Monitoring contaminant transport from a stormwater infiltration facility to ground water. [DNR-168] 2003

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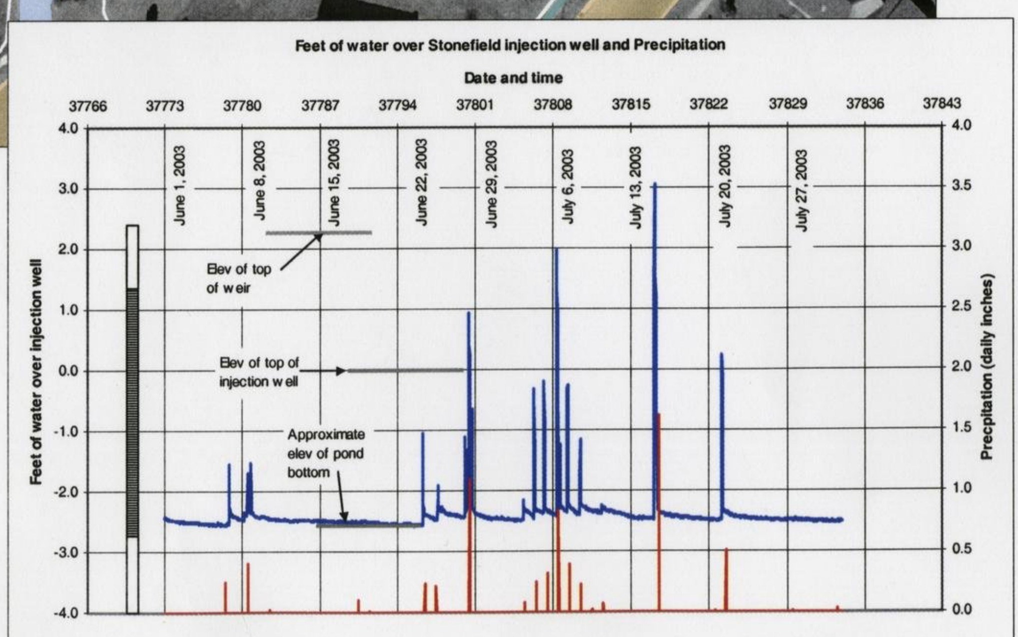
DNR Project #168

C.P. Dunning (USGS) and R.T. Bannerman (WDNR)

December 2003



Title: Monitoring Contaminant Transport from a Stormwater Infiltration Facility to Ground Water

Project I.D.: DNR Project #168

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Period of Contract: July2001 through June 2003

Background/Need: The State of Wisconsin has recently finalized administrative code NR 151 which will, in part, define performance standards for infiltration of stormwater from new developments. The stormwater infiltration standards are intended to preserve ground-water recharge and stream baseflow. However, depending on the landuse characteristics of a drainage area, stormwater may contain significant amounts of contaminants including hydrocarbons, metals, and chloride. In such cases, enforcement of infiltration performance standards has the potential to adversely affect ground-water quality.

Objectives: Monitoring contaminant transport to ground water resulting from infiltration at a site with specific physical characteristics (land use, contaminants, soil type, vadose zone characteristics) has been carried out in only a few settings around the country. This study was undertaken to quantify the relation between the quality of stormwater from the Stonefield neighborhood in Middleton, Wisconsin, and the transport of contaminants to the ground-water system.

Methods: The hydrology of the Stonefield infiltration site was characterized by defining the contributing watershed, coring and describing the sediments from ground surface in the basin to the ground-water table, monitoring pond stage during stormwater runoff events, monitoring water-table elevation, and monitoring flow into the injection well. Water was sampled for chemical analysis from ponded stormwater, from the water table, and from the vadose zone above the water table. Water-quality sampling was done on a routine schedule as well as in response to events. The period of study began July 2001, with data collection for different study aspects beginning at different times. Data continue to be collected beyond the June 2003 end of project, using additional WDNR and USGS funds.

Results and Discussion: Hydrology – Data collected during this investigation suggest that infiltration of ponded stormwater through the basin bottom does occur, but at fairly modest rates (between 0.1 and 1 inch per hour). It is most likely that stormwater recharges ground water by introduction to the unsaturated zone through the injection well in the basin. Data demonstrate that when ponded stormwater overtops the injection well, water flows into the well infiltrating into permeable sediments below a shallow clayey interval and has a measurable effect on the water-table elevation. Conversely, there is no strong signal of infiltration through the basin bottom on water-table elevation data collected to date. Changes made to the infiltration basin and surrounding area by the City of Middleton midway in the study introduced a measurable change on the relation between precipitation and the stage of ponded stormwater. Currently, precipitation in excess of 0.5 inch (daily average) is necessary for ponded stormwater to overtop the injection well. Hydrologic data continue to be collected, and quantifying the complex inflows to, and outflows from, the infiltration basin is a focus of the ongoing work.

Water chemistry - The chemistry of stormwater at the Stonefield site is consistent with reported stormwater chemistry for Wisconsin and Michigan, and reflects the chemistry of precipitation with addition of metals and polynuclear aromatic hydrocarbon (PAH) constituents from residential land use within the Stonefield watershed. Major ion chemistry of ground water at the Stonefield site is consistent with that of the sand and gravel aquifer of Wisconsin, though generally at the higher end of the concentration ranges. In addition, ground water and vadose-zone water have appreciably higher solids concentrations and generally higher metals concentrations than the stormwater. These data for ground water and vadose-zone water are believed to be representative because they have been confirmed by samples collected from the monitoring well using a low-flow method and through the porous cup of suction lysimeters. PAHs are present in the stormwater at the Stonefield site, but are not found in vadose or ground water. Some interesting trends in water quality are becoming apparent, however, with less than a year of sampling complete, further analysis of current and pending water quality data will be needed to quantify transport of contaminants from stormwater to ground water at the Stonefield Infiltration Site.

Conclusions/ Implications/ Recommendations: The Stonefield basin appears to be working as an infiltration site largely because the injection well routes ponded stormwater to porous, unsaturated sediments below. Infiltration is generally slow through the basin bottom, but could probably be improved with conditioning of the shallow soils, establishment of appropriate vegetation, and strict control of sediment and debris in the watershed. Water-quality analyses to date suggest that the concentration of many constituents is lower in the site stormwater than in vadose or ground water; this is particularly true of the concentration of solids and most metals. While much work is yet to be done in interpreting these data, it appears that for such constituents, infiltration of stormwater from this watershed will benefit rather than degrade ground-water quality. Hydrologic and water-quality data collected during stormwater events may yet reveal some interesting relations between stormwater quality and transport of contaminants at the Stonefield site. Data continue to be collected and interpretation is ongoing.

Related Publications: A USGS report is expected to be released following the third year of project activities (likely in 2005)

Key Words: Infiltration, stormwater, water quality, ground water, injection well

Funding: Wisconsin Department of Natural Resources and US Geological Survey

Final Report: A final report containing more detailed information on this project is available for loan at the Water Resources Institute Library, University of Wisconsin - Madison, 1975 Willow Drive, Madison, Wisconsin 53706 (608) 262-3069.

Acknowledgements

The authors thank the City of Middleton for allowing access to the Stonefield infiltration site, and their staff for assistance in many phases of the study. Thanks to Tim Asplund, coordinator of the Joint Solicitation funds for the Wisconsin Department of Natural Resources, for his administrative support. And thanks to Jim Rauman, Greg Mueller, Paul Juckem, and Cheryl Buchwald of the US Geological Survey-Wisconsin District for assistance on site and in the office.

Monitoring Contaminant Transport from a Stormwater Infiltration Facility to Ground Water

C.P. Dunning (USGS) and R.T. Bannerman (WDNR)

DNR Project #168

INTRODUCTION

Wisconsin recently finalized administrative code NR 151 which will, in part, define performance standards for infiltration of stormwater from new developments. The stormwater infiltration standards are intended to preserve stream baseflow and ground-water recharge. However, depending on the landuse characteristics of a drainage area, stormwater may contain significant amounts of contaminants including hydrocarbons, pesticides, bacteria, and chloride. Because of the impending performance standards for infiltration it is imperative to quantify the relationship between quality of infiltrated stormwater and the transport of contaminants to the ground-water system. The state should not be in a position of enforcing infiltration performance standards at new developments to the detriment of ground-water quality (possibly violating ground-water quality standards – NR 140).

Monitoring contaminant transport to ground water resulting from infiltration at a site with specific physical characteristics (land use, contaminants, soil type, vadose zone characteristics) has been carried out in only a few settings around the country. The proposed study will quantify, through field data, the relationship between the quality of infiltrated stormwater and the transport of contaminants through the unsaturated zone to ground water. In addition, these data will be essential for numerical simulation of contaminant transport under infiltration facilities, and for extrapolating field observations to other hydrogeologic settings around the state. Understanding the complex relation between stormwater quality and contaminant transport will provide a science-based rational for satisfying the goals of NR 151 and abiding by the Wisconsin ground-water standards.

This investigation is continuing for at least a year beyond the period of record presented in this summary. Hydrologic and water quality data continue to be collected; interpretations presented here are preliminary. A USGS Water Resources Investigation Report summarizing all collected data is expected to be released in 2005.

Purpose and Scope

This summary presents and interprets hydrologic and water-quality data collected by the USGS and the WDNN. Included in this summary is information on the physical setting of the infiltration basin and its drainage area, information on wells and suction lysimeters installed for the investigation, ground-water and surface-water level data, and water-quality analytical results. Data on transport of contaminants found in stormwater to ground water are presented, and preliminary interpretations are provided.

