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STATE OF MICHIGAN
IN THE SUPREME COURT

DETROIT ALLIANCE AGAINST THE RAIN TAX, a voluntary unincorporated association, and DETROIT IRON AND METAL CO., AMERICAN IRON & METAL CO., MCNICHOLS SCRAP IRON & METAL CO., MONIER KHALIL LIVING TRUST, and BAGLEY PROPERTIES, LLC, individually, and on behalf of similarly situated persons,

Plaintiffs-Appellants,

v.

CITY OF DETROIT, a municipal corporation, the DETROIT WATER AND SEWERAGE DEPARTMENT, and the DETROIT BOARD OF WATER COMMISSIONERS,

Defendants-Appellees.

Supreme Court Case No. 158852

Court of Appeals Case No. 339176

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APPENDIX TO

PLAINTIFFS-APPELLANTS' (AMENDED) REPLY TO DEFENDANTS-APPELLEES' ANSWER TO THEIR ARGUMENT ON THE APPLICATION FOR LEAVE

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Exhibit A, "Roads and Freeways in Metropolitan Detroit"

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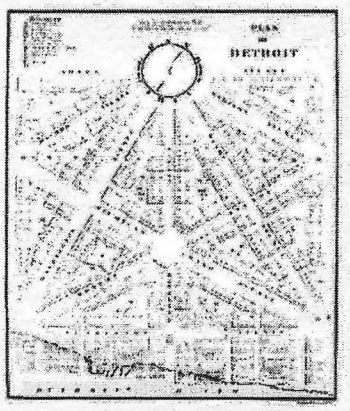
Roads and freeways in metropolitan Detroit

The **roads and freeways in metropolitan Detroit** comprise the main thoroughfares in the region. The freeways consist of an advanced network of interconnecting freeways which include Interstate highways. The Metro Detroit region's extensive toll-free freeway system, together with its status as a major port city, provide advantages to its location as a global business center.[2] There are no toll roads in Michigan.[3]

Detroiters may refer to freeways by the formal name more often where one has been designated rather than route number. Other freeways without formal names are known by the number such as I-275 and M-59. M-53, while not officially designated may be locally referred to by its name "Van Dyke". Detroit area freeways are typically sunken below ground level to permit local traffic to pass over the freeway and for appearance.[4]

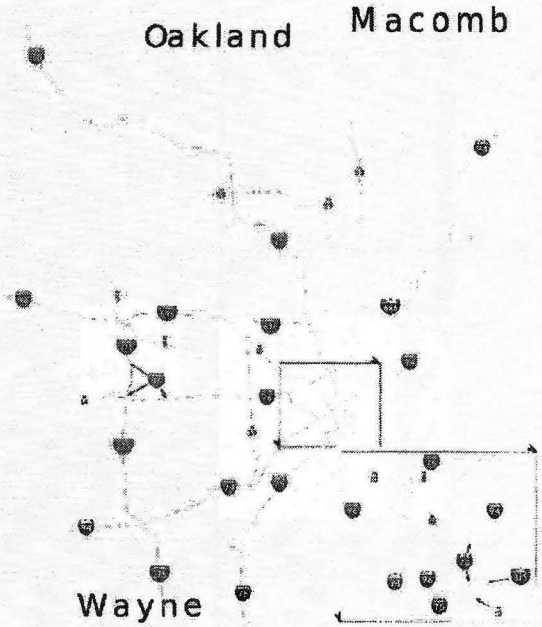


Augustus Woodward's plan following the 1805 fire for Detroit's baroque styled radial avenues and Grand Circus Park.

Following a historic fire in 1805, Judge Augustus B. Woodward devised a plan similar to Pierre Charles L'Enfant's design for Washington, D.C.. Detroit's monumental avenues and traffic circles fan out in a baroque styled radial fashion from Grand Circus Park in the heart of the city's theater district, which facilitates traffic patterns along the city's tree-lined boulevards and parks.[5] The 'Woodward plan' proposed a system of hexagonal street blocks, with the Grand Circus at its center. Wide avenues, alternatively 200 feet (61 m) and 120 feet (37 m), would

Roads and Freeways in Metropolitan Detroit

Highway markers for I-75 and M-10



Map of Detroit Metro Area freeways

System information

Formed	1805[1]

Highway names

Interstates	Interstate nn (I-nn)
US Highways	US Highway nn (US nn)
State	M-nn

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emanate from large circular plazas like spokes from the hub of a wheel. As the city grew these would spread in all directions from the banks of the Detroit River. When Woodward presented his proposal, Detroit had fewer than 1,000 residents. Elements of the plan were implemented. Most prominent of these are the five main "spokes" of Woodward, Michigan, Gratiot, Grand River and Jefferson Avenues.

System links

Michigan State Trunkline Highway System

Interstate · US · State · Byways

The **Mile Road System** in Metro Detroit and Southeast Michigan facilitates ease of navigation in the region. It was established as a way to delineate east–west roads through the Detroit area and the surrounding rural rim. The Mile Road system, and its most famous road, 8 Mile Road, came about largely as a result of the Land Ordinance of 1785, which established the basis for the Public Land Survey System in which land throughout the Northwest Territory was surveyed and divided into survey townships by reference to a baseline (east–west line) and meridian (north–south line). In Southeast Michigan, many roads would be developed parallel to the base line and the meridian, and many of the east–west roads would be incorporated into the Mile Road System.

The Mile Road System extended easterly into Detroit, but is interrupted, because much of Detroit's early settlements and farms were based on early French land grants that were aligned northwest-to-southeast with frontage along the Detroit River and on later development along roads running into downtown Detroit in a star pattern, such as Woodward, Jefferson, Grand River, Gratiot, and Michigan Avenues, developed by Augustus Woodward in imitation of Washington, D.C.'s system. As Detroit grew, several Mile Roads were given new names within the city borders, while some roads incorporated as part of the Mile Road System have traditionally been known by their non-mile names. It is unclear if they ever bore mile numbers formally.

The baseline used in the survey of Michigan lands runs along 8 Mile Road, which is approximately eight miles directly north of the junction of Woodward Avenue and Michigan Avenue in downtown Detroit. As a result, the direct east–west portion of Michigan Avenue, and M-153 (Ford Road) west of Wyoming Avenue, forms the "zero mile" baseline for this mile road system.

The precise point of origin is located in Campus Martius Park, marked by a medallion[6] embedded in the stone walkway. It is situated in the western point of the diamond surrounding Woodward Fountain,[7] just in front of the Fountain Bistro (http://www.campusmartiuspark.org/amen_cafe.htm).

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Exhibit A, "Roads and Freeways in Metropolitan Detroit"

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Freeways

- I-75 (known as the Walter P. Chrysler Freeway from Downtown Detroit to Pontiac in the north and Fisher Freeway though southern and central Detroit) is the region's main north–south route, serving Flint (and points north to Sault Ste. Marie), Pontiac, Troy, and Detroit, before continuing south (as the Detroit-Toledo and Seaway Freeways) to serve the Downriver communities and further south, many of the communities along the shore of Lake Erie, most notably Toledo, Ohio before continuing to Florida.
- I-94 (Edsel Ford Freeway & Detroit Industrial Freeway) runs east–west through Detroit and serves Ann Arbor to the west (where it continues to West Michigan and Chicago) and Port Huron to the northeast. The stretch of the current I-94 freeway from Ypsilanti to Detroit was one of America's earlier limited-access highways. Henry Ford built it to link his factories at Willow Run and Dearborn during World War II. It also serves the North Access to the Detroit Metro Airport in Romulus. A portion was known as the Willow Run Expressway.
- I-96 runs east–west through Livingston, Oakland and Wayne counties and has its eastern terminus in downtown Detroit. The portion east of I-275 is known and signed as the Jeffries Freeway, named for Edward Jeffries (a former mayor of Detroit); however, this portion of I-96 was officially renamed by the state legislature as the Rosa Parks Memorial Highway in December 2005.[8]
- I-275 runs north–south from I-75 in the south to the junction of I-96 and I-696 in the north, providing a bypass through the western suburbs of Detroit. Originally intended to travel north 23

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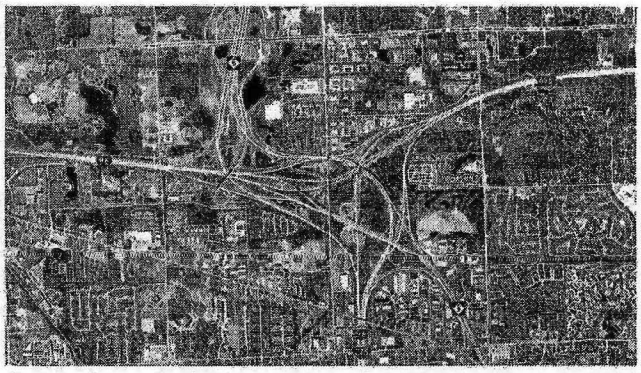
miles (originally as I-275 and later changed to M-275) from the I-696/I-96/I-275/M-5 junction to the I-75/US 24 (Dixie Hwy.) junction in Waterford Twp., where I-75's median was significantly widened in its initial construction to accommodate the future interchange. The planned M-275 has essentially been scrapped, with the northward extension of M-5 utilizing the original M-275 right-of-way but terminating after just six miles at Pontiac Trail in West Bloomfield.

- I-375 is a short spur route in downtown Detroit, an extension of the Chrysler Freeway.
- I-696 (Walter P. Reuther Freeway) runs east–west from the junction of I-96 and I-275 on the west to I-94 on the east, providing a route through the northern suburbs of Detroit. Taken together, I-275 and I-696 form a beltway around Detroit. The Lodge Freeway was previously designated a Business Spur of I-696 before it was redesignated as part of US 10 and later as M-10.
- M-5 This freeway begins as the stub left over from the Brighton-Farmington Expressway after Interstate 96 was rerouted to the Jeffries. Originally designated as I-96 and later as an extension of M-102. From 1994 to 2002, it was extended north as the Haggerty Connector.[9]
- M-8 is the Davison Freeway. Opened in 1942, this was the first modern depressed limited-access freeway in America. Originally supposed to run as a freeway from I-96 east to Mound Rd. and then north to join the already-existing M-53 freeway at Van Dyke Ave. in Sterling Heights. In 1996, the Davison was closed for a year and a half to reconstruct it to Interstate Highway standards with an additional through travel lane and a wider left shoulder for improved safety and traffic handling as well as a new interchange with Woodward Avenue. The reconstructed freeway was reopened 18 months later on October 8, 1997
- M-10 (John C. Lodge Freeway) runs largely parallel to I-75 from Downtown Detroit to

View of southbound lanes of Northwestern Highway in Metro Detroit passing beside John C. Lodge Freeway M-10 which is sunken below street level in front of the Southfield Town Center



Satellite image of the terminus at I-275 nicknamed the "mixing bowl"

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Wyoming Ave., where it turns northwesterly and largely maintains this trajectory through the I-696/Telegraph Rd. interchange in Southfield and then continues as a surface boulevard as Northwestern Highway, terminating at Orchard Lake Rd. in Farmington Hills.

- M-14 runs east–west from I-275 in Livonia to Ann Arbor.
- M-39 (Southfield Freeway) runs north–south from Southfield to Allen Park. North of 9 Mile Road and south of I-94, the freeway ends and continues as Southfield Road into Birmingham and Ecorse respectively.
- M-53 (Christopher Columbus Freeway from Sterling Heights to Washington), more commonly known as the Van Dyke Expressway or Van Dyke Freeway. Continues as Van Dyke Road or Van Dyke Avenue north to Port Austin and south through Warren to Gratiot Avenue in Detroit.
- M-59 (Veterans Memorial Freeway from Utica to Pontiac), continues east as Hall Road to Clinton Township and west as Huron Road through Pontiac and Waterford, and as Highland Road further west through Highland and Milford to I-96 near Howell. Originally intended to be a limited-access freeway between US 23 on the west and I-94 on the east.

Other selected major roads

- M-102 (8 Mile Road), known by many through the film *8 Mile*, forms the dividing line between Detroit on the south and the suburbs of Macomb and Oakland counties on the north. Outside of Detroit it is also known as Base Line Road, because it coincides with the baseline used in surveying Michigan; that baseline is also a boundary for several other Michigan counties. 8 Mile is designated as M-102 for much of its length in Wayne County. For several years the M-102 designation continued from its current terminus at Grand River Ave. and followed the old I-96 freeway to the I-96/I-696/I-275 interchange; this stretch, along with the rest of Grand River southeast to Downtown Detroit, is now signed as M-5. The portion of M-102 from Grand River Avenue east to M-3 (Gratiot Avenue) is designated as the "Columbus Memorial Highway".
- M-3 (Gratiot Avenue) is a major road that runs from Port Huron to downtown Detroit.
- Jefferson Avenue is a scenic highway whose northern leg runs between M-10 in Downtown Detroit along the Detroit River and Lakes St. Clair to New Baltimore. The portion is also the principal thoroughfare for the Grosse Pointes, where it is called Lake Shore Drive. Another important dividing line between Detroit and the city of Grosse Pointe Park is Alter Road, where portions of some intersecting streets have been reconfigured or walled-off in order to thwart vehicular and pedestrian movement from Detroit into Grosse Pointe Park. As a major thoroughfare, Jefferson's southern leg (sometimes designated as Biddle Rd. in some Downriver communities) runs from Dearborn St. in Detroit south (again, running mostly adjacent to the Detroit River) to a point just north of Huron River Dr. in Newport, where its name changes to U.S. Turnpike Rd. and then Dixie Hwy., (both segments of which parallel the Lake Erie shoreline) to terminate in Monroe. In Detroit north of Dearborn St., Jefferson is reduced to two-lane road that is disjointed at Clark St. It resumes one block north at Scotten St. as a side street north to 21st St. (at the Ambassador Bridge over-crossing), at which point a gate frequently prevents traffic from proceeding. From 21st St. to Rosa Parks Blvd., Jefferson is largely unpaved. And between Rosa Parks and M-10, Jefferson is a four lane road, although this segment is not nearly utilized as much as the portion north of M-10. The portion of Jefferson between the Rouge River over-crossing and Rosa Parks Blvd. is heavily industrial and bucks the avenue's otherwise consistent

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Exhibit B, "List of State Trunkline Highways in Michigan"

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List of state trunkline highways in Michigan

The **state trunkline highways in Michigan** are the segments of the State Trunkline Highway System maintained by the Michigan Department of Transportation and numbered with the "M-" prefix officially.

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State Trunkline Highway System

Highway markers from different years for former M-12 (1919), former M-7 (1926), former M-76 (1948), and current M-28

System information

Maintained by MDOT

Length	5,976.147 mi[3] (9,617.676 km) Plus 14.775 mi [3] (23.778 km) of special routes and 24.079 mi [3] (38.751 km) of unsigned connectors
Formed	May 13, 1913,[1] signed by July 1, 1919[2]
Highway system	
State	M-nn
Special Routes:	Alternate M-nn (Alt. M-nn or M-nnA) Business M-nn (Bus. M-nn) Bypass M-nn (Byp. M-nn) Connector M-nn (Conn. M-nn) Truck M-nn (Truck M-nn)
Auxiliary routes	

Michigan State Trunkline Highway System

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Exhibit B, "List of State Trunkline Highways in Michigan"

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Mainline highways

Number	Length (mi)[3]	Length (km)	Southern or western terminus	Northern or eastern terminus	Formed	Removed	Notes
M-1	21.488	34.582	Adams Avenue in Detroit	BL I-75/Bus. US 24 in Pontiac	1970[4]	current	Woodward Avenue
M-2	—	—	Never assigned		—	—	May have been assigned to service drives along I-96 in Livonia, but not marked on official state maps as such
M-3	7.807	12.564	US 25 in Detroit	US 16 in Detroit	1937[5]	1939[6]	Became M-39 (now Schaefer Highway)
M-3	27.081	43.583	M-10 & BS I-375 in Detroit	I-94 and M-29 in Chesterfield Township	1973[7]	current	Gratiot Avenue
M-4	—	—	St. Ignace	DeTour Village	1936[8]	1939[9]	Became M-39, now M-134
M-4	4.687	7.543	Southfield	West Bloomfield Township	1979[10]	1986[11]	Northwestern Highway; now part of M-10
M-5	—	—	Cedarville	Sault Ste. Marie	1933[12]	1939[13]	Became M-129
M-5	27.890	44.885	Pontiac Trail in Commerce Township	Cass Avenue in Detroit[14]	1977[15]	current	Grand River Avenue
M-6	—	—	Phoenix	Eagle River	1926[16]	1938[17]	Became M-111 (now part of M-26)
M-6	—	—	I-96 in Novi	I-94 in Roseville	1970	1979[18]	Signed along the service drives for the eastern section of I-696[19]
M-6	19.696	31.698	I-196 near Hudsonville	I-96 near Cascade	2001[20]	current	Paul B. Henry Freeway, South Beltline Freeway
M-7	34.059	54.813	Three Rivers	Coldwater	1927[21]	1940[22]	Replaced by M-86
M-8	5.491	8.837	I-96 in Detroit	Conant Avenue near Hamtramck	1993[23]	current	Davison Freeway; built in the 1940s as the first urban, depressed freeway in the world
							Replaced by M-64 (became M-129,

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Exhibit B, "List of State Trunkline Highways in Michigan"

M-31	166.910	268.616	M-21 in Port Huron	M-20 in Bay City	1919[26]	1926[16]	(this section now M-25) and M-83 (this section now M-142)
M-32	100.003	160.939	M-66 in East Jordan	US 23 in Alpena	1919[26]	current	
M-33	121.858	196.111	I-75 in Alger	M-27 near Cheboygan	1919[26]	current	
M-34	28.938	46.571	M-99 near Osseo	Bus. US 223 in Adrian	1919[26]	current	
M-35	128.388	206.620	US 41 in Menominee	US 41/M-28 in Negaunee Township	1919[31]	current	
M-36	—	—	M-21 in Attica	M-53 in Burnside	1919[26]	1930[35]	
M-36	43.298	69.681	US 127 in Mason	US 23 in Whitmore Lake	1930[35]	current	
M-37	221.892	357.101	I-94 & BL I-94 in Battle Creek	Cul-de-sac at Old Mission Point	1919[26]	current	
M-38	—	—	US 23 in Bridgeport	M-53 in Marlette	1919[26]	1961[41]	
M-38	42.225	67.955	US 45 & M-64 in Ontonagon	US 41 in Baraga	1968[42]	current	Formerly part of M-35
M-39	—	—	Woodbury	Lansing	1919[26]	1937[43]	Became an extension of M-43
M-39	7.807	12.564	US 25 in Detroit	US 16 in Detroit	1939[44]	1959[45]	
M-39	17.006	27.369	Lafayette Boulevard in Lincoln Park	M-10 in Southfield	1959[45]	current	Southfield Freeway, Southfield Highway; roadway continues as Southfield Road at northern end
M-40	74.266	119.520	Union	Holland	1919[26]	current	
M-41	38.1	61.3	M-24 in Holton	M-11 in Hart	1919[26]	1926[16]	Replaced in part by M-20, now M-120
M-42	10.339	16.639	Bus. US 131 in Manton	M-66 near Lake City	1919[26]	current	
M-43	136.723	220.034	BL I-196 in South Haven	I-96 in Webberville	1919[26]	current	
M-44	37.463	60.291	M-11 and M-37 in Kentwood	M-66 near Ionia	1919[26]	current	
M-45	—	—	Wisconsin border south of Kingsford	Humboldt Township	1919[31]	1934[46]	Renumbered to M-95 because of designation of US 45 in Michigan
M-45	24.434	39.323	US 31 in Agnew	I-196 in Grand Rapids	1964[47]	current	Lake Michigan Drive

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Exhibit B, "List of State Trunkline Highways in Michigan"

M-85	21.882	35.216	I-75 near Rockwood	Detroit	1956[73]	current	Fort Street
M-86	—	—	Six Lakes	Remus	1921[74]	1924[60]	Replaced by M-66
M-86	—	—	Orleans	Woods Corners	1924[60]	1929[24]	Replaced by M-44
M-86	34.059	54.813	Bus. US 131/M-60 in Three Rivers	US 12 near Coldwater	1940[22]	current	Replaced M-7
M-87	11.564	18.610	Bus. US 23 in Fenton	US 10 in Holly	1919[26]	1960[75]	
M-88	26.215	42.189	US 31 in Eastport	US 131 & C-38 in Mancelona	1919[26]	current	
M-89	61.153	98.416	I-196/US 31 near Ganges	BL I-94 in Battle Creek	1919[26]	current	
M-90	16.553	26.639	M-45 near Sagola	Foster City	1919[31]	1927[21]	Replaced by M-69
M-90	44.178	71.098	M-24 near North Branch	M-25 in Lexington	1927[21]	current	
M-91	—	—	M-15 in Menominee, Michigan	Cedar River	1919[31]	1927[21]	Replaced by M-35
M-91	—	—	US 23 in Rogers City	CR 646 near Huron Beach	1927[21]	1940[76]	Replaced by US 23
M-91	24.464	39.371	M-44 near Belding	M-46 in Lakeview	1942[77]	current	
M-92	36.639	58.965	SR 109 near Clinton	US 12 in Stockbridge	1919[26]	1962[78]	Replaced by M-52
M-93	11.810	19.006	Camp Grayling	Hartwick Pines State Park	1919[26]	current	
M-94	86.983	139.986	M-553 near K.I. Sawyer	US 2 in Manistique	c. 1927[21]	current	
M-95	5.147	8.283	M-68 in Onaway	Onaway State Park	1919[26]	1934[79]	Replaced by M-211
M-95	55.162	88.775	CTH-N at Aurora, WI	US 41/M-28 in Humboldt Township	1934[46]	current	Leif Erickson Highway; replaced M-45
M-96	33.379	53.718	BS I-94 in Kalamazoo	BL I-94 in Marshall	1926[16]	current	
M-97	17.169	27.631	M-3 in Detroit	M-59 near Mount Clemens	1929[80]	current	
M-98	16.2	26.1	US 2 near Germfask	M-28 near McMillan	1919[31]	1960[81]	Now H-33 and H-44
M-99	—	—	US 31 in Muskegon	Hart	1919[26]	1929[24]	
M-99	—	—	US 2 in Gulliver	Port Inland	1931[32]	1939[82]	
M-99	86.058	138.497	SR 15 near Pioneer, OH	I-496 & Capitol Loop in Lansing	1940[25]	current	Replaced M-9

