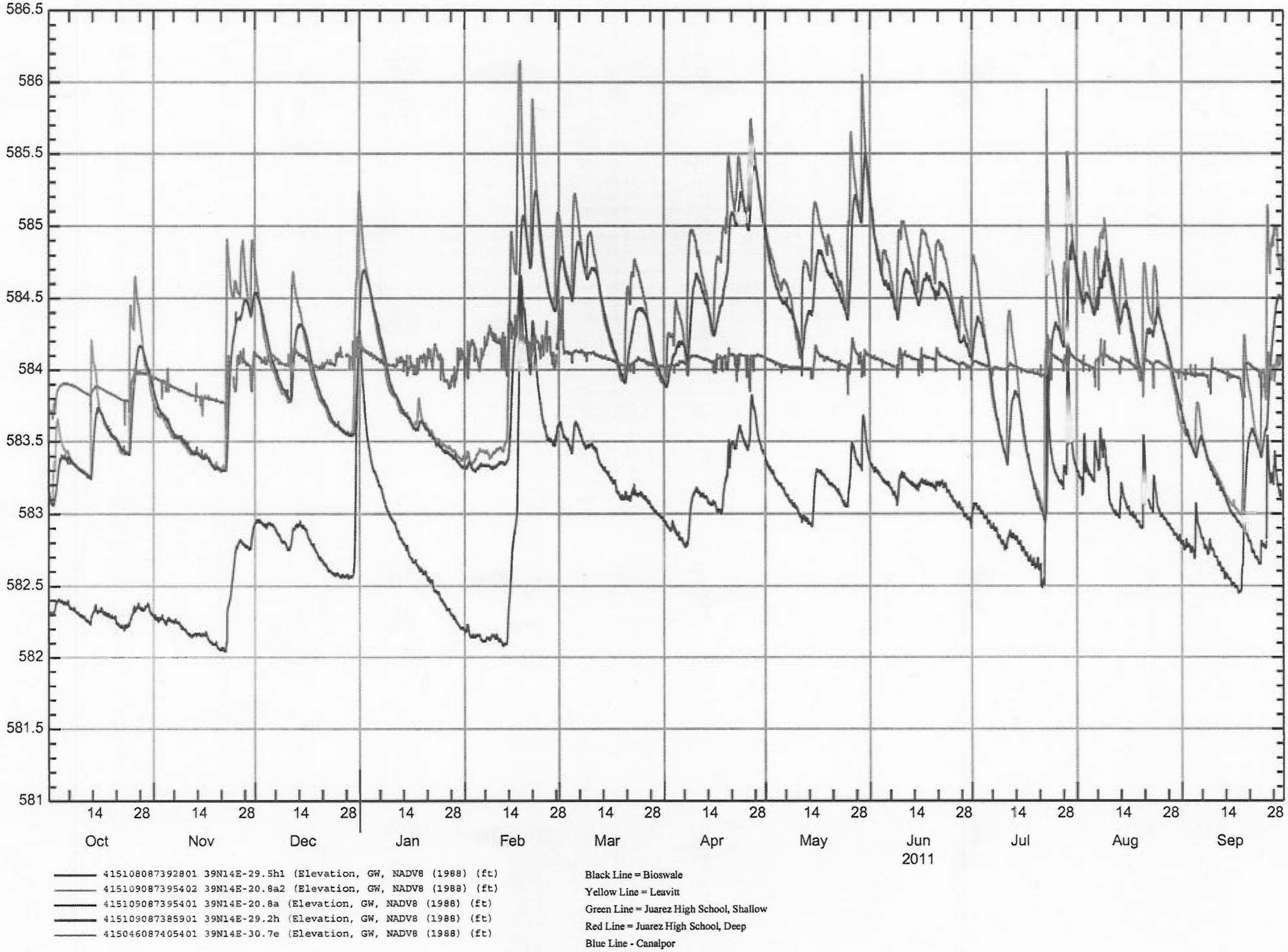
Red Line = SMH-2 Leavitt Street

APPENDIX D: GROUND WATER ELEVATION HYDROGRAPHS FOR FIVE SHALLOW GROUND WATER MONITORING WELLS LOCATED IN THE VICINITY OF THE STREETSCAPE PROJECT SITE FROM 2010 to 2015