Hydrogeologic Setting

Site history – At the outset of this investigation a number of potential sites were visited to evaluate their appropriateness for the study. Two sites were identified in Middleton, Wisconsin, that appeared to be good candidates for study. One site failed early on during the study, and, though likely to be repaired, was abandoned. The remaining site, the one that has been monitored during the past two years, is the Stonefield Infiltration Basin located in the Stonefield residential neighborhood (fig. 1) in Middleton, Wisconsin. The infiltration basin at Stonefield was constructed early in the development of the residential neighborhood (approximately 15 years ago). Though most of the homes were constructed in the 1990's, several homes have been completed during the past several years on lots close to the infiltration basin. It is believed that construction has now been completed within the drainage basin.

Stormwater drainage basin – The drainage basin contributing stormwater to the infiltration basin was delineated using aerial photographs supplied by the City of Middleton (Gary Hougth, City of Middleton, Wisconsin, personal comm., 2001), and ground-truthing to determine the precise location of surface water divides, storm sewer inlets and the direction of stormwater flow. This information has been incorporated into a Geographic Information System (GIS) (fig. 2). The area of the drainage basin contributing stormwater to the Stonefield Infiltration Basin is estimated, using the GIS, to be 55.2 acres.

Stormwater outfalls – Stormwater within the neighborhood generally flows from roofs and other impermeable surfaces to the street. Some rain gutters are directed to lawns and gardens, but it is likely that some of the rain falling on pervious areas ends up in the street. Once in the street water flows to stormwater inlets, and then flows through the stormwater sewer to one of three outfalls that feed into the infiltration basin. The largest of the stormwater outfalls is located to the east of the basinjust west of Clovernook Road (fig. 3). This outfall collects runoff from about 47.1 acres, or about 85% of the total area. From this outfall the stormwater flows over a grass spillway about 100 yards to the infiltration basin. A second outfall collects runoff from about 3.8 acres, or about 7% of the total area. This outfall is located on the south side of the infiltration basin(fig. 3), and stormwater flows directly into the basin during events. A third outfall collects runoff from about 1.1 acres, or about 2% of the total area. This outfall is located on the north side of the infiltration basin(fig. 3) and stormwater flows a short distance down a fairly steep incline with sparse vegetation to the basin during stormwater events. The remaining 6% of the total area is the 3.1 acres that drains as overland flow from the areas directly adjacent to the basin.

Infiltration basin - The area of the infiltration basin covered by ponded stormwater during an event is approximately 0.2 acres. This pond area is 1/276 of the area contributing stormwater (55.2 acres).

Injection well – An injection well located in the infiltration basin was a part of the original construction (figs. 3 and 4). This injection well is constructed of a 3-ft diameter concrete culvert installed vertically in the ground. The distance from the top of the injection well to the bottom is about 12 feet. The top of the well is covered with a cast iron grate. Filter fabric was installed under the steel grate to prevent sediment, organic debris, and animals from getting into the injection well. In spring of 2003 this filter fabric was replaced with new fabric installed over top of the grate to minimize the accumulation of sediment and debris, and make it easier to clean – all to preserve the ability of the fabric to allow water to flow into the injection well. In the bottom of the injection well are six, 4-in diameter, perforated pipes that radiate in all directions. The injection well was tested by the City of Middleton in June, 2002, by pumping it full of water, and then observing how the water level dropped. The rate at which the water level was observed to fall suggested that the well is still able to distribute water to the underlying formation at a good rate. The top of the injection well is used as the elevation datum, and is presented as 0.00 feet elevation.

