Additional Geologic Studies

MoPac (State Loop 1) Intersections, Austin District

From North of Slaughter Lane to South of La Crosse Avenue
CSJ: 3136-01-015
Travis County, Texas
October 2014

The environmental review, consultation, and other actions required by applicable Federal environmental laws for this project are being, or have been, carried-out by TxDOT pursuant to 23 U.S.C. 327 and a Memorandum of Understanding dated December 16, 2014, and executed by FHWA and TxDOT.

This page intentionally left blank.

ZARA
ENVIRONMENTAL LLC
1707 West FM 1626
Manchaca, Texas 78652
512-291-4555
www.zaraenvironmental.com

MEMORANDUM

Date	29 October 2014
To	Jimmy Robertson, AICP
cc:	Sean Beal, P.E., Rose Marie Klee, P.E., Heather Ashley-Nguyen, P.E., Michael Barrett, Ph.D., Tricia Bruck, PMP
From	Zara Environmental LLC (Brian Cowan, P.G., Clover Clamons, P.G., Peter Sprouse)
Subject	MoPac Intersections Project – Additional Geologic Studies – DRAFT Final Deliverable

Introduction

The proposed MoPac Intersections Project, located in southwestern Travis County, Texas, would provide needed operational and safety improvements to two heavily used intersections—Slaughter Lane and La Crosse Avenue. The proposed project is approximately two miles long from South of La Crosse Avenue to north of Slaughter Lane and would include two separate cuts to provide grade separations at these two intersections. The Slaughter Lane cut area is between station 1018+00 and station 1035+00 as shown on the attached graphic (Plate 1- Slaughter Lane). In the 1,700-foot long Slaughter Lane cut area, the maximum cut ranges from 6.4 to 22.7 ft below the existing grade (ground surface). The La Crosse Avenue cut area is between station 1056+00 and station 1084+00 as shown on the attached graphic. In the 2,800 foot-long La Crosse Avenue cut area, the maximum cut ranges from 4.4 to 24.6 ft below the existing grade. Elevations provided are based on maximum depth of cut in the current schematic (Plate 2 - La Crosse Avenue) and are subject to change as design work continues. Although grading exists beyond these limits, the cuts associated with that grading is minimal. Caves and karst features are known occur in the geologic units present in the project area; therefore, it is possible that karst voids will be intersected anywhere grading or downcutting into bedrock occurs.

Based on comments and questions received from the Texas Department of Transportation, the Central Texas Regional Mobility Authority (CTRMA), and the City of Austin, Zara Environmental LLC (Zara) was asked to gather additional data and perform additional analysis of potential impacts to nearby caves and karst features resulting from the proposed MoPac Intersections Project beyond the scope of what was included in the Geologic Assessment. The purpose of this memo is to document efforts to evaluate the potential for a significant hydrogeological connection between the MoPac Intersections Project area and known area caves that could affect water quality, quantity, and protected species.

Additional Data Gathering

- Well data, aquifer water level data, and geologic data were obtained from the Barton Springs/Edwards Aquifer Conservation District on 21 August 2014.
- Cave and karst feature data from the City of Austin and Texas Speleological Society extending out to 1 mile from the existing right-of way (ROW) was obtained on 22 August 2014. A search area of 1 mile was used to obtain a larger dataset for review of area caves. This value has no regulatory or hydrogeologic significance.

Additional Analysis and Documentation

Geologic Mapping **-** *Prepare cross-sections depicting the location of faults, dips, and the shallow nature of the MoPac Intersections project profile compared to surrounding caves (e.g., Blowing Sink Cave).*

A cross section of the Slaughter Lane intersection area was constructed extending 1,000 ft along the center of the MoPac ROW north and south of the centerline of the intersection (Plate 3 Cross Section - separate file). Topography, elevation of proposed down-cutting and the water table were plotted in the cross section. The entire Slaughter Lane intersection area cross section is within one fault block (no faults cross the ROW within the cross section boundaries), and no borehole data is available for that fault block; therefore, the elevation of geological contacts was estimated based on surface geological mapping[1,2] and known thicknesses of geologic members.[3,4] Hydrostratigraphic members outcropping on the fault block where the Slaughter Lane intersection is located include: the Regional Dense member of the Person Formation, and the Grainstone, and Kirschberg members of the Kainer Formation, both of which are in the Edwards Group limestones (Table 1). Previous studies have determined the thicknesses of these members to be: Regional Dense - 14.8 to 32.8 ft, Grainstone - 45.9 to 59.1 ft, and Kirschberg - 39.4 to 75.5 ft.[5] In the study area, the geologic units appear to dip very little, causing geologic contacts within fault blocks to occur at roughly the same elevation; therefore, the elevation of mapped contacts was used to estimate the elevation of subsurface contacts.