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Exhibit B, "List of State Trunkline Highways in Michigan"

M-100	12.460	20.052	I-69 near Potterville	I-96 near Grand Ledge	1927[21]	current	
M-101	1.22	1.96	Millersburg	US 23 near Millersburg	—	—	
M-102	20.804	33.481	M-5 on the Livonia–Farmington Hills city line	I-94 in Harper Woods	c. 1928[56]	current	8 Mile Road
M-103	—	—	SR 13 near Bristol, IN	US 12 in White Pigeon	1932[83]	c. 1960[84]	Replaced by US 131
M-103	3.055	4.917	SR 15 near Bristol, IN	US 12 in Mottville	c. 1960[84]	current	Replaced part of US 131
M-104	—	—	M-47 at Pittsburg	DeWitt	1927[21]	1939[85]	
M-104	7.677	12.355	US 31 in Ferrysburg	I-96 near Nunica	1940[86]	current	Replaced part of US 16
M-105	3.548	5.710	M-53 near Bad Axe	M-83 near Elkton	1928[56]	1939[87]	
M-106	27.041	43.518	BL I-94/Bus. US 127/M-50 in Jackson	M-36 near Gregory	1928[56]	current	
M-107	9.576	15.411	Lake of the Clouds	M-64 in Silver City	1935[88]	2008[89]	
M-108	—	—	Three-legged highway in Mackinaw City		1928[56]	1957[90]	Connected the State Highway Ferry Docks with the Fort Michilimackinac State Historic Park and US 31
M-108	1.069	1.720	I-75 near Mackinaw City	Michigan Welcome Center in Mackinaw City	1960[91]	2010[92]	
M-109	6.831	10.993	M-22 near Empire	M-22 in Glen Arbor	c. 1929[24]	current	Leelanau Scenic Heritage Route; runs through the Sleeping Bear Dunes National Lakeshore
M-110	1.715	2.760	US 31 in Parkdale	Orchard Beach State Park	1927[93]	2003[94]	
M-111	—	—	Bay City	Bay City State Park	1928	1938	
M-111	—	—	Phoenix	Eagle River, Michigan	1939	1940	
M-112	8.70	14.00	Ypsilanti	Dearborn	1942[95]	1956[96]	Replaced by I-94
M-113	16.573	26.672	M-37 near Hannah	US 131 in Walton Junction	1927[21]	current	
							Former bypass routing around Grand Rapids;

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Exhibit B, "List of State Trunkline Highways in Michigan"

Connector 3	0.724	1.165	I-75 & I-375 in Detroit	M-3 in Detroit	1968[234]	current	Part of the Fisher Freeway without a posted highway number; previously Connector 8[231]
Connector 5	0.836	1.345	M-5 in Farmington Hills	I-696 in Farmington Hills	1964[235]	current	Connector ramp between I-696 and M-5 in the I-96/I-275/I-696/M-5 interchange
Connector 13	2.414	3.885	I-75/US 23 in Monitor Township	M-13 in Monitor Township	1967[198]	current	Signed as Conn. M-13; previously Connector 14[231]
Connector 24	2.379	3.829	US 24 in Brownstown Township	I-75 in Brownstown Township	1973[236]	current	Part of Dix–Toledo Highway; labeled "I-75 connector" on state maps; previously part of US 25 and later Connector 3[231]
Connector 25	0.265	0.426	BL I-69/BL I-94 in Port Huron	M-25 in Port Huron	1973[237]	current	Labeled "I-94 connector" on state maps; previously part of US 25[237] and later Connector 13[231]
Connector 30	0.629	1.012	I-94 in Roseville	M-3 in Roseville	1963[238]	current	Previously Connector 10[231]
Connector 34	0.366	0.589	M-34 in Adrian	US 223 in Adrian	2003[239]	current	Industrial Drive
Connector 44	4.185	6.735	I-96/M-37 in Plainfield Township	M-44 in Plainfield Township	1969[213]	current	Signed as Conn. M-44
Connector 58	0.557	0.896	M-58 in Saginaw	I-675 in Saginaw	1971[59]	current	Part of Hill Street and Michigan Avenue
Connector 69	0.935	1.505	Lapeer Road in Port Huron Township	I-94/I-69 in Port Huron Township	1966[240]	current	Labeled as "Lapeer Connector" on maps; replaced M-146;[240] previously Connector 9[231]
Connector 75	2.992	4.815	I-75 in Erie Township	M-125 in Erie Township	1956[241]	current	Replaced part of US 24A;[241] previously Connector 2[231]
Connector 85	0.219	0.352	M-85 in Detroit	I-75 on the Detroit–Melvindale city line	1956[242]	current	Schaefer Highway
			I-96 in Watertown	I-69 in Watertown			Connector in the

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Exhibit B, "List of State Trunkline Highways in Michigan"

Connector 96	2.365	3.806	Township	Township	1984[243]	current	I-96/I-69 interchange
Connector 102	0.201	0.323	M-10 in Detroit	M-102 on the Detroit–Southfield city line	1963[244]	current	Part of Greenfield Road and Greenlodge Street; previously Connector 23[231]
Connector 104	0.326	0.525	M-104 in Ferrysburg	US 31 in Ferrysburg	1961[245]	current	Part of Pine Street and 3rd Street
Connector 125	0.572	0.921	US 24 in Erie Township	M-125 in Erie Township	1965[246]	current	Luna Pier Road, replaced part of M-151;[246] previously Connector 1[231]
Connector 240	1.589	2.557	I-75 in Taylor	US 24 in Taylor	1963[244]	current	Previously Connector 4[231]
Connector 496	2.398	3.859	I-496 & M-99 in Lansing	I-496 & BL I-96 in Lansing	1989[247]	current	Signed as the Capitol Loop; previously Connector 81[231]
Connector 850	0.127	0.204	M-85 in Detroit	I-75 in Detroit	1973[236]	current	Part of Clark Street; replaced part of US 25; previously Connector 7[231]

See also

- Michigan Highways portal

References

Footnotes

1. Michigan Legislature (1915) [enacted May 13, 1913]. "Chapter 91: State Reward Trunk Line Highways" (https://books.google.com/books?id=7kXiAAAAMAAJ&pg=PA1868). In Shields, Edmund C.; Black, Cyrenius P.; Broomfield, Archibald (eds.). *The Compiled Laws of the State of Michigan*. Vol. I. Lansing, MI: Wynkoop, Hallenbeck, Crawford. pp. 1868–72. OCLC 44724558 (https://www.worldcat.org/oclc/44724558). Retrieved January 24, 2012.
2. MSHD (1919), Upper Peninsula and Lower Peninsula sheets.
3. Michigan Department of Transportation & Michigan Center for Shared Solutions and Technology Partnerships (2009). *MDOT Physical Reference Finder Application* (http://www.mcgi.state.mi.us/prfinder/) (Map). Michigan Department of Transportation. Retrieved August 13, 2013.
4. Baulch, Vivian M. (June 13, 1999). "Woodward Avenue, Detroit's Grand Old 'Main Street' " (https://www.webcitation.org/6A4hAw5WB?url=http://apps.detnews.com/apps/history/index.php?id=205). *The Detroit News*. ISSN 1055-2715 (https://www.worldcat.org/issn/1055-2715). OCLC 137348716 (https://www.worldcat.org/oclc/137348716). Archived from the original (http://apps.detnews.com/apps/history/index.php?id=205) on August 21, 2012. Retrieved June 6, 2012.

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Exhibit C, "Unsigned State highways and Trunklines"

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Unsigned State Trunklines & Connectors

Unsigned State Trunklines | Signed & Unsigned Connectors | Jump to Bottom

When people think of the state trunkline system, most immediately think of the Interstate, US and State-numbered highways which crisscross the state. Few, however, realize there are many miles of unsigned state trunklines and connectors (both signed and unsigned) maintained by MDOT but carrying no route number or other identifying markings.

Of the unsigned state trunklines, there are two types: numbered but unsigned routes, of which there are only a few, and formerly numbered routes which have been superceeded by other highways or are earmarked for being turned back to local control. The former are included with the regular route listings elsewhere on this site, while the latter are usually designated as "Old M-nn" or "Old US-nn" officially by MDOT. The information on unsigned state trunklines is taken from MDOT sources and is believed to be accurate and correct to date.

Unsigned State Trunklines

Jump to:
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OLD M-20
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OLD M-21 (East GR)
OLD M-24
OLD US-27 (Eaton)
OLD US-27 (Clinton)
OLD US-27 (St Johns)
OLD US-31 (Oceana)
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OLD M-99 (South)
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OLD US-12

Western Terminus: E Main St at the Berrien/Cass Co line, 1-3/4 miles southeast of downtown Niles

Eastern Terminus: Jct US-12 & M-60, two miles southeast of downtown Niles

Length: 0.348 miles

Map: Route Map of OLD US-12

Notes: This OLD US-12 routing is a very small remnant of what was once part of the BUS US-12 routing through downtown Niles from January 1962 until January 1994. Prior to that it was part of BUS US-112 from the late-1950s and even earlier, it was designated as mainline US-112. Interestingly, OLD US-12 was never signed as mainline US-12.

OLD US-12 is known as E Main St.

History: **1994 (Jan 3)** - The portion of BUS US-12 from BUS M-60/Oak St southeasterly via Main St to the US-12 & M-60 interchange southeast of Niles is removed from this routing and transferred onto the 11th St alignment, joining BUS US-31 there and supplanting the US-33 designation in the process. US-33 is scaled back to a terminus at the US-12 interchange south of the city at the new eastern terminus of BUS US-12 as well. Main St from BUS M-60/Oak St southeasterly to the Berrien/Cass Co line is turned back to local control, while the (very) short portion of the former BUS US-12 from the county line to the US-12 & M-60 junction remains as a short unsigned state highway stub. It has been reported, however, that this change may have been made in 1987 in terms of signage in the field with the actual jurisdictional transfer taking place in 1994. —*Thanks Marc!*

OLD M-14

Western Terminus: Washtenaw/Wayne Co line along Ann Arbor Rd (at cnr Napier Rd)

Eastern Terminus: Redford Twp/City of Detroit boundary along Plymouth Rd (1/2 block east of Hazelton St)

Length: 14.75 miles

Map: Route Map of OLD M-14

Notes: This former alignment of M-14 was bypassed in 1977-1979 when the I-96/Jeffries Frwy and the M-14 freeway connecting Ann Arbor with Detroit via Livonia was completed and opened to traffic. While the portions of the former M-14 within Washtenaw Co to the west and the City of Detroit to the east were turned back to local control, this segment in Plymouth & Redford Twps and the City of Livonia was never transferred.

While OLD M-14 has not been a signed state trunkline since the late-1970s, that has not prevented the posting of some M-14 route markers along or near Plymouth Rd in the Redford area. In addition, even though the route does not appear on any official state highway maps, a few commercial mapmakers have either continued to label M-14 as running along Plymouth Rd east of I-275 or have shown the route as BUS M-14—a designation which has never existed.

History: **1977** - With the completion of the final segment of the I-96/Jeffries Frwy in Detroit and Livonia between M-39/Southfield Frwy and I-275, M-14 is scaled back to end at I-275, shortening the route by more than 14 miles. The

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Exhibit C, "Unsigned State highways and Trunklines"

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History: **2019 (Jan 7)** NEW! – The Kalamazoo City Commission agrees to the Memorandum of Understanding from MDOT on the conditions of the trasfer of the affected streets in the city, thereby removing them from the state trunkline highway system and transferring them to the city primary street system. For BL I-94, this affects the entire route from Ramblind Rd west of downtown to the intersection of Mills St east of downtown, including the one-way pair of Michigan Ave (eastbound) and Kalamazoo Ave/Michikal St (westbound) through the heart of the city.

2019 (June 3–7) NEW! – MDOT crews remove the state trunkline route markers from both the transferred roadways in dowtown Kalamazoo as well as along those segments which will remain as unsigned state trunkline routes. Thus, in the field, BL I-94 is designated as BS I-94 (Business SPUR I-94) beginning at I-94 at Exit 81 east of the city and terminating at Mills St and the portion from Mills St westerly through downtown to Rambling Rd is now a city street. The portion of what had been designated as BL I-94 and BUS US-131 along Stadium Dr from Rambling Rd westerly to US-131 at Exit 36 becomes an unsigned state trunkline highway as OLD I-94BL/US-131BR.

OLD I-96BL

Western Terminus: Cnr Grand River Ave & 10 Mile Rd, 2/10 mile west of the M-5 & Grand River Ave Interchange in Farmington Hills (west of downtown Farmington)

Eastern Terminus: M-5 at the eastern end of the M-5 freeway in Farmington Hills (southeast of downtown Farmington)

Length: 4.34 miles

Map: Route Map of OLD BL I-96

Notes: One can trace this history of Farmington's OLD I-96BL back to 1933 when the State Highway Department constructed the first bypass of the city via Freedom Rd. This bypass for US-16 traffic was, oddly enough, for eastbound traffic only, while existing US-16 along Grand River through the city remained available for both directions of traffic. In 1957, the present-day M-5 freeway bypass of Farmington was completed and signed as part of US-16 with the former route through the city becoming BUS US-16. Within a few years, the bypass was co-signed as I-96 and in 1961 BUS US-16 though downtown Farmington was redesignated as BL I-96. Then in October 1977 when the final portion of the Jeffries Frwy through Livonia was completed, I-96 was transferred to its present routing and the Farmington bypass was integrated into M-102 and the BL I-96 routing through the city was removed and Grand River between the M-102 (now M-5) junctions became the unsigned trunkline it remains to this day.

History: **1976** - Six miles of I-275 are completed between the future I-96/Jeffries Frwy near Plymoth and the jct of I-96 & I-696 in Farmington Hills. Sources show this stretch of freeway is designated only as I-275 pending completion of the Jeffries Frwy through Redford Twp and Livonia. I-96 is still signed along the "Farmington Cutoff," while BS I-96 is still signed along Grand River from Farmington into downtown Detroit.

1977 - The biggest changes to the route of I-96 in 14 years occur as the Jeffries Frwy is completed from M-39/Southfield Frwy in Detroit, through Redford Twp and Livonia, to I-275 near Plymouth. The I-96 designation is applied to this freeway, then runs northerly concurrently with I-275 to the former route of I-96 in Farmington Hills. The former spur-route of I-96 around Farmington is re-designated as an extension of M-102 (present-day M-5). BL I-96 through downtown Farmington loses is posted route markers, but is retained as an unsigned state trunkline designated OLD I-96BL.

FORMER OLD I-96BS

Fmr. West Terminus: I-96/Jeffries Frwy at Exit 185 (jct I-96 & M-5) in northwest Detroit

Fmr. East Terminus: Cnr Grand River Ave, Middle St & Cass Ave in downtown Detroit.

Former Length: 7.08 miles

Map: Route Map of OLD I-96BS

Notes: This unsigned/old state trunkline was the route along Grand River Ave in Detroit was formerly the route of M-16 into the city from the northwest until 1926, the route of US-16 from 1926-1962 and then was designated BS I-96 from 1962 until 1977. At that point, the western half of BS I-96 became modern-day M-5 while the remainder from I-96/Jeffries Frwy at Exit 105 southeasterly into downtown Detroit became an unsigned trunkline as OLD I-96BS.

UPDATED! There had been consideration to re-sign this trunkline as a southeasterly continuation of M-5 into downtown Detroit over the years, however as the trunkline had a "dangling end," meaning it does not connect with any other trunkline routes at its eastern end and would likely need such a connection before it route markers were again posted along Grand River here, it didn't happen for some time. While MDOT could've signed Grand Rive Ave as M-5 southeasterly from I-96 at Exit 185 to the I-75/Fisher Frwy frontage streets (a "trunkline connection," if you will) leaving only the last few blocks as an unsigned trunkline until any future jurisdictional transfers can be effected, it chose not to for several years.

UPDATED! In c.2000, MDOT moved to more directly control the regular maintenance on the "surface" state trunklines in the City of Detroit. Regular maintenance on all non-freeway state highways within Detroit had long been contracted to the city, but had begun to decline over the years. When MDOT re-took control of maintenance, a few trunkline designation changes within the city were made as well, some actual and some on paper. Beginning with the 2001 Official Transportation Map, it seemed as if MDOT was indicating that M-5 continued southeasterly along Grand River Ave all the way into downtown Detroit, supplanting the OLD BS I-96 unsigned trunkline designation. However, the state made no attempt at signing this portion of Grand River Ave as M-5 and it was later learned that while the department has a general rule to not mark unsigned state trunklines on its official transportation map, the OLD BS I-96 extension of M-5 was included as a red line (indicating state trunkline status) into downtown Detroit for unknown (possibly political) reasons. Then during April–May 2016, as part of a signing and streetlighting upgrade, MDOT erected M-5 route markers along the entire OLD BS I-96 portion of Grand River Ave from I-96/Jeffires Frwy (Exit 185) southeasterly into downtown Detroit at the cnr of Grand River Ave & Cass Ave, thus signalling the end of unsigned OLD BS I-96 as a

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Exhibit C, "Unsigned State highways and Trunklines"

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hidden trunkline designation.

History: **1962** - The final 59 miles of I-96 freeway from the Eagle/Grand Ledge area past Lansing and Howell to Brighton are completed and opened to traffic. As of this time, all of US-16 in the state of Michigan is "decommissioned" and all US-16 route markers are taken down, ending a 36-year run for that route designation in the state. However, since I-96 has not been completed into the City of Detroit, the portion of Grand River Ave from the end of the freeway southeast of downtown Farmington into downtown Detroit is designated as BS I-96 ("Business Spur I-96").

1977 - The Jeffries Frwy is completed from M-39/Southfield Frwy in Detroit, through Redford Twp and Livonia, to I-275 near Plymouth. The I-96 designation is applied to this freeway, then runs northerly concurrently with I-275 to the former route of I-96 in Farmington Hills. The former spur-route of I-96 around Farmington is re-designated as an extension of M-102 (present-day M-5). BS I-96 from the former end of I-96 to M-102/Eight Mile Rd becomes part of the extension of M-102 (now part of M-5), while the portion of BS I-96 from Eight Mile Rd to I-96 at Exit 185 is designated as M-5. From the southeastern end of M-5, BS I-96/Grand River Ave is retained as an unsigned state trunkline as OLD BS I-96.

2004 (Apr 1) - The easternmost six or so blocks of OLD BS I-96 are transferred to city control, truncating the trunkline back to a new terminus at the cnr of Grand River Ave, Middle St & Cass Ave in downtown Detroit. Transferred are Grand River Ave (Cass Ave to Washington Blvd), Washington Blvd (Michigan Ave to Clifford St). Middle St (Grand River Ave to Clifford St) and Clifford St (Middle St to Washington Blvd).

2016 (Apr-May) NEW! – As part of a signing and streetlighting replacement project, M-5 route markers are installed along Grand River Ave in Detroit from the previous eastern terminus of M-5 at I-96/Jeffries Frwy (at Exit 185) along the unsigned state trunkline route (OLD BS I-96) to the terminus of OLD BS I-96 at the cnr of Grand River Ave & Cass Ave in downtown Detroit. OLD BS I-96 is now no longer a hidden or internal MDOT route designation.

Weblinks: • **Downtown Detroit Trunklines Map** - PDF map showing the official routings and termini of all state trunklines in downtown Detroit. Many of these termini and some of the trunklines themselves are unsigned, making this map particularly helpful.

OLD M-99 (So. Part)

Southern Terminus: Cnr M-99/Carleton Rd & Beck Rd (near Industrial Dr) in northern Hillsdale

Northern Terminus: Cnr M-99/Carleton Rd just southeast of the M-99 & Moore Rd intersection in Hillsdale

Length: 0.681 miles

Map: Route Map of OLD M-99 (South Portion)

Notes: This segment of unsigned/old state trunkline is one of a pair of OLD M-99 routings between Hillsdale and Jonesville resulting from the improvement of M-99 between those communities in the mid-1970s. This section is the southern of the two portions of OLD M-99, the other lying approximately 1/2 mile north of this one on the opposite side of the highway.

History: **1975 (Mar 6)** - M-99 between Hillsdale and Jonesville is completely reconstructed, largely on a new, modern alignment with less sharp turns and a new sweeping curve on the south side of Jonesville. Two segments of the former alignment to surive—e.g. that were not obliterated by the new highway—remain as unsigned/old state trunklines, both officially designated internally as OLD M-99. The segments include Beck Rd on the north side of Hillsdale, looping west of the new highway, and Beck Rd/St from south of Jonesville northerly into the village, to the east of the new highway.

OLD M-99 (No. Part)

Southern Terminus: Cnr M-99/Carleton Rd & Beck Rd southeast of the M-99 & Lake Wilson Rd intersection between Hillsdale and Jonesville

Northern Terminus: Cnr M-99/Olds St & Beck St in Jonesville

Length: 1.43 miles

Map: Route Map of OLD M-99 (North Portion)

Notes: This segment of unsigned/old state trunkline is one of a pair of OLD M-99 routings between Hillsdale and Jonesville resulting from the improvement of M-99 between those communities in the mid-1970s. This section is the northern of the two portions of OLD M-99, the other lying approximately 1/2 mile south of this one on the opposite side of the highway.