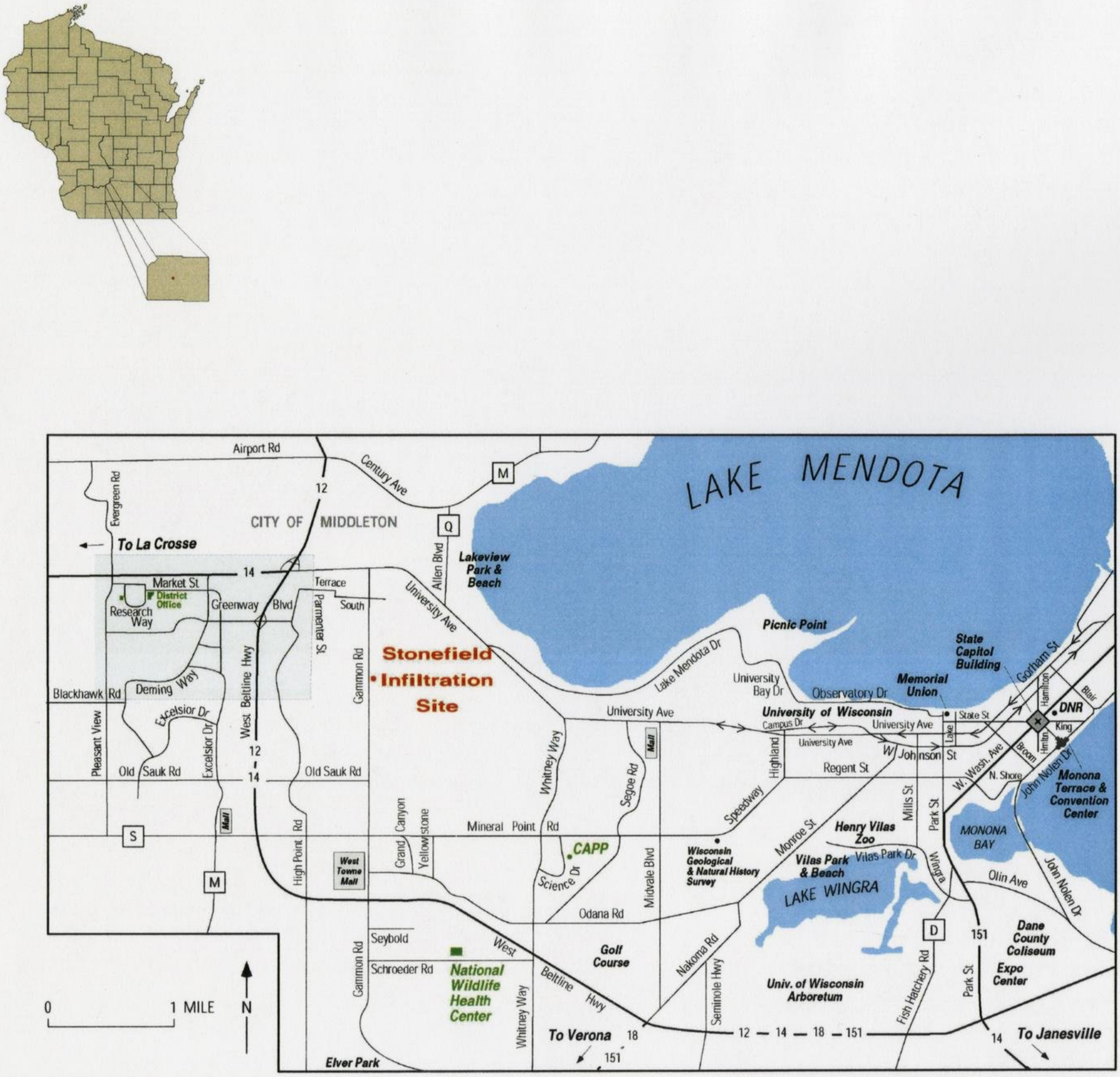

Figure 1. Location of the Stonefield Infiltration Basin in Middleton, Wisconsin

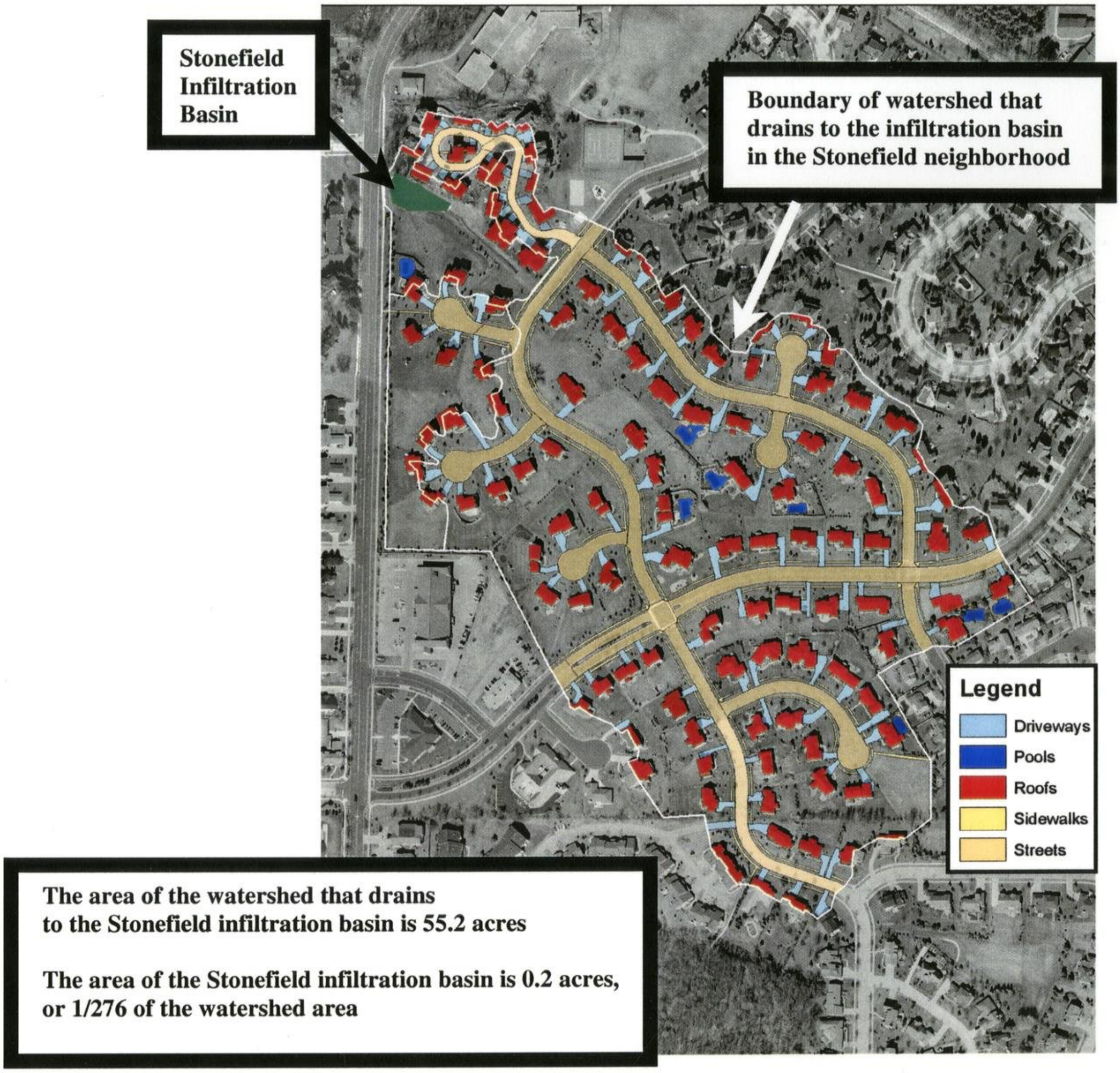

Figure 2. Geographic Information System representation of area contributing stormwater to the Stonefield Infiltration Basin.

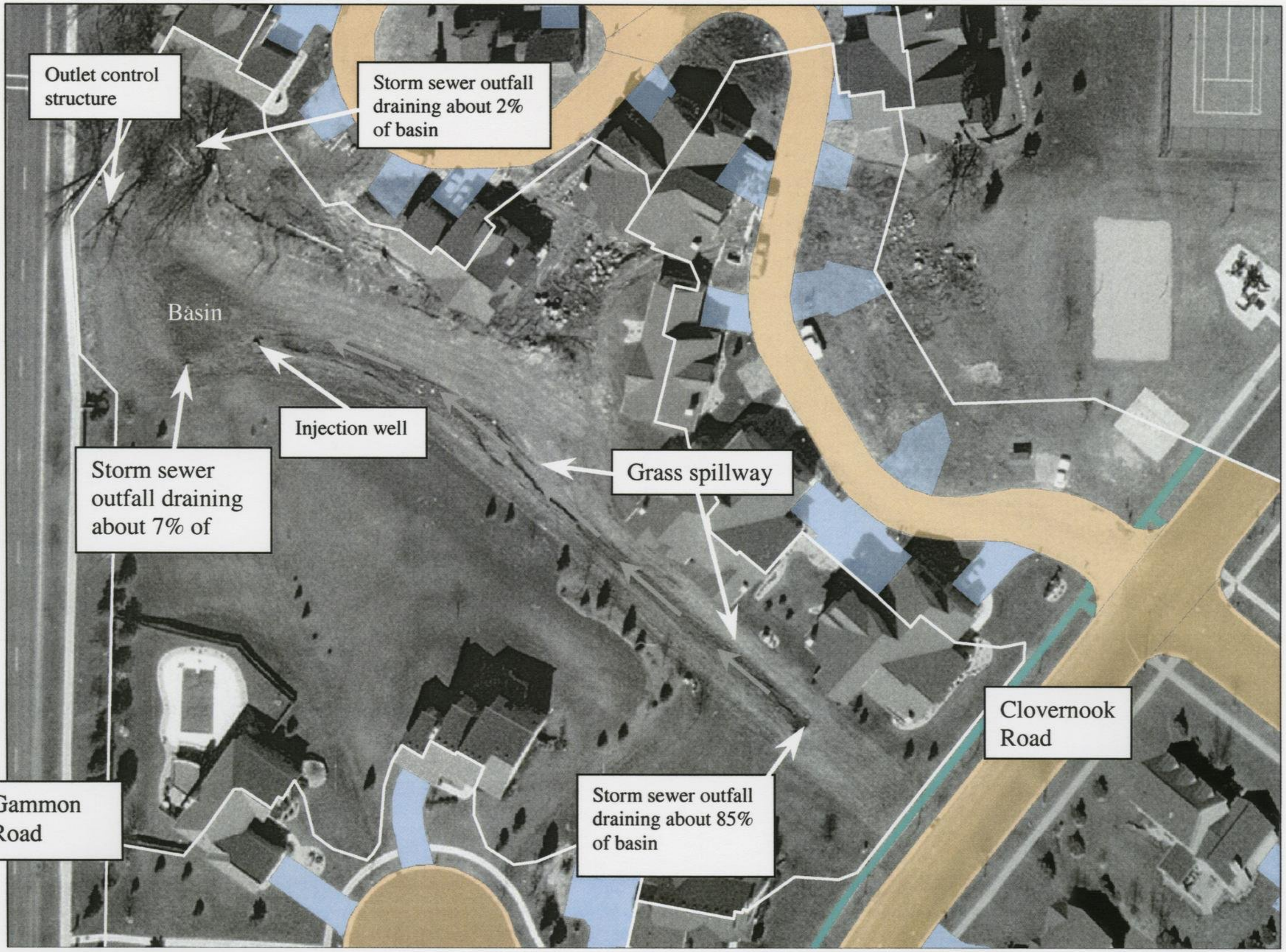

Figure 3. Aerial view of Stonefield Infiltration Basin showing location of sewer outfalls, the outlet structure and the injection well

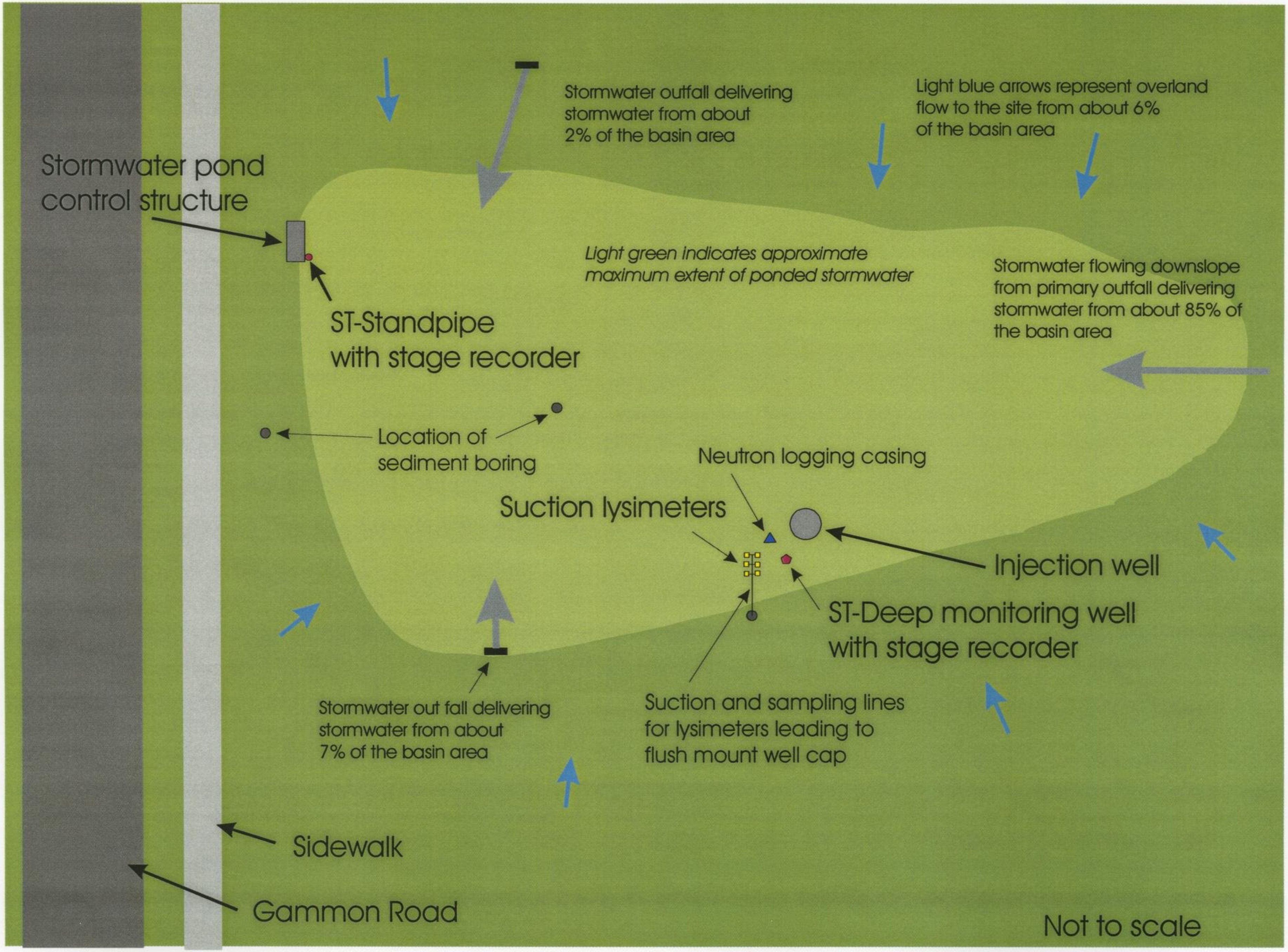

Figure 4. Schematic of plan view at Stonefield infiltration site

Control structure – Located at the northwest corner of the infiltration basin is a control structure that releases ponded stormwater to a stormwater sewer system (figs. 4 and 5). During the early part of the study this control structure was comprised of wooden stop planks set into slots in the concrete walls of the structure. These planks were designed to hold back the stormwater, letting the basin fill and allowing the water to flow over the top plank into the storm water sewer. In reality however, several of the wooden planks would usually float up and away from the control structure, resulting in a variable elevation of the top plank and variable pond stages. In addition, an appreciable amount of water flowed between and around the outside of the planks. During improvements made by the City of Middleton at the infiltration (September, 2002), the planks were replaced with a solid metal, sharp-crested weir. This weir has significantly reduced the leaking of water, and its crest has a constant site elevation of 2.16 feet.

