PL201900171
PL2019-171

BRAUN INTERTEC
The Science You Build On.

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September 19, 2019

Project B1908801.00

Dave Gotham, PE
Senior Project Executive, Construction
Ryan Companies US, Inc.
533 South Third Street, Suite 100
Minneapolis, MN 55415

Re: Groundwater Infiltration and Flow Assessment Summary
Phase 2B Development
Mall of America
Bloomington, Minnesota

Dear Mr. Gotham:

The purpose of this report is to present a conceptual model of groundwater flow conditions associated with the proposed design and construction of the Mall of America (MOA) Phase 2B Expansion in Bloomington, Minnesota (Site). Groundwater flow characteristics are presented to aid in determining the ability to divert a portion of stormwater as part of the planned expansion north of the existing Mall, and to evaluate potential impacts on the mall lower levels.

Project Understanding

We understand this specific project will include the construction of a Water Park, Hotel, and Parking Structure as depicted on Figure 1. As part of this construction effort, the City of Bloomington is requiring the diversion of a portion of the projected stormwater runoff from the existing management system, utilizing focused infiltration basins or other means to reduce stormwater conveyance to the current management system. This letter presents a conceptual hydrologic model that presents the rate, direction, and sensitivity of infiltrating water on the Site. Additionally, an understanding of the rate of groundwater flow from the site is necessary to alleviate concerns regarding temperature mixing of infiltrated water that may impact trout streams south of the Mall property.

Geologic Materials

Fill has been placed throughout the site area over the past decades and extends typically from the surface to depths extending 1 to approximately 18 feet below grade. Below the fill, the native alluvial sands are present with these soils typically extending down to 30 to 45 feet below grade. Silt intermixed with clays exists below the sands to depths of more than 150 feet below grade.

Grain size distribution testing was conducted on samples collected from some of the many geotechnical borings completed for the various evaluations of the soils across the Site at the interval coincidental to the groundwater table, approximately 20 feet below grade, at locations ST-9, ST-10, ST-12, ST-4003, and ST-4007 (attached). These analyses showed the sand profile at and below the water table consisted of an average of 19 percent gravel, 75 percent sand, and 6 percent silt and clay fraction.

Vibro Compacted Soil Correction

The sands across the site above and below the water table ranged in relative density from loose to medium dense. Based on the design building loads, the relative density of the in-place sands both above and below the water table were densified in specific areas of the site using vibro-compaction to increase their load carrying capacity and to reduce their settlement potential. Soils were vibro-compacted at the Ikea store, the Ikea parking ramp, the east parking ramp for MOA and for the Radisson Blu. Additionally, vibro-compaction is planned for the proposed Water Park, Water Park Hotel, and adjacent parking structures because of the estimated building loads and loose sand profile as depicted on Figure 2. The vibro-compaction will target the unconsolidated sand profile from the bottom-of-footing elevation to the surface to the silt and clay layer at depths extending approximately 30 to 45 feet below grade.

The vibro-compaction effort creates a very dense, compact soil profile that greatly reduces the soil to allow water to flow through it. This has been validated by excavation activities we have observed during recent construction projects around MOA that extended below the water table near previously vibro-compacted areas. Our observations have shown the compacted soils had little or no soil moisture, even though being below the area groundwater surface, showing these soils to be a barrier to groundwater saturation and a barrier to lateral groundwater flow.

Groundwater Characteristics, Flow Direction and Gradient

In general, based on known soil profile information and the results of historic groundwater level monitoring with piezometers, the depth to the water table ranges between approximately 14 and 24 feet below grade with the depth decreasing to the east corresponding to a drop in topography. Based on groundwater elevations determined from piezometers advanced on the proposed construction Site in July 2015, groundwater elevations ranged between an elevation MSL of approximately 803.6 and 799.8 with a groundwater gradient dipping to the southeast at 0.003 ft/ft. The groundwater flow map is shown on Figure 3. It should be noted that a drain system underlies Cedar Avenue west of the Mall Site.

Although the invert could not be determined, this drain system would likely direct groundwater from the Mall west toward the drain tile underlying Cedar Avenue.

Groundwater was recently noted at an elevation of approximately 798 at the Metro Transit Station associated with the East Parking Structure. The lowest level of the MOA/Marriot Parking Ramp notes a slab elevation of approximately 802.

Hydraulic Conductivity Values

Hydraulic conductivity values of the subsurface materials underlying the site were determined from the available grain size analyses utilizing the Krumbein and Monk equation (attached). This method utilizes the 5 percent, 16 percent, 60 percent, 84 percent and 95 percent passing the corresponding millimeter grain size values. The results of the hydraulic conductivity evaluations are presented below. Hydraulic conductivity values ranged between 10.43 and 103.75 feet per day (ft/day). It should be noted that the grain size for the soil sample collected at ST-4003 resulted in a high hydraulic conductivity value of 13.75 ft/day, but also showed the lowest fines percentage of 4 percent. Based on the single high value, we concluded that using the geometric mean value of 22.13 ft/day to characterize the site would be reasonable.