---

[1] Blome, C.D., Faith, J.R., Pedraza, D.E., Ozuna, G.B., Cole, J.B., Clark, A.K., Small, T.A., and R.R. Morris. 2005. Geologic Map of the Edwards Aquifer Recharge Zone, South-central Texas. US Geological Survey Scientific Investigations Map 2873.

[2] Nico Hauwert, City of Austin Geologist, Personal communication.

[3] Small, T. A., Hanson, J. A., & Hauwert, N. M. (1996). Geologic Framework and Hydrogeologic Characteristics of the Edwards Aquifer Outcrop (Barton Springs Segment), Northeastern Hays and Southwestern Travis Counties, Texas. *U.S. Geological Survey, Water-Resources Investigations Report 96-4306*, 1–21.

[4] Hauwert, N.M. 2009. Groundwater Flow and Recharge within the Barton Springs Segment of the Edwards Aquifer, Southern Travis and Northern Hays Counties, Texas. Dissertation presented to the faculty of the graduate school of the University of Texas at Austin. Copyright by Nico Mark Hauwert. May 2009.

[5] Small, et al. 1996 (see footnote 3).

Table 1. Stratigraphic column showing the regional geologic units and the members cropping out in the project area (highlighted in orange).[6]

Hydrogeologic subdivision		Group	Formation	Member	Full Thickness (m)	Lithology	Field Identification	General Hydrogeologic Properties
Quaternary		Alluvium			<10	gravel	loosely or unconsolidated limestone or shale	high permeability
		Colorado River Terrace Deposits			<10	gravel	loosely or poorly consolidated with quartz cobbles	high permeability
Upper Cretaceous	Overlying Confining Units	Taylor	Sprinkle		120	calcareous clay	dark clay	low permeability
		Austin			119	chalk	*Inoceramus subquadratus*, *Inoceramus undulatoplicatus*, *Exogyra ponderosa*, *Phyrygia aucella* and occasional igneous deposits	gen. low permeabilty, conduits possible where faulted or weathered on surface
		Eagle Ford		South Bosque Shale Bouldin Flags Cloice Shale Pepper Shale	12 - 14	calcareous sandy shale	*Fish fossils*, *Acanthoceras sp.*, *Eucalycoceras bentonianum*, *Neocardioceras*, *Romaniceras*, *Colopoceras*, *Prionotropia*, *Alectryonia lugubris*	general low permeability
		Washita	Buda		11 - 18	nodular to massive porcelaneous limestone	Orange pelloids in massive beds, *Budaiceras*, ammonites, *Exogyra clarki*, *Pecten roemeri*, *Codiopsis texana* Whitney, and *Mantelliceras*	commonly feeds shallow wells and small springs
			Del Rio		15 - 18	clay	*Ilymatogyra arietina*, pyrite, gypsum seams	low permeability clay
Lower Cretaceous	Edwards Aquifer		Georgetown		12 - 18	nodular to massive fossilferous limestone	*Waconella wacoensis*, *Arctostrea carinata*, *Texigryphaea washitaensis*, *Neithea texana*, echinoids, and ammonites.	vertical fissure development
		Edwards	Person	Cyclic and Marine undiv.	0 - 21	massive limestone	chert and caprinids	cavernous
				Leached and Collapsed undivided	21 - < 7	wackestone, mudstone, and grainstone with well-sorted matrix	*Toucasia*, *Chondrodonta*, and sparse miliolid foraminifera	horizontal and vertical extensive cave deveopment
				Regional Dense	4.5 - 10	well-sorted lt tan fissile mudstone	*Pleuromya knowltoni*, rarely *Ceratostreon texanum*, iron-oxide stains	local aquitard frequently breached with vertical fissures
			Kainer	Grainstone	14 - 18	lt gray-white massive grainstone	Miliolid foramnifera, *Chondrodonta*, caprinids, turitella, mudcracks, and bedded chert	small corkscrew passages and rooms. Serves as competent roof over Kirschberg Mbr
				Kirschberg	12 - 23	crystalline limestone and dolomite pulverulite	Terra rosa. *Cladophyllia, toucasia, caprinid-bearing siliceous remnants*	extensive cave development esp. in pulverulitic beds
				Dolomitic	~ 43	Highly bedded gen. with poorly-sorted matrix	*Toucasia, Caprinid, Dictyoconus wahutensis.* Nodular chert	significant cave development primarily along fissures
				Basal Nodular	16 - 18	fossilferous, nodular limestone	*Texigryphaea* packestone intermediate miliolid grainstones and burrowed mudstone, echinoids, lower *Ceratostreon Texanum* packstone	vertical pits and fissures. Produces many minor springs.
	Underlying units	Trinity	Glen Rose		150 - 250	Alternating massive limestone/dolomite and marl layers	dinosaur tracks, plant fossils, celestite nodules, *Trigonia*, *Pecten*, *Alectryonia carinata*, *Orbitolina texana* foraminifera, various echinoids	little cave development documented here although supports abundant springs/wells.