History: **1975 (Mar 6)** - M-99 between Hillsdale and Jonesville is completely reconstructed, largely on a new, modern alignment with less sharp turns and a new sweeping curve on the south side of Jonesville. Two segments of the former alignment to surive—e.g. that were not obliterated by the new highway—remain as unsigned/old state trunklines, both officially designated internally as OLD M-99. The segments include Beck Rd on the north side of Hillsdale, looping west of the new highway, and Beck Rd/St from south of Jonesville northerly into the village, to the east of the new highway.

OLD M-106

Southern Terminus: BL I-94/BUS US-127/M-50 at the cnr of Francis (formerly Cooper) St & Louis Glic Hwy in downtown Jackson

Northern Terminus: M-106 at cnr Cooper St & Francis St north of downtown Jackson

Length: 0.551 miles

Map: Route Map of OLD M-106

Notes: In 2004, both streets comprising the former one-way pair couplet of M-106 on the north side of downtown Jackson were converted to two-way traffic. The former northbound side along Cooper (formerly Milwaukee) St from Michigan Ave to Francis (formerly Cooper) St retained the M-106 designation while the former southbound side along Francis (formerly Cooper) St from Cooper (formerly Milwaukee) southerly to Glick Hwy became an unsigned trunkline route.

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Exhibit C, "Unsigned State highways and Trunklines"

signed, such as CONN M-13 at Bay City, CONN M-44 at Grand Rapids and Lansing's Capitol Loop, most are not or simply feature route signage pointing to the trunklines at either end that these connectors "connect." In c.2006-08, MDOT redesignated most of the internal connector designations to make them more closely match one of the highways they connect with. For example, internal "Connector 13" was the BL I-94/M-25 connector in Port Huron, but was given the new designation of "Conncetor 25." (This allowed CONN M-13 to be internally designated as "Connector 13" as well.) For completeness sake, the signed connectors are also listed below, however links to their full route listings elsewhere in the site are included in boldface.

CONNECTOR	COUNTY	START	END	SECONDARY NAME/NOTES	LENGTH
Connector 3	Wayne	Jct I-75 & I-375 in downtown Detroit	M-3/Gratiot Ave	(Formerly "Connector 8")	0.724 mile
Connector 5	Oakland	I-696 in the I-96/I-275/I-696/M-5 interchange	M-5 in the I-96/I-275/I-696/M-5 interch.	(See "Connector 5" note on M-5 route listing.)	1.334 mile
Connector 13	Bay	I-75/US-23 at Exit 163 west of Bay City	M-13 south of Kawkawlin	**CONN M-13** (formerly "Connector 14")	2.435 miles
Connector 24	Wayne	US-24 at cnr Telegraph Rd & Dix Toledo Hwy	I-75 at Exit 34 in Brownstown Twp	**CONN US-24 (Woodhaven)**, I-75 Connector (formerly "Connector 3")	2.379 miles
Connector 25	St Clair	BL I-94/BL I-69 at Hancock St in Port Huron	M-25/Pine Grove Ave in Port Huron	I-94 Connector (formerly "Connector 13")	0.273 mile
Connector 30	Macomb	I-94 at Exit 231 in Roseville	M-3/Gratiot Ave north of 13 Mile Rd	(Formerly "Connector 10")	0.630 mile
Connector 34	Lenawee	M-34/Beecher Rd west of Adrian	US-223 "Adrian Bypass"	Industrial Dr	0.399 mile
Connector 44	Kent	I-96/M-37 at Exit 33 in Grand Rapids	M-44/East Beltline Ave-Northland Dr	**CONN M-44**	4.205 miles
Connector 58	Saginaw	Hill St-Michigan Ave at M-58/State St	Hill St-Michigan Ave at I-675 ramps	Hill St, Michigan Ave	0.464 mile
Connector 69	St Clair	Lapeer Rd between 32nd & Botsford Sts	I-94/I-69 at Exit 274 in Port Huron	(Formerly "Connector 9")	0.910 mile
Connector 75	Monroe	I-75 at Exit 2 near Erie	M-125/Dixie Hwy at Summit St	**CONN US-24 (Erie)**, I-75/M-125 Connector (formerly "Connector 2")	2.992 miles
Connector 85	Wayne	M-85/Fort St & Schaefer Hwy in southwest Detroit	I-75/Fisher Frwy at Exit 43	Schaefer Hwy	0.219 mile
Connector 96	Clinton	I-96 at Exit 89 northwest of Lansing	I-69 at Exit 81 northwest of Lansing		2.365 miles
Connector 102	Wayne	M-10/J C Lodge Expwy at Greenfield	M-102/Eight Mile Rd at Greenfield	Greenfield/Greenlodge (formerly "Connector 23")	0.201 mile
Connector 104	Ottawa	M-104/Savidge St in Ferrysburg	US-31 at 3rd St interchange	Pine St, 3rd St	0.326 mile
Connector 125	Monroe	US-24/Telegraph Rd at Luna Pier Rd	M-125/Dixie Hwy at Luna Pier Rd	**CONN US-24 (Erie)**, Luna Pier Rd (formerly "Connector 1")	0.572 mile
Connector 240	Wayne	I-75 at Exit 35 in Taylor	US-24/Telegraph Rd south of Eureka Rd	**CONN US-24 (Taylor)** (Formerly "Connector 4")	1.514 miles
Connector 496	Ingham	Jct I-496 & M-99, Lansing	Jct I-496 & BL I-96, Lansing	**CAPITOL LOOP** (formerly "Connector 81")	2.243 miles
Connector 850	Wayne	M-85/Fort St at Clark St in Detroit	I-75 at Exit 47 (Clark St interchange)	Clark St (formerly "Connector 7")	0.127 mile

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Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit).

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Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit).

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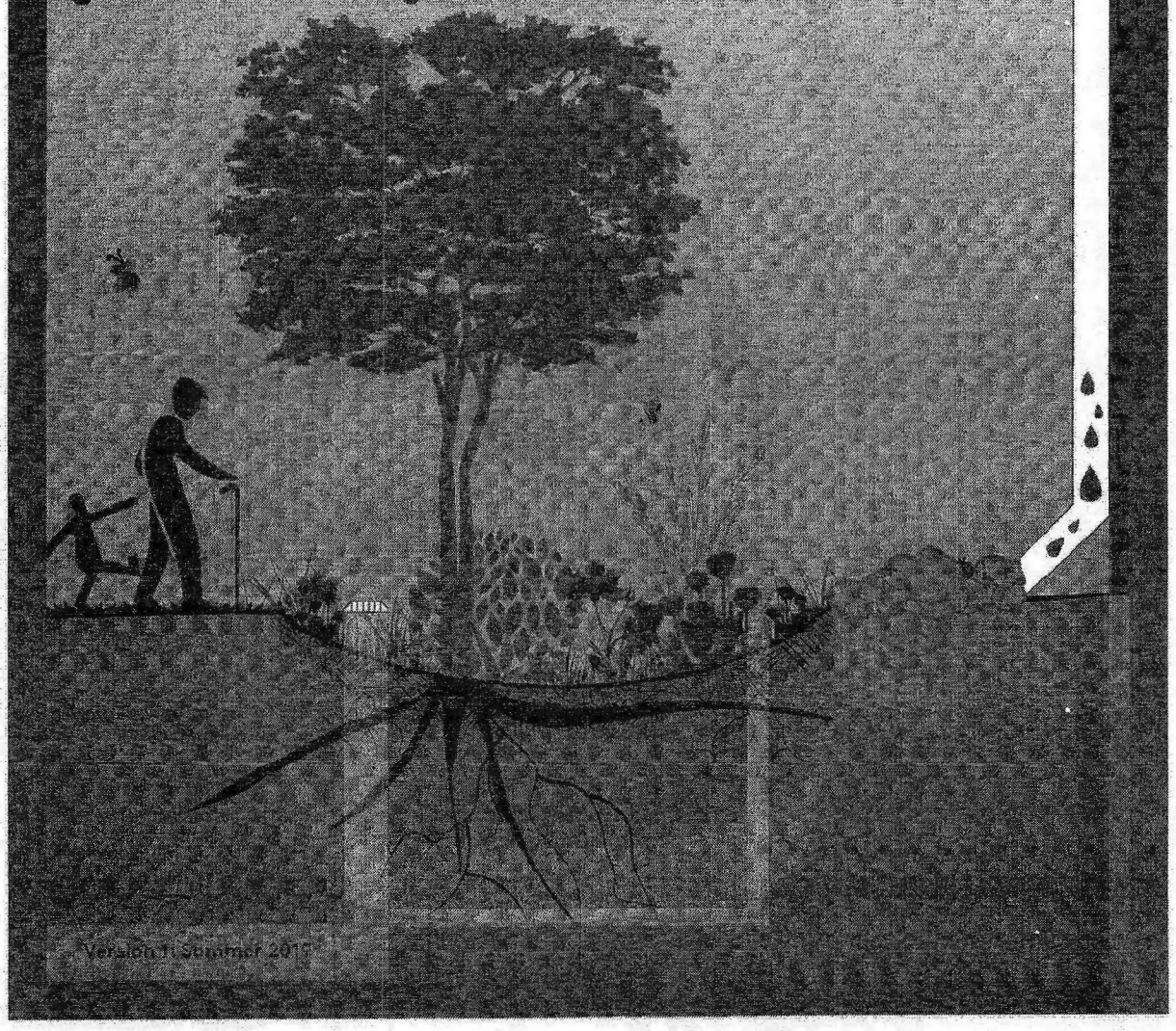
A Detroit Property Owner's Guide to Bioretention

How to manage stormwater on your non-residential property and get DWSD drainage credit



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For more information or for help with your project, contact: stormwater@detroitfuturecity.com or call (313) 259-4407.

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Introduction

Who is this guide for?

Have you tried to understand stormwater management in Detroit? Are you interested in installing a Green Stormwater Infrastructure (GSI) practice on your property, but need more information about how to get the project done? Would you like to invest in a GSI practice that could beautify your property and potentially improve your bottom line through a DWSD drainage credit? If so, this guide is for you.

The information here will be particularly useful for **small business owners, nonprofits and faith-based organizations in Detroit** who are looking to retrofit or add a GSI practice to their existing property. This guide will provide details on how to plan for and implement a bioretention basin on your non-residential property to better manage stormwater runoff.

**DISCLAIMER: The information in this document was created as a general guideline to be educational in nature and to help people better understand the DWSD Drainage charges, and the overall process of attempting to receive credits, site conditions, stormwater management, bioretention practices, hiring consultants and contractors, etc. The information contained herein is not intended to replace, dispute, or contradict any DWSD program documents and regulations. In all instances, any questions or clarifications regarding DWSD policies and programs should be directed to DWSD directly, or their documentation and guides published on their website. This document is only supplemental to any DWSD documentation.

What is Stormwater Runoff and Green Stormwater Infrastructure (GSI)?

Combined Sewer Overflow pipes directed into the Detroit River[1]

Land + Water WORKS tour visiting a bioretention practice installed by the City of Detroit at Viola Liuzzo Park in Northwest Detroit[2]

Stormwater runoff is rain and snowmelt that flows over roads, parking lots, building roofs and other hard surfaces that don't allow water to soak into the ground. During heavy rain storm events and spring snow melts, this water can flow into nearby bodies of water without undergoing treatment. The runoff can cause flooding and, when untreated, it can flow into our rivers, resulting in pollution of our rivers and the Great Lakes.

Detroit has a combined sewer system, meaning both sewage and stormwater runoff flow through its treatment plants. According to the Detroit Water and Sewerage Department (DWSD), *"During wet weather, too much stormwater can overload the combined system. This might cause basement backups, street flooding, and polluted wastewater to flow into the Rouge River, the Detroit River, and eventually, Lake Erie. These overflows of both stormwater and sewage waste are called combined sewer overflows, or CSOs. CSOs are a last resort to prevent sewer backups and basement flooding."*

In the past, we have used costly "gray", or conventional stormwater infrastructure to move, store and treat stormwater, but there is a better way. Green Stormwater Infrastructure allows us to manage stormwater where it falls, using vegetation, soils, and other elements to filter, absorb and slow down stormwater runoff. GSI can be a cost-effective, resilient approach to managing rain more naturally while also delivering environmental, social, and economic benefits. GSI can help reduce the combined sewer overflows into the Detroit and Rouge Rivers, keeping these important bodies of water healthy and safe for people and wildlife.

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit).

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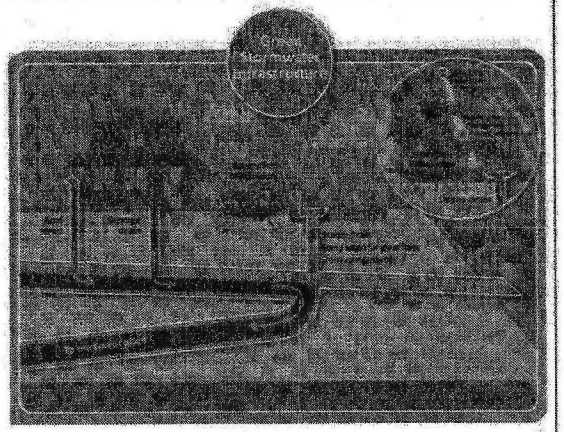
Green Infrastructure: How It Works



The Detroit Water and Sewerage Department (DWSD) has built $1.5 billion in wet weather management systems to keep our water safe and reduce CSOs. The drainage fee that it charges to property owners supports the installation and maintenance of that system. Detroit property owners can now get a credit on their drainage charge for installing certain types of GSI on their properties. This guide will give basic information on implementing GSI practices (with more detail specifically on bioretention practices) for DWSD drainage charge credit. A full explanation of drainage fees and credits is on DWSD's website at: www.detroitmi.gov/drainage

We can all do our part to help maintain the health of our water resources by installing GSI.

What happens:

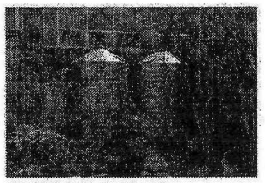
1. Water runs off of impervious "hard" surfaces (roofs, parking lots, streets) to "soft" surfaces (plants, grass, trees)
2. Pervious "soft" surfaces soak up the water
3. With large amounts of rainwater, roots of plants, grass, and trees help water return to the ground by increasing porosity.
4. Green infrastructure keeps rain water out of the sewer system and from overflowing.
5. Thus the treatment facility doesn't cause overflows or backups into homes.

Types Of GSI Practices

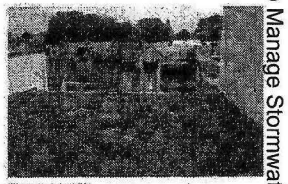
When making a plan to manage stormwater runoff from your property, you should be aware of and consider all types of Green Stormwater Infrastructure (GSI) practices, including: bioretention, cisterns and rain barrels to store and reuse rainwater, green roofs, permeable pavement, permeable pavers, and subsurface storage systems. Deciding which of these GSI practices is most suitable depends on your site conditions and constraints, budget, and goals for your building and landscape.

See the DWSD GSI Starter Guides[4] for more information on these other types of GSI practices.

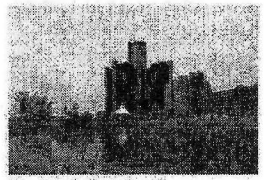
Porous pavement (with permeable pavers)[4]



Above-ground cistern[5]



Green roof[6]



Constructed wetland[7]

Subsurface storage[8]

Stormwater detention basin[9]

See chart on page 22 showing the potential DWSD drainage credits available for different types of GSI practices.

Bioretention is one of just three GSI practice types that have the potential to achieve both volume and peak flow credits.

Bioretention[10]

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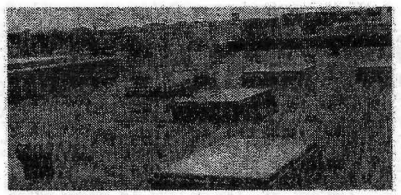
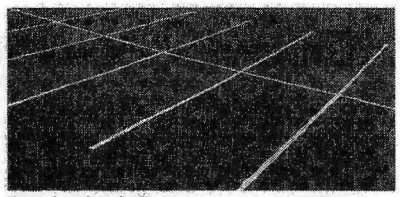
What are Impervious and Pervious Surfaces?

An impervious surface is any surface that prevents or significantly slows stormwater from flowing into the soil and causes the water to "run off" the surface rather than soak into it. Such surfaces include rooftops, compacted gravel, asphalt or concrete paving, driveways and parking lots, walkways and sidewalks, patio areas, storage areas, or other surfaces that similarly affect the way that water is absorbed into the ground.

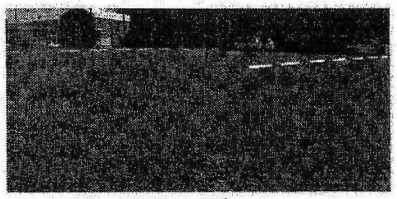
Examples of Impervious Surfaces



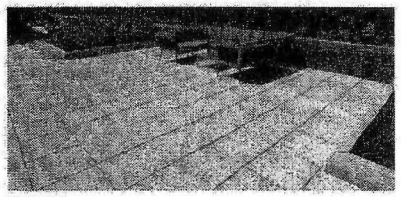
Rooftop[11]



Typical parking lot[12]



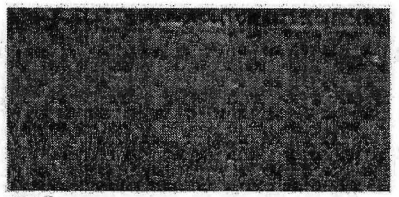
Compacted gravel parking lot[13]



Pavers[14]

Surfaces such as lawn, landscaped beds, ponds, green roofs, swimming pools, and non-compacted gravel walks are considered pervious surfaces. Pervious surfaces allow the stormwater to infiltrate into the underlying soil rather than running off the surface into the City sewer system.

Examples of Pervious Surfaces



Grass[15]

Mulched garden bed[16]

Grass and trees[17]

Stone pathway[18]

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Bioretention Basics

This guide is focused on bioretention because it is typically the **most cost-effective** GSI practice to implement and maintain over time. It also is the most commonly implemented type of GSI practice in Detroit, in part because we have more open space available than many other cities. Bioretention practices can be relatively easy and less expensive to construct than other types of GSI practices. Bioretention also has other important benefits. For example, its planted areas can **beautify your property** and introduce other ecological **benefits for birds and pollinators.** It can also be used to create or enhance community gathering spaces.

This guide will go into detail on the process to plan, build and maintain a bioretention basin to manage runoff from a non-residential property.

Bioretention is a type of GSI practice that uses soils and plants to collect, filter, and slow down stormwater runoff from roofs, parking lots, or roadways. It cleans water by using plant materials to filter things like oil and dirt from the rain water picked up from roofs and driveways. Bioretention refers to how the GSI practice retains, or keeps, stormwater from leaving the site by holding it and allowing the stormwater to infiltrate into the ground on-site. Additionally, a bioretention practice can also be designed to detain, or temporarily keep, stormwater on-site and slowly release it into the sewer system via a controlled connection pipe. This additional component would technically turn it into a Bioretention with Detention practice, and can increase the stormwater management capacity of the practice. However, adding a connection to the sewer system also increases the complexity and cost to implement the practice.

Basic Components of a Bioretention Practice

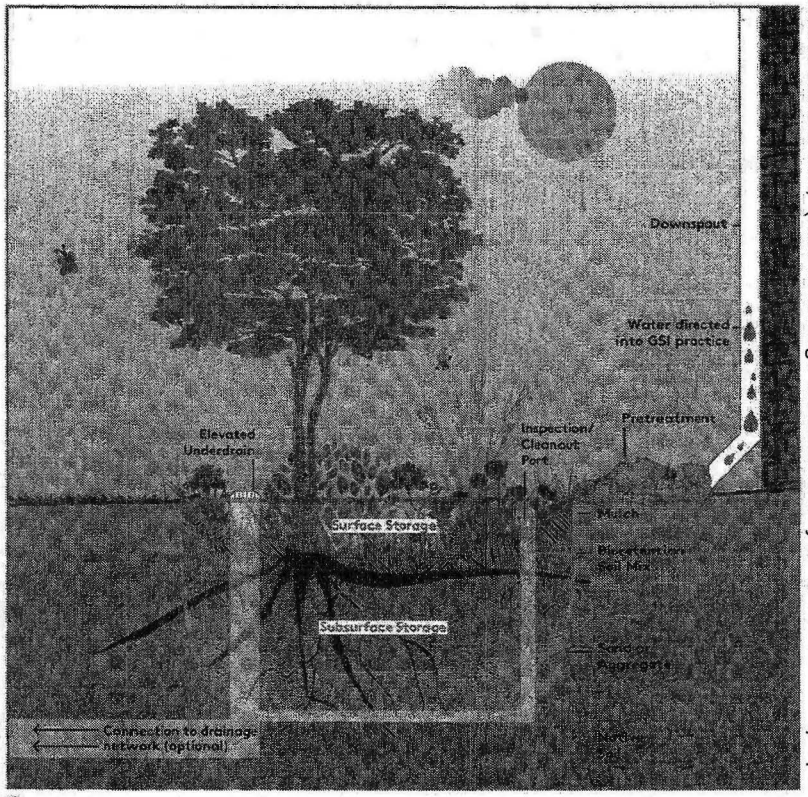

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit),

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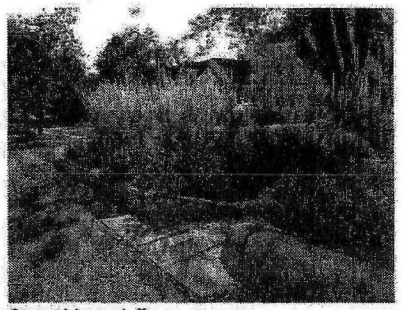
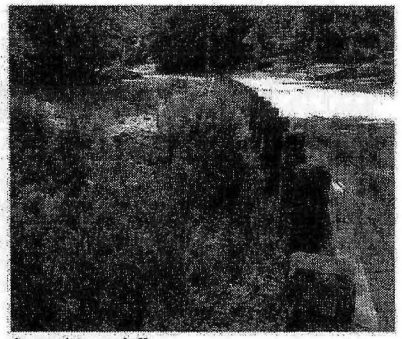
Examples of Bioretention Practices

Residential rain garden[20]

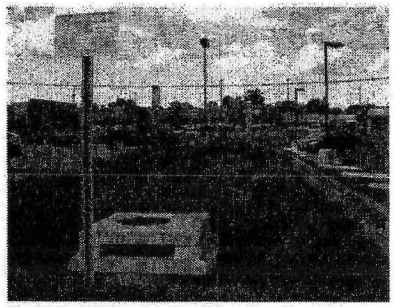


Street bioswale[21]

Park bioswale[22]



Street bioswale[23]



Parking lot bioretention[24]

Bioretention basin [25]

At the end of 2018, over 100 bioretention practices were documented in Detroit. The three most common types found in Detroit are rain gardens, bioretention basins and bioswales.