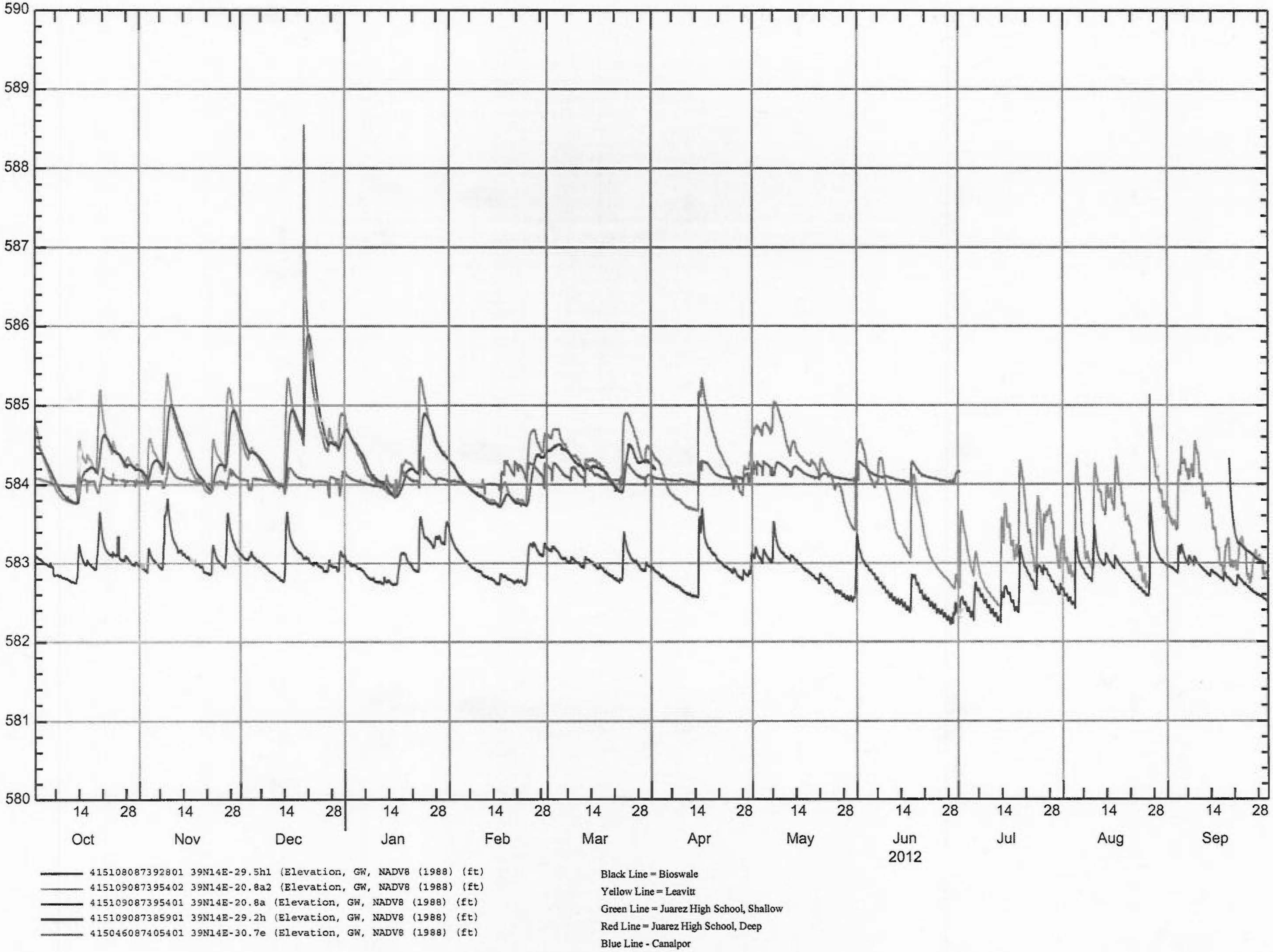
D-1

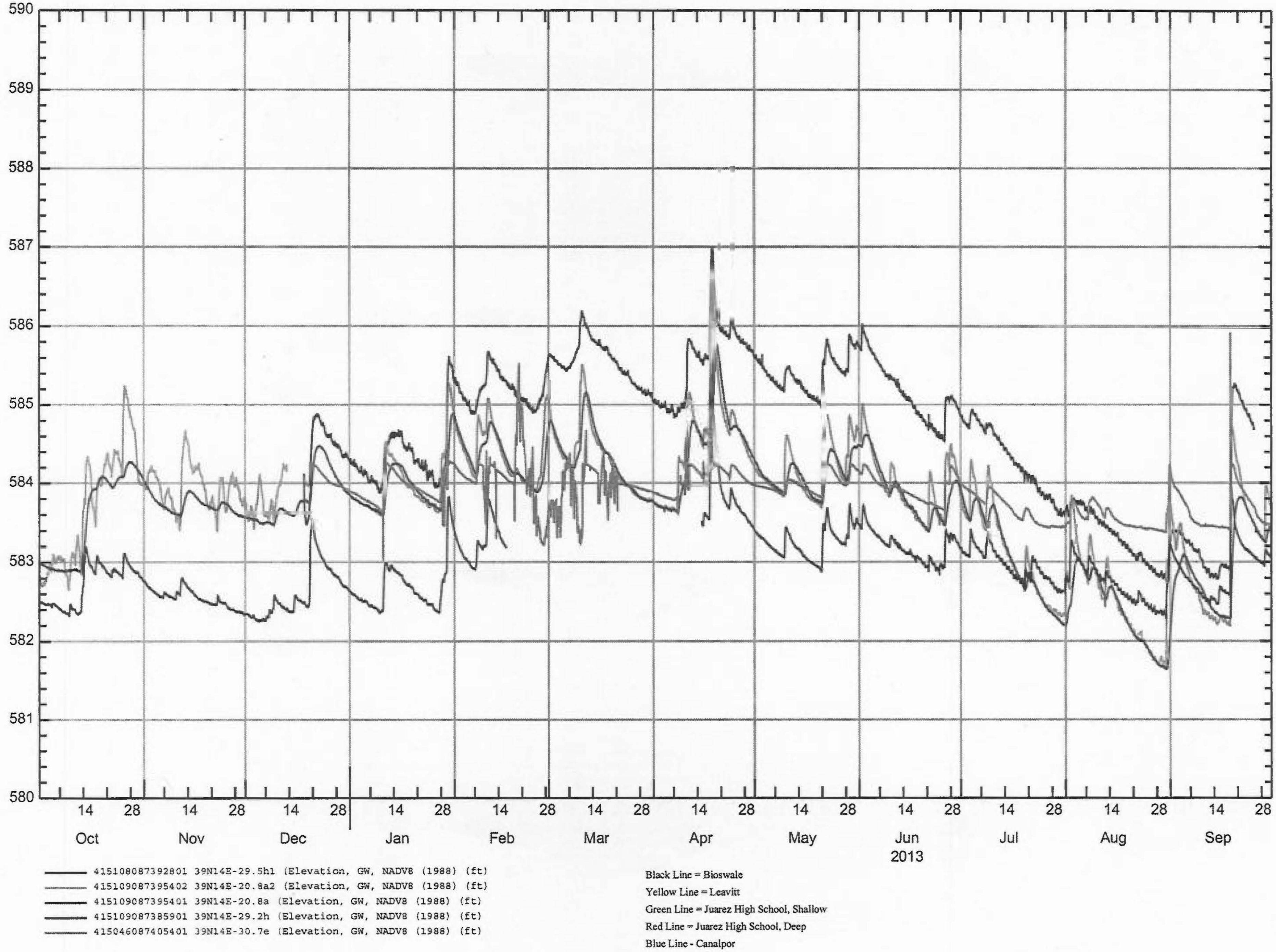