[6] Hauwert 2009 (see footnote 4).

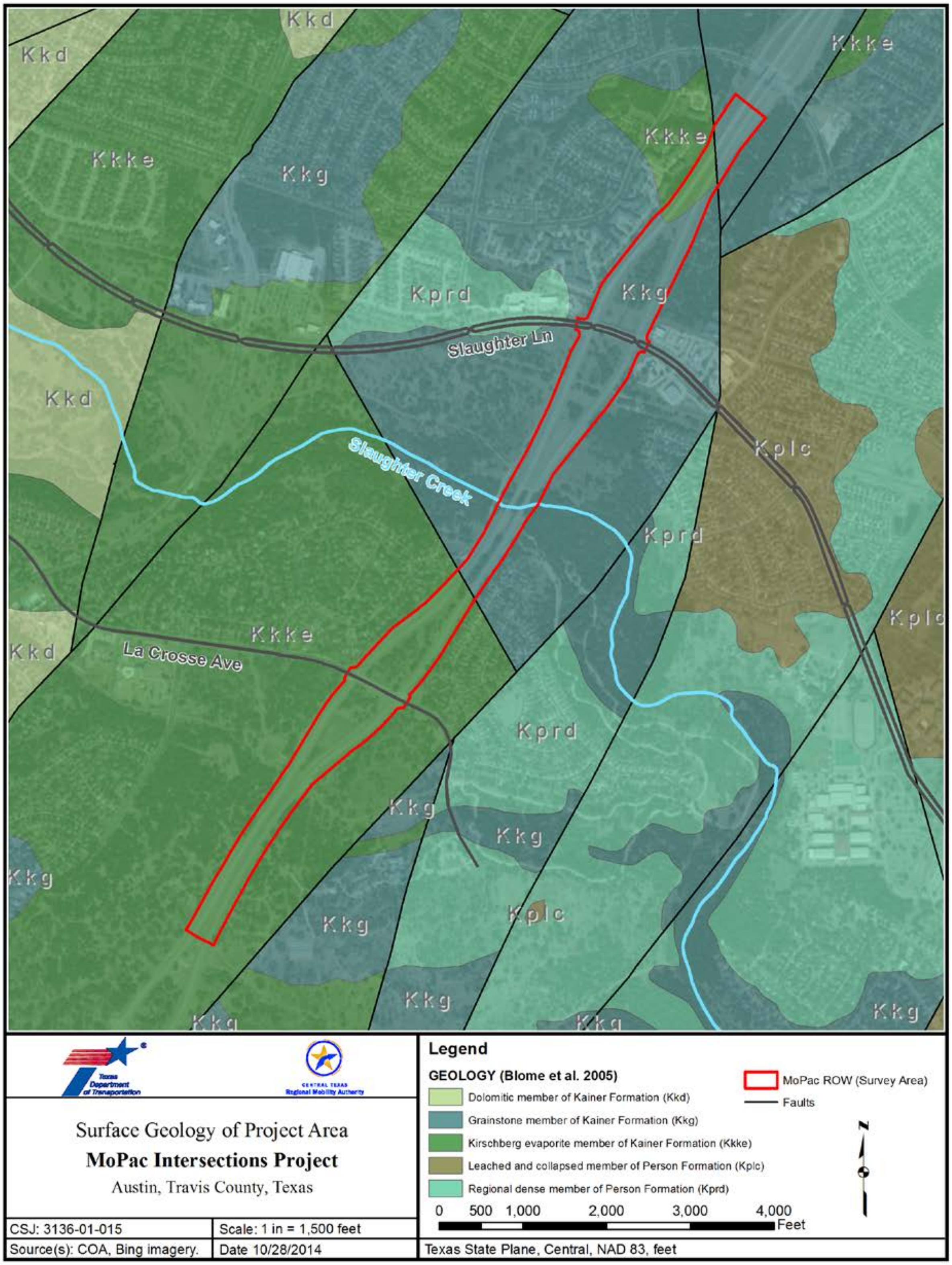


Figure 1. Surface Geology of the MoPac Intersections Project Area.