Rain Garden

Rain gardens are an example of a small bioretention practice, usually installed on residential properties. As the name suggests, it can also double as a beautiful garden.

Bioswale

A bioswale has the same function as a bioretention basin, but is more linear in shape and is usually installed along public streets and in parking lots. It can also be used to move stormwater runoff from one place to another, while filtering and absorbing it along the way.

Bioretention Basin

A bioretention basin is essentially a larger and more highly designed and engineered rain garden that has increased stormwater management capacity. Bioretention basins are typically installed on commercial and institutional scales.

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit).

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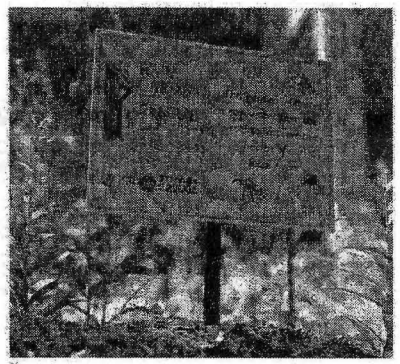
This guide will go into more detail on the process to plan, build and maintain a bioretention basin on non-residential property. It is focused on practices that manage stormwater runoff from the same property, rather than the street or neighboring properties. However, here is some information to help you if you just want to do a simple rain garden, or if you are planning a more complex bioretention project!

Residential Rain Gardens

If you are interested in simply building a rain garden on your residential property, there are many resources available to support you. A good place to start is with the Friends of the Rouge and Sierra Club's Rain Gardens to the Rescue program. For more information, please visit: therouge.org/rain-gardens-to-the-rescue/

Please note that a residential rain garden will typically not be large enough to allow a homeowner to receive any drainage credit from DWSD beyond the 25% residential credit that DWSD automatically gives to residential properties.



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Managing Runoff From The Street

It is possible to install a GSI practice on your private property that manages stormwater runoff from a public street or other public right-of-way, but these types of projects can be more complicated to design, acquire permits, and potentially obtain drainage credits for.

The Eastside Community Network recently installed a GSI practice that manages runoff from a public street, as part of the Hamilton Outdoor Learning Lab. For more information on this project, please visit: www.ecn-detroit.org/hamilton-outdoor-learning-lab

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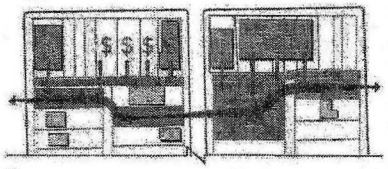

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Shared Stormwater Practices

It is also possible for multiple property owners to direct runoff from their impervious surfaces into a shared green stormwater practice. In this situation, the property owners might share the cost of implementation and maintenance. Each property owner would receive drainage credit from DWSD according to how much of their total stormwater runoff is being directed into the GSI practice.

The Detroit Collaborative Design Center (DCDC) recently did an in-depth study on shared stormwater management practices. For more information on this study, please visit: www.dcdc-udm.org/community/stormwater.html

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Will Bioretention Work On My Site?

To determine if bioretention is the ideal GSI practice for your property, follow this simple checklist to get started:

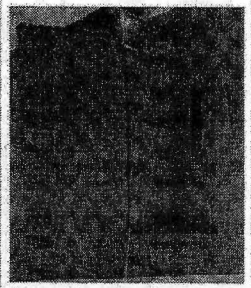
- ☐ Does your building roof have external downspouts?
- ☐ Do you have an open, unpaved area on your lot, at least 10 feet from your building (or an area where pavement can be removed)?
- ☐ Can water be easily directed from the downspouts or paved surfaces towards the open area?
- ☐ Would you enjoy having a planted garden area on your property, and are you willing to maintain it?

There are more detailed site conditions and considerations that a landscape architect or engineer will review before determining the best GSI practice for your property and the potential cost and benefits of these practices, but these are a good start.

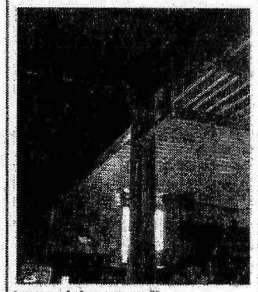
Bioretention needs to be located near a downspout, or water needs to be able to be directed towards it in some way, whether through grading or routing the water through a gutter or pipe system. If you have a parking lot on your property and there are already catch basins in the center of it, it will be more expensive (but not impossible) to disconnect them and direct the water towards a bioretention practice. It is possible to reroute and re-pitch gutters, and add trench drains or pipes to direct water towards a bioretention practice.

Know your Roof Drains!

If you have internal downspouts, you should have a commercial plumber look at the building to assess how much it would cost to reroute some or all of the downspouts to the exterior. If it is very expensive, it may not make sense to do a bioretention project. You could focus on capturing runoff from your parking lot or other paved surfaces using bioretention or another type of GSI practice.



External downspout[19]



Internal downspout[20]

Depaving: A Quick Fix!

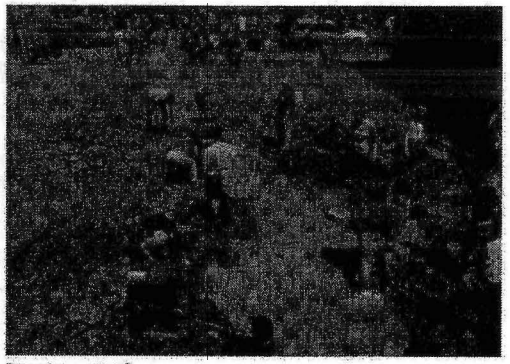
Do you have excess parking or other paved surfaces on your property that you don't need? Think about de-paving it! If you remove impervious surfaces from your property, you will reduce your drainage charge. This approach is not considered a 'credit', but simply an adjustment to the amount of impervious surface from which the drainage charge is calculated.

DWSD has a useful starter guide for property owners interested in doing a depaving, or "Impervious Cover Removal,"[18] project. The organization Depave, based in Portland, Oregon, has a detailed guide, titled "How to Depave: The Guide to Freeing Your Soil"[19] available for free on its website. Detroit Future City and the Land + Water WORKS Coalition are planning a pilot depaving project in Detroit in 2019.

PLEASE NOTE!

You need to remove at least 435 square feet of impervious surface in order to qualify for a drainage charge adjustment from DWSD. This is about the size of a two-car garage.

You could simply do a depaving project and establish grass or other site material in the depaved area, or you could also incorporate a bioretention practice in the depaved area for a drainage charge credit.



Depaving project[21]

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit)
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DWSD Drainage Charge and Credit Program Basics

DWSD = Detroit Water and Sewerage Department

All parcels throughout the city are subject to drainage charges, regardless of their zoning, land-use, size, or classification. Drainage charges are billed on all parcels regardless of whether the property has active water service.

How does DWSD calculate how much each parcel is charged? In simple terms, it is the total area (in acres) of impervious surface on the property multiplied by a rate per "impervious acre." The part of this equation that is important to understand is that the amount that each parcel is being charged is directly proportional to the total impervious surface area that is on the property. The more impervious surface area on the property, the higher the drainage charge on the water bill. Also, the impervious acre rate is approved annually by the Board of Water Commissioners and is subject to change each year, depending on DWSD's revenue requirements. In DWSD's fiscal year 2019 (July 2018–June 2019), the impervious acre rate was $598; in fiscal year 2020, the impervious acre rate is $602.

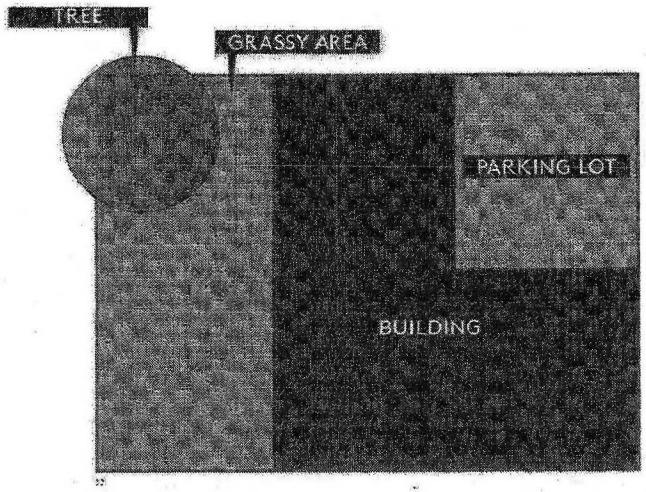
You can check to see how much impervious surface DWSD has estimated on any parcel in Detroit through the Parcel Viewer.

Visit the website to confirm that the impervious surface data for your property is correct. If it is not, submit a Drainage Charge Adjustment Application to DWSD.

For more detailed information, see the Detroit Water and Sewerage Department's (DWSD) A Guide to the Drainage Charge.

** DISCLAIMER: The information in this document was created as a general guideline to be educational in nature and to help people better understand the DWSD Drainage charges, and the overall process of attempting to receive credits, site conditions, stormwater management, bioretention practices, hiring consultants and contractors, etc. The information contained herein is not intended to replace, dispute, or contradict any DWSD program documents and regulations. In all instances, any questions or clarifications should be directed to DWSD directly, or their documentation and guides published on their website. This document is only supplemental to any DWSD documentation.**

How are Drainage Charges Calculated for Each Property?



0.15 Acre Building + 0.05 Acre Parking Lot = **0.2 Acre, Total Impervious Area**

0.2 Acre Total Impervious Area + 0.1 Acre Grassy Area = **0.3 Acre, Total Site Area**

To calculate a property's monthly drainage charge, multiply
Total Impervious Area, in acres X DWSD Impervious Acre Rate (currently $598)

So this property's monthly drainage charge,
0.2 Acre, Total Impervious Area X $598 = **$119.60 monthly drainage charge**

Multiply monthly charge times 12 (months) to get the annual drainage charge,
$119.60 X 12 = **$1,435.20 annual drainage charge**

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit)."

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Drainage Charge Credits

The Detroit Water and Sewerage Department (DWSD) offers an opportunity for customers to reduce the drainage charge for their property though Drainage Charge Credits. Credits are a reduction in the drainage charge based on the successful implementation and operation of a Green Stormwater Infrastructure (GSI) practice. These practices, if properly installed and operated, are intended to reduce stormwater flow into the sewer system and therefore protect against flooding and sewer overflows.

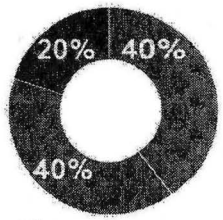
See DWSD's "A Guide to Drainage Charge Credits"[6] for some examples and descriptions of common Stormwater Management Practices.

Also see the chart "Drainage Credits for GSI Practices" in the appendix page 22 to see which GSI practices are eligible for volume and/or peak flow credits. Bioretention is one of three different GSI practice types that have the potential to receive both volume and peak flow credits.

Two different types of drainage credits can be achieved, and when added together could potentially result in a maximum of 80% total site credit. A site credit is equivalent to the percent at which a property's drainage charge is reduced.

The two types of credit are called "Volume Credits" and "Peak Flow Credits." Volume-based drainage charge credits are determined based on the average annual stormwater volume reductions that result from managing stormwater on-site. In other words, the higher volume of water a practice keeps on the property and out of the sewer system on an annual basis, the higher the credit that will be awarded. Typically, the maximum credit that can be achieved through volumetric control is 40% (one-half of the potential 80% credit that can be earned).

Credit Breakdown



- Annual Volume of Flow
- Base Costs
- Peak Flow Rate

Peak flow-related credits are based on the ability of the site to control peak flows (heavy rain events) by reducing the rate, or speed, at which the stormwater enters the sewer system. Practices that control peak flows receive credits by controlling the water on-site and slowly releasing the water into the sewer through a controlled outlet. Typically, the maximum credit that can be achieved through peak flow control is 40% (one-half of the potential 80% credit that can be earned).

Each practice, whether volumetric, peak flow, or both, receives an individual credit in the form of a percentage. Each practice credit applies to the area that is draining to the stormwater management practice. When added together, the sum of all the practice credits equals the total site credit for a property. The total site credit is the percentage at which a property's drainage charge is reduced.

Please note, an 80% site credit is rare, and only possible if 100% of a property's impervious surface is managed by GSI that is designed to manage the amount of stormwater runoff created from a 100-year storm event. In many cases, it is very difficult to redirect the flow of stormwater runoff to the desired areas on an existing site. Also, designing for a 100-year storm event doesn't always make sense because of the high cost of building such a practice and the additional space required to do so.

See Tables 2 and 3 in "A Guide to Drainage Charge Credits"[6] for more information on calculating drainage credits.

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit).

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This chart shows the potential credits available for different types of GSI practices. Bioretention is one of just three GSI practice types that have the potential to achieve both volume and peak flow credits.

This chart is based off Table 1 in DWSD's "A Guide to Drainage Charge Credits" for credits for commonly used stormwater management practices.

Drainage Credits for GSI Practices

Practice Type	Volume Credit	Peak Flow Credit	Potential Credit for Area Managed (%)
Downspout disconnection	X		0-40%
Disconnected impervious area	X		0-40%
Bioretention	X	X	0-80%
Detention basins		X	0-40%
Subsurface detention storage		X	0-40%
Permeable pavements	X	X	0-80%
Green roof	X		0-30%
Water harvesting*	X	X	0-80%

*For water harvesting, peak flow volume evaluated on a case-by-case basis.

Transition Credits

This chart shows how DWSD is phasing in the drainage charge rates over five years for property owners that were previously not being billed for drainage (such as a parking lot with no water service) or those that were previously billed based on their meter size. This information is based on a DWSD presentation from January 2019, but projected rates are subject to Board of Water Commissioner approval. For official information, contact DWSD.

Five Year Rate Phase-in for Meter-Billed and Newly Billed Customers

Date	Impervious Acre Rate*	Industrial Rate*	Commercial & Exempt Rate*	Faith-Based Rate*
		Meter-Billed and Newly-Billed Customers		
July 1, 2015	$852	N/A	N/A	N/A
July 1, 2016	$750	$125	$125	N/A
July 1, 2017	$651	$250	$250	N/A
July 1, 2018	$598	$375	$375	$125
July 1, 2019	$602	$500	$500	$250
July 1, 2020	$626	$625	$625	$375
July 1, 2021	$651	$677	$677	$500
July 1, 2022	$677	$677	$677	$625
July 1, 2023	$677	$677	$677	$677

Rate billed will be based on previous billing method, classification, and tax staus.

*For discussion purposes only. Projected rates are subject to Board of Water Commissioners approval

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit).

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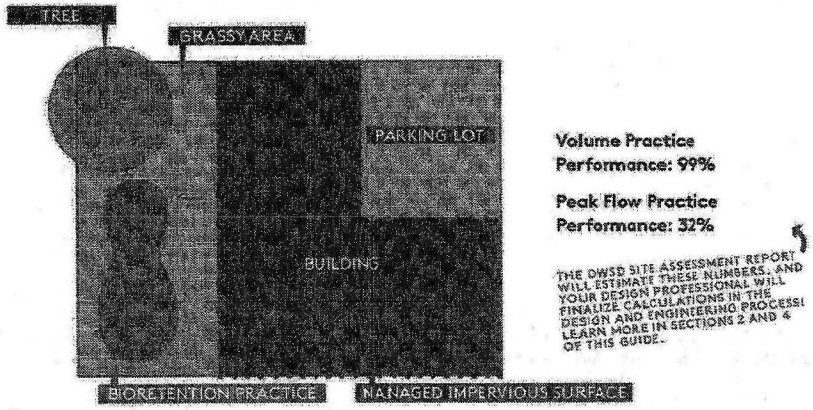
Sample Credit Calculation



Each practice can achieve up to 40% volume and up to 40% peak flow credit for the impervious surface area it is managing. A practice that has 100% volume practice performance and 100% peak flow practice performance (meaning it is sized to retain and detain a 100-year, 24-hour storm), for example will have a 40% volume credit and a 40% peak flow credit for the practice.

Volume Practice Credit = 99 x .4 = 39.6%

Peak Flow Practice Credit = 32x .4 = 12.8%

Total Practice Credit = 52.4%

The bioretention practice only manages the runoff from the building (0.15 acres) and not the parking lot (0.05 acres). Thus, the practice is only managing 75% of the site's total impervious area.

To calculate the site credit, multiply the total practice credit x the percentage of the impervious area managed:

52.4% x .75 = 39.3% Site Credit

In this example, the bioretention practice provides a **39.3%** site credit, which will reduce the **$119.60** monthly property drainage charge by $47.00 per month. Over the course of a year, the drainage charge will be reduced by **$563**.

$119.60 x .393 = $47.00 Monthly Drainage Charge Reduction

$47 x 12 months = $563 Annual Drainage Charge Reduction

Original Annual Property Drainage Charge: $1,435.20

New Annual Property Drainage Charge: $871.20 (after installation of bioretention practice)

The report produced from your DWSD site assessment (discussed in Section 2 of this guide) will give you estimates on potential credits for GSI practices that could work on your site, as well as conceptual cost estimates.

In Section 3: Determining Project Feasibility, this guide discusses how to estimate a return on investment for a bioretention project, taking into account the cost of the project and the potential cost savings expected from the drainage credit.

Next, we will walk you through the steps of installing a typical bioretention practice.

Introduction Links

A. "Nonresidential Drainage Credits": https://detroitmi.gov/departments/water-and-sewerage-department/drainage-charge/nonresidential-drainage-credits#starterguides

B. "DWSD Drainage Program Guide: Green Stormwater Infrastructure (GSI) Best Management Practice: Impervious Cover Removal": https://detroitmi.gov/Portals/0/docs/DWSD/DCCP%20Site%20App%20-%20Impervious%20Cover%20Removal_WEB.pdf?ver=2017-08-09-164458-853

C. "How to Depave: A Guide to Freeing Your Soil by Depave in Portland, Oregon": https://depave.org/learn/how-to-depave/

D. "Detroit Water and Sewerage Department Parcel Viewer for Impervious Surfaces": https://www.arcgis.com/apps/webappviewer/index.html?id=ce1eaf8deee347439687dcafe822372c

E. "DWSD Drainage Guides and Forms" https://detroitmi.gov/departments/water-and-sewerage-department/drainage-charge/drainage-guides-and-forms

Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit).

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Introduction Photo Sources

1. Combined Sewer Overflow pipes directed into the Detroit River, Photo Credit: Sarah Hayosh
2. Land + Water WORKS tour visiting a bioretention practice installed by the City of Detroit at Viola Liuzzo Park in Northwest Detroit, Photo Credit: Andrew Potter
3. "Green Infrastructure How It Works", King County Seattle Water Department, https://kingcounty.gov/services/environment/wastewater/cso/about/natural.aspx
4. Porous pavement (with permeable pavers), Philadelphia Water via Flickr, https://www.flickr.com/photos/philadelphiawater/15894506417/
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10. Bioretention, Visitation Church Rain Garden, courtesy of Vireo Kansas City/Omaha, https://www.bevireo.com/
11. Rooftop, Heinrichs Roofing, https://www.heinrichsroofing.com/services/commercial-roofing/
12. Typical parking lot, Cathedral City Economic Development, http://www.ccedd.org/de-update/public-investment-presentation/
13. Compacted gravel parking lot, Green Giant Home & Commercial, https://www.greengianthc.com/vegetation-management/stone-gravel-driveways-parking-lots/
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16. Mulched garden bed, SoilCo, https://www.soilco.com.au/portfolio_page/pine-bark-15mm/

17. Grass and trees, Photo Credit: Sarah Hayosh
18. Stone pathway, Envy Exteriors, https://envyexteriors.com/blog/2015/12/15/how-to-fix-drainage-problems-in-your-yard
19. Basic Components of a Bioretention Practice, Detroit Future City
20. Residential rain garden, Department of Environmental Protection – Montgomery County, Maryland, https://www.montgomerycountymd.gov/water/rainscapes/about.html
21. Street bioswale, courtesy of Vireo Kansas City/Omaha, https://www.bevireo.com/
22. Park bioswale, Project Groundwork, Metropolitan Sewer District of Greater Cincinnati, http://projectgroundwork.org/projects/lowermillcreek/sustainable/lickrun/alternative/rapid_run_park.htm
23. Street bioswale, courtesy of Vireo Kansas City/Omaha, https://www.bevireo.com/
24. Parking lot bioretention, Bridgeton, MO via Flickr User Aaron Volkening, https://www.flickr.com/photos/87297882@N03/9753768921/
25. Bioretention basin, courtesy of Vireo Kansas City/Omaha, https://www.bevireo.com/
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29. External downspout, Detroit Future City
30. Internal downspout, Detroit Future City
31. Depaving project, Depave Portland, Eric Roswell, https://depave.org/fargo-forest-garden/
32. How are Drainage Charges Calculated for Each Property?, Detroit Future City
33. Credit Breakdown, A Guide to Drainage Charge Credits, Detroit Water and Sewerage Department
34. Sample Credit Calculation, Detroit Future City

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Exhibit D, "Property Owner's Guide to Bioretention," (How to Manage Stormwater on your non-residential property and get DWSD drainage credit)
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A Guide to Drainage Charge Credits

A drainage charge credit is a reduction in the drainage charge to a property based on the implementation and continuing proper operation of a stormwater management practice, also referred to as Green Stormwater Infrastructure (GSI). Customers are encouraged to adopt sustainable methods of stormwater management practices that reduce stormwater flows to the drainage system, enhance the natural environment, and protect against flooding and sewer overflows. The installation of stormwater management practices that result in a measurable reduction in volume and/or peak flow rates will qualify the property owner for a credit to their bill.