Other improvements include:

- Removal of sediment that had accumulated in the basin bottom over the past decade or so
- Restoration of the original design grade
- Repair of the outfall and buried drain pipe on the grass "spillway" to basin (fig. 3)
- Addition of gaskets to injection well to seal joints and plugging lifting holes to limit flow into the well to that flowing into the top as designed

At the control structure accumulated sediment was removed, lowering the elevation of the basin bottom about 1.5 feet. In addition the elevation of the basin bottom at the injection well was raised several feet, so that now the contour of the slope and basin bottom will direct stormflow past the injection well to the weir until the basin begins to fill up. Though these improvements have altered the characteristics of flow into and out of the basin midway through the investigation, the new configuration will have fewer un-quantifiable sinks for stormflow.

METHODS OF DATA COLLECTION AND ANALYSIS

Changes to Investigative Approach

The approach taken for monitoring the transport of stormwater contaminants from the Stonefield Infiltration Basin to ground water has changed from that of the original proposal, though the objectives and scope of the investigation are the same. The proposal called for the installation of an equilibrium-tension lysimeter to collect water percolating through the vadose zone beneath an infiltration structure. However, early in the investigation the decision was made to abandon the equilibrium-tension lysimeter approach. Instead porous cup suction lysimeters were install at several depths to recover samples from the vadose zone, and multiple water-table monitoring wells were installed to observe the specific relation between stormflow events and the response of the water table. The advantage of this approach is flexibility and simplicity. Adding porous cup lysimeters in response to knowledge gained at the site is relatively cheap and easy. Conversely, once the equilibrium-tension lysimeter were in place it would be cost prohibitive to move. The disadvantage of the new approach is that it will be more difficult to infer with precision the hydrologic balance of stormflow infiltration and/or mass-balance of contaminants than would have been possible with the equilibrium-tension lysimeter

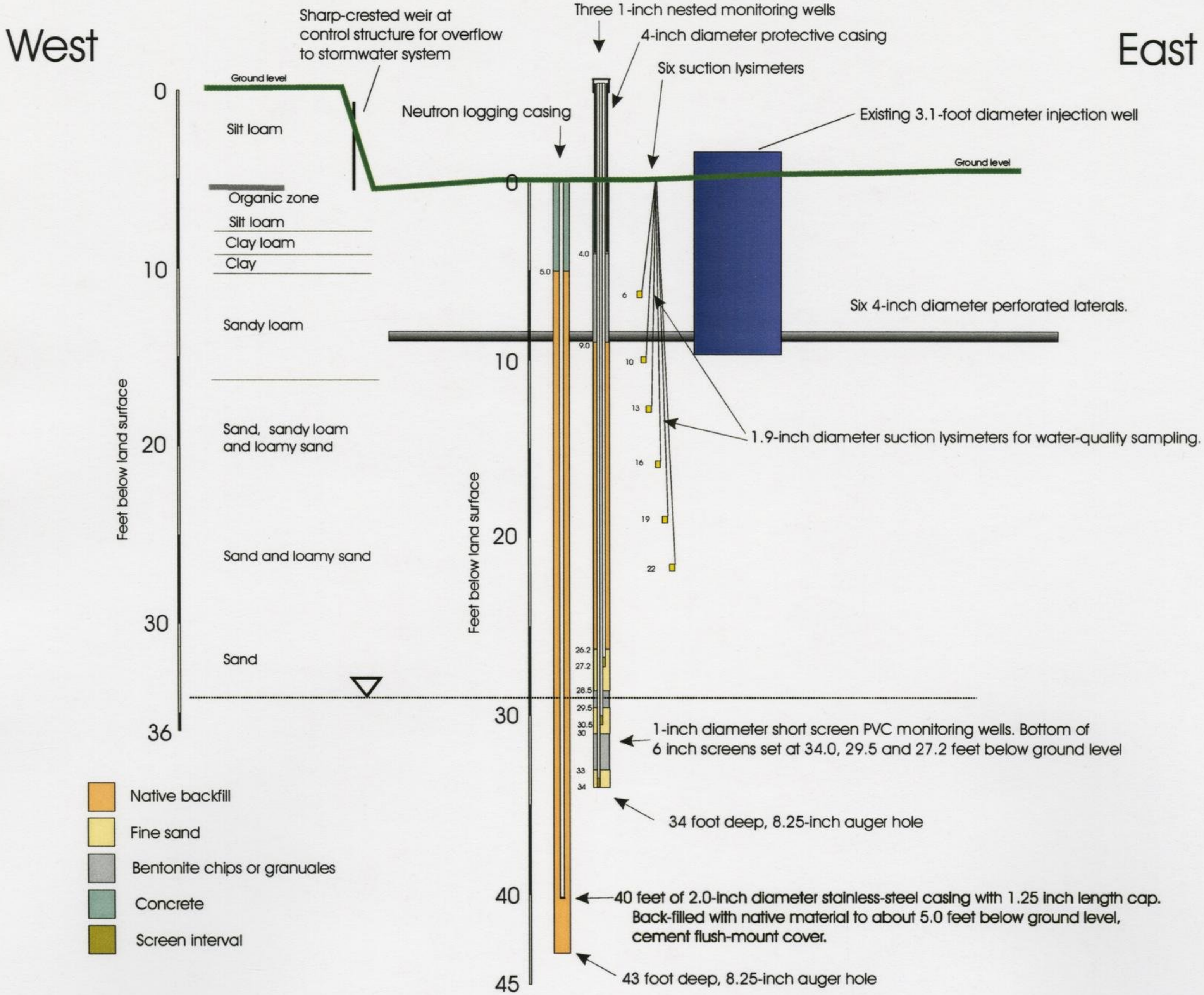

Figure 5. Installations at Stonefield Infiltration Basin

Sediment core

Sediment cores were taken using direct push rigs on two dates, March 8, and August 24, 2002. The March 8 coring operations were conducted on the berm to the west of the infiltration basin (fig. 4 and 5). The site elevation at ground level for this boring is 3.78 feet (above the top of the injection well). Operations ended at 29.5 ft bgl when the equipment could not penetrate any deeper. The August 24 coring operations were conducted with a larger rig that was able to penetrate deeper at the core location on the berm, and also provided a second sediment core in the bottom of the infiltration basin itself. The site elevation at ground level for the boring in the basin bottom is –1.22 feet.

Infiltration capacity

Infiltration capacity was estimated for areas in and around the infiltration basin using a standard double-ring infiltrometer and standard methods from July 2 to August 2, 2002.

Precipitation

Precipitation reported in this summary through July 26, 2002 is National Oceanographic & Atmospheric Administration data for Madison obtained over the internet at http://www.crh.noaa.gov/mkx/climate. Precipitation reported July 27, 2002 and later is data collected at USGS Wisconsin District Office weather station.

Water levels

The infiltration basin fills with ponded stormwater only during a stormwater event, it is otherwise dry. The stage of ponded stormwater was measured by a pressure transducer housed in a 2-in stainless steel screen that was hand-driven into the ground adjacent to the control structure (fig. 4). This installation was completed in early April 2002. Continuous data have been collected beginning April 2002, with the exception of the period of winter freeze. Collection of data continues. This pressure transducer is identified as ST-Standpipe in data tables. The transducer in the standpipe is set at a site elevation of –3.47 feet and the top of the casing is 2.93 feet.

Three 1-in monitoring wells were constructed and nested in a single 8-in augered borehole; installation was completed on January 1, 2003 (figs. 4 and 5). These wells are constructed of pvc, and each has a 6-in length of slotted screen at the bottom. When installed, one screen interval was above the water table, and two were below; these wells are identified as ST-Shallow, ST-Middle, and ST-Deep. The wells are housed in protective casing that stands about 5 ft above ground. Only ST-Deep is instrumented with a pressure transducer, identified as ST-Deep on data tables. Continuous data have been collected from January 2003 through the end of the project; collection of data continues. Periodic steel tape or electric tape measurements have also been taken during this period. The transducer is set at a site elevation of -32.6 feet, and the top of ST-Deep PVC is 5.25 feet.

A reference pressure transducer monitors barometric pressure. The difference between values measured by the reference transducer and ST-Standpipe and ST-Deep represents the pressure due to standing water over the submerged transducers.