A contact between the Regional Dense and Grainstone members occurs to the west of the cross section area roughly coincident with the 842 ft topographic contour. Because the Grainstone member is known to be 45.9 to 59.1 ft thick, the contact between the Grainstone and underlying Kirschberg member likely occurs between 796.1 ft and 782.9 ft in elevation. A contact between the Grainstone and Kirschberg members occurs north of the cross section area at approximately 796 ft in elevation, which is consistent with the range of elevations that the contact between the two members would likely occur at based on the thickness of the Grainstone member. Based on the information above, the contact between the Grainstone and Kirschberg members was estimated to occur at approximately 796 ft in elevation. The lowest elevation that roadbed down cutting will occur at near Slaughter Lane is approximately 800 ft, which is approximately 4 ft above the estimated contact between the Grainstone and Kirschberg members. The lowest elevation within the Slaughter Lane cut area (800 ft) will be within detention pond A.1 near the northwestern edge of the cut shown on page 1 of Plate 1 (separate file). Cut elevation increases to the south as surface elevation increases approaching Slaughter Lane.

The contacts between other geologic members are also shown on Plate 2, but because no geotechnical borehole data is available, the exact depth of the contacts is estimated based on thicknesses given by Small et al. 1996 and Hauwert 2009 (see footnotes 3 and 4). Consequently, the other contacts are depicted as gradational based on the estimated range of thicknesses of the geologic members. The approximate elevation of the phreatic zone (saturated area/water table) is estimated based on water levels during times of high flow (February 2002) and low flow (March 2009).[7] Because the project area is along the edge of two major groundwater flow routes (Sunset Valley and Manchaca flow routes [discussed further in the Water Resources Technical Memorandum[8]]), the elevation of the phreatic zone fluctuates little compared to other portions of the aquifer. Phreatic water levels measured during drought conditions in March 2009 ranged from 645 to 655 ft in elevation and water levels measured during high flow conditions in February 2002 ranged from 655 to 680 ft in elevation.

The La Crosse Avenue intersection is also within one fault block; however, it is not possible to estimate the elevation of geologic contacts, as no clearly defined geologic contact occurs within that fault block, and no subsurface borehole or geotechnical data within that fault block was available. The deepest cut elevation within the La Crosse Avenue cut is 816 ft, which is 24.6 ft below grade, in detention pond F.1 shown on page 2 of Plate 1 (separate file). The entire La Crosse Avenue intersection cut is within an area where the surface geology is mapped as the Kirschberg member of the Kainer Formation; therefore, this area is already stratigraphically below the Grainstone/Kirschberg contact. The Grainstone/Kirschberg contact is known for some of the most laterally extensive cavernous zones within the Barton Springs Segment. The

---

[7] Brian Hunt, Geologist, Barton Springs/Edwards Aquifer Conservation District, Personal Communication 2014.

[8] Central Texas Regional Mobility Authority and Texas Department of Transportation. 2014. Water Resources Technical Memorandum Draft. MoPac Intersections Environmental Study from South of La Crosse Avenue to North of Slaughter Lane CSJ: 3136-01-015. July 2014.

Kirschberg is also well known for cave development in certain beds; therefore, there is a risk of encountering voids and caves developed and contained within the in the Kirschberg at the La Crosse Avenue intersection cut. Engineered solutions to protect water quantity and quality should be implemented if voids are encountered.

Dip Analysis - *Conduct a geologic dip analysis using existing borehole and/or well information.*

All readily available data to conduct this evaluation was received; however, insufficient data was available to complete this analysis. Dip (tilt angle) of the of the geologic units underlying the project area and vicinity can vary by fault block but is generally thought to be flat to nearly flat[9], although some have reported dips up to 70 to 75 feet per mile (~1% gradient)[10], generally to the east and southeast.

Cave Dimensions - *Estimate the normal range of cave dimensions in the area using information from existing features.*