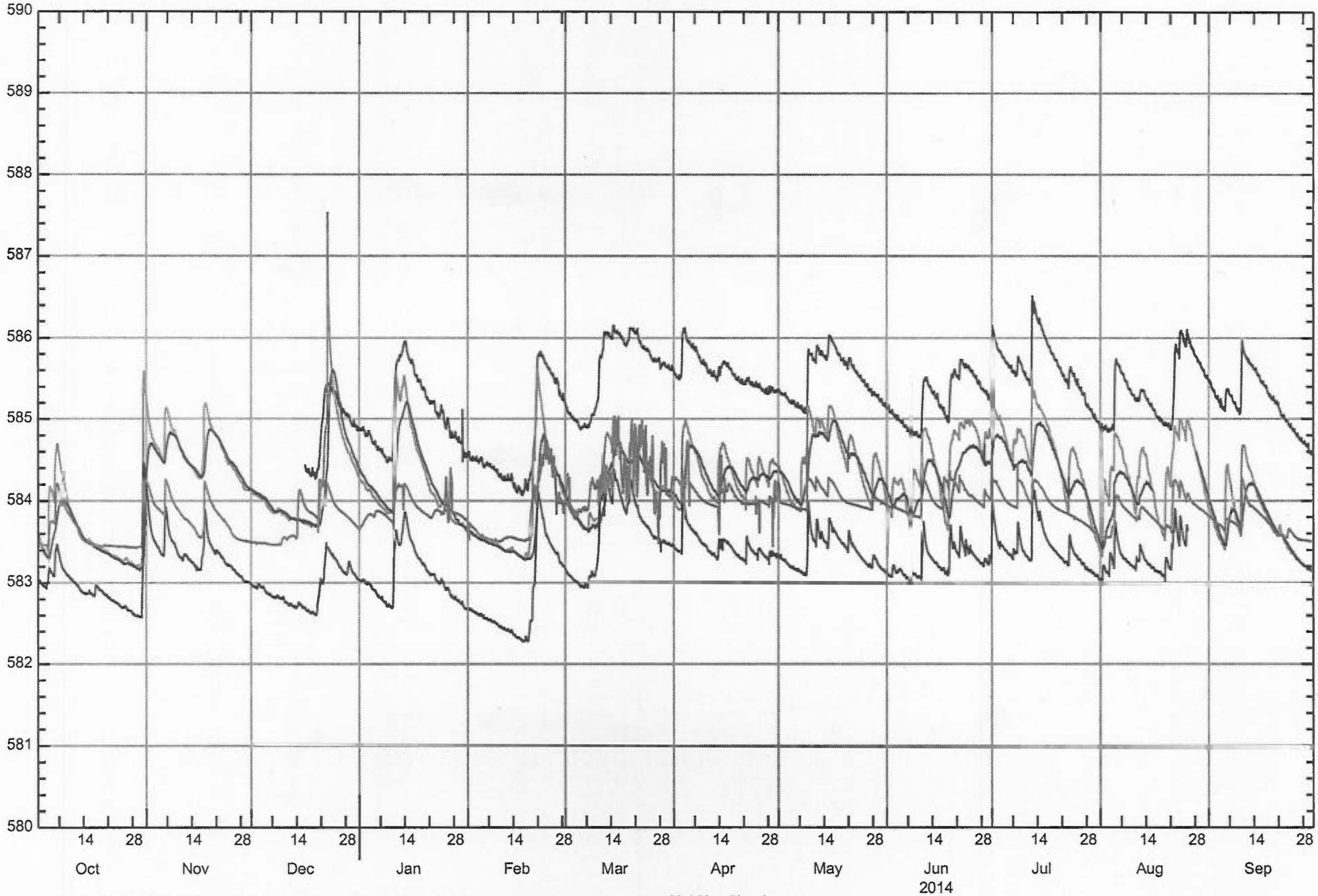
Black Line = Bioswale
Yellow Line = Leavitt
Green Line = Juarez High School, Shallow
Red Line = Juarez High School, Deep
Blue Line - Canalport