Due to concerns about the ability of stormwater to pass through the filter fabric covering the injection well grate, a pressure transducer was placed in the injection well in late May 2003 to measure water levels during events. Data continue to be collected.

Water quality

Water quality samples were collected from ponded stormwater, and from the monitoring well ST-Deep. Samples from these points are designated ST-Pond and ST-Deep respectively. Samples of ponded water were taken by filling bottles near the water's edge on the west bank of the basin. Samples were recovered from ST Deep using a plastic bailer on a nylon line. During each sampling visit, one well-bore volume was bailed and discarded, followed by bailing to recover the sample. On two occasions a bladder pump was used to obtain samples from ST Deep. These samples were analyzed for PAHs, inorganics, and metals.

Suction lysimeters (2 bar porous ceramic cup) were installed at six depths above the water table in order to obtain water-quality samples from the unsaturated zone. Lysimeter installation was done with the use of a direct push rig with rotating head, turning 2-in frost augers. These augers are just slightly larger than the 1.9-in diameter of the lysimeters. The lysimeters are constructed with a porous silica cup at the bottom through which the water passes. To establish a hydraulic connection between the porous cup and the native material, silica flour is placed between the porous cup and the borehole. In this installation, silica flour was mixed with water to form a paste and the paste was applied to the lysimeter porous cup and along the body. This paste was frozen in place on the lysimeter. A hole was augered to the desired depth, and the lysimeter was lowered on its suction and sampling lines to the bottom of the hole. Once in position the lysimeter was allowed to sit for several hours so that the frozen silica paste could thaw. After this, water was poured through a 1-in pipe to the top of the lysimeter to wash the silica flour into place around the porous cup. Native backfill was then added on top of the lysimeter in roughly the order it came out of the hole. Suction and sampling flow lines were run underground up the nearby slope to a flush mounted casing cover (Appendix A).

The lysimeters were installed on three dates, January 13, January 17, and March 13, 2003. On January 13, a lysimeter was installed at a depth of 6.5 feet below the ground surface (bgs); on January 17, lysimeters were installed at depths of 10 and 13 ft bgs, and on March 13, lysimeters were installed at depths of 16, 19, and 22 feet bgs. All lysimeters were installed near the injection well (figs. 4 and 5). These lysimeters are designated ST-6, ST-10, ST-13, ST-16, ST-19, and ST-22.

Neutron logging casing

On December 31, a 2-in stainless steel casing was installed to a depth of 40 ft (figs. 4 and 5) to allow logging with a neutron probe. Neutron logs can be used to estimate the moisture content of the adjacent soils. The casing was set in an 8 in augered hole and backfilled with native material. The casing is protected by a flush mount casing cover. Due to training and access problems, no neutron logging was conducted during this period of study.

STORMWATER HYDROLOGY OF THE STONEFIELD INFILTRATION BASIN

Sediment

Sediments encountered at the berm that borders the basin on the west begin with about 5 ft of soil and silt loam (fig. 5) (Appendix B). An organic zone is found from about 5 to about 6 ft bgl, and silt loam, clay loam and clay to about 12 ft bgl. A pronounced clay and clay loam interval occurs between 8 and 10.3 feet. Sand, sandy loam and loamy sand are found from 10.3 ft to about 24 ft bgl. From 24 ft to 36 ft bgl (total depth) is primarily clean, fine-grained sand. The depth to water at the berm location was measured to be 31.1 bgl (-27.3 ft site elevation).

The core collected in the bottom of the infiltration basin revealed a similar soil profile to a total depth of 12 feet (fig. 5), though with a less pronounced clay layer above the sandy loam and sand (Appendix B).

The soil profile encountered at the Stonefield basin may provide an important test of rules that are part of NR 151. Specifically, rules state that a low permeability layer can be no closer than 3 feet to the bottom of an infiltration feature serving a residential area. The infiltration characteristics of the sediment profile at this site and observation of infiltration of stormwater events will provide some insight into the appropriateness of the proposed rules. Initial surveying by the City of Middleton indicates that the laterals from the base of the infiltration well are at about 9 feet below the bottom of the basin, in an interval of sandy loam. So storms that provide sufficient stormwater to the Stonefield basin to cause flow into the infiltration well, result in water routed to infiltrate below the clay layer.

Infiltration capacity

Stabilized infiltration rates determined using double ring infiltrometer in and around the infiltration basin are from essentially zero to 2.0 inches per hour (Appendix C). These measurements were taken prior to the improvements made to the basin in September, 2002. These data suggests that the basin bottom has lower infiltration rates than the slopes surrounding the basin and the grass alongside the sidewalk along Gammon Road (figs. 3 and 4). The rate of infiltration in the pond bottom is less than 1 inch per hour, and in some places less than 0.1 inch per hour. The preliminary interpretation of these data is that sediment carried in the stormwater over the years has settled in the low areas of the basin and tends to restrict the infiltration of the stormwater. The vegetation found in the basin bottom is largely grass, but perhaps only half the area is vegetated and the rest is bare ground. The infiltration rates for Stonefield are considerably less than rates measured at a stormwater catch basin at the nearby Coach Lite Condominiums that has cattails growing in it. Infiltration rates in condominium basin were measured to be as great as 8.5 inches per hour (Appendix C).

Water levels

Appendix D contains plots showing the stormwater events at the Stonefield Infiltration Basin over the period of record. The plots show the daily precipitation and the site elevation of the stage of ponded stormwater. Apparent on the plots are periods that have experienced frequent rain, and periods that have experienced little rain. Also apparent is a period between early January and late March 2003 during which the standpipe was frozen and no data could be collected. Though snow did accumulate during that period, no stormwater events occurred. The greatest daily precipitation during the period of record is 1.87 inches on April 30, 2003. The greatest pond stage during the period of record is 2.89 feet (site elevation) on October 4, 2003. Twenty times during the period of record the pond stage exceeded a site elevation of 0.00 feet. During these events ponded stormwater overtopped the infiltration well, and assuming the filter fabric would allow, stormwater flowed into the well. Two times since the addition of the metal weir at the outlet structure (September, 2002) the pond stage exceeded the weir crest elevation of 2.16 feet. During these events pond water flowed over the weir to the stormwater sewer system. On four dates prior to the installation of the metal weir, pond stages were likely great enough to flow over the stop planks at the outlet structure. Because the planks would often float out of place and away during events, there is no way to know for sure what the weir crest elevations were during those events. Figures 6 and 7 show the relation between daily precipitation and elevation of ponded stormwater over the period of record. There is a slightly different relation before improvements were made to the infiltration basin in September of

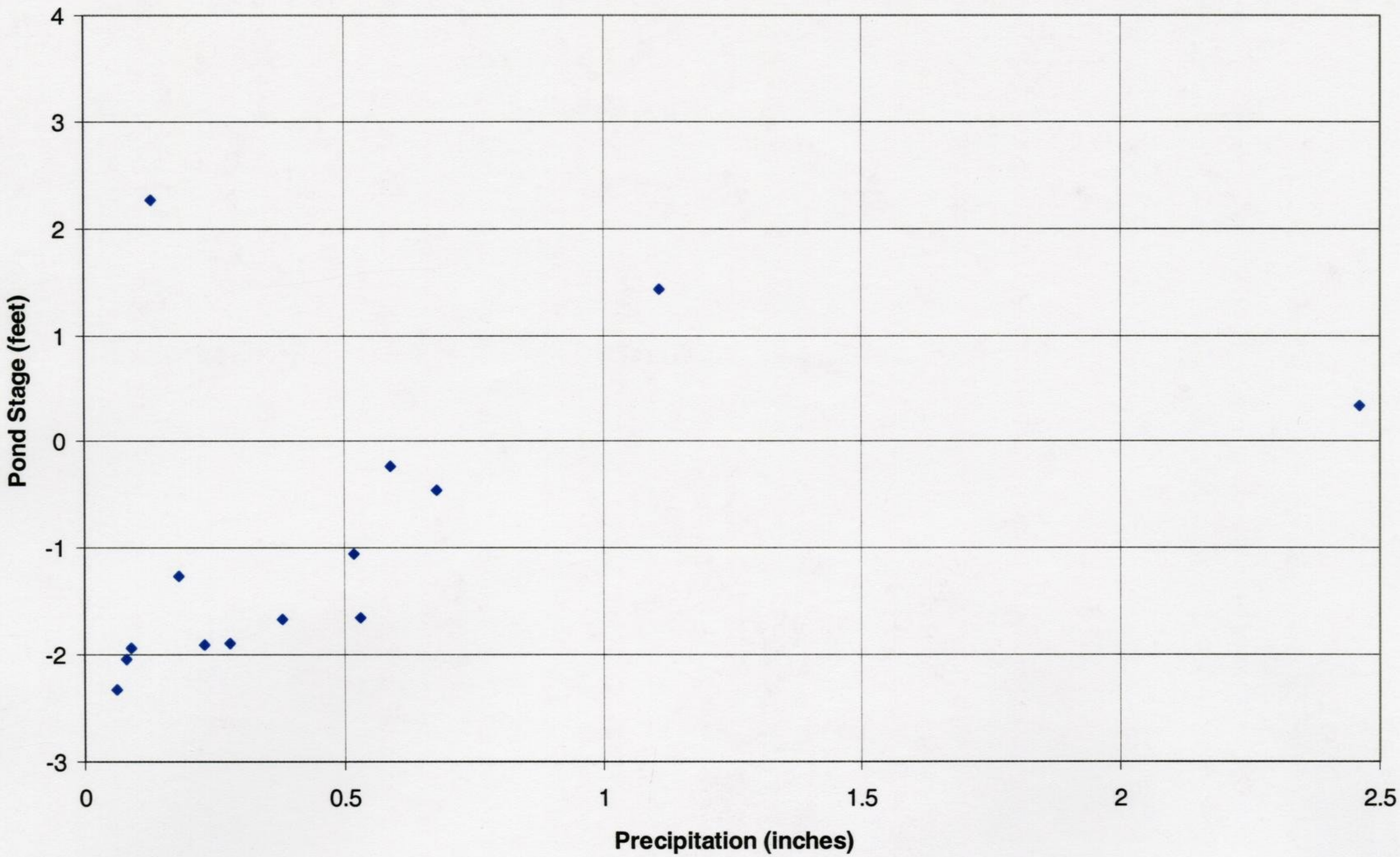

Figure 6. Elevation of ponded stormwater at the Stonefield Infiltration Basin plotted versus precipitation
(Data prior to October 1, 2002)