This guide provides an overview of the types of credits available for common stormwater management practices.

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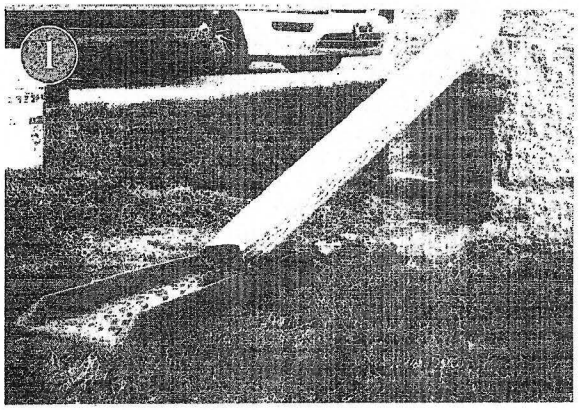
What is a Stormwater Management Practice?

Stormwater management practices, also referred to as Green Stormwater Infrastructure (GSI), are designed or constructed to reduce or control the volume and rate at which stormwater leaves a site. Stormwater management practices can be structural or non-structural. Stormwater management practices may use vegetation, soils, and other elements to restore some of the natural processes that reduce runoff. Examples of stormwater management practices include disconnected downspouts, rain gardens, bioretention practices, permeable pavement, green roofs, and detention ponds.



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1. Disconnected Downspout
2. Bioretention in an Open Space
3. Bioretention in Parking Lots
4. Subsurface Detention Storage
5. Traditional Detention Basin

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Removing Impervious Cover

Reducing a drainage charge does not necessarily require implementation of a structural stormwater management practice. By simply reducing the impervious cover on a property, customers reduce the amount of stormwater leaving their property and thus reduce their drainage charge. Examples of impervious cover reduction include removal of asphalt or concrete parking spaces and replacing the impervious cover.

Note: Because the drainage charge is calculated using the amount of impervious cover on a site, the removal of impervious cover is not considered a drainage charge credit but rather an adjustment to the impervious area.

Information
Removal of excess
parking requires
zoning review by
the City's Building,
Safety Engineering,
& Environmental
Department (BSEED)

Drainage Charge Credits

The amount of the drainage charge credit is determined based on how well a customer can control the volume and peak flow characteristics of their runoff. Credits of up to 80 percent of the total drainage charge bill may be earned for reductions of:

- Annual Volume of Flow (40%)
- Peak Flow Rate (40%)

The maximum total drainage charge credit is 80 percent.

Figure 1: Drainage Charge Credits

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Volume-Related Costs

The vast majority of stormwater that enters Detroit's combined sewer system reaches the wastewater treatment plant (WWTP). Detroit's share of the cost associated with running the regional WWTP is based on the total volume of flow from the City. In addition, some components of the cost associated with combined sewer overflow control (CSO), facilities such as chemical use and power use, are also related to flow volume. Efforts that customers make to reduce the total volume of flow that is handled by the sewer system over the course of the year helps to reduce these costs to DWSD.

Peak Flow Rate Related Costs

Detroit has invested approximately $1 billion in CSO facilities since the 1990's. These facilities treat overflows caused by large storm events. Detroit faces the prospect of being mandated to invest up to $2 billion in additional costs (based on 2010 reports) to control additional CSO points along the Detroit and Rouge Rivers if stormwater management practice measures prove insufficient to prevent overflows.

Detroit's Wastewater Treatment Plant

When customers implement measures to limit the peak rate of flow from their properties to the sewer system it helps to reduce the need for these facilities. The majority of peak flow related costs are for the construction and ongoing operation expense of the CSO facilities.

Base Costs

In addition to the costs associated with the WWTP and the CSO facilities, DWSD operates an extensive system of sewers and pump stations. These system elements are necessary to make centralized sewer and stormwater management practice services available. The systems must be maintained in order to be ready to serve each property in the City. In addition, there are various costs associated with administering the drainage charge system such as data management, billing, customer service, and credit administration.

Conner Creek CSO

Volume Credit

Volume-based drainage charge credits are determined based on the average annual volume reductions that result from managing stormwater on-site. The annual runoff volume is computed prior to and after construction of the stormwater management practice. The volume credit is calculated as the fraction of average annual runoff volume that is reduced as a result of implementing stormwater management practices on-site.

$$\%\,Volume\ Credit = \frac{Average\ Annual\ Runoff\ Volume\ Retained}{Total\ \ Average\ Annual\ Runoff\ Volume}$$

As the maximum credit that can be earned for volumetric control is 40 percent, the result of the above equation is multiplied by 40 percent. The site credit is prorated based on how much of the site is managed.

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Peak Flow Credit

In order to earn a peak flow credit, the outlet capacity for the managed portion of the site must be limited to 0.15 cfs/acre.

Peak flow-related drainage charge credits are based on the ability of the site to control peak flows of stormwater. Generally this credit is earned by the construction of an above or below ground detention system. In order to qualify for a peak credit, the detention system MUST have a controlled outlet. Once the system has a controlled outlet, the peak flow credit is calculated as the fraction of the volume associated with a 100-year, 24-hour rain event that is detained.

$$\%\ Peak\ Flow\ Credit = \frac{Storage\ Volume\ Provided}{100-yr, 24-hr\ Storage\ Volume\ Required}$$

As the maximum credit that can be earned for peak flow control is 40 percent, the result of the above equation is multiplied by 40 percent. The site credit is prorated based on how much of the site is managed.

How Much Credit Will Various Practices Accomplish?

Various types of stormwater management practices are able to control either annual volume, peak flow or both. Table 1 identifies anticipated ranges of credit that various common stormwater management practices can earn. The credit applies to the area draining to the stormwater management practice. Common stormwater management practices are described in the following sections.

DID YOU KNOW?

Retention is the process of permanently keeping stormwater from leaving a property. It can be accomplished through infiltration, evaporation, transpiration (water uptake through plants) or water reuse. This process helps to reduce volumes of stormwater from the sewer system. It is through retention that most of the allowed credit is earned.

Detention is the process of temporarily storing stormwater runoff to mitigate sewer overflows. This process helps reduce the flow rate (volume per unit time) of stormwater through the sewer system. The stormwater is later released into the system after the rainfall or snow melt subsides. It is through detention that most properties earn credits for peak flow credits.

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TABLE 1 – Credits for Commonly Used Stormwater Management Practices

Practice Type	Volume Credit	Peak Flow Credit	Potential Credit for Area Managed (%)
Downspout disconnection	✓		**0-40**
Disconnected impervious area	✓		**0-40**
Bioretention	✓	✓	**0-80**
Detention basins		✓	**0-40**
Subsurface detention storage		✓	**0-40**
Permeable pavement	✓	✓	**0-80**
Green roof	✓		**0-40**
Water harvesting*	✓	✓	**0-80**

For water harvesting, peak flow volume evaluated on a case-by-case basis.

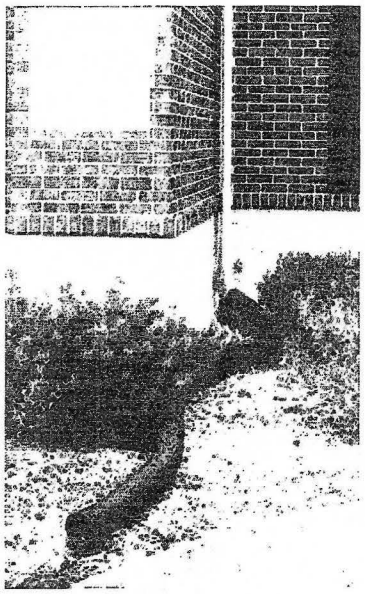
Downspout Disconnection

Downspout disconnection is the process of disconnecting roof downspouts from the sewer system and redirecting the roof runoff onto pervious surfaces, most commonly a lawn. This reduces the amount of directly connected impervious area in a drainage area.

Typically an existing downspout is cut above ground level. An elbow and an extension are then added to the downspout in order to divert rainwater and snowmelt away from the building or structure and onto the ground. The abandoned drain pipe is then capped. A splash pad may also be attached at the end of the downspout extension to prevent erosion in garden areas and help direct the flow of water.

Required: Disconnected downspouts must be directed to pervious or lawn areas that will not result in flooding, icing hazards or discharge to public right of ways and/or neighboring properties. They must be properly extended away from the building foundation.

Increasing a credit: The credit for downspout disconnection is directly related to the size of the lawn area or the type of outlet location (lawn or bioretention area). Larger lawn areas and more highly designed stormwater management practices will result in a larger credit.



Extended Downspout

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Disconnected Impervious Area

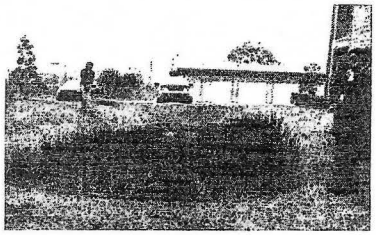
When impervious surface areas such as roofs, driveways, sidewalks, and parking lots are directed to pervious areas that allow for infiltration, customers may qualify for a disconnected impervious area credit. The pervious area to which stormwater is directed may be a grass lawn or vegetated landscaped area.

Required: Disconnected impervious areas must be directed to pervious or lawn areas that will not result in flooding, icing hazards or discharge to public right of ways and/or neighboring properties.

Increasing a credit: The credit for disconnected impervious areas is directly related to the size of the pervious vegetated area where the stormwater is directed. Larger ratios of pervious area to impervious area will result in higher credit percentages.

Bioretention

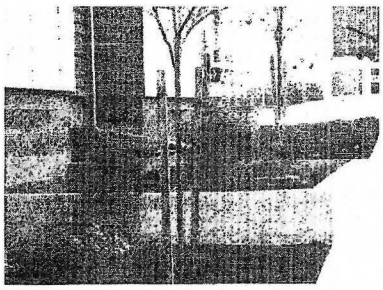
Bioretention is typically sited in an area of natural or constructed depression and consists of vegetation, a ponding area, mulch layer, and planting or engineered soil media and released through an underdrain. The vegetation may include perennials, grasses, shrubs, and trees. It typically incorporates a vegetated groundcover or mulch that can withstand urban environments and tolerate periodic inundation and dry periods. Runoff intercepted by the practice is temporarily captured in the depression and then infiltrated into the underlying soil. Flow that doesn't infiltrate is filtered through the soil (often engineered soil) media. Pretreatment of stormwater flowing into the bioretention area is recommended to remove large debris, trash, and larger particulates. Pretreatment may include a grass filter strip, sediment forebay, or grass swale. Ponding areas can be designed to provide detention.



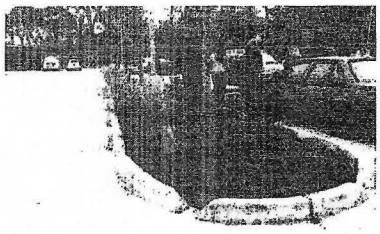
Bioretention in an Open Space

Required: Bioretention systems must promote infiltration and evapotranspiration. However the system must also be able to drain below the ground surface within 24 hours.

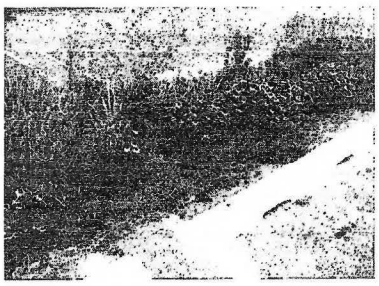
Increasing a credit: The credit for bioretention systems is most directly related to the size (area and volume) of the bioretention relative to the tributary area. Examples of bioretention can include bioretention planter boxes, bioretention islands in parking lots or parking lot aisles.



Bioretention in Planter Boxes



Bioretention Islands in Parking Lots



Bioretention between Parking Lot Aisles

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Detention Basins

Detention is a stormwater management practice that temporarily stores runoff volume and slowly releases it to the sewer system with a controlled outlet. Detention systems include dry detention and wet detention where the control structure is offset from the bottom of the basin which creates a landscape feature such as a permanent wet pool.

Required: Detention basins must have a controlled outlet to be eligible for a credit.

Traditional Dry Detention Basin

Increasing a credit: The credit for detention basins is based on the volume of the detention basin relative to the volume of a 100-year, 24-hour event storm. The larger the basin, the larger the credit. Water stored in a detention basin can also be reused for irrigation, which would result in a volume credit.

Subsurface Detention Storage

Underground detention performs the same function as a detention basin. Stormwater (and snowmelt) is routed to underground vaults or a system of large-diameter or low-profile storage pipes. Pipe or manufactured systems can be used. As with detention basins, a controlled outlet is required. In some cases where soils have available infiltration capacity, these systems can also function as an infiltration practice for a retention credit. Alternatively, they can function as cisterns for water reuse.

Required: Subsurface detention basins must have a controlled outlet to be eligible for a credit. Pretreatment is required to prevent a buildup of solids and other debris in the subsurface detention.

Subsurface Detention Storage

Increasing a credit: The credit for subsurface detention is based on the volume of the detention relative to the volume of a 100-year, 24-hour event storm. The larger the detention, the larger the credit.

Permeable Pavement

Permeable pavement is sometimes used in highly impervious areas to help infiltrate stormwater runoff that would otherwise enter the sewer system. This practice includes an aggregate stone layer to provide both structural support and volume storage, and a porous pavement layer that allows runoff to infiltrate. Because it can replace traditional impervious pavement, permeable pavement is an effective option for parking lots in urban areas.

Required: A stone/aggregate layer to control stormwater. To be eligible for credits, installations must follow important design considerations.

Permeable Pavement

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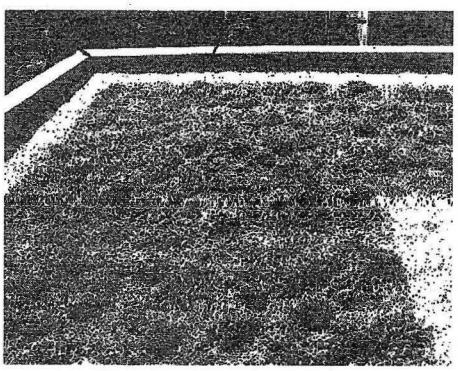
Increasing a credit: The depth of stone under a parking area significantly affects the volume available to manage stormwater. The more storage volume, the larger the credit will be. The stone storage area, if properly sized, can also be used for roof drains and other impervious surfaces.



Green Roof

Green Roofs

Green roofs are used to introduce vegetation onto sections of roof tops to absorb and filter rainfall. Between rain events, some of the rain water is held in the plants and evaporates. At a minimum, a green roof consists of a waterproof membrane and root barrier system to protect the roof structure, a drainage layer, filter fabric, a lightweight soil media, and vegetation that filters, absorbs, and retains/ detains the rainfall. The overall thickness of a green roof commonly ranges from two to six inches. A green roof may be connected to other stormwater management practices such as a bioretention, bioswale, or cistern.

Green roofs are most often applied to buildings with flat roofs, but can be installed on roofs with slopes with the use of mesh, stabilization panels, fully contained trays, or battens.

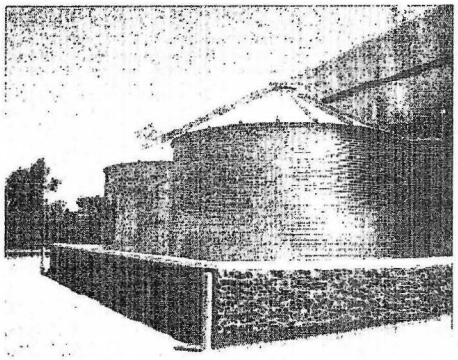
Increasing a credit: The credit associated with a green roof is dependent on size of the green roof area and depth of the media. The larger these two are, the more significant the credit.

Water Harvesting (Reuse)

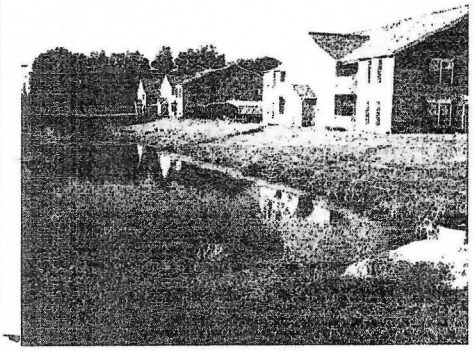
Water harvesting practices are generally used to collect stormwater runoff from impervious areas and store it in large cisterns or ponds. Runoff can then be used in non-potable applications such as watering vegetation or greywater systems. Cisterns as well as smaller rainwater harvesting systems can be constructed above or below ground depending on the space constraints of the site.

Required: Any water reuse system must include a means of using the water on a routine basis and a meter to measure the water used OR measure the residual flow to the sewer system.

Increasing a credit: Reuse systems are only as effective as the ability to use the water. The credit will be increased if more uses for the stored water are identified. For example, some industrial customers are reusing stormwater for the facility's industrial processes. This likely requires sufficient treatment of the water for the desired purpose.



Cistern



Irrigation Pond

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Full or Partial Site Credits

DWSD does not require stormwater from the entire site to be managed in order to take advantage of the credit system. However, drainage charge credits will be calculated for only that fraction of a property that is "managed", meaning the area from where stormwater runoff is directed to a stormwater management practice. Runoff from an "unmanaged" area of a property will not be eligible for a drainage credit. Figure 2 represents these concepts.

For the example in Figure 2, the portion of the site that is tributary to the stormwater management practice would be eligible for a credit. The unmanaged portion (shaded area) would not be eligible for a credit.

Figure 2: Managed versus Unmanaged Area

Example for partial Site Credits: Due to the layout of the site, 6 of the 10 impervious acres drain to a detention basin. The basin is sized to detain 70 percent of the 100-year, 24-hour storm event's runoff volume for the impervious acres draining to it. This makes it eligible for a peak flow credit, however the practice has no infiltration capabilities, so it cannot earn a volume credit.

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The credit is calculated as shown in Table 2:

TABLE 2: Partial Site Credits

Area	Credit Type	Volume Performance (%)	Managed Impervious Area (acres)	Credit Calculation	Credit Amount (%)
Managed Area	**Volume**	**70**	**6**	**(6/10) * 0.7 * 0.4**	**17**
Non-managed	**None**	**0**	**0**	**N/A**	**0**
				Total	**17**

Multiple Credits

In cases where more than one stormwater management practice is present, the credit will be determined based on the total site's potential to manage stormwater. The customer can earn multiple drainage charge credits.

Note: While multiple credits can be given to eligible properties, the total drainage charge credit to any property cannot exceed 80 percent for that property. If customer is receiving a transition credit, they get either the transition credit or the stormwater management practice credit, whichever is greater.

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Figure 3: Multiple Credits

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Example for Multiple Credits: A site with 8.7 impervious acres drains to 3 different locations. Of the 8.7 impervious acres, 2.3 drain to a detention basin that can detain 80% of the 100 year, 24 hour storm even volume making it eligible for a peak flow credit. Then 2.4 acres of impervious area drain to a separate bioretention practice that retains 90% of the annual rainfall volume; making the second practice eligible for a volume credit. The remaining 4 impervious acres drain to a DWSD sewer and are not managed.

The credit that this site can earn is shown in Table 3:

TABLE 3 - Multiple Credits

Subcatchment	Credit Type	Practice Performance (%)	Managed Impervious Area (ac)	Credit Calculation	% Credit Awarded (%)
Detention Basin	**Peak Flow**	**80**	**2.3**	**(2.3/8.7) * 0.8 * 0.4**	**8**
Bioretention	**Volume**	**90**	**2.4**	**(2.4/8.7) * 0.9 * 0.4**	**10**
Not Managed	**None**	**0**	**4.0**	**N/A**	**0**
Total			**8.7**		**18**

Shared Stormwater Management Practices

DWSD allows the location of the stormwater management practice to be on a separate parcel from where the stormwater is generated. There are two circumstances where this may happen:

- A single property owner owns multiple parcels
- Multiple property owners construct a shared stormwater practice

Situation #1: Single Property Owner

Required: A single property owner with multiple adjacent parcels must:

- Have consistent owner names and addresses on each parcel

Situation #2: Multiple Property Owners

Required: A legal agreement between the property owners documenting that this is a shared stormwater management practice.

DWSD will assess the practice performance and, if credit requirements are achieved by a joint practice, each property owner will be granted a credit for their contributing impervious area.

Note: DWSD encourages cost-sharing to support the design, construction, and maintenance of shared stormwater management practices. DWSD will not intervene in private transactions associated with financing and maintenance. DWSD will apply credits to the properties whose flow is managed.

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EXAMPLE: Four individual properties have entered into an agreement whereby a single detention basin will control peak flow from each of their properties. The detention basin is sized to detain 60 percent of the 100-year, 24-hour event storm runoff volume from all impervious cover on each property. Therefore, the properties are eligible for the peak flow rate credit. Because the detention basin has no infiltration capabilities, no property will receive volume credits. With the information below, the total credits allocated to each property are calculated.