586.5
586
585.5
585
584.5
584
583.5
583
582.5
582
581.5
581
14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2011
Jul
Aug
Sep
415108087392801 39N14E-29.5h1 (Elevation, GW, NADV8 (1988) (ft)
415109087395402 39N14E-20.8a2 (Elevation, GW, NADV8 (1988) (ft)
415109087395401 39N14E-20.8a (Elevation, GW, NADV8 (1988) (ft)
415109087385901 39N14E-29.2h (Elevation, GW, NADV8 (1988) (ft)
415046087405401 39N14E-30.7e (Elevation, GW, NADV8 (1988) (ft)
Black Line = Bioswale
Yellow Line = Leavitt
Green Line = Juarez High School, Shallow
Red Line = Juarez High School, Deep
Blue Line - Canalpor

D-2

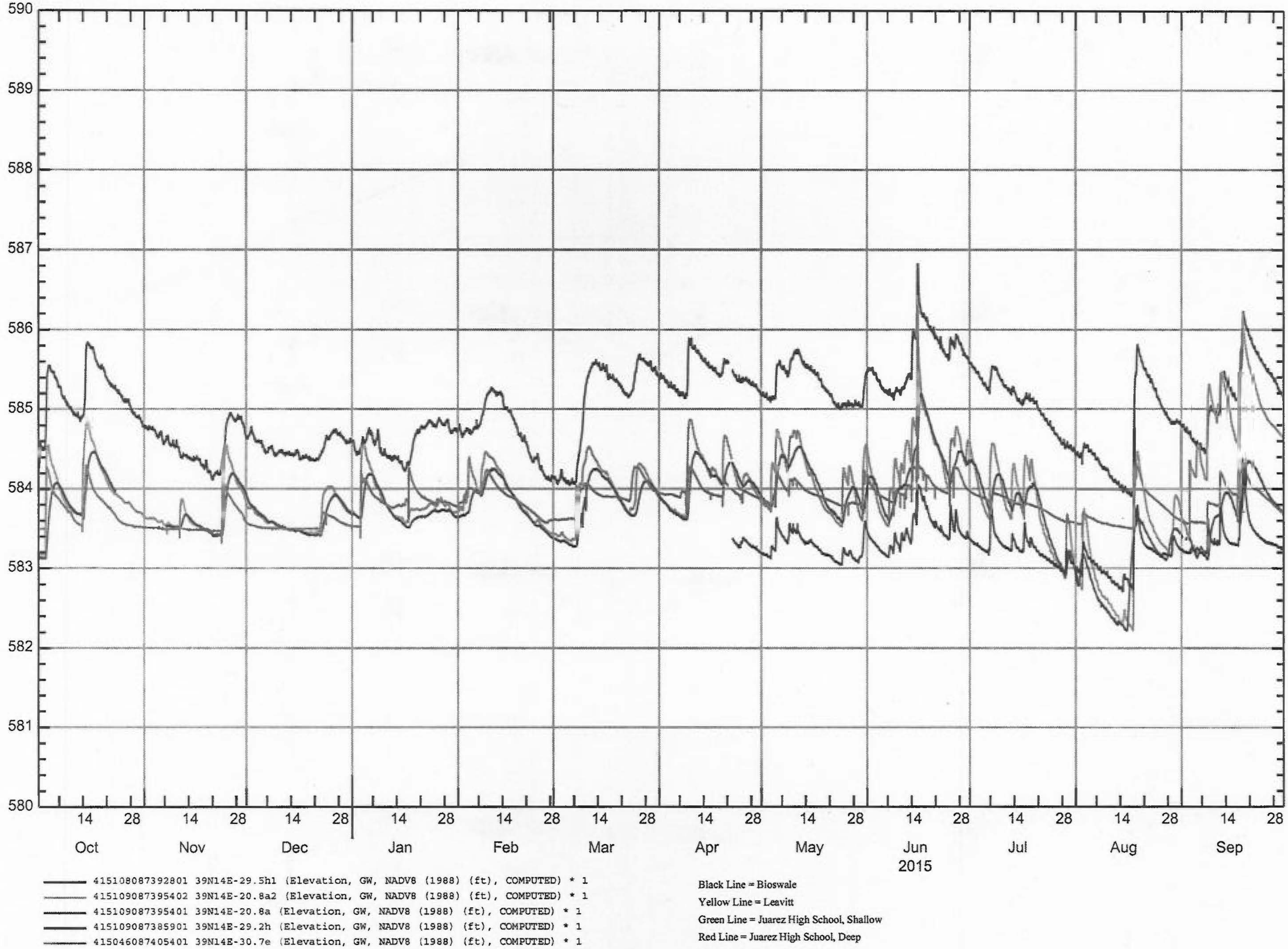

590
589
588
587
586
585
584
583
582
581
580
14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2012
Jul
Aug
Sep
415108087392801 39N14E-29.5h1 (Elevation, GW, NADV8 (1988) (ft)
415109087395402 39N14E-20.8a2 (Elevation, GW, NADV8 (1988) (ft)
415109087395401 39N14E-20.8a (Elevation, GW, NADV8 (1988) (ft)
415109087385901 39N14E-29.2h (Elevation, GW, NADV8 (1988) (ft)
415046087405401 39N14E-30.7e (Elevation, GW, NADV8 (1988) (ft)
Black Line = Bioswale
Yellow Line = Leavitt
Green Line = Juarez High School, Shallow
Red Line = Juarez High School, Deep
Blue Line - Canalpor


590
589
588
587
586
585
584
583
582
581
580