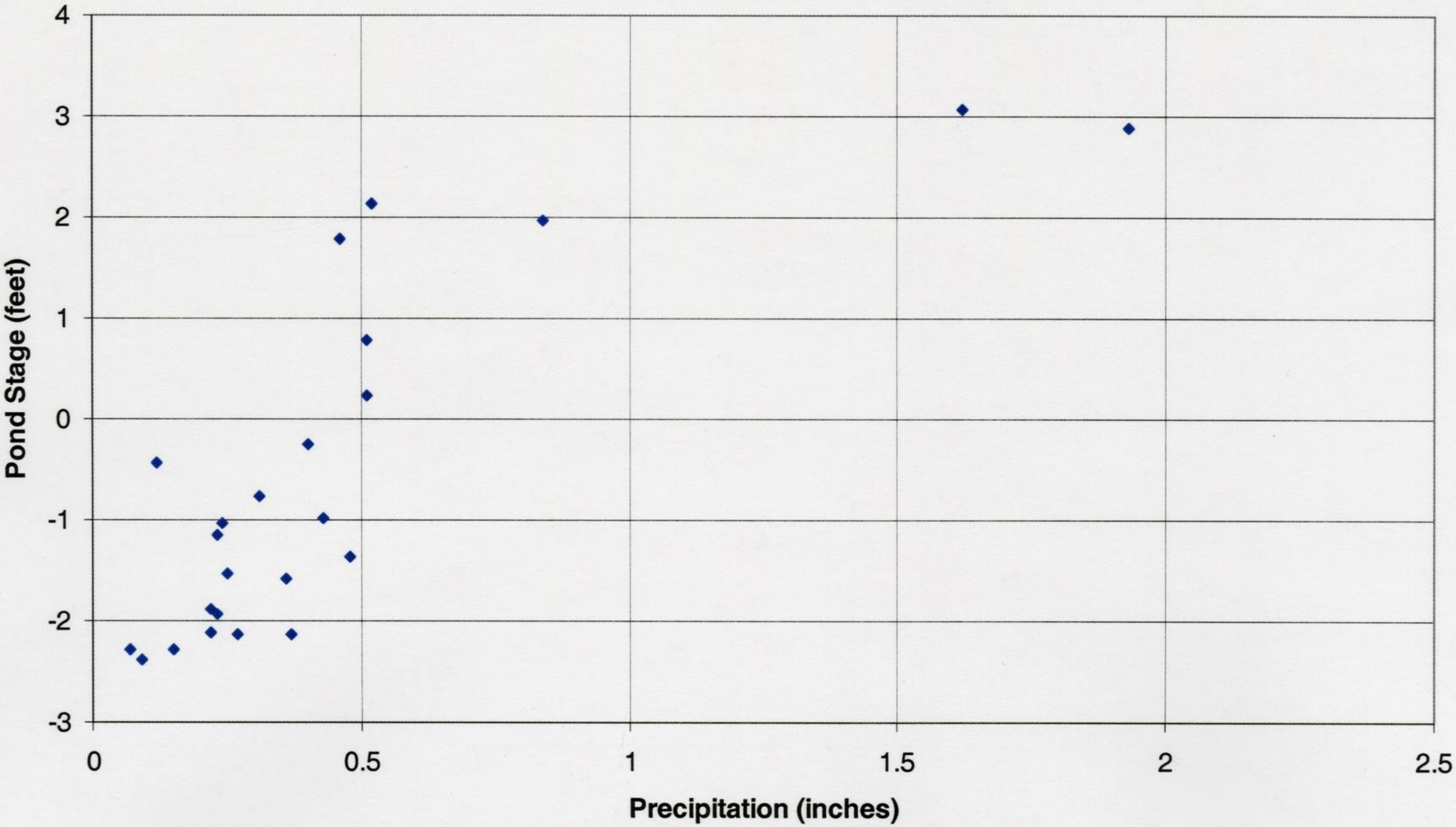

Figure 7. Elevation of ponded stormwater at the Stonefield Infiltration Basin plotted versus precipitation
(Data October 1, 2002 and later)

2002 (fig. 6), compared to the relation following improvements (fig. 7). Following improvements, the depth of ponded stormwater appears to increase more quickly with increasing precipitation. Precipitation in excess of 0.5 in (daily average) is necessary for ponded stormwater to overtop the injection well (fig. 7).

Appendix E contains plots showing the elevation of the water table at the Stonefield Infiltration basin over the period of record. Data show that the elevation of the water table measured in ST-Deep has dropped from -30.00 feet elevation (site datum) on January 25, 2003 to -31.35 feet elevation on July 31, 3003. During this period of record, ponded stormwater overtopped the infiltration well 10 times, and exceeded the weir crest once. The events during which the injection well was overtopped, particularly during periods of more frequent rainfall, appear to have affected the water table elevation. For example, following the general decline in water-table elevation during the winter months of 2003, stormwater events that overtopped the injection well on April 18 and between May 1 and May 11 resulted in a reversal of the decline in water table for a period of time (fig. 8). The decline in water level resumed during the drier period of late May and June. Conversely, there is no strong signal of infiltration through the basin bottom on water-table elevation data collected to date.

Appendix F contains a plot showing the elevation of water in the injection well. This is a qualitative look at whether stormwater is in fact passing through the filter fabric to fill the injection well. Data have been collected for only a short period of time following the relocation of the filter fabric from below the injection well grate to overlying the top. Transducer data show that the injection well is filling during events, though with limited data the relation between pond stage (and duration) and water depth in the injection well is not yet well defined.

Water quality

Sampling for water quality analysis began on August 21, 2002 and continued through the end of the project. Appendix G presents a table showing the sampling dates, locations and constituents that make up the data set for this investigation. Sampling is identified as either routine or event sampling. Routine samples were taken from the water table (ST-Deep) and the suction lysimeter at 19 feet (ST-19) on roughly a weekly basis. Additional samples were taken at these locations during stormwater events, as were samples of ponded stormwater. Lysimeters shallower than ST 19 did not produce any sample, and ST 22 (22 ft bgl) produced sample only rarely. From early May into late June, 2003, there were few event sampling opportunities. From June 20 through June 27, 2003 samples were taken daily to evaluate very short-term variations in water quality. While analyses have been conducted on only a few blanks and duplicates to date, additional quality-assurance/quality-control procedures are planned. Appendix H presents the ranges of concentration measured for each constituent for samples taken for all sampling points. This is to provide a basis for broadly comparing the concentrations of stormwater, of the unsaturated zone, and the water table.

Water-quality of stormwater at the Stonefield Infiltration Basin

Table 1 summarizes the range of concentrations for constituents measured in stormwater at the Stonefield Infiltration Basin (ST Pond), and compares these ranges to measured values elsewhere in Wisconsin and Michigan.