Summary of Hydraulic Conductivity Values
Mall of America Site

Location	Sieve Depth (ft)	Sieve Test K (ft/day)
ST-9	25.00	10.43
ST-10	17.50	20.54
ST-12	22.50	12.77
ST-4003	20.00	103.75
ST-4007	20.00	18.72
Average		33.24
Geometric Mean		22.13

Groundwater Flow Velocity

Horizontal groundwater pore velocity values can be calculated by the following equation:

$$V = \frac{(K)\,(I)}{n}$$

Where: V = Groundwater pore velocity (feet/sec)
K = Horizontal hydraulic conductivity value (ft./sec)
I = Hydraulic gradient (ft./ft.)
n = Effective porosity (as a percent)

Based on a hydraulic conductivity value of the shallow saturated materials of 22.13 ft./day, a hydraulic gradient of 0.003 ft./ft., and an estimated effective porosity of the sand of 0.30 (30 percent), the horizontal groundwater flow velocity was evaluated at 0.22 ft./day, or 81 ft./year.

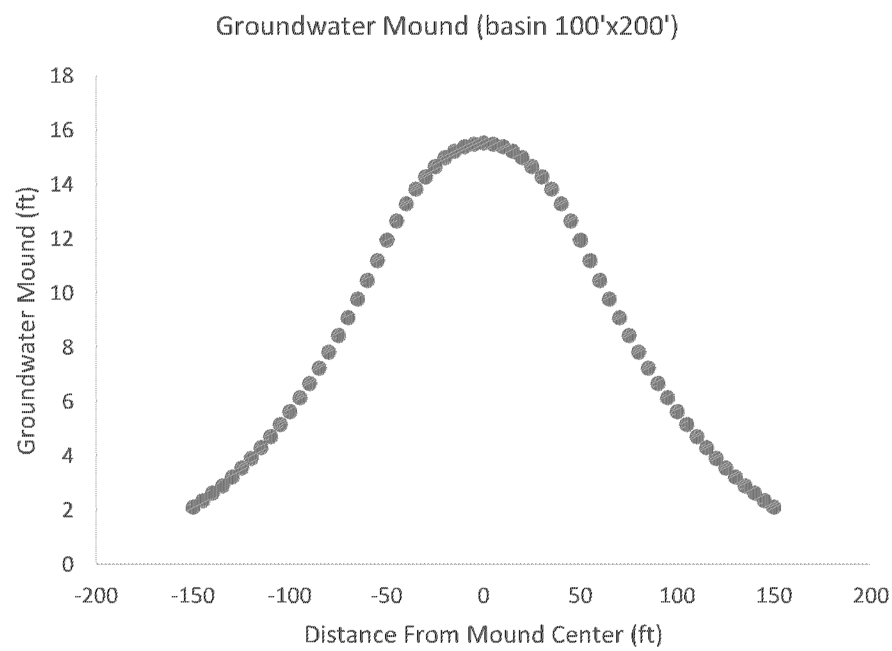
Evaluation of Infiltration Mounding

Groundwater mounding beneath stormwater management structures is a well-known occurrence and for this evaluation was calculated utilizing a spreadsheet developed by the United States Geological Survey (Scientific Investigations Report 2010–5102). The Hantush analytical equation was used to calculate groundwater mounding. The Hantush equation incorporates soil permeability, initial saturated aquifer thickness, specific yield, basin length, basin width, and duration and magnitude of infiltration to predict the maximum mound height and lateral extent of mounding.

For the purpose of predicting the mounding under stormwater infiltration basins, we used the following assumptions:

- The hydraulic conductivity of the shallow saturated materials of 22.13 ft./day determined from sieve analyses.
- A basin size of 100 x 200 feet.
- A saturated sand thickness of 20 feet based on soil borings completed on site.
- A recharge rate of 62,500 ft^3 of water as presented as the target diversion volume based on a 1.1 inch rainfall event.
- A duration of recharge of 1 day.

Utilizing the Hantush method for determining the height of the mound with the assumptions presented above resulted in a maximum groundwater mound height extending 15.54 feet above the water table (model output attached). Additionally, the groundwater mound greater than 10 feet extends 63 feet from the basin. The results of the mounding evaluation extending to a lateral distance of 150 feet is presented below.



Carleton, G.B., 2010, Simulation of groundwater mounding beneath hypothetical stormwater infiltration basins: U.S. Geological Survey Scientific Investigations Report 2010–5102, 64 p.

Trout Stream Considerations

The Minnesota Department of Natural resources (DNR) trout Stream Map is presented on Figure 4. All mapped trout streams within the Mall area are south of the Minnesota River which acts as a hydrologic divide between the Mall property and these streams. There is an unnamed stream mapped approximately 1,200 feet southeast of the Mall property, however this feature is not mapped as a trout stream.

As presented above, even considering the unnamed stream southeast of the Mall, the lateral velocity of groundwater movement from the Mall property would well exceed the Minnesota Stormwater Manual recommendation of at least 48 hours of travel time of infiltrated water to reach temperature equilibration prior to reaching a sensitive receptor.