Figure 4: Shared Ownership of Stormwater Management Practice

TABLE 4 - Shared Ownership of a Stormwater Management Practice

Owner Calculation	Credit Type	Practice Performance (%)	Managed Impervious Area (Acres)	Credit Calculation	Credit Amount
1	Peak	60	3	(3/3) * 0.6 * 0.4	24
2	Peak	60	2	(2/2) * 0.6 * 0.4	24
3	Peak	60	2	(2/2) * 0.6 * 0.4	24
4	Peak	60	2.1	(2.1/2.1) * 0.6 * 0.4	24

Note: All impervious area on each site is controlled.

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How to Get a Drainage Charge Credit

In order to be eligible for a drainage charge credit, the stormwater management practice must be approved by DWSD. To obtain a drainage charge credit, the property owner will need to meet eligibility requirements, apply for and receive an approval from DWSD, and fulfill on-going operations and maintenance (O&M) requirements. The customer's name must be on the account.

To be eligible for a credit, the stormwater management practices must:

- Reduce annual runoff volume and/or control peak flow rate;
- Be documented in terms of design and performance in a manner acceptable to DWSD;
- Comply with all applicable city, county, state, and federal construction, building, and stormwater codes and permits;
- Be fully installed and functioning properly;
- Not create a safety hazard or nuisance; and
- Be located on a property that is geographically located within DWSD's Drainage Service Area.

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Exhibit F, United States Geological Survey, "Surface Runoff and the Water Cycle,

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Exhibit F, United States Geological Survey, "Surface Runoff and the Water Cycle,

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Surface Runoff and the Water Cycle

Runoff is nothing more than water "running off" the land surface. Just as the water you wash your car with runs off down the driveway as you work, the rain that Mother Nature covers the landscape with runs off downhill, too (due to gravity). Runoff is an important component of the natural water cycle.

Note: This section of the Water Science School discusses the Earth's "natural" water cycle without human interference.

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Surface runoff is precipitation runoff over the landscape

In our section about water storage in the oceans we describe how the oceans act as a large storehouse of water that evaporates to become atmospheric moisture. The oceans are kept full by precipitation and also by runoff and discharge from rivers and the ground. Many people probably have an overly-simplified idea that precipitation falls on the land, flows overland (runoff), and runs into rivers, which then empty into the oceans. That is "overly simplified" because rivers also gain and lose water to the ground. Still, it is true that much of the water in rivers comes directly from runoff from the land surface, which is defined as surface runoff.

Impervious areas cause excessive runoff.

When rain hits saturated or impervious ground it begins to flow overland downhill. It is easy to see if it flows down your driveway to the curb and into a storm sewer, but it is harder to notice it flowing overland in a natural setting. During a heavy rain you might notice small rivulets of water flowing downhill. Water will flow along channels as it moves into larger creeks, streams, and rivers. This picture gives a graphic example of how surface runoff (here flowing off a road) enters a small creek. The runoff in this case is flowing over bare soil and is depositing sediment into the river (not good for water quality). The runoff entering this creek is beginning its journey back to the ocean.

As with all aspects of the water cycle, the interaction between precipitation and surface runoff varies according to time and geography. Similar storms occurring in the Amazon jungle and in the desert Southwest of the United States will produce different surface-runoff effects. Surface runoff is affected by both meteorological factors and the physical geology and topography of the land. Only about a third of the precipitation that falls over land runs off into streams and rivers and is returned to the oceans. The other two-thirds is evaporated, transpired, or soaks (infiltrates) into groundwater. Surface runoff can also be diverted by humans for their own uses.

Much of the water in rivers comes directly from rainfall

The small creek shown in the picture above will merge with another creek, eventually flowing into a larger river. Thus, this creek is a tributary to a river somewhere downstream, and the water in that river will eventually flow into an ocean. The concept is not that much different from the small capillaries in your body carrying blood to larger arteries, eventually finding its way to your heart, analogous to the ocean.

Meteorological factors affecting runoff:

- Type of precipitation (rain, snow, sleet, etc.)
- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over the drainage basin
- Direction of storm movement
- Precipitation that occurred earlier and resulting soil moisture
- Other meteorological and climatic conditions that affect

Exhibit F, United States Geological Survey, "Surface Runoff and the Water Cycle,

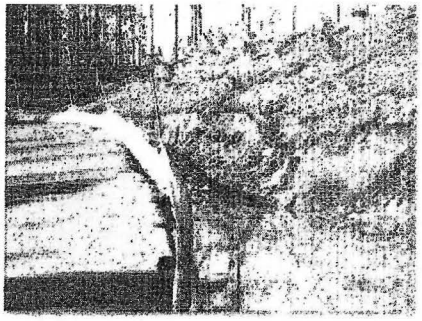
evapotranspiration, such as temperature, wind, relative humidity, and season

runoff from the landscape. (Credit: Galen Hoogestraat, USGS)

Physical characteristics affecting runoff:

- Land use
- Vegetation
- Soil type
- Drainage area
- Basin shape
- Elevation
- Topography, especially the slope of the land
- Drainage network patterns
- Ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or delay runoff from continuing downstream

Human activities can affect runoff



Severe erosion can occur when people manipulate the landscape without regard to how flowing rainfall runoff will erode exposed soil. (Credit: Howard Perlman, USGS)

As more and more people inhabit the Earth, and as more development and urbanization occur, more of the natural landscape is replaced by impervious surfaces, such as roads, houses, parking lots, and buildings that reduce infiltration of water into the ground and accelerate runoff to ditches and streams. In addition to increasing imperviousness, removal of vegetation and soil, grading the land surface, and constructing drainage networks increase runoff volumes and shorten runoff time into streams from rainfall and snowmelt. As a result, the peak discharge, volume, and frequency of floods increase in nearby streams.

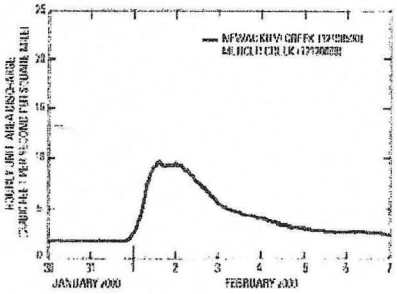
Urban development and flooding

Urbanization can have a great effect on hydrologic processes, such as surface-runoff patterns. Imagine it this way: in a natural environment, think of the land in the watershed alongside a stream as a sponge (more precisely, as layers of sponges of different porosities) sloping uphill away from the stream. When it rains some water is absorbed into the sponge (infiltration) and some runs off the surface of the sponge into the stream (runoff). Assume a storm lasting one hour occurs and one-half of the rainfall enters the stream and the rest is absorbed by the sponges. Now, gravity is still at play here, so the water in the sponges will start moving in a general downward direction, with most of it seeping out and into the streambanks during the next day or two.

Next, imagine that roads and buildings have replaced most of the watershed surface. When that one inch of rainfall occurs, it can't infiltrate these impervious surfaces and will runoff directly into the stream, and very quickly, too! The result is a very quick and short-lived urban flood, rather than a gradual rise and fall in the river. Still, a flood lasting even 10 short minutes is enough to ruin your basement.

This concept is illustrated by this hydrograph of a rural (Newaukum Creek - blue line) and an urban (Mercer Creek - green line) creek in Washington State. If you measured the area under both curves (the total volume of water that flowed by the measurement location for the time period shown on the X axis) in the chart, they might be the same. But in the urban stream, the water at the measurement site rose at a much higher rate and reached a much higher stage (height) than the rural stream did. The tall, steep curve of Mercer Creek showed that much higher streamflows occurred in the urban stream. The urban stream stage fell back towards baseflow much quicker, too, indicating that it wasn't receiving much seepage from groundwater. "Base flow" is the sustained flow of a stream in the absence of direct runoff. It includes natural and human-induced streamflows. Natural base flow is sustained largely by groundwater discharges.

The rural stream rose much slower and reached a lower peak, meaning it may not have flooded at all. It took longer to fall back to baseflow as groundwater slowly seeped into the streambanks over the next week.



Streamflow in Mercer Creek, an urban stream in western Washington, increases more quickly, reaches a higher peak discharge, and has a larger volume during a one-day storm on February 1, 2000, than streamflow in Newaukum Creek, a nearby rural stream, a nearby rural stream that drains a basin of simlar size.

More topics and other components of the water cycle:

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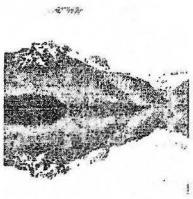
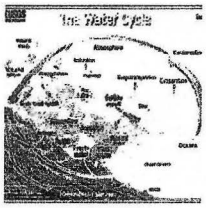


Date published: JULY 10, 2019
Status: Active

The Fundamentals of the Water Cycle

Earth's water is always in movement, and the natural water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. Water is always changing states between liquid, vapor, and ice, with these processes happening in the blink of an eye and over millions of years.

Contacts: Ask USGS



Date published: NOVEMBER 6, 2019
Status: Completed

The Water Cycle for Adults and Advanced Students

Earth's water is always in movement, and the natural water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. Water is always changing states between liquid, vapor, and ice, with these processes happening in the blink of an eye and over millions of years.

Note: This section of the Water Science School...

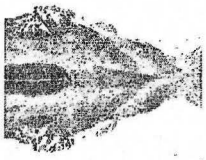
Contacts: Ask USGS

Date published: SEPTEMBER 8, 2019
Status: Completed

Precipitation and the Water Cycle

The air is full of water, even if you can't see it. Higher in the sky where it is colder than at the land surface, invisible water vapor condenses into tiny liquid water droplets—clouds. When the cloud droplets combine to form heavier cloud drops which can no longer "float" in the surrounding air, it can start to rain, snow, and hail... all forms of precipitation, the superhighway moving water...

Contacts: Ask USGS



Date published: JULY 16, 2019
Status: Completed

A Comprehensive Study of the Natural Water Cycle

Earth's water is always in movement, and the natural water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above, and below the surface of the Earth. Water is always changing states between liquid, vapor, and ice, with these processes happening in the blink of an eye and over millions of years.

Note: This section of the Water Science School...

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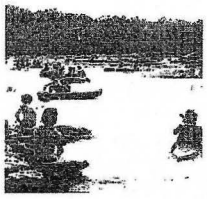

Date published: JUNE 12, 2019
Status: Completed

Streamflow and the Water Cycle

What is streamflow? How do streams get their water? To learn about streamflow and its role in the water cycle, continue reading.

Note: This section of the Water Science School discusses the Earth's "natural" water cycle without human interference.

Contacts: Ask USGS

Date published: JUNE 12, 2019
Status: Completed

Snowmelt Runoff and the Water Cycle

Perhaps you've never seen snow. Or, perhaps you built a snowman this very afternoon and perhaps you saw your snowman begin to melt. Regardless of your experience with snow and associated snowmelt, runoff from snowmelt is a major component of the global movement of water, possibly even if you live where it never snows.

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Exhibit F, United States Geological Survey, "Surface Runoff and the Water Cycle,

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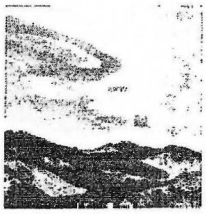


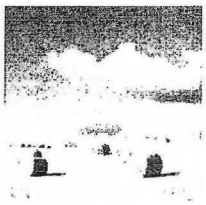
Date published: JUNE 8, 2019
Status: Completed

The Atmosphere and the Water Cycle

The atmosphere is the superhighway in the sky that moves water everywhere over the Earth. Water at the Earth's surface evaporates into water vapor which rises up into the sky to become part of a cloud which will float off with the winds, eventually releasing water back to Earth as precipitation.

Note: This section of the Water Science School discusses the Earth's "natural" water...

Contacts: Ask USGS



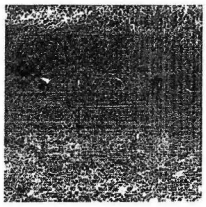
Date published: JUNE 8, 2019
Status: Completed

Condensation and the Water Cycle

The air is full of water, as water vapor, even if you can't see it. Condensation is the process of water vapor turning back into liquid water, with the best example being those big, fluffy clouds floating over your head. And when the water droplets in clouds combine, they become heavy enough to form raindrops to rain down onto your head.

Note: This section of the Water Science...

Contacts: Ask USGS



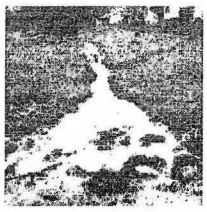
Date published: JUNE 8, 2019
Status: Completed

Infiltration and the Water Cycle

You can't see it, but a large portion of the world's freshwater lies underground. It may all start as precipitation, but through infiltration and seepage, water soaks into the ground in vast amounts. Water in the ground keeps all plant life alive and serves peoples' needs, too.

Note: This section of the Water Science School discusses the Earth's "natural" water cycle without human...

Contacts: Ask USGS



Date published: JUNE 8, 2019
Status: Completed

Surface Runoff and the Water Cycle

Runoff is nothing more than water "running off" the land surface. Just as the water you wash your car with runs off down the driveway as you work, the rain that Mother Nature covers the landscape with runs off downhill, too (due to gravity). Runoff is an important component of the natural water cycle.

Note: This section of the Water Science School discusses the Earth's "natural"...

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Status: Completed

Springs and the Water Cycle

A spring is a place where water moving underground finds an opening to the land surface and emerges, sometimes as just a trickle, maybe only after a rain, and sometimes in a continuous flow. Spring water can also emerge from heated rock underground, giving rise to hot springs, which people have found to make a delightful way of soaking away their problems.

Note: This section of the...

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Exhibit G, United States Geological Survey, "Runoff: Surface and Overland Runoff"

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Runoff: Surface and Overland Water Runoff

When rain falls onto the landscape, it doesn't just sit there and wait to be evaporated by the sun or lapped up by the local wildlife—it begins to move (due to gravity). Some of it seeps into the ground to refresh groundwater, but most of it flows down gradient as surface runoff. Runoff is an intricate part of the natural water cycle.

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Runoff: Surface and Overland Water Runoff

When rain falls onto the earth, it just doesn't sit there, it starts moving according to the laws of gravity. A portion of the precipitation seeps into the ground to replenish Earth's groundwater. Most of it flows downhill as runoff. Runoff is extremely important in that not only does it keep rivers and lakes full of water, but it also changes the landscape by the action of erosion. Flowing water has tremendous power—it can move boulders and carve out canyons; check out the Grand Canyon!

Runoff of course occurs during storms, and much more water flows in rivers (and as runoff) during storms. For example, in 2001 during a major storm at Peachtree Creek in Atlanta, Georgia, the amount of water that flowed in the river in one day was 7 percent of all the streamflow for the year.

After a heavy rainfall you might see sheets of water running downhill...always seeking a stream it can run into, so it can continue to participate in the natural water cycle.

Some definitions of runoff:

1. That part of the precipitation, snow melt, or irrigation water that appears in uncontrolled (not regulated by a dam upstream) surface streams, rivers, drains or sewers. Runoff may be classified according to speed of appearance after rainfall or melting snow as direct runoff or base runoff, and according to source as surface runoff, storm interflow, or groundwater runoff.

2. The sum of total discharges described in (1), above, during a specified period of time.

3. The depth to which a watershed (drainage area) would be covered if all of the runoff for a given period of time were uniformly distributed over it.

Meteorological factors affecting runoff:

- Type of precipitation (rain, snow, sleet, etc.)
- Rainfall intensity
- Rainfall amount
- Rainfall duration
- Distribution of rainfall over the watersheds
- Direction of storm movement
- Antecedent precipitation and resulting soil moisture
- Other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season.

Physical characteristics affecting runoff:

- Land use
- Vegetation
- Soil type
- Drainage area
- Basin shape
- Elevation
- Slope
- Topography
- Direction of orientation
- Drainage network patterns
- Ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or alter runoff from continuing downstream

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Exhibit G, United States Geological Survey, "Runoff: Surface and Overland Runoff"

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Runoff and water quality

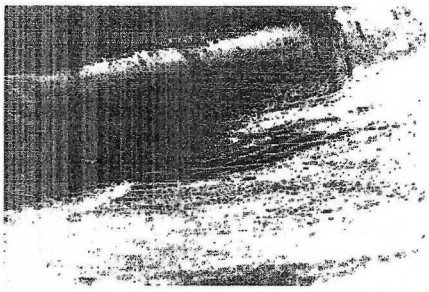
A significant portion of rainfall in forested watersheds is absorbed into soils (infiltration), is stored as groundwater, and is slowly discharged to streams through seeps and springs. Flooding is less significant in these more natural conditions because some of the runoff during a storm is absorbed into the ground, thus lessening the amount of runoff into a stream during the storm.

As watersheds are urbanized, much of the vegetation is replaced by impervious surfaces, thus reducing the area where infiltration to groundwater can occur. Thus, more stormwater runoff occurs—runoff that must be collected by extensive drainage systems that combine curbs, storm sewers (as shown in this picture), and ditches to carry stormwater runoff directly to streams. More simply, in a developed watershed, much more water arrives into a stream much more quickly, resulting in an increased likelihood of more frequent and more severe flooding.

A storm sewer intake such as the one in this picture is a common site on almost all streets. Rainfall runoff, and sometimes small kids' toys left out in the rain, are collected by these drains and the water is delivered via the street curb or drainage ditch alongside the street to the storm-sewer drain to pipes that help to move runoff to nearby creeks and streams. ; storm sewers help to prevent flooding on neighborhood streets.

Drainage ditches to carry stormwater runoff to storage ponds are often built to hold runoff and collect excess sediment in order to keep it out of streams.

Runoff from agricultural land (and even our own yards) can carry excess nutrients, such as nitrogen and phosphorus into streams, lakes, and groundwater supplies. These excess nutrients have the potential to degrade water quality.



What if the street you live on had only a curb built around it, with no stormwater intake such as the one pictured here. Any low points in your street would collect water when it rained. And if your street was surrounded by houses with yards sloping uphill, then all the runoff from those yards and driveways would collect in a lake at the bottom of the street. (Credit: Robert Lawton)

Why might stormwater runoff be a problem?

As it flows over the land surface, stormwater picks up potential pollutants that may include sediment, nutrients (from lawn fertilizers), bacteria (from animal and human waste), pesticides (from lawn and garden chemicals), metals (from rooftops and roadways), and petroleum by-products (from leaking vehicles). Pollution originating over a large land area without a single point of origin and generally carried by stormwater is considered non-point pollution. In contrast, point sources of pollution originate from a single point, such as a municipal or industrial discharge pipe. Polluted stormwater runoff can be harmful to plants, animals, and people.

Runoff can carry a lot of sediment

When storms hit and streamflows increase, the sediment moved into the river by runoff can end up being seen from hundreds of miles up by satellites. The right-side pictures shows the aftermath of Hurricane Irene in Florida in October 1999. Sediment-filled rivers are dumping tremendous amounts of suspended sediment into the Atlantic Ocean. The sediment being dumped into the oceans has an effect on the ecology of the oceans, both in a good and bad way. And, this is one of the ways that the oceans have become what they are: salty.

Florida, Oct. 14, 1999. When Hurricane Irene passed

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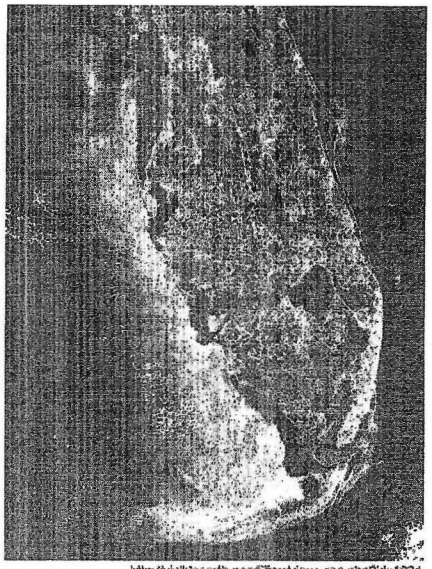
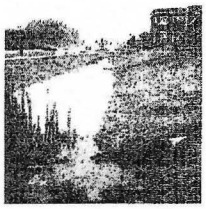
over Florida in 1999, the heavy rainfall over land caused extensive amounts of runoff that first entered Florida's rivers which then dumped the runoff water, containing lots of sediment, into the Atlantic Ocean. *(Credit: NASA Visible Earth.)*



http://visibleearth.nasa.gov/view_rec.php?id=1064
NASA Visible Earth

Florida, Dec. 16, 2002. The east coast of Florida is mostly clear of sediment from runoff. The shallow coastal waters to the west of Florida are very turbid (sediment-filled), perhaps from a storm that passed over a few days earlier.
(Credit: NASA Visible Earth)

Below are map products associated with surface and overland runoff.



Date published: NOVEMBER 20, 2017

GLRI Urban Stormwater Monitoring: Assessing stormwater reduction using green infrastructure (story map)

The GLRI Urban Stormwater Monitoring effort brings together the expertise of the USGS with local and national partners to assess the ability of green infrastructure to reduce stormwater runoff in Great Lakes urban areas. This story map discusses the problem with stormwater, the potential benefits and challenges of green infrastructure, and how this effort is evaluating its effectiveness.

Attribution: Great Lakes Restoration Initiative, Upper Midwest Water Science Center

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https://onlinelibrary.wiley.com/doi/full/10.1111/1752-1688.12814

Full Water-Cycle Monitoring in an Urban Catchment Reveals Unexpected Water Transfers (Detroit MI, USA)

Christopher J. Hoard

A goal in urban water management is to reduce the volume of stormwater runoff in urban systems and the effect of combined sewer overflows into receiving waters. Effective management of stormwater runoff in urban systems requires an accounting of various components of the urban water balance. To that end, precipitation, evapotranspiration (ET), sewer flow, and groundwater in a 3.40-hectare sewershed in Detroit, Michigan were monitored to capture the response of the sewershed to stormwater flow prior to implementation of stormwater control measures. Monitoring results indicate that stormflow in sewers was not initiated unless rain depth was 3.6 mm or greater. ET removed more than 40% of the precipitation in the sewershed, whereas pipe flow accounted for 19%–85% of the losses. Flows within the sewer that could not be associated with direct precipitation indicate an unexpected exchange of water between the leaky sewer and the groundwater system, pathways through abandoned or failing residential infrastructure, or a combination of both. Groundwater data indicate that groundwater flows into the leaky combined sewer rather than out. This research demonstrates that urban hydrologic fluxes can modulate the local water cycle in complex ways which affect the efficiency of the wastewater system, effectiveness of stormwater management, and, ultimately, public health.

Introduction

Like all water cycles, the urban water cycle is composed of inputs and losses, yet the manner in which typical hydrologic fluxes are activated and

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otherwise regulated are quite different than their undisturbed counterparts. The main reasons for differences in water cycling arise from wastewater collection and treatment systems that provide critical public health services; address the runoff generated from increased impervious area; generate hydrologic segmentation of the urban landscape; and impact hydrologic processes due to how socio-economic forces trigger development, demolition, and then either re-development or fallowing of urban landscapes. It is these forces of urban change in land use that have had great impact on how water moves through cities. Additionally, the decline of postindustrial economies has cascading effects, leaving large swaths of land vacant and fallowed, yet still underlain by extensive wastewater collection and conveyance infrastructure. Stormwater flows in combined sewers are a driver of combined sewer overflows which typically discharge untreated wastewater directly into surface-water bodies and degrade water quality, thus they are the focus of regulatory actions. For the purposes of this work, we define the catchment area of the local stormwater and wastewater collection and the underlying conveyance system to constitute a sewershed. Effective management of system functioning and compliance can benefit from accounting for all fluxes within a given sewershed.

Interest in how stormwater runoff is generated in urban settings has driven complementary research regarding how runoff management affects other aspects of the urban hydrologic cycle (see Göbel et al. ; Fletcher et al. ; Hamel et al. ; Schirmer et al. ; Barron, Barr, and Donn). Model simulations of stormwater management systems such as those described in Göbel et al. (), Barr and Barron (), Endreny and Collins (), Barron, Barr, and Donn (), and Barron, Donn, and Barr () examine how various parts of the urban water balance may be influenced by stormwater control measures (SCMs), but these modeling efforts typically lack calibration data. Monitoring and real-world examples of quantitative evaluations of urban water balances are few. Locatelli et al. () used 40 years of continuous groundwater-level data to examine urbanization in Perth, Australia to demonstrate that stormwater infiltration affects nearly all aspects of the local water cycle. Andres et al. (), Bhaskar et al. (), and Edwards et al. () note that influences on groundwater resources are poorly understood, especially with respect

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to groundwater mounding and potential changes in baseflow characteristics. Their results suggest that, if rainfall is coupled via infiltration and percolation to groundwater, changes in groundwater levels may increase inflows or infiltration into leaky sewer conveyances during both dry-weather and stormflow conditions.

In 2014, the United States (U.S.) Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency, began several studies to characterize the hydrology at urban sites, including Detroit, Michigan; Cincinnati, Ohio; Cleveland, Ohio; Omaha, Nebraska; Buffalo, New York; and Gary, Indiana (https://wim.usgs.gov/geonarrative/GLRI_urban_stormwater/) where SCMs were implemented to reduce the impact of stormwater flows on street flooding, water in basements, and excessive inflow into the centralized wastewater collection system. The objective of those studies was to document stormwater volume reduction attributed to SCMs. This paper presents baseline data collected at RecoveryPark, Detroit, Michigan prior to the implementation of SCMs to identify and scale the impacts of posturban landscape and subsurface conditions on the urban water balance. Specifically, we collected hydrologic data to evaluate rainfall, pipe flow, and groundwater levels in a postresidential setting where houses were abandoned leaving infrastructure in decay. These data will serve as a baseline for future research as restoration and rejuvenation efforts commence.

Methods

The approach utilized in this study was to characterize various parts of the urban water cycle by making high-frequency measurements of the inflows and outflows into and out of the sewershed starting in late 2014 through early 2017. Additional hydrologic site characterization information collected during this study includes a soil survey and review of relevant geologic descriptions. Data sources included meteorology (air temperature, humidity, rainfall, wind speed, wind direction, net solar radiation, and calculated potential evapotranspiration [ET]); groundwater (water levels and temperatures); and volumetric pipe flows within the combined sewer.

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For the purposes of this study, the study area is defined as the sewershed within a six-block area bounded by Ferry Street on the north, Farnsworth Street on the south, St. Aubin Street on the west, and Chene Street on the east (Figure 1). Within the study area, drainage areas to the combined sewers (and pipe flow meters therein) were reported by Pieschek () and were confirmed through field reconnaissance. Pieschek () did this by observing directions of flow of surface runoff during rainfall events. Additionally, different segments of the sewershed were individually flooded during dry-weather conditions by discharges from a local fire hydrant at flow rates exceeding 150 L/min. Based on observations by Pieschek (), the area of drainage to pipe-flow monitoring location E (the most downgradient monitoring location shown in Figure 1) is estimated to be 3.40 hectares.

Figure 1
RecoveryPark study area Detroit, Michigan.

Setting

The City of Detroit grew into an industrial center in the mid- to late-1800s largely because of access to water and train lines which fostered transportation and shipping throughout the Great Lakes region. As the automobile industry grew in the early 1900s through the early 1950s, metropolitan Detroit's population increased to a maximum of about 1.85 million people (Sugrue ; World Population Review). In the 1960s, decreases in population and housing density paralleled similar declines in Detroit's automobile industry which was related to decentralization of the automobile assembly plants and relocation of parts manufacturers to areas outside of Detroit. By 2015, the population of Detroit dwindled to 677,000; however, all of the old infrastructure (specifically combined sewers) remained. Between 1958 and 1985, housing prices declined approximately 67%, and, as estimated in 2013, were only about 20% of their adjusted value based on 1958 valuations (Detroit Free Press). This shift in valuation

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was a major factor in large-scale abandonment of residential and business properties.

Within the City of Detroit, Michigan, combined sewers convey dry-weather flow and a large portion of the wet-weather flow to the Detroit Wastewater Treatment plant in accordance with their National Pollutant Discharge Elimination System permit (City of Detroit). During regular operations, effluent from sewers and stormwater flow is treated and discharged either into the Detroit or Rouge Rivers. However, when conveyance of any given part of the combined sewer system is exceeded during stormflow, combined sewer overflows may occur at up to 56 sites in the service area. The volume of combined sewer overflows are declining in Detroit, from an estimated 85.2 Mm^3 in 1993, to 15.9 Mm^3 between July 2010 and June 2011, to a goal of <5.7 Mm^3 in 2019 (City of Detroit ; Michigan Department of Environmental Quality). To deal with these remaining overflows, the City of Detroit's Stormwater Management Program Plan (City of Detroit) includes implementation of green infrastructure, one of many SCMs available to city planners.

The study site is within an area named RecoveryPark, which lies within an urban-residential area about 4 km northeast of downtown Detroit (Figure 1). From aerial photographs (available through Google Earth at https://www.google.com/earth/), we estimate that the housing density in the late 1950s at the study site was approximately 15 houses per hectare, but this declined to <3 houses per hectare in 2014. As the population diminished, demolition of houses in blighted neighborhoods often involved filling in the old foundations with demolition debris and covering with fill (Nolan ; City of Detroit). However, beginning in the early 2010s, this practice was no longer followed and removal of all debris (including the foundations) started to be the accepted practice. Prior to demolition, water supply and sewer lines were sealed off or removed to separate the abandoned properties from the main lines beneath streets and alleys, yet this practice was not always followed, and otherwise, the long-term condition of these seals remains unclear. Abandoned house foundations filled with construction debris may serve to store water infiltrating from the surface. Seepage and drainage of water accumulated in

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these below-grade structures through cracks and fissures in foundation materials may contribute additional flow into the combined sewer system. Abandoned foundations that were covered by backfill soil are known to be present in the RecoveryPark area, but there was no additional information available regarding their locations or extent. During the course of this study, several open building foundations along Chene Street were observed to be partially filled with construction debris and accumulated large volumes of water during rain events.

The combined sewer and storm-drain system was initially built in the late 1800s and, based on accounts reported in Pieschek (), consists of vitrified clay pipe and brick pipe. In 2016, compromised sections of the pipe network were lined with a polyvinyl chloride product; however, much of the combined sewer system remains in varying states of disrepair. Based on examination of aerial photographs and site reconnaissance, there were only two households within the sewershed that might have been contributing domestic wastewater to the combined sewer during the course of this study.

Climate

Detroit and the rest of southeastern Michigan have a humid continental climate influenced by the Great Lakes (National Weather Service Forecast Office). The monthly daily mean air temperature ranges from −3.6°C in January to 23.1°C in July. Mean air temperature from 2000 to 2017 was 9.86°C. The average growing season is approximately 180 days with temperatures below freezing occurring from late October thru late April. Precipitation averages about 78–81 cm/yr and is evenly distributed throughout the year. Snowfall averages 1.08 m per season.

Topography and Local Drainage

The topographic setting of the study area is characterized by relatively flat to gently sloping surfaces toward the southeast, eventually terminating at the Detroit River 4 km to the south-southeast at a gradient of less than 0.2 m/km. The land surface ranges between about 191 and 193 m above

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mean sea level. Stage at the nearby Detroit River (USGS Station 04165710 https://waterdata.usgs.gov/nwis/uv?site_no=04165710) averages about 174.8 m above mean sea level. Information regarding the natural, ancestral drainage is sparse; however, historic maps show a small tributary named Parent's Creek to the southeast. Through urbanization, it appears as though most of Parent's Creek was filled in (presumably with local fill materials), but the stream still daylights at Elmwood Cemetery, about 2.8 km south-southeast of the RecoveryPark study site. The upstream trace of Parent's Creek at the cemetery is at an elevation of about 182 m above mean sea level, which is approximately 6 m below the surface of the surrounding residential development. Further exploration of LiDAR elevation data from U.S. Geological Survey () indicates that there is no surface expression of the stream or any other surface-water drainage features in or near the study area.

Through examination of aerial photography of RecoveryPark from April 2016 (available through Google Earth at https://www.google.com/earth/), we estimate that approximately 29% of the 3.40-hectare sewershed was covered by impervious surfaces that included roads, sidewalks, alleys, and houses. Roads (comprising approximately 15% of the study area) were generally in fair condition; however, sidewalks (comprising approximately 6% of the study area) and alleys (comprising approximately 8% of the study area) were in poor to extremely poor condition. The two houses within the study area comprised less than 1% of the land cover. In comparison, Pieschek () used an estimate of 22% impervious cover in model simulations and accounted for poor condition or absence of sidewalks and alleys as disconnected impervious surfaces.

Using the terminology of Bell et al. (), the effective imperviousness (portion of the watershed covered by impervious surfaces directly connected to the sewer collection-drainage network) was limited to the roads and houses (15%) unless clogged sewer drains prevented flow into the drain or residential downspouts were disconnected, plus about half of the sidewalk area (3%) for a total of 18%. Examination of aerial photography from June 2011 provides an estimated 23% tree cover at the site, which is defined as

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the extent of tree canopy during leaf-on conditions. In addition to the impervious areas and tree cover, field surveys of the study area indicated much of the open, permeable area was occupied by tall grasses, dense shrubs, trees, and numerous trash and debris piles.

Soils

Soils in this sewershed were characterized as Shebeon-Urban land complex (loamy human-transported material over loamy till; Natural Resources Conservation Service), which is the best-known, preurbanization soil series for this area. The different phases of urbanization (development, demolition-backfill, fallowing) has impacted these native soils, leaving behind a complex set of soil profiles observed as representative soil borings taken in the northern and southern parts of the study site (Figure 2). Increased complexity in these urban soils is due to anthropogenic activity, which is characterized by demolition activities, subsequent soil excavation, and placement of imported backfill material (ca. 1985–2008). Soil texture ranges from fine sandy loam to silty clay loam (Figure 2), with relatively permeable loam lenses interspersed between less-permeable horizons constituted from clay and clay-loam soils. Deeper within the profile, the soils transition to hydraulically restrictive glacial and lake-bed clay-rich sediments with sporadic fine sand lenses. The most significant differences between pre and posturbanization soils are an increase in number of horizons from post to preurbanization profiles, and that more coarsely textured loamy soil lenses are interspersed between lower-permeability clayey layers.

Figure 2
Soil-core descriptions with horizon breaks identified by Munsell soil color and soil texture from two well sites at RecoveryPark, Detroit, Michigan and a preurbanization reference site as described in Natural Resources Conservation Service ().

We measured both infiltration and drainage rate of soils in permeable areas of the study area as described in Shuster et al. () and reported in Hoard et

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al. (). Infiltration rate was measured at 6-m intervals along two parallel 55-m transects of permeable, fallowed areas with tension infiltrometers set to approximately 2 cm of suction head. Drainage rate was measured as saturated hydraulic conductivity with a compact, constant-head permeameter at a single location each with several boreholes augered to different depths separated by 0.91 m. The measured, average infiltration rate of permeable areas was 1.9 cm/hr (±std. err. 0.2 cm/hr; n = 18; with a range of 0.4–4 cm/hr). Drainage (saturated hydraulic conductivity in subsoils) at the site declined with increasing depth of measurement, from 0.9 cm/hr at 25 cm below land surface to 0.1 cm/hr at 60 cm below land surface.

Surficial and Bedrock Geology

Surficial and bedrock geology of the Detroit area are summarized by Mozola () and Howard (). Surficial geology is dominated by glacial, lacustrine, and glacio-fluvial sediments predominantly comprised of clay- and silt-sized sediments. The glacial till is known as the River Rouge Till of Wisconsinan age with thicknesses ranging from 27 to 45 m (Howard). Devonian-age limestones and shales including the Dundee Limestone, the undifferentiated Traverse Group (consisting of limestones and shales), and the Antrim Shale underlie the unconsolidated glacial and lake sediments. Based on the thickness and clay-rich character of the overlying sediments, bedrock formations are decoupled from the local flow system and do not impart any effects (e.g., deep drainage influences) on hydrology at the study site.

Instrumentation

A Campbell ET-107 weather station was installed in 2014 to measure precipitation, wind speed, wind direction, air temperature, relative humidity, and net solar radiation. Although it would have been ideal to locate the weather station directly at the study site, there were concerns about vandalism and theft, therefore, the station was installed approximately 1.45 km northwest of the study site at a secure location (Figure 1). Calibration, installation, and maintenance of the instruments

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equaled or exceeded manufacturer's specifications. Potential ET (combined evaporation and transpiration) was calculated using the modified Penman–Monteith equation that includes measurements of solar radiation, air temperature, wind speed, and relative humidity (American Society of Civil Engineers). This calculation provides estimates of the maximum amount of ET available if there were nonlimiting soil moisture content.

An exploratory well-drilling program was begun in 2014 to characterize the local groundwater at the site. Initially, four core holes were drilled at the corners of the study site at well locations SE 01D, SW 02D, NW 03D, and NE 04D (Figure 1 and Table 1) with target depths of about 6 m from land surface using a Geoprobe Model (Geoprobe Systems®, Salina, KS) 5400 series direct-push probing machine. Depth of coring was dictated by the relatively shallow depth of combined sewer lines (3–4.5 m from land surface), and the first appearance of saturated sediments defining a shallow or perched water table. Small-diameter (2.5 cm) wells were installed within each remaining core hole (Table 1). After examination of the cores and recording water levels for several months, a second round of drilling added 16 more wells to fill in gaps between the corners. Additionally, wells C 05S, C 05D, C 04S, C 03S, S 07S, and S 06S were installed within a few meters of known combined sewer pipes to evaluate the extent to which leaking pipes might interact with the groundwater system (Figure 1). All wells were outfitted with Schlumberger Diver pressure transducers that recorded water levels every 15 min with a reported accuracy of ±2.0 cm.

Table 1. Monitoring-well location and description at RecoveryPark, Detroit, Michigan.

Station name	USGS station number	Latitude	Longitude	Land surface elevation (m)	Date drilled	Well depth (m)
C 01D	422202083023702	42.36729	−83.04371	192.28	Oct-14-2015	6.16
C 01S	422202083023701	42.36729	−83.04372	192.28	Oct-14-2015	2.50
C 02D	422203083023602	42.36746	−83.04326	192.11	Oct-15-2015	6.16

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Station name	USGS station number	Latitude	Longitude	Land surface elevation (m)	Date drilled	Well depth (m)
C 02S	422203083023601	42.36746	−83.04324	192.09	Oct-14-2015	2.45
C 03S	422203083023301	42.36736	−83.04261	192.17	Oct-16-2015	2.47
C 04S	422203083023401	42.36750	−83.04270	191.94	Oct-16-2015	2.46
C 05D	422203083023403	42.36762	−83.04279	191.95	Oct-16-2015	6.14
C 05S	422203083023402	42.36763	−83.04278	191.96	Oct-16-2015	2.50
N 05D	422209083023602	42.36911	−83.04323	192.02	Oct-17-2015	6.05
N 05S	422209083023601	42.36911	−83.04322	192.04	Oct-17-2015	2.52
N 06D	422207083023502	42.36865	−83.04302	191.96	Oct-19-2015	6.16
N 06S	422207083023501	42.36867	−83.04299	191.89	Oct-19-2015	2.46
NE 04D	422207083024102	42.36853	−83.04464	192.14	Nov-15-2014	6.04
NE 04S	422207083024101	42.36853	−83.04464	192.15	Nov-14-2014	2.46
NW 03D	422206083024402	42.36824	−83.04544	192.33	Nov-13-2014	5.97
NW 03S	422206083024401	42.36825	−83.04545	192.37	Nov-14-2014	2.41
S 05D	422202083023102	42.36718	−83.04193	191.67	Oct-15-2015	6.14
S 05S	422202083023101	42.36718	−83.04193	191.65	Oct-15-2015	2.44
S 06S	422202083023301	42.36713	−83.04248	192.24	Oct-15-2015	2.46
S 07S	422202083023302	42.36727	−83.04256	192.23	Oct-15-2015	2.19
SE 01D	422201083023702	42.36686	−83.04355	192.50	Nov-13-2014	4.81

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Station name	USGS station number	Latitude	Longitude	Land surface elevation (m)	Date drilled	Well depth (m)
SE 01S	422201083023701	42.36685	−83.04354	192.51	Nov-13-2014	2.35
SW 02D	422200083023902	42.36654	−83.04431	192.62	Nov-14-2014	6.09
SW 02S	422200083023901	42.36655	−83.04431	192.67	Nov-14-2014	2.40

Temperature also was measured in wells using Schlumberger CTD Divers, with temperature accuracy of ±0.16°C. Temperature monitoring of groundwater was done to determine whether changes could be observed because of water leaking out of the combined sewer and into the surrounding sediments.

Pipe-flow measurement was done by the Detroit Water and Sewerage Department at several locations in and around the study area. Measurements were made through a combination of velocity and stage sensors installed within the pipes behind v-notch weirs. Combined sewer conveyances were generally in poor condition, such that flow was often impeded due to clogging from sediment and debris. The pipe-flow data are available in Hoard et al. ().

To explore the flow characteristics in the combined sewer, a hydrograph-separation technique developed by Lyne and Hollick () was used to estimate baseflow in the pipe-flow record. The term "baseflow" is most often associated with perennial streamflow during dry-weather conditions that can be attributed to groundwater seepage into stream channels; however, for the purposes of this study, we use the term to describe flow within the combined sewer during dry-weather conditions when no runoff from precipitation or snowmelt is directly contributing to pipe flow. This usage is similar to that of Kaushal and Belt () who describe it as "buried baseflow." The EcoHydRology library (Fuka et al.) for the R statistical computing environment (R Core Team) was used to perform hydrograph separation. The filter parameter used for the separation was 0.99 and the number of passes done by the filter was set to 3. An aggressive filter

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parameter was used that is outside the range of suggested filter parameters (0.90–0.95) to ensure that we could remove the stormwater runoff component from the flow observed in the sewer. Flows within the combined sewer were compared to precipitation records to explore the relation between rainfall and pipe flow at the study site. When runoff events were separated from their baseflow component, we calculated peak unit discharges at pipe flow location E and compared them to rainfall amounts.

Results

Summary precipitation data and potential ET calculations from October 1, 2015 through September 30, 2016 are shown in Figure 3. These and all other weather data for this study are available through USGS National Water Information System at https://goo.gl/WNDFqG. Precipitation totaled 1,253 mm for October 1, 2015 through September 30, 2016. Precipitation during this period was higher than the long-term average of 786.6 mm reported in U.S. Climate Data () for the period 1961–1990. Maximum precipitation fell in August and September 2016 with monthly totals of 232.4 and 260.4 mm, respectively. Air temperature averaged 12.26°C during the period from October 1, 2015 to September 30, 2016. Potential ET followed seasonal patterns with maximum of 139.1 mm/month in June 2016, and minimum potential ET of 21.2 mm/month in January 2016. No attempt was made to convert the reference ET determined from the weather station to an actual ET estimate. The uncertainty in the amount and type of vegetation required for determining appropriate crop coefficients to estimate the actual ET was likely on the order of the uncertainty in the reference measurement itself.

Figure 3
Meteorological conditions at USGS weather station 422239083032401 for October 2015 through September 2016 for (a) precipitation; (b) air temperature; and (c) potential evapotranspiration (ET).

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Groundwater levels in wells across the site responded in varying degrees to precipitation events and exhibited discernable seasonal patterns. (Data are available through the USGS National Water Information System (NWIS) at https://goo.gl/WNDFqG) Water levels in shallow wells C 03S, S 06S, and S 07S all behaved similarly with a more gradual response to precipitation than other wells in the study area (Figure 4). Water levels in other wells also responded to these same events, but water-level rise was typically <10 cm. Perimeter wells, including NW 03S, NE 04S, and S 05S were consistent in that they responded to precipitation events with more than 30-cm rise between March 1, 2016 and March 30, 2016. These three wells were set in the more permeable soils and sediments facilitating downward flow. Vertical gradients between all of the shallow and deep nested wells were downward during the majority of the study period. Horizontal gradients indicated groundwater flow was from the southeast to northwest.

Figure 4
Groundwater levels in wells at RecoveryPark, Detroit, Michigan for October 2015 through September 2016.

Water levels in wells situated near the southeast part of the study area and closest to the combined sewer (including wells C 05S, C 05D, C 04S, C 03S, S 07S, and S 06S) showed a similar response to precipitation events consistent with other wells. Based on groundwater levels, we did not discern exfiltration from the combined sewer pipes which would have been evident if rapid rises in groundwater levels coincided with large flow events in the combined sewer. Within a majority of wells, groundwater levels were consistently higher than the combined sewer approximately 3–4.5 m below land surface. This would suggest that the combined sewer pipes — if made permeable by separation of pipe joints, cracking, and (or) collapse over their long service life — could be a sink for excess soil moisture and groundwater. In addition, preferential flow within and through more structured higher-permeability lining-bedding materials laid into the combined-sewer excavation (which may have included gravel,

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bricks, local soils, and fill materials) could bypass the surrounding clay-rich sediments.

We used groundwater temperature as an additional indicator to identify exfiltration, and in this case, confirm the absence of exfiltration as a major component of the sewershed water cycle. Groundwater temperatures from wells follow the anticipated seasonal sinusoidal responses, with more dampened amplitude in the deeper than shallower wells (Figure 5). As compared to average air temperatures, highest and lowest groundwater temperatures lag behind due to the thermal properties of the surrounding soils. Shallow groundwater temperatures were highest in late September, with a lag between peak air and groundwater temperatures of about 1–2 months, whereas deep groundwater temperatures peaked in November and December with a correspondingly longer lag of about 4–5 months. Well SE 01D (shown in magenta coloring on Figure 5) was 1.3 m shallower than the other deep wells and responded with a shorter lag time to atmospheric changes. During site reconnaissance, water temperatures in the combined sewer were measured during dry-weather conditions at monitoring location E (data available through NWIS at https://waterdata.usgs.gov/nwis) and during a rain event. In both cases, water temperature in the sewer was within 0.56°C of ambient air temperatures. We found that groundwater temperatures for wells closest to the sewer conveyances were similar to those farther away indicating no apparent exchange of water flowing out of the sewer, which would present themselves as warmer temperatures in the summer and cooler temperatures in the winter compared to the adjacent groundwater temperatures.

Figure 5
Groundwater temperature in (a) shallow wells (<2.52 m deep) and (b) deep wells (>4.81 m deep) at RecoveryPark, Detroit, Michigan for October 2015 through September 2016.

Pipe flows normalized to sewershed drainage area at monitoring locations within the combined sewer during the study period are shown in Figure 6.

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For the most part, flow within the combined sewer responds rapidly to rainfall events. Hydrograph separation (Lyne and Hollick) was used to estimate baseflow in the pipe-flow record at monitoring location E from October 1, 2015 to August 31, 2016. Pipe flow location E was chosen because it incorporated the largest drainage area (3.40 hectares) of the different monitoring locations, thus better representing the sewershed as a whole. The period from October 2015 through August 2016 is shown in Figure 7 to illustrate the portion of the pipe flow discharge estimated to be baseflow.

Figure 6
Pipe flows, normalized to drainage area, in the combined sewer at monitoring locations B (a), C (b), and E (c) at RecoveryPark, Detroit, Michigan for October 2015 through August 2016.

Figure 7
Box plots of estimated baseflow by month in the combined sewer at monitoring location E at RecoveryPark, Detroit, Michigan for October 2015 through August 2016.

Linear regression of rainfall vs. peak unit discharge within the combined sewer showed two characteristic flow regimes (Figure 8). The breakpoint at which rainfall appeared to cause sewer-discharge events was determined using the segmented package in R (Muggeo). The rainfall and peak unit discharge data were log transformed prior to a linear model being applied. The linear model was then used as input to the segmented package which estimated a new segmented model that identified one breakpoint at 3.6 mm of rainfall, where the linear relation between rainfall and peak unit discharge changed. The relation between rainfall and peak unit discharge was relatively flat for rainfall amounts less than 3.6 mm within a 24-hour period. For events that exceeded 3.6 mm of rainfall within a given 24-hour period, the peak unit discharge increased monotonically with increasing rainfall volume.

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Figure 8
Relation between peak unit discharge and rainfall at RecoveryPark, Detroit, Michigan for October 2015 through August 2016.

Discussion

We interpret our results in the contextual setting of urban karst — as a uniquely urban lithology dissected by leaky conveyances and sediments with a wide-ranging permeability — which has been described by Sharp et al. (), Kaushal and Belt (), and Bonneau et al. (). This term appropriately describes the shallow subsurface at RecoveryPark. In addition to perforation of urbanized substrata by the combined sewer pipes, the findings of Shuster et al. () suggest that vacant parcels have highly variable fill material that can affect lateral and vertical water movement. Vacant parcels in the study catchment present as one of several morphologies: (1) unfinished demolitions as open pits enclosed by a perimeter of cracked concrete, stone, or brick foundations, (2) finished demolition sites that had been backfilled with soils and a variable amount of debris as rock fragments, and (3) finished demolition sites with unconsolidated debris possessing structural macroporosity as a high proportion of void space or, as megapore networks as described by Bonneau et al. ().

The layering of soils in this area are a strong influence on patterns of water movement. The soils and unconsolidated materials overlying bedrock in Detroit are characterized by a relatively shallow layer of topsoil transitioning to finer, hydraulically restrictive layers at 1–2 m below ground surface which may extend up to 45 m down to bedrock. This circumstance indicates a propensity toward shallow and (or) perched water tables. Yet, the interspersion of the soils with fine sand lenses and highly variable fill material underlying demolished parcels presents tradeoffs in terms of how water cycles through the subsurface.

The conditions described above provide multiple opportunities for transfers of water between elements of the urban water cycle. We conceptualize the urban water cycle at RecoveryPark starting with rainfall

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and snowmelt that infiltrates the surface flowing through the unsaturated and saturated zones within soils and sediment with nonzero conductivity. We measured infiltration rates in the shallow soils that averaged 1.9 cm/hr, which was slightly higher than Pieschek () who estimated a value of 1.3 cm/hr. The clay-rich sediments at depths >1.8 m from ground surface shown in Figure 2 act as a hydraulically restrictive surface. Water that infiltrated and percolated downward through layers with low (though nonzero) hydraulic conductivity eventually reached this restrictive layer. At the top of this layer, it is likely that water moved laterally and (or) into coarser textured loamy lenses interspersed among the clay-rich sediments. Any further downward movement of water would have been facilitated by higher-permeability (from legacy disturbance and enhanced soil structure) soils and bedding around the combined sewer pipes.

Water also may flow along preferential flow paths that include natural fractures and void spaces within construction, demolition, and other debris and horizontally within fine sand lenses. Vertical flow within the unsaturated zone may encounter discontinuities that can limit or delay subsurface flows or lead to accumulation and retention of soil moisture (as in the different kinds of vacant lot parcels). Yet, some portion of the total water flux can and does (as observed in open foundations) accumulate in foundations or backfilled excavations. This arrangement creates a positive hydraulic head at the invert elevation of the excavated area. In addition to variants on vacant land, poor sealing of residential sewer lateral pipes cause inflow and infiltration into the combined sewer. Overall, the posturban landscape can facilitate as much as limit water movement in the subsurface. We find that this highly modified landscape facilitates increased volume inputs — and at faster or more direct routes of delivery — to the system, increasing the degree to which water is available for inflow and infiltration to the conveyance system.

In this study, we leveraged extensive water-cycle monitoring to understand the linkages between seasonal precipitation and how it was redistributed into ET, groundwater storage, and pipe flow. These relations have implications for scoping the management of sewer systems with a focus on minimizing inflow and infiltration into the sewer collection and conveyance

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system, which otherwise depletes system capacity and leads to subsequent malfunction. In addition to rainfall that fell on impervious surfaces and ended up as runoff that entered storm drains at RecoveryPark, rainfall that fell on pervious surfaces percolated downward and entered the sewer system as rainfall-derived infiltration and inflow (RDII). Infiltrated water eventually reached the sewer conveyances where it would accumulate and form a positive head around and over the pipes.

Pipe-flow time series for the combined sewers showed that dry-weather flows were substantial (Figures 6 and 9). Pieschek () attributed 0.453 L/sec (7.18 gpm) of this flow to a leaking potable water supply pipe. Dry-weather flow did not come from domestic wastewater because, during the study period, there were only two occupied houses connected to the combined sewer within the sewershed. If we estimate that 378.5 L (100 gallons) of water was used per person per day multiplied by an estimated 4 people per house, as suggested by U.S. Environmental Protection Agency () and U.S. Geological Survey (), we would expect about 3,028 L of water per day (0.035 L/sec) flowing in the combined sewers at monitoring location E. However, flow in pipes measured at monitoring location E during dry-weather conditions averaged about 0.44 to 0.63 L/sec, which is more than ten times greater than the estimated household use. Additionally, there did not appear to be any diurnal patterns (Figure 9b) that would otherwise suggest increased sanitary sewage inputs during peak usage hours from ordinary household use as described by Lerner (). Although the sources of this water within the combined sewers were not identified, it is possible that a combination of factors may be contributing to this flow, including water inflow from broken potable water pipes (of which there were at least one during the course of this study), groundwater contributions into leaky combined sewer pipes, and, as we pointed out earlier, slow release of rainfall accumulated in abandoned foundations. Inspection of the data from one week in March 2016 (Figure 9) illustrates the varied response of the groundwater and sewer network to a precipitation event. As previously described, some shallow wells (NW 03S, NE 04S, and S 05S, Figure 9c) respond quickly, whereas others have almost no response (S 07S and C 05S) to precipitation events. The hydrograph of pipe flow within the sewer at monitoring location E (Figure 9b) illustrates how the flow in the sewer

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quickly recedes after a precipitation event but that some baseflow is maintained even when no rainfall is occurring. Water levels in shallow wells that responded to precipitation events also recede, but at a slower and more gradual rate. As shallow groundwater levels recede, water is slowly released from storage into the sewer, which acted to maintain the relatively high amount of baseflow in the sewer pipes.

Figure 9
Plots of (a) precipitation; (b) pipe flow at sewer monitoring location E; (c) groundwater levels in shallow wells (<2.52 m deep); and (d) deep wells (>4.81 m deep) at RecoveryPark, Detroit, Michigan, March 24–29, 2016.

As shown on Figure 7, estimated monthly baseflow varies during the year and tends to be larger during the late winter and early spring months and smaller and less variable in the summer months. The estimated volume of baseflow in the combined sewer at monitoring location E exceeded 17,900 m^3 of water for the period from October 1, 2015 to August 31, 2016. The seasonal component of baseflow is likely related to snowmelt and overall increased precipitation and runoff during the spring. Although snowfall and snowmelt data were not collected as part of this study, a weather station at Detroit Metropolitan Airport (approximately 29 km west-southwest from the study site) recorded 897 mm of snow during this period (National Oceanic and Atmospheric Administration). Given evidence of RDII, additional rain and snowmelt would lead to higher groundwater levels and a steeper gradient between groundwater and the combined sewer, thus promoting greater groundwater flow into the compromised sections of sewer pipes presenting itself as baseflow.

The rainfall — runoff (represented by peak unit discharge) graph shown in Figure 8 shows that 3.6 mm of rainfall are needed before increased flow is observed at pipe flow monitoring site E. The change in slope between the two regression lines represents a change in how the sewershed responds to rainfall, with the first line with relatively flat slope representing total catchment detention capacity, and the second line with much steeper slope illustrating average catchment response after catchment detention capacity

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is exceeded. When we performed the segmented regression analysis, the threshold of 3.6 mm rainfall was found to be significant and is within the range of less than 1 to over 30 mm reported by Bell et al. () for 16 sites in Charlotte, North Carolina.

At rainfall amounts <3.6 mm, the slope is relatively flat because detention capacity is in the process of being filled by rainfall, and only small amounts of runoff are generated. Sewershed detention capacity affects this first segment and includes:

- Infiltration capacity of the pervious urban soils and is averaged over (unmeasured) antecedent soil moisture conditions. We measured infiltration to average 1.9 cm/hr, which is considerable. Infiltrated rainfall would be captured as soil moisture, and thereby detained. Not all pervious surface are contiguous, nor are they all connected to the stormwater inlets. This spatial arrangement imposes further regulation on source areas, and once a pervious surface is saturated and runoff is initiated, routing to sewer inlets is apparently minimal at rainfall depth below an average of 3.6 mm, which would be the early-term of a given storm.
- Detention capacity of impervious areas can range between 1–2 mm in rough asphaltic road surface. At this study site, the amount of impervious area was relatively low as compared to other urban sites. Most paved surfaces were generally in poor condition, with larger depressions and potholes. Detention would be higher in these areas. Again, the spatial distribution of these potholes and the crowned cross section of the roads would route direct runoff from the road into surface depression storage.
- Condition of infrastructure, including combined sewer pipes, connections, and junctions all contributed toward transient exchange and storage. Combined sewers were in poor condition and a small amount of storage could occur within cracks, seams, and behind debris and sediment jams. Additionally, leakage out of the combined sewer could occur in cases where groundwater

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levels were below these cracks, loose joints, or other damage to pipes.

When rainfall exceeded overall catchment storage capacity, the flow characteristics in the combined sewer display a steeper slope that — on average — scales linearly with additional storm rainfall depth above the threshold depth of 3.6 mm.

Bell et al. () note that as total imperviousness of a sewershed increases, the value at the intersection decreases, so conceptually, the intersection of the two lines shown on Figure 8 should shift to the right after a decrease in impervious area and implementation of SCMs, such that larger rainfall events would be required to initiate flows within the combined sewer. Water directed into the SCMs and leaving through underdrains, overflows, or infiltration would have to be isolated from the sewer system so as to not supply any further increase in RDII.

Additional understanding of the hydrologic setting is provided in the form of two water budgets (Table 2). Water-budget components included precipitation and potential ET computed from parameters recorded at the weather station, estimated domestic potable water usage, pipe flow at sewer monitoring location E, and groundwater storage represented by changes in groundwater levels in shallow groundwater monitoring wells throughout the sewershed area. Water budgets were developed for two separate one-month periods representing fall conditions (October 15–November 15, 2015) and summer conditions (June 1–July 1, 2016). These time periods were selected primarily because of availability of reliable data from all data sources and exclusion of periods of snow accumulation and sub-freezing temperatures (December and January), for which we did not have reliable snowpack and snowmelt data. It was assumed that groundwater inflow from upgradient areas outside the sewershed was equal to groundwater outflow toward downgradient areas, thereby cancelling out this potential change in groundwater storage.

Table 2. Water budgets for the sewershed draining to monitoring location E during one-month periods with and without baseflow in fall 2015 and

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summer 2016 at RecoveryPark, Detroit, Michigan. Potable water supply was estimated by multiplying four people per house by two houses by 0.38 m³ per day by number of days during the period. Gains or losses from groundwater storage were estimated by multiplying the groundwater level change by 25% effective porosity by the 3.40-hectare sewershed. Runoff coefficient is calculated as pipe flow divided by precipitation (m³, cubic meters; pct, percent (calculated as percent of total inflows); n/a, not applicable).

Water-budget component	Fall (32 days)				Summer (31 days)			
	With baseflow		Without baseflow		With baseflow		Without baseflow	
	(m³)	(pct)	(m³)	(pct)	(m³)	(pct)	(m³)	(pct)
Inflows								
Precipitation	470	83	470	83	210	69	210	69
Potable water supply (estimated)	97	17	97	17	94	31	94	31
Outflows								
Potential ET	−240	42	−240	42	−640	210	−640	210
Pipe flow at location E	−280	49	−110	19	−260	85	−98	32
Difference (unaccounted outflows)	47	8	220	39	−600	200	−430	−140
Gained or lost from groundwater storage	−53	11	110	23	−690	330	−530	250
Runoff coefficient (dimensionless)	0.60	n/a	0.24	n/a	1.3	n/a	0.47	n/a

For the fall conditions in 2015, precipitation volume was 470 m³ and estimated domestic potable water supply was 97 m³ (Table 2). Losses included ET and pipe flow that accounted for 240 and 280 m³, respectively. The difference between input and output loss terms produce a net gain of 47 m³ (about 8% of the total inflow) which could be within the level of uncertainty of our measurements or attributed to a change in storage in the groundwater system or other surface storage (based on site surveys, surface storage was likely only a very small contribution to this budget). If we assume a 25% effective porosity (a conservative value for clay-rich sediments, as reported in Driscoll) over the 3.40-hectare sewershed, that

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would equate to an approximate groundwater elevation rise of 4.0 cm. However, we observed a decline in water-level elevation of approximately 30 cm during the same time period indicating loss of storage from the groundwater system.

To examine the relative proportions of the water budget within the combined sewer without baseflow (as it was designed to function), we removed 0.453 L/sec (165 m^3) as estimated by Pieschek (). The calculated volume of water from the pipe-flow record at monitoring location E then becomes 110 m^3 for the fall period, which is approximately equal to the estimated potable water supply of 97 m^3. With all other things remaining the same, and as described above, this circumstance would result in an even greater positive residual than for the case where baseflow was retained. With baseflow removed from the water balance, we find that water moves into storage increasing groundwater levels by an estimated 18.4 cm. This is not what we see in the groundwater record, so it is possible that this excess water could be infiltrating into the soils, but not fast enough nor deep enough to influence the groundwater levels at the site.

For the summer period in 2016, precipitation amounted to a volume of 210 m^3 and estimated domestic potable water supply was 94 m^3. ET and pipe flow accounted for 640 and 260 m^3, respectively. Balancing these terms produced a difference of 600 m^3. With the same assumption as above of 25% effective porosity, this would be an approximate groundwater elevation decline of 52.7 cm. Water-level elevations monitored in wells during the summer period display a range of responses: some are consistent with that level of decline, whereas others did not respond at all. If we subtract baseflow in the combined sewers, the residual becomes 430 m^3 which is equivalent to a decrease in groundwater level of 38.7 cm and also is consistent with water-level changes observed in the area. The majority of our groundwater data, including water levels (and the gradient between water levels and the combined sewer) and temperature, indicate that groundwater likely flows into the combined sewer rather than pipe flow flowing out of the sewer.

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As with any hydrologic study, the question of representative hydrologic conditions in the context of a short-term study must be considered. There were no changes in the distribution of houses, buildings, or paved surfaces within the study period; therefore, land use and land cover remained constant. Weather conditions during the study period as measured at our meteorological station were slightly warmer and wetter than long-term average conditions reported by the National Weather Service Forecast Office () for Detroit. This could result in higher than average ET (greater transpiration from vegetative cover) and higher than average pipe flow (due to a proportional increase in direct runoff entering the collection system from impervious surfaces) within the combined sewers during warm season storm events. Within our water-budget estimations, other sources of potential error include unequal groundwater inflow or discharge from outside the study area, actual ET values that are less than our computed potential ET, and storage and evaporation in abandoned foundations.

The predominant source of water into the groundwater system at RecoveryPark is precipitation and the predominant sinks are ET and pipe flow conveyed off site. In contrast to other settings, groundwater leakage into the combined sewer provides a sink for percolating water. Overall, changes in storage occurring within the groundwater system are dominated by relatively large groundwater-level rises and declines, which apparently translate to corresponding rises and declines in pipe flows. Indeed, the rise and fall of monthly baseflow estimates shown on Figure 7 approximate the rise and fall of groundwater levels shown in Figures 4 and 9. Similar to the observations of Lerner (), the depth of the sewers relative to the water table is probably a major control on leakage rates into sewers and, as described by Kaushal and Belt (), leaky combined sewers may be behaving similar to tile drains in an agricultural setting by conveying groundwater downgradient within the combined sewer system.

Conclusions

The approach taken here represents a unique opportunity to evaluate different parts of the urban water cycle and improve our understanding of

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the sources and sinks of water in an urban catchment. The combined meteorologic and hydrologic data provide information toward the extent of potential ET, infiltration, pipe flow, and pipe leakage that are not commonly measured in urban settings. At RecoveryPark, an urban-residential site in Detroit MI, our conceptualization of the urban hydrologic system includes a complex interaction between impervious surfaces, pervious surfaces, and flow within well-developed soils, clay-rich sediments, and poor condition local wastewater infrastructure that includes abandoned foundations (as a discontinuity in surface runoff along the subgrade) and leaky combined sewers. These interactions change with seasonal conditions as demonstrated by comparison of water budgets computed for fall and summer conditions.

The hydrologic system responds to rainfall events; however, continuous flows within the sewers from a variety of potential sources represent a large volume of water when compared with water derived from rainfall alone. Our results show that change in groundwater storage can play a major role in increasing the dry-weather flow in sewer conveyances due to high groundwater tables relative to the elevation of these pipes, which allow a substantial amount of inflow and infiltration. The estimated volume of baseflow in the combined sewer exceeded 14,300 m^3 of water per year in both 2015 and 2016, most of which ended up being treated by the City of Detroit at their wastewater facility. While this research suggests a correlation between higher groundwater levels and higher pipe flows, more work should be done to account for these water transfers. These relations will guide the design and implementation of green infrastructure as SCMs, and such that they will not contribute to flows within the combined sewer (i.e., return flow). This study aids in scoping efforts to eventually minimize the amount of baseflow in the conveyance system, with anticipated savings through maintaining system volume capacity and not treating relatively "clean" groundwater that was conveyed to the wastewater treatment plant.

Acknowledgments

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