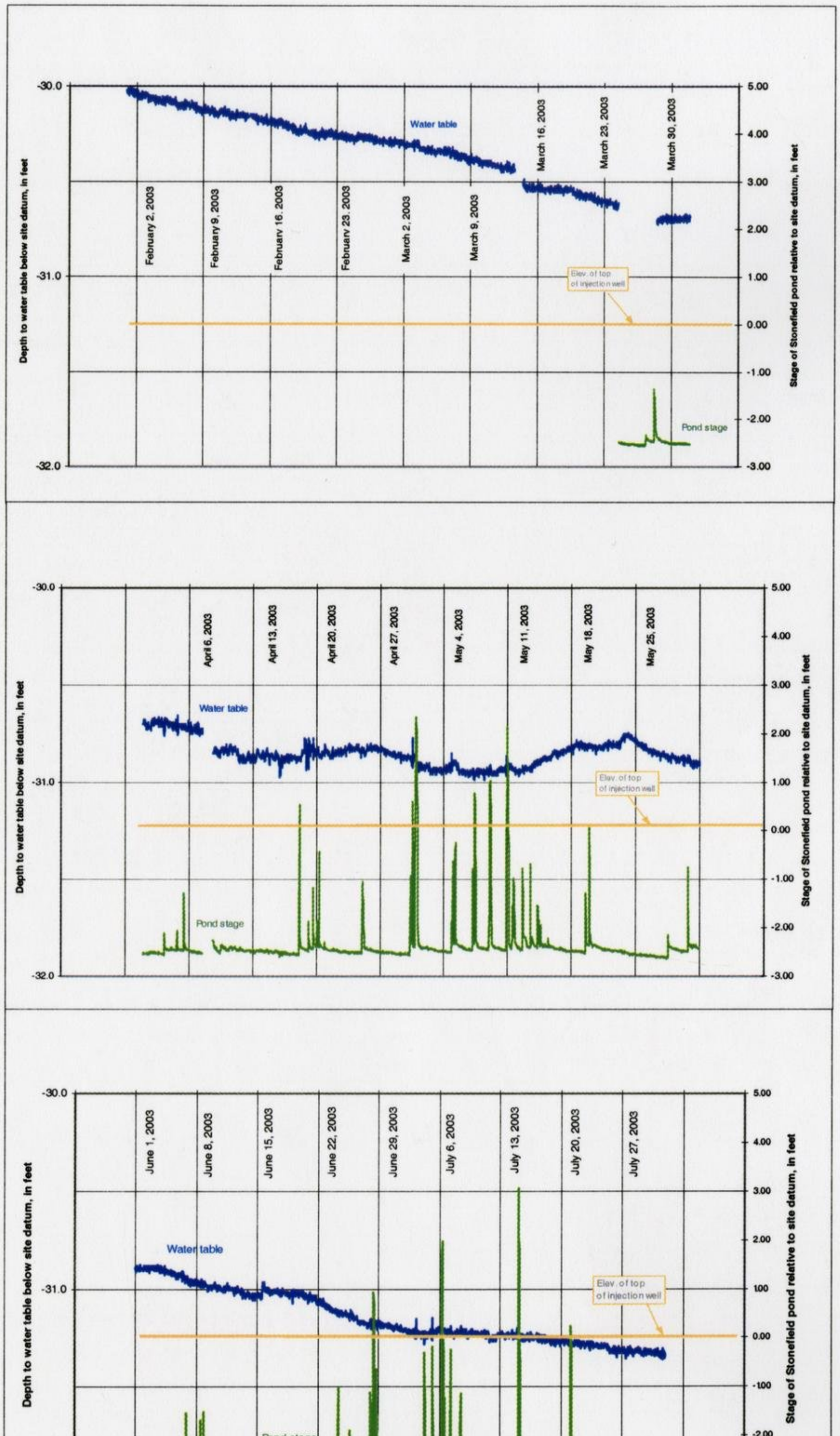

Figure 8. Depth to water table and stage of Stonefield pond (relative to site datum)

Table 1. Summary of chemical analysis of stormwater in Wisconsin (Bannerman and others, 1996) and Negaunee, Michigan (Steuer and others, 1996), and from the Stonefield Infiltration Basin (ST Pond). [ND, not detected; -, not reported; --, not analysed]

Constituent	Units	ST Pond		Bannerman and others, 1996 [1]		Steuer and others, 1996 [2]	
		Range	Median	Range	Median	Range	Median
Alkalinity whole FET	mg/L	1-113	32	2-149	34.5	7-25	16
Cadmium Dissolved	μg/L	-	-	-	-	-	-
Calcium Total Recoverable	mg/L	4-71	10.6	-	-	2.0-23	5.9
Calcium Dissolved	mg/L	4-52	9.25	-	-	-	-
Chlorides Dissolved	MEQ/L	1-206	14.2	<0.01-1000	10	1.8-997	4.2
Chromium Total Recoverable	μg/L	ND-2	ND	<3-90	7	-	-
Chromium Dissolved	μg/L	ND-1	ND	-	-	-	-
Copper Total Recoverable	μg/L	7-16	11	<3-210	18	12-50	17
Copper Dissolved	μg/L	7-14	8.1	<3-33	5	-	-
Hardness as $CaCO_3$	mg/L	11-251	34	-	-	-	-
Hardness Total Recoverable	mg/L	25-121	39.6	3-900	51	7-73	20
Hardness Dissolved	mg/L	24-107	33.7	<6-220	26	-	-
Iron Total Recoverable	mg/L	ND-2	0.45	-	-	-	-
Iron Dissolved	mg/L	ND-1	0.2	-	-	-	-
Lead Total Recoverable	μg/L	ND-2	1.1	<1-570	24	4-36	9
Lead Dissolved	μg/L	ND	ND	<1-13	<3	-	-
Magnesium Total Recoverable	mg/L	1-31	4.05	-	-	<1-4	<2
Magnesium Dissolved	mg/L	1-24	2.95	-	-	-	-
Manganese Total Recoverable	μg/L	38-181	57.5	-	-	-	-
Manganese Dissolved	μg/L	31-166	48.5	-	-	-	-
PH		6.8-8.2	7.03	5.6-8.1	7.3	6.2-6.8	6.5
Potassium Total Recoverable	mg/L	3-14	6.5	-	-	-	-
Potassium Dissolved	mg/L	4-12	5.5	-	-	-	-
Sodium Total Recoverable	mg/L	1-135	12.1	-	-	-	-
Sodium Dissolved	mg/L	3-142	10	-	-	-	-
Solids Total	mg/L	54-692	182	<10-2810	256	20-2000	100
Solids Suspended	mg/L	3-268	35	<2-1850	120	4-324	34
Specific Conductance	micro siemans /cm	38-1120	168	-	-	-	59
Zinc Total Recoverable	μg/L	ND-49	18	<10-1500	150	38-150	65
Zinc Dissolved	μg/L	ND-27	ND	-	70	-	-

Constituent	Units	ST Pond		Bannerman and others, 1996 [1]		Steuer and others, 1996 [2]	
		Range	Median	Range	Median	Range	Median
Acenaphthene	μ g/L	ND-ND	ND	<0.05-6	<3.4	<3.4	<3.4
Acenaphthylene	μ g/L	ND-ND	ND	<0.05-.27	0.075	<8.2	<8.2
Anthracene	μ g/L	ND-ND	ND	<0.12-19	.23	<0.12	<0.12
Benzo (A) Anthracene	μ g/L	ND-ND	ND	<0.003-23	0.9	.0070-.041	0.014
Benzo (A) Pyrene	μ g/L	ND-.15	ND	<0.002-16	1.3	<0.012-.065	0.019
Benzo (B) Fluoranthene	μ g/L	ND-0.12	ND	<0.045-23	1.4	.018-.12	0.039
Benzo (G,H,I) Perylene	μ g/L	ND-0.11	0.0475	<0.047-15	1	.019-.11	0.041
Benzo (K) Fluoranthene	μ g/L	ND - ND	ND	<0.003 4-14	0.88	.008-.055	0.020
Chrysene	μ g/L	ND-0.079	0.025	<0.023-24	1.4	<0.023-.055	0.030
Dibenzo (A,H) Anthracene	μ g/L	ND-ND	ND	-	-	<0.005 4	<0.005 4
Fluoranthene	μ g/L	ND-0.18	0.06	<0.009-88	3.2	.060-.22	0.11
Fluorene	μ g/L	ND-ND	ND	<0.5-7	<0.6	<0.60	<0.60
Indeno (1,2,3-C, D) Pyrene	μ g/L	ND-ND	ND	<0.02-17	1.4	<0.020-.14	0.078
1-Methylnaphthalene	μ g/L	ND-0.047	ND	-	-	-	-
2-Methylnaphthalene	μ g/L	ND-0.066	ND	-	-	-	-
Naphthalene	μ g/L	ND-0.043	ND	-	-	<10	<10
Phenanthrene	μ g/L	ND-0.098	0.0395	<0.17-52	1.6	<0.17	<0.17
Pyrene	μ g/L	ND-0.12	0.044	<0.007-66	1.8	.052-.16	0.11

[1] Table 7, Summary statistics for event mean concentrations of constituents with detection frequencies of at least 10 percent at Wisconsin storm-sewer-monitoring sites.

[2] Table 1, Contaminant concentrations in stormwater, Michigan sites. Concentration ranges for Negaunee, Michigan, having similar size (58.2 acres) and land use (71% residential, 15% streets, 4.8% open spaces, and 6% institutional/miscellaneous) as the watershed for the Stonefield Infiltration Basin.

In all cases, concentration ranges in samples from the Stonefield Infiltration Basin fall within the ranges reported by Bannerman (1996) (table 1). Comparison to stormwater sampled from Negaunee, Michigan (an area having similar size [58.2 acres] and land use [71% residential, 15% streets, 4.8% open spaces, and 6% institutional/miscellaneous] as the watershed for the Stonefield infiltration basin) finds generally similar ranges (Steuer, 1996). Copper, iron, and lead are found in relatively low concentrations in the Stonefield stormwater. Zinc is found in somewhat greater concentrations, but still on the low end of ranges reported in Bannerman (1996) and Steuer (1996). PAH concentrations in Stonefield stormwater are found to be about the same order of magnitude as found in Negaunee, Michigan. By comparison the high end of the PAH range reported by Bannerman (1996) is significantly greater than either Stonefield or Negaunee. The Bannerman data includes commercial and industrial sites, so the higher PAH concentrations defining the upper bound of the range is not unexpected.

Water-quality of vadose water and ground water at the Stonefield Infiltration Basin

Table 2 summarizes the range of concentrations for constituents in ground water and the unsaturated zone at the Stonefield Infiltration Basin (ST Deep and ST 19) compared to reported values in sand and gravel aquifers across Wisconsin.