Conclusions

The Site subsurface conditions are characterized by fill extending to approximately 18 feet below grade, underlain by native alluvial sand extending to a silt and clay layer 30 to 45 feet below grade. Groundwater was noted approximately 14 to 24 feet below grade resulting in approximately 20 feet of saturated fill and sand materials underlying the site. For this study, we assumed the bottom of any infiltration basin would penetrate the existing fill, with the native sands being exposed.

There are many areas of the overall site south of any potential infiltration basin where the soil profile at and below the known groundwater levels have been densified using vibro-compaction. The vibro-compacted soils present a significant barrier to the natural migration of groundwater from north to south. These barriers will tend to divert the natural directional flow of the groundwater and also potentially allow it to buildup in these areas.

Based on previous groundwater elevation data collected on Site, groundwater flow is from the northwest to the southeast at a gradient of 0.003 ft. /ft. Hydraulic conductivity value used to characterize the Site was determined to be 22.13 ft./day resulting in a lateral groundwater velocity of 0.22 ft./day (81 ft./year). As such, there is little concern for mixing time of infiltrated water flow from the Mall to the unnamed stream 1,200 feet southeast of the Mall based on the relatively slow lateral groundwater flow velocity.

Mounding calculations show a groundwater mound resulting from a 1.1 inch rainfall event managed with a 200 x 100-foot basin could potentially extend 15.54 feet above the water table. Additionally, the mounding calculations showed the groundwater mound of up to 10 feet could potentially develop extending 63 feet from the basin center. This mound will further extend until it ultimately dissipates to the groundwater surface. Because of the barriers that exist to the natural migration of groundwater, infiltration of significant volumes of water along the northern extent of the Site presents a high potential for the development of groundwater mounding in the vibro-compacted areas, or channeled along discrete paths around the compacted areas. This occurrence then has a higher potential for impacting the lower levels of the MOA facilities which were built with only a few feet of clear zone between the groundwater surface at that time and the slab elevations.

Groundwater was noted at an elevation of approximately 798 based on recent work with the Metro Transit Station at the East Parking Structure. Groundwater levels were recorded at about elevation 800 during the construction of the facilities around Lindau Lane. The lowest level of the MOA/Marriot Parking Ramp is at about elevation 802, resulting in only about 2 feet of unsaturated materials separating the Mall slab and water table in that specific area. As such, it can only be concluded that the use and placement of focused infiltration basins north of the existing MOA facilities will result in a significant increased risk of higher groundwater levels in that area that will impact the below grade levels of MOA and other subsurface building components.

We appreciate the opportunity to provide professional services for you on this project. If you have questions regarding the contents of this report, please call Dan Barrett at 952.995.2098.

Sincerely,

BRAUN INTERTEC CORPORATION

Daniel P. Barrett, PG
Associate Principal - Principal Scientist

Holly Vetter fr:

Michael M. Heuer, PE
Vice President - Principal Engineer

Attachments:
Figure 1 Water Park Plan
Figure 2 Vibro Compacted Soil Locations
Figure 3 Groundwater Contour Map
Figure 4 Trout Stream Locations
Hydraulic Conductivity Results
USGS Hantush Model Output

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Drawing Information

Project No: B1908801.00

Drawing No: B1908801

Drawn By:	JAG
Date Drawn:	8/22/19
Checked By:	MMH
Last Modified:	8/26/19

Project Information

WaterPark at MOA

60 E. Broadway

Bloomington, Minnesota

Site Sketch

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VIBRO COMPACTED SOIL - EXTREMELY LOW PERMEABILITY

200' 0 400'

SCALE: 1"= 400'

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Project Information

WaterPark at MOA

60 E. Broadway

Bloomington, Minnesota

Site Sketch

DENOTES APPROXIMATE LOCATION OF STANDARD PENETRATION TEST BORING (BRAUN PROJECT NO. B1504839)

VIBRO COMPACTED SOIL - EXTREMELY LOW PERMEABILITY

GROUNDWATER ELEVATION (JULY 2015)

DIRECTION OF GROUNDWATER FLOW

200' 0 400'

SCALE: 1"= 400'

