About this Project
The Stormwater Solutions for Ohio project evaluated bioretention and permeable pavement performance on poorly draining soils at 6 sites. The permeable pavement and bioretention cell at the Orange Village annex building were among the stormwater control measures (SCMs) monitored. The information gathered through this project is being used to improve design guidance and stormwater policies at the state and local level.

In 2009, Orange Village purchased a property adjacent to their Village Hall and Fire Department. The existing buildings were renovated for use as offices for the service department, a community room, and a transfer facility for electronic and hazardous household waste. This site drains to Willey Creek, a coldwater habitat tributary to the Chagrin River. The cul-de-sac style driveway was built of permeable interlocking concrete pavers (PICP), and a small swale and a pipe conveys roof runoff from the building’s roof to a bioretention cell. The project team monitored the hydrologic performance of the PICP installation and the bioretention cell.

Design
Because of concerns about the high water table present during the first round of infiltration tests, two 6 inch diameter curtain drains were installed beneath the SCMs to dewater the groundwater table at the site. The final design included a large permeable paver cul-de-sac and driveway and a bioretention cell. The site required substantial regrading to deliver water to the bioretention cell.

The PICP system included a minimum of 23 inches of aggregate. The cross-section was underlain by a geogrid at the interface with the in situ soils, which was covered by 2 inches of sand. On top of the sand was 15 – 21 inches of #1 and #2 stone, with 6 inches of #57 stone forming the next level, and 2 inches of #8 stone forming the bedding course for the pavers. The designer incorporated a 6 inch sump (internal water storage [IWS] zone) by raising the 6 inch diameter underdrain above the bottom of the subgrade. The subgrade of this system was sloped slightly away from the buildings to prevent seepage toward the foundations.

Construction
A general contractor coordinated and completed most of the construction, but the permeable paver and curb installations were performed by specialist subcontractors. The paving installer was ICPI (Interlocking Concrete Pavement Institute) certified and experienced with installing pavers.

Site Evaluation
The existing conditions were typical of other redevelopment properties in northern Ohio with highly disturbed soils, primarily consisting of fill from prior construction activity onsite mixed with or covering the native Wadsworth Silt Loam soil. This made evaluation of drainage and infiltrative capacity difficult. The first series of soil infiltration tests yielded very poor results (0.01, 0.00, 0.01 in/hr). Standing water in two deeper test pits likely reflected a significant amount of rainfall (> 5 inches) in the week prior to testing. A second series of tests performed during excavation for the permeable pavement system in July (about 7 months later) produced highly variable results ranging from 0.01 to 1.54 in/hr, and no standing water was present in the test pits. The stark contrast between testing results indicated that the fill material and native soils have different infiltration rates and that preferential pathways for drainage are likely.

The design engineer included a 6 inch ponding depth in the bioretention cell. From the surface, the bioretention cell cross-section consisted of 3 inches of double shredded hardwood mulch, 30 inches of bioretention soil media, 3 inches of #8 limestone, and 12 inches of #57 stone. An upturned elbow in the underdrain provided a 3 inch IWS zone.

All underdrains and the curtain drains tied into one large precast circular vault accessible by a single manhole.
The first tasks were to demolish the existing pavement, and excavate soil where the PICP, bioretention area, and swale were installed. An abandoned septic tank was discovered under the PICP cul-de-sac that was not recorded on any site documentation. The tank was first examined to make sure that it was not in use, and then it was pumped dry and removed.

Although the construction plans specified “double washed angular stone,” unwashed stone was delivered and accepted for construction. In addition to being covered in stone dust (which could reduce the infiltration rate of the native soil), the #57 stone was river run gravel, which could lead to differential settling, rutting, or other long term performance issues. Angular aggregate should always be utilized in permeable pavement construction to ensure proper stone-to-stone contact. Additionally, the #57 stone was initially installed before curb installation, but was subsequently removed, temporarily stored nearby, and washed before being reinstalled after curb installation. The concrete curbs were installed along the driveway by a subcontractor while a separate crew continued to work on construction of the bioretention cell. To prepare for paver installation, a bedding course of #8 limestone aggregate was spread and graded. Next, Eco-Optiloc pavers were installed using a Probst VM-series “PaverMAX” mechanical paver installation system. The machine was used to install the vast majority of the parking lot, but pavers abutting curbs needed to be manually cut to size. The cul-de-sac design was aesthetically pleasing, but required a lot of manual work for contractors since nearly every paver next to a curb had to be cut with a saw. The increased labor associated with such designs will likely increase construction costs.

The bioretention soil was mixed onsite. It consisted of 60% sand, 40% topsoil, 8% clay/silt, and 2% organics. The design plans simply stated “bioretention soil mix,” which is not enough detail to ensure that soil media matches the Ohio Rainwater and Land Development Manual specifications. Following installation of the bioretention cell, a silt fence was erected to help protect the practice from sediment from the cut slopes. The silt fence used to protect the bioretention cell failed, and a 3 inch layer of sediment settled on the surface of the bioretention media. This was corrected by removing the sediment and regrating the bioretention area. Mulch was then placed on top of the media. Observations of drawdown after storm events showed that drawdown of the bowl of the bioretention cell was occurring within 12 hours (as required by the Ohio Rainwater and Land Development Manual), meaning that the removal of the clogging layer was successful.

Monitoring
North Carolina State University (NCSU) installed three v-notch weirs in the precast concrete vault to monitor outflow from the permeable pavement, bioretention cell, and curtain drains. Weirs were constructed so that they could be installed on the curved walls of the vault. In addition, long PVC pipes and rope were used to develop a means for calibrating and deploying water level loggers without requiring confined space entry into the deep manhole each time the data were downloaded. Another v-notch weir was used to measure outflow from the drainage swale, which was co-located at the inlet to the bioretention cell. Due to a construction mistake, water table monitoring wells were not installed at this site. This prevented the use of the data for monitoring simulations in SWMM and DRAINMOD. NCSU measured surface infiltration rates of the PICP every 3 months at five established locations: in a parking stall, under a tree, two locations near the entry drive, and a location in the cul-de-sac. Surface infiltration rates were measured over the first 1.5 years of the pavement life.

Because the curtain drains dewatered a larger area than the SCMs, it was difficult to calculate the total water balance for the SCMs. Since the curtain drains lie beneath the PICP and the bioretention cell, exfiltration from these practices may be routed to the curtain drains during or after the storm. Given this caveat, over 98% of the inflow left the permeable pavement system as exfiltration or evaporation. No runoff was observed during the monitoring period, suggesting that surface infiltration rates were still quite high after one year of operation. Tests indicated that surface infiltration rates were at least 400 in/hr after 1.5 years of operation, indicating that the pavement was still functioning as designed. No surface defects or structural problems were observed after this period, including after two winters of plowing after snowfall.

All rainfall received at minimum filtration, providing reduction of sediment to Willey Creek. The longer flow path for water to reach the storm sewer, as well as interactions with the aggregate and the soil beneath the pavement resulted in temperature reduction as the water passed through the pavement. This, combined with exfiltration observed from the PICP, resulted in major reductions in thermal load.