Table 2. Summary of chemical analysis of ground water in Wisconsin (Hindall, 1979; Kammerer, 1981) and at the Stonefield Infiltration basin (ST Deep), and of water from the vadose zone at the Stonefield Infiltration basin (ST 19). [ND, not detected; -, not reported; --, not analysed]

Constituent	Units	ST Deep	ST 19	Hindall, 1979	Kammerer, 1981
					Mean
Alkalinity whole FET	mg/L	355-398	355-398	-	-
Cadmium Dissolved	μg/L	--	89	ND-7	-
Calcium Total Recoverable	mg/L	93-266	96-177	ND-245	68
Calcium Dissolved	mg/L	78-120	86-174	-	-
Chlorides Dissolved	MEQ/L	23-241	183-588	ND-170	8
Chromium Total Recoverable	μg/L	5-26	ND -1	-	-
Chromium Dissolved	μg/L	2-5	ND	-	-
Copper Total Recoverable	μg/L	6-22	5-24	ND-180	-
Copper Dissolved	μg/L	6-15	5-21	-	-
Hardness as $CaCO_3$	mg/L	346-418	325-475	-	246
Hardness Total Recoverable	mg/L	459-586	394-758	-	-
Hardness Dissolved	mg/L	426-532	356-741	-	-
Iron Total Recoverable	mg/L	ND -8	ND	ND-17,100	-
Iron Dissolved	mg/L	ND	ND	-	
Lead Total Recoverable	μg/L	ND -16	ND	-	2714
Lead Dissolved	μg/L	ND -1	ND	-	-
Magnesium Total Recoverable	mg/L	48-142	37-77	ND-100	33
Magnesium Dissolved	mg/L	38-59	34-74	-	-
Manganese Total Recoverable	μg/L	8-306	ND -4	-	119

Constituent	Units	ST Deep	ST 19	Hindall, 1979	Kammerer, 1981
					Mean
Manganese Dissolved	μ g/L	4-19	ND -3	-	-
pH		7.3-8.1	7.5-8.2	-	-
Potassium Total Recoverable	mg/L	6-7	5-8	ND-42	2
Potassium Dissolved	mg/L	4-6	5-7	-	-
Sodium Total Recoverable	mg/L	23-77	154-184	ND-110	-
Sodium Dissolved	mg/L	22-75	50-178	-	-
Solids Total	mg/L	167-15,400	848-1,090	-	4
Solids Suspended	mg/L	7-13200	5-20	-	
Specific Conductance	micro siemans /cm	794-1,430	1,390-2,360	-	-
Zinc Total Recoverable	μ g/L	ND -245	18-165	-	-
Zinc Dissolved	μ g/L	ND -78	ND -82	-	-
Acenaphthene	μ g/L	ND	--	-	-
Acenaphthylene	μ g/L	ND	--	-	-
Anthracene	μ g/L	ND	--	-	-
Benzo (A) Anthracene	μ g/L	ND	--	-	-
Benzo (A) Pyrene	μ g/L	ND	--	-	-
Benzo (B) Fluoranthene	μ g/L	ND	--	-	-
Benzo (G,H,I) Perylene	μ g/L	ND	--	-	-
Benzo (K) Fluoranthene	μ g/L	ND	--	-	-
Chrysene	μ g/L	ND	--	-	-
Dibenzo (A,H) Anthracene	μ g/L	ND	--	-	-
Fluoranthene	μ g/L	ND	--	-	-
Fluorene	μ g/L	ND	--	-	-
Indeno (1,2,3-C, D) Pyrene	μ g/L	ND	--	-	-
1-Methylnaphthalene	μ g/L	ND	--	-	-
2-Methylnaphthalene	μ g/L	ND	--	-	-
Naphthalene	μ g/L	ND	--	-	-
Phenanthrene	μ g/L	ND	--	-	-
Pyrene	μ g/L	ND	--	-	-

Ion and metal concentrations in ground water at the Stonefield basin are found to fall within the range of concentrations reported for the sand and gravel aquifer in Wisconsin (Hindall, 1979). However, ion concentrations at Stonefield are generally on the high side of each constituent range. Conversely, the metal concentrations in ground water at the Stonefield basin are found to be generally on the low side of the reported concentration ranges for the sand and gravel aquifer in Wisconsin. PAH's were not detected in ground water at the Stonefield Infiltration basin.

A comparison of stormwater, vadose water, and ground water at the Stonefield Infiltration Basin

Stormwater (ST Pond), vadose water (ST 19), and ground water (ST Deep) have similar ranges of pH at the Stonefield Infiltration Basin (tables 1 and 2). Specific conductance values of all mirror the chloride concentrations. ST 19 has the highest range of specific conductance values (1,390-2,360 microsiemens/cm); ST Deep range is similar (794-1,430 microsiemens/cm), though slightly greater than ST Pond (38-1120 microsiemens/cm). Metal concentrations are low relative to reported ranges (Bannerman, 1996; and Steuer, 1996). Copper concentration ranges are similar, though ST 19 has highest values (5-24 μg/L). Iron and lead concentrations are very low; ST Deep has the highest values of both these constituents (Non Detect [ND] -8 μg/L iron, ND-16 μg/L lead). Zinc concentrations are the greatest among the metals, with ST Pond (ND-49 μg/L) having concentrations lower than either ST 19 (18-165 μg/L) or ST Deep (ND-245 μg/L). Total recoverable manganese concentrations were greatest in ST Deep (8-306 μg/L), next highest in ST Pond (38-181 μg/L), and lowest in ST 19 (ND-4 μg/L). Dissolved manganese is the only constituent that was measured in greater concentrations in ST Pond (31-166 μg/L) than either ST 19 (ND-3 μg/L) or ST Deep (4-19 μg/L).

Vadose and ground water at the Stonefield basin have an appreciably greater concentration of total and suspended solids, compared to stormwater (tables 1 and 2). The solids concentrations and generally higher metals concentrations in ground water raised concerns about turbulence created using a bailer to sample from the monitoring well. However, analyses of samples recovered from the monitoring well using a bladder pump (low-flow, less disruptive method) show no appreciable difference in constituent concentration. In addition, concentrations of many constituents measured in ST 19 are similar to concentrations in ground water, even though ST 19 samples are filtered through the porous cup as the sample collects in the lysimeter. This argues for the observed differences in concentrations between stormwater, vadose water, and ground water to be real.

Appendix H presents the concentration of constituents plotted by their date of sampling. These plots will help identify any relation between the chemistry of the ponded stormwater, and chemistry of the vadose water and the ground water. Measured concentrations show variation through time, relating to stormwater events and perhaps seasonal effects. The concentration of calcium in ST Deep and ST 19 are fairly consistent over the week of daily sampling conducted during the end of June, 2003. Other constituents also show this consistency, though may vary over a greater range at other times. These constituents include magnesium, potassium, and sodium. Sodium concentrations in ST Deep and ST 19 tend to increase together, though ST 19 has the greater concentration. As mentioned before, specific conductance values mirror closely variations in chloride concentration. Chloride concentrations in stormwater appear to be at their greatest during spring snowmelt and early spring rains. This is also reflected in higher concentrations in ST 19, though ST 19 concentrations are consistently greater than the highest concentration in stormwater. Because so many of the measured constituents are found in greater concentrations in the vadose water and ground water, it is difficult to identify specific effects of the infiltration of stormwater. Continued evaluation of site hydrology and water chemistry will help quantify the transport of contaminants and establish whether there is in fact any concern with infiltration of stormwater with constituent concentrations lower than that found in the unsaturated zone or ground water.

SUMMARY

Hydrology – Data collected during this investigation suggest that infiltration of ponded stormwater through the pond bottom does occur, but probably at a fairly modest rate (between 0.1 and 1 inch per hour). It is most likely that stormwater will be introduced to the unsaturated zone through the injection well. Data demonstrate that when ponded stormwater overtops the injection well, water flows into the well infiltrating into permeable sediments below a shallow clayey interval and has a measurable effect on the water-table elevation. Conversely, there is no strong signal of infiltration through the basin bottom on water-table elevation data collected to date. Changes made to the infiltration basin and surrounding area by the City of Middleton midway in the study introduced a measurable change on the relation between precipitation and the stage of ponded stormwater. Currently, precipitation in excess of 0.5 inch (daily average) is necessary for ponded stormwater to overtop the injection well. Hydrologic data continue to be collected, and quantifying the complex inflows to, and outflows from, the infiltration basin is a focus of the ongoing work. Data collected will be used to model the volumes of stormflow that infiltrate through the pond bottom, flow to the injection well, and flow over the weir during a variety of stormwater events.

Water chemistry - The chemistry of stormwater at the Stonefield Infiltration Basin is consistent with reported values in Wisconsin and Michigan, reflecting the chemistry of precipitation plus metals and PAH constituents from residential land use within the Stonefield watershed. Major ion chemistry of ground water at the Stonefield basin is consistent with that of the sand and gravel aquifer of Wisconsin, though generally at the higher end of the concentration ranges. In addition, ground water and vadose zone water have appreciably higher solids concentrations and generally higher metals concentrations than the stormwater. These data are believed to be representative because they have been confirmed by samples collected from the monitoring well with the use of a low-flow method, and because samples of vadose zone water are collected through the porous cup of the suction lysimeters. PAH's are present in stormwater, but are not found in vadose or ground water at the site. Some interesting trends in water quality are becoming apparent, however, with less than a year of sampling complete, further analysis of current and pending water quality data will be needed to quantify transport of contaminants from stormwater to ground water at the Stonefield Infiltration Basin. This is an active, ongoing project and the preliminary interpretations presented here will almost certainly evolve.

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Appendices A through I are available by request from:

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