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Drawing Information

Project No: B1908801.00

Drawing No: B1908801

Drawn By:	JAG
Date Drawn:	8/22/19
Checked By:	MMH
Last Modified:	9/5/19

Project Information

WaterPark at MOA

60 E. Broadway

Bloomington, Minnesota

Vibro Compacted Soil Areas

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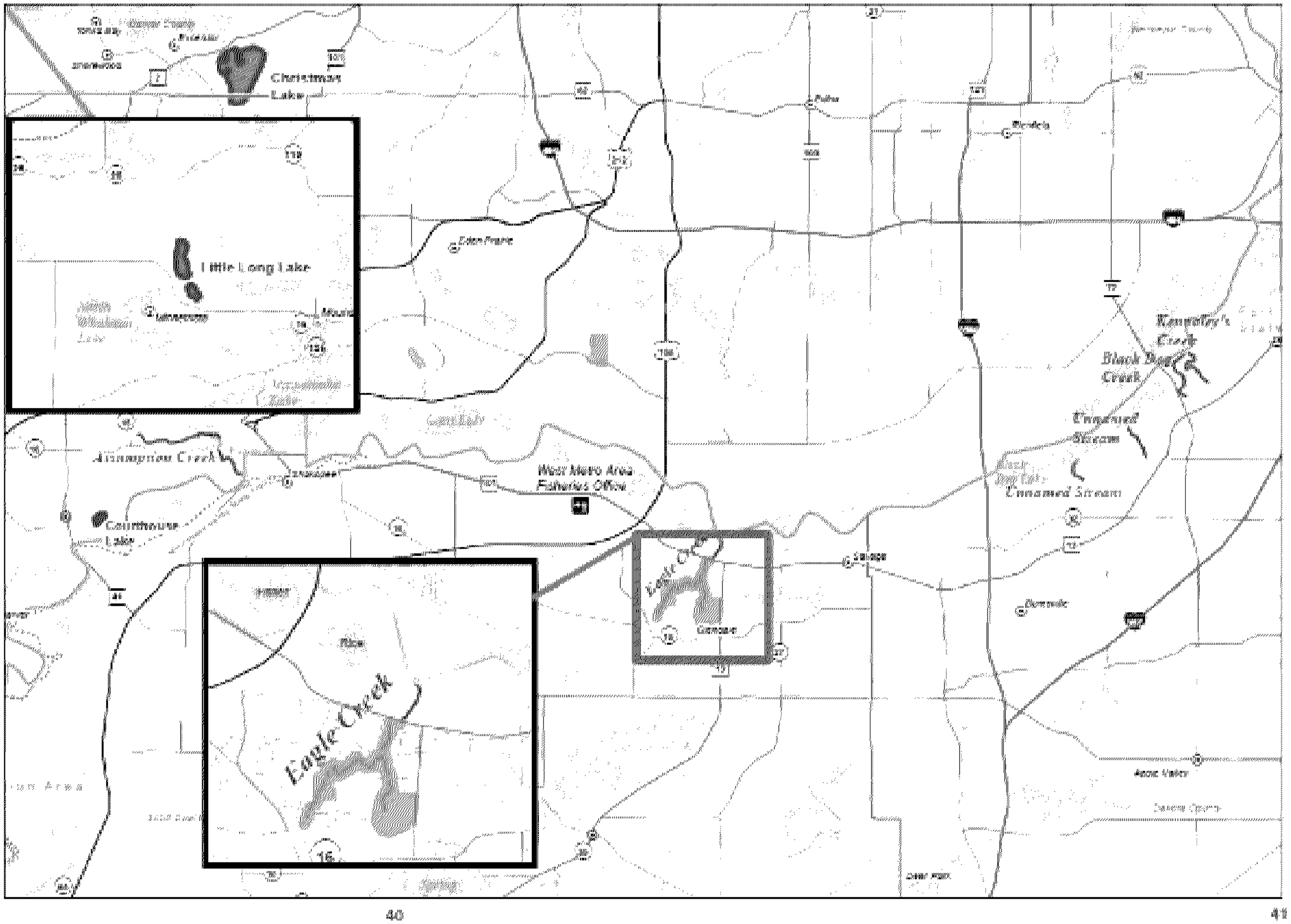

Legend
- State Parks Trout Regulation
- Fisheries Offices
- Interstates
- Federal Highways
- State Highways
- County Roads
- Township Roads
- DNR Administered State Trails
- 12 to 16 Inch Protected Slot for All Trout (Artificial Lures or Flies Only)
- 12 to 16 Inch Protected Slot for All Trout (Bait Allowed)
- 12 Inch Minimum for Brook Trout, Bag Limit of 1 (Artificial Lures or Flies Only)
- Catch & Release for All Trout (Artificial Lures or Flies Only)
- Catch & Release for All Trout (Bait Allowed)
- Catch & Release for Brook Trout
- Fishable Trout Streams
- Streams
- Lakes
- Designated Trout Lakes
- DNR Managed Trout Lakes - non designated
- Minnesota Valley Wildlife Refuge
- State Park Boundary
- Wildlife Managment Areas - Publicly Accessable
- Scientific and Natural Area Boundaries
- Forestry Land
- Fishing Easements or Public Land
- County Boundaries

For detailed information on trout angling regulations see the Minnesota Fishing Regulations booklet and observe signs posted on the stream.