An analysis of cave dimensions was performed for 28 caves within 1 mile of the existing ROW based on the data received. This is not the total length of the cave, but the longest straight-line segment that could be drawn through the cave (i.e., if the cave were in the road cut and oriented the right way, the length of the longest void that could be encountered). Cave lengths were divided into 20 ft increments and the number caves within each increment was plotted (Figure 2). Analysis shows that 17 of 28 caves (61%) are 60 ft long or smaller, an additional seven caves (25%) are between 60 and 100 ft long, and the longest segment length of four caves (14%) are greater than 100 ft in length. The longest segment was in Grassy Cove Cave and was 400 ft in length. This analysis suggests that a variety of voids sizes may be encountered, but the majority of caves (86%) longest segment is less than 100 ft, suggesting that that the any cave encountered will likely be smaller in size (<100 ft) and likely would not extend across the full width of either of the cut areas. This analysis is based solely on data from caves where maps and/or cave dimensions were available and did not include an analysis smaller karst features, therefore it is likely biased toward larger feature dimensions as caves, by definition, are larger than most other karst features (i.e., vugs, some sinkholes, bedding planes, etc.). This analysis only takes into account known caves within 1 mi of the existing ROW. It is likely that there are caves within the search area with no surface expression that may be larger or smaller than the caves included in this analysis. Additionally, this analysis cannot provide any assessment of the probability of encountering a void within either cut area.

[9] Hauwert, N.M. 2009 (see footnote 4).

[10] Baker, E. T., Slade, R. M., Dorsey, M. E., Ruiz, L. M., & Duffin, G. L. (1986). Geohydrology of the Edwards Aquifer in the Austin Area, Texas. *Texas Water Development Board Report #293*.

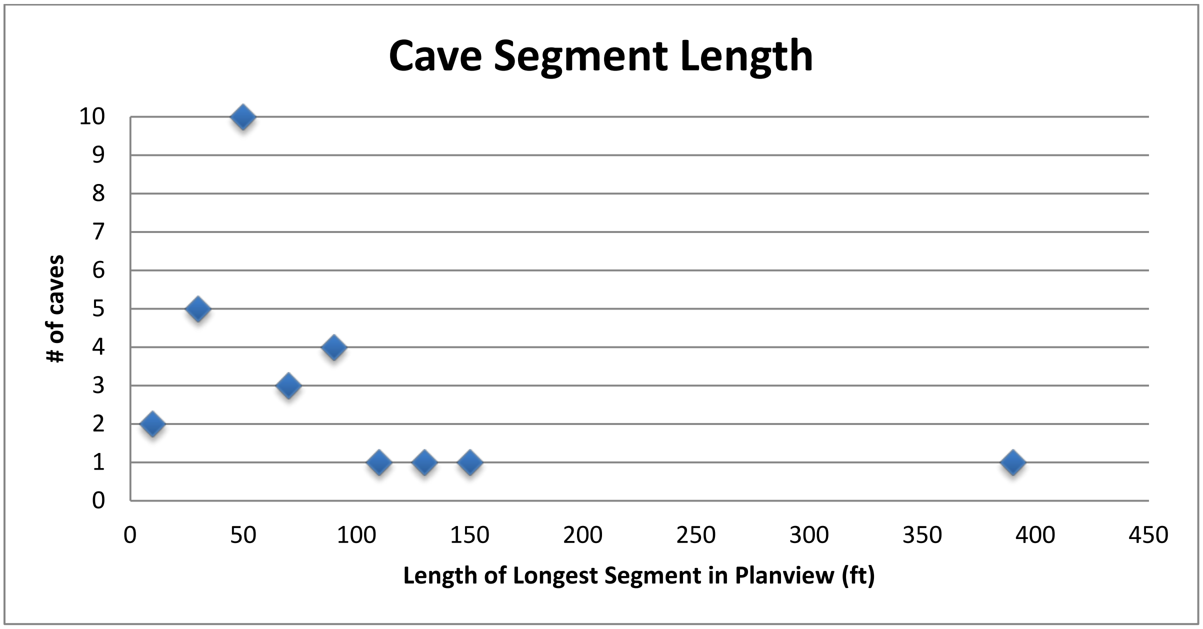


Figure 2. Length of longest cave segment for 28 caves located within one mile of the MoPac ROW in the project area.

Relative Elevations *- Describe and depict cave entrance elevations and cave depth relative to the cut locations/depths of the proposed project. Determine if impacts to Balcones Canyonlands Conservation Plan (BCCP) caves and other caves are possible via groundwater flow from project area.*

When considering shallow, vadose (unsaturated zone above the regional water table) groundwater flow, topographic lows, such as the deepest elevation within the channel of Slaughter Creek and its tributaries, may isolate or separate some shallow caves from potential water quality and quantity impacts by cutting off or blocking vadose flows from the cut areas into nearby caves. This may be true if the topographic low is situated between the proposed cut area and the cave, and especially if the topographic low is lower than both the lowest point in the cave and the lowest point in the cut. In these cases, the caves are topographically separated, meaning that shallow groundwater would reach the topographic low and "daylight" or flow out as a seep/spring instead of flowing from the cave to the cut or from the cut to the cave, dependent on