14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28 14 28
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
2013
Jul
Aug
Sep
415108087392801 39N14E-29.5h1 (Elevation, GW, NADV8 (1988) (ft)
415109087395402 39N14E-20.8a2 (Elevation, GW, NADV8 (1988) (ft)
415109087395401 39N14E-20.8a (Elevation, GW, NADV8 (1988) (ft)
415109087385901 39N14E-29.2h (Elevation, GW, NADV8 (1988) (ft)
415046087405401 39N14E-30.7e (Elevation, GW, NADV8 (1988) (ft)
Black Line = Bioswale
Yellow Line = Leavitt
Green Line = Juarez High School, Shallow
Red Line = Juarez High School, Deep
Blue Line - Canalpor



415108087392801 39N14E-29.5h1 (Elevation, GW, NADV8 (1988) (ft), COMPUTED) * 1
415109087395402 39N14E-20.8a2 (Elevation, GW, NADV8 (1988) (ft), COMPUTED) * 1
415109087395401 39N14E-20.8a (Elevation, GW, NADV8 (1988) (ft), COMPUTED) * 1
415109087385901 39N14E-29.2h (Elevation, GW, NADV8 (1988) (ft), COMPUTED) * 1
415046087405401 39N14E-30.7e (Elevation, GW, NADV8 (1988) (ft), COMPUTED) * 1

Black Line = Bioswale
Yellow Line = Leavitt
Green Line = Juarez High School, Shallow
Red Line = Juarez High School, Deep
Blue Line - Canalpor



Black Line = Bioswale
Yellow Line = Leavitt
Green Line = Juarez High School, Shallow
Red Line = Juarez High School, Deep
Blue Line - Canalpor