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Base Drawing Provided By

Drawing Information

Project No: B1908801.00
Drawing No::

Drawn By:
Drawn Drawn:
Checked By:
Last Modified:

Project Information

Water Park at MOA

60 E Broadway

Bloomington, Minnesota

Mapped Trout Streams

Figure 4

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Sieve Analysis Data Sheet

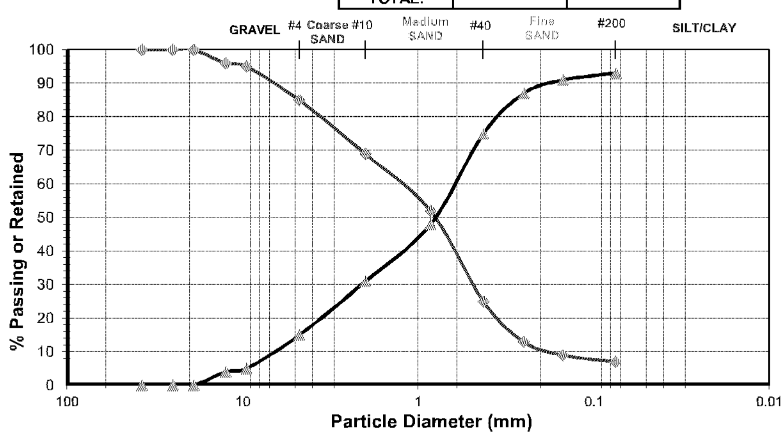
ASTM D422-63(2007)

Project Name: Mall of America **Tested By:** ________ **Date:** ________
Location: Lindau Grade Sep. **Checked By:** ________ **Date:** ________
Boring No: ST-9 **Test Number:** ________
Sample Depth: 25' **Gnd Elev.:** ________

USCS Soil Classification: ________
AASHTO Soil Classification: ________

Weight of Container (g): ________ **Weight of Container & Soil (g):** ________
Weight of Dry Sample (g): ________

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
63 (2.5")	63					
50 (2")	50					
37.5 (1.5")	37.5				**0.0**	100.0
25 (1")	25				**0.0**	100.0
19 (3/4")	19				**0.0**	100.0
12.5 (1/2")	12.5				**4.0**	96.0
9.5 (3/8")	9.5				**5.0**	95.0
#4	4.75				**15.0**	85.0
#8	2.36					
#10	2.00				**31.0**	69.0
#16	1.18					
#20	0.85				**48.0**	52.0
#30	0.60					
#40	0.43				**75.0**	25.0
#50	0.30					
#60	0.25				**87.0**	13.0
#80	0.18					
#100	0.15				**91.0**	9.0
#200	0.075				**93.0**	7.0
	0.036					
	0.023					
	0.014					
	0.010					
	0.007					
	0.003					
Pan						
			TOTAL:			



Grain Size Distribution Curve Results:

% Gravel: 15.0
% Sand: 78.0
% Fines: 7.0

	Passing mm	Passing ϕ	Retained mm	Retained ϕ
D_5:	0.03	5.0589	12.4	-3.6323
D_{10}:	0.18	2.4739	6.9	-2.7866
D_{16}:	0.3	1.7370	4.75	-2.2479
D_{50}:	0.79	0.3401	0.79	0.3401
D_{60}:	1.3	-0.3785	0.61	0.7131
D_{84}:	4.75	-2.2479	0.3	1.7370
D_{95}:	12.4	-3.6323	0.03	5.0589

	mm	ϕ
Geometric Mean	0.95	0.0674
Graphic Median	0.79	0.3401
Graphic Standard Deviation	0.20	2.3131

Coefficient of Uniformity 7.22 >4 = well graded soil

Krumbein and Monk Intrinsic Permeability 33.4 darcy
3.76E-08 cm^2

Krumbein and Monk Derived Hydraulic Conductivity 3.68E-03 cm/sec
10.43 ft/day

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Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: Mall of America **Tested By:** ________ **Date:** ________

Location: Lindau Grade Sep. **Checked By:** ________ **Date:** ________

Boring No: ST-10 **Test Number:** ________

Sample Depth: 17.5' **Gnd Elev.:** ________

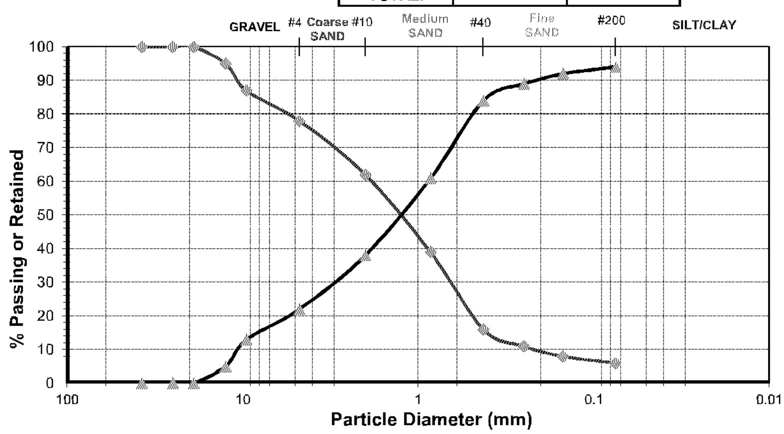
USCS Soil Classification: ________

AASHTO Soil Classification: ________

Weight of Container (g): ________ **Weight of Container & Soil (g):** ________

Weight of Dry Sample (g): ________

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
63 (2.5")	63					
50 (2")	50					
37.5 (1.5")	37.5				**0.0**	100.0
25 (1")	25				**0.0**	100.0
19 (3/4")	19				**0.0**	100.0
12.5 (1/2")	12.5				**5.0**	95.0
9.5 (3/8")	9.5				**13.0**	87.0
#4	4.75				**22.0**	78.0
#8	2.36					
#10	2.00				**38.0**	62.0
#16	1.18					
#20	0.85				**61.0**	39.0
#30	0.60					
#40	0.43				**84.0**	16.0
#50	0.30					
#60	0.25				**89.0**	11.0
#80	0.18					
#100	0.15				**92.0**	8.0
#200	0.075				**94.0**	6.0
	0.036					
	0.023					
	0.014					
	0.010					
	0.007					
	0.003					
Pan						
			TOTAL:			



Grain Size Distribution Curve Results:

% Gravel: 22.0

% Sand: 72.0

% Fines: 6.0

	Passing mm	Passing ϕ	Retained mm	Retained ϕ
D_5:	0.04	4.6439	12.5	-3.6439
D_{10}:	0.2	2.3219	11.5	-3.5236
D_{16}:	0.4	1.3219	7.5	-2.9069
D_{50}:	1.35	-0.4330	1.35	-0.4330
D_{60}:	1.9	-0.9260	0.8	0.3219
D_{84}:	7.5	-2.9069	0.4	1.3219
D_{95}:	12.5	-3.6439	0.04	4.6439

	mm	ϕ
Geometric Mean	1.34	-0.4210
Graphic Median	1.35	-0.4330
Graphic Standard Deviation	0.20	2.3129

Coefficient of Uniformity 9.50 >4 = well graded soil

Krumbein and Monk Intrinsic Permeability 65.8 darcy

7.41E-08 cm^2

Krumbein and Monk Derived Hydraulic Conductivity 7.24E-03 cm/sec

20.54 ft/day

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name:	Mall of America	**Tested By:**		**Date:**	
Location:	Lindau Grade Sep.	**Checked By:**		**Date:**	
Boring No:	ST-12	**Test Number:**			
Sample Depth:	22.5'	**Gnd Elev.:**			

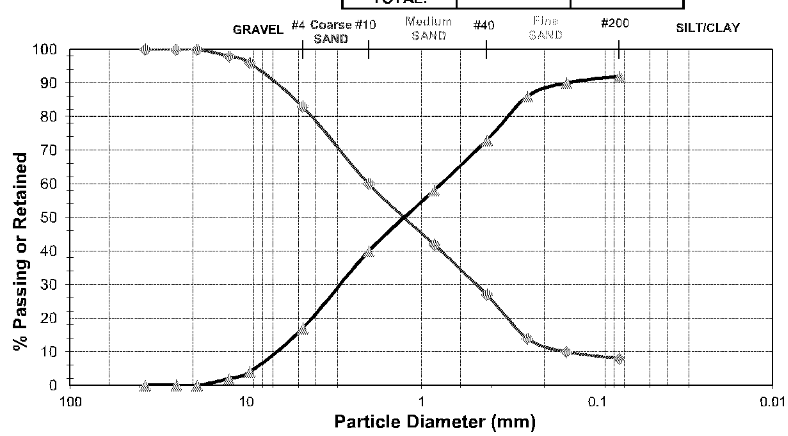
USCS Soil Classification: ____________

AASHTO Soil Classification: ____________

Weight of Container (g): ________ **Weight of Container & Soil (g):** ________

Weight of Dry Sample (g): ________

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
63 (2.5")	63					
50 (2")	50					
37.5 (1.5")	37.5				**0.0**	100.0
25 (1")	25				**0.0**	100.0
19 (3/4")	19				**0.0**	100.0
12.5 (1/2")	12.5				**2.0**	98.0
9.5 (3/8")	9.5				**4.0**	96.0
#4	4.75				**17.0**	83.0
#8	2.36					
#10	2.00				**40.0**	60.1
#16	1.18					
#20	0.85				**58.0**	42.0
#30	0.60					
#40	0.43				**73.0**	27.0
#50	0.30					
#60	0.25				**86.0**	14.0
#80	0.18					
#100	0.15				**90.0**	10.0
#200	0.075				**92.0**	8.0
	0.036					
	0.023					
	0.014					
	0.010					
	0.007					
	0.003					
Pan						
			TOTAL:			



Grain Size Distribution Curve Results:

% Gravel:	17.0
% Sand:	75.0
% Fines:	8.0

	Passing mm	Passing ϕ	Retained mm	Retained ϕ
D_5:	0.03	5.0589	9	-3.1699
D_{10}:	0.15	2.7370	6.8	-2.7655
D_{16}:	0.28	1.8365	5.4	-2.4330
D_{50}:	1.3	-0.3785	1.3	-0.3785
D_{60}:	2	-1.0000	0.78	0.3585
D_{84}:	5.4	-2.4330	0.28	1.8365
D_{95}:	9	-3.1699	0.03	5.0589

	mm	ϕ
Geometric Mean	1.06	-0.0793
Graphic Median	1.30	-0.3785
Graphic Standard Deviation	0.20	2.3142

Coefficient of Uniformity 13.33 >4 = well graded soil

Krumbein and Monk Intrinsic Permeability 40.9 darcy
4.60E-08 cm^2

Krumbein and Monk Derived Hydraulic Conductivity 4.50E-03 cm/sec
12.77 ft/day

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Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name:	Mall of America	**Tested By:**		**Date:**	
Location:		**Checked By:**		**Date:**	
Boring No:	ST-4003	**Test Number:**			
Sample Depth:	20'	**Gnd Elev.:**			

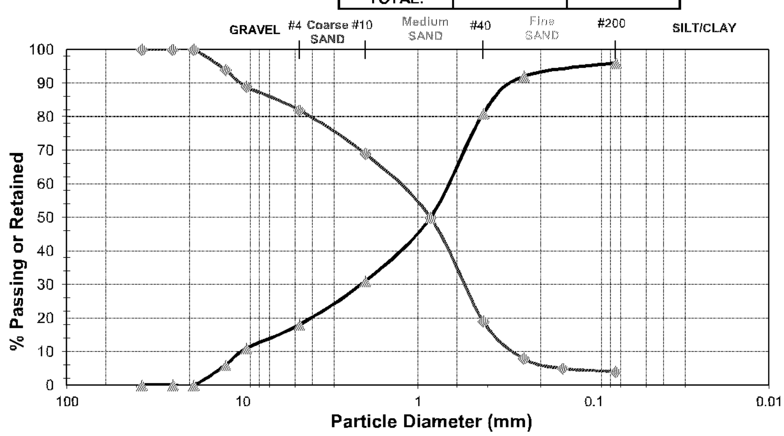
USCS Soil Classification: ____________________

AASHTO Soil Classification: ____________________

Weight of Container (g): __________ **Weight of Container & Soil (g):** __________

Weight of Dry Sample (g): __________

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
63 (2.5")	63					
50 (2")	50					
37.5 (1.5")	37.5				**0.0**	100.0
25 (1")	25				**0.0**	100.0
19 (3/4")	19				**0.0**	100.0
12.5 (1/2")	12.5				**6.0**	94.0
9.5 (3/8")	9.5				**11.0**	89.0
#4	4.75				**18.0**	82.0
#8	2.36					
#10	2.00				**31.0**	69.0
#16	1.18					
#20	0.85				**50.0**	50.0
#30	0.60					
#40	0.43				**81.0**	19.0
#50	0.30					
#60	0.25				**92.0**	8.0
#80	0.18					
#100	0.15					5.0
#200	0.075				**96.0**	4.0
	0.036					
	0.023					
	0.014					
	0.010					
	0.007					
	0.003					
Pan						
			TOTAL:			



Grain Size Distribution Curve Results:

% Gravel:	18.0
% Sand:	78.0
% Fines:	4.0

	Passing mm	Passing ϕ	Retained mm	Retained ϕ
D_5:	0.15	2.7370	12	-3.5850
D_{10}:	0.29	1.7859	9.5	-3.2479
D_{16}:	0.4	1.3219	6	-2.5850
D_{50}:	0.85	0.2345	0.85	0.2345
D_{60}:	1.3	-0.3785	5.4	-2.4330
D_{84}:	6	-2.5850	0.4	1.3219
D_{95}:	12	-3.5850	0.15	2.7370

	mm	ϕ
Geometric Mean	2.35	-1.2320
Graphic Median	0.85	0.2345
Graphic Standard Deviation	0.26	1.9346

Coefficient of Uniformity 4.48 >4 = well graded soil

Krumbein and Monk Intrinsic Permeability 332.6 darcy
3.74E-07 cm^2

Krumbein and Monk Derived Hydraulic Conductivity 3.66E-02 cm/sec
103.75 ft/day

PL201900171
PL2019-171
Sieve Analysis Data Sheet
ASTM D422-63(2007)

Project Name:	Mall of America	**Tested By:**		**Date:**	
Location:		**Checked By:**		**Date:**	
Boring No:	ST-4007	**Test Number:**			
Sample Depth:	20'	**Gnd Elev.:**			

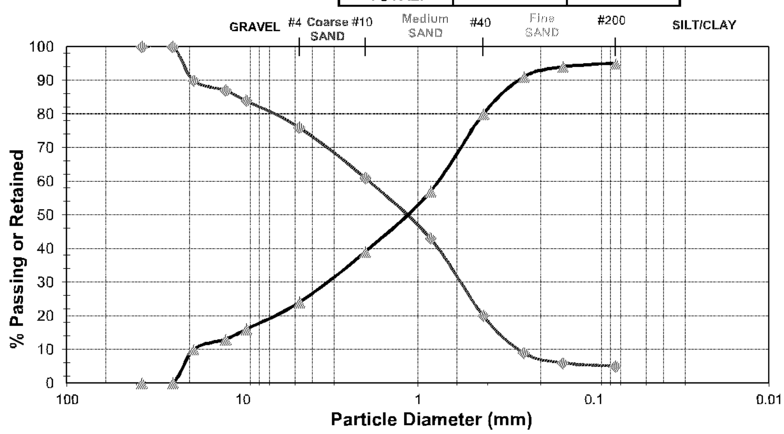
USCS Soil Classification: ____________

AASHTO Soil Classification: ____________

Weight of Container (g): ________ **Weight of Container & Soil (g):** ________

Weight of Dry Sample (g): ________

Sieve Number	Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
63 (2.5")	63					
50 (2")	50					
37.5 (1.5")	37.5				**0.0**	100.0
25 (1")	25				**0.0**	100.0
19 (3/4")	19				**10.0**	90.0
12.5 (1/2")	12.5				**13.0**	87.0
9.5 (3/8")	9.5				**16.0**	84.0
#4	4.75				**24.0**	76.0
#8	2.36					
#10	2.00				**39.0**	61.0
#16	1.18					
#20	0.85				**57.0**	43.0
#30	0.60					
#40	0.43				**80.0**	20.0
#50	0.30					
#60	0.25				**91.0**	9.0
#80	0.18					
#100	0.15				**94.0**	6.0
#200	0.075				**95.0**	5.0
	0.036					
	0.023					
	0.014					
	0.010					
	0.007					
	0.003					
Pan						
			TOTAL:			



Grain Size Distribution Curve Results:

% Gravel:	24.0
% Sand:	71.0
% Fines:	5.0

	Passing mm	Passing ϕ	Retained mm	Retained ϕ
D_5:	0.075	3.7370	24	-4.5850
D_{10}:	0.27	1.8890	18	-4.1699
D_{16}:	0.37	1.4344	9.5	-3.2479
D_{50}:	1.2	-0.2630	1.2	-0.2630
D_{60}:	1.9	-0.9260	0.75	0.4150
D_{84}:	9.5	-3.2479	0.37	1.4344
D_{95}:	24	-4.5850	0.075	3.7370

	mm	ϕ
Geometric Mean	1.38	-0.4662
Graphic Median	1.20	-0.2630
Graphic Standard Deviation	0.19	2.4315

Coefficient of Uniformity 7.04 >4 = well graded soil

Krumbein and Monk Intrinsic Permeability 60.0 darcy
6.75E-08 cm^2

Krumbein and Monk Derived Hydraulic Conductivity 6.60E-03 cm/sec
18.72 ft/day

USGS Hantush Model Output

use consistent units (e.g. feet & days or inches & hours)

Input Values		
3.1300	*R*	Recharge (infiltration) rate (feet/day)
0.085	Sy	Specific yield, Sy (dimensionless, between 0 and 1)
22.13	K	Horizontal hydraulic conductivity, Kh (feet/day)*
50.000	x	1/2 length of basin (x direction, in feet)
100.000	y	1/2 width of basin (y direction, in feet)
1.000	t	duration of infiltration period (days)
20.000	hi(0)	initial thickness of saturated zone (feet)

Conversion Table

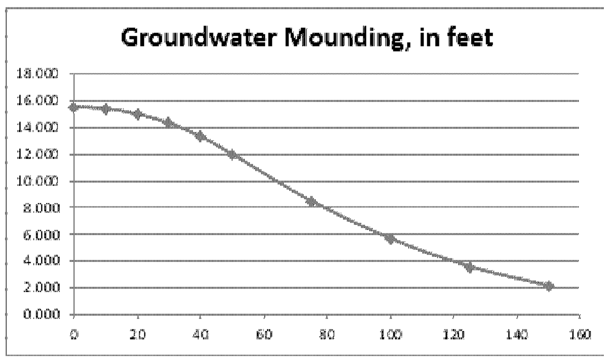
inch/hour	**feet/day**
0.67	1.33
2.00	4.00
hours	days
36	1.50

In the report accompanying this spreadsheet (USGS SIR 2010-5102), vertical soil permeability (ft/d) is assumed to be one-tenth horizontal hydraulic conductivity (ft/d).

35.541	h(max)	maximum thickness of saturated zone (beneath center of basin at end of infiltration period)
15.541	Δh(max)	maximum groundwater mounding (beneath center of basin at end of infiltration period)

Ground-water Mounding, in feet	**from center of basin in x direction, in feet**
15.541	0
15.407	10
15.001	20
14.310	30
13.310	40
11.971	50
8.464	75
5.652	100
3.566	125
2.133	150

Re-Calculate Now



Disclaimer

This spreadsheet solving the Hantush (1967) equation for ground-water mounding beneath an infiltration basin is made available to the general public as a convenience for those wishing to replicate values documented in the USGS Scientific Investigations Report 2010-5102 "Groundwater mounding beneath hypothetical stormwater infiltration basins" or to calculate values based on user-specified site conditions. Any changes made to the spreadsheet (other than values identified as user-specified) after transmission from the USGS could have unintended, undesirable consequences. These consequences could include, but may not be limited to: erroneous output, numerical instabilities, and violations of underlying assumptions that are inherent in results presented in the accompanying USGS published report. The USGS assumes no responsibility for the consequences of any changes made to the spreadsheet. If changes are made to the spreadsheet, the user is responsible for documenting the changes and justifying the results and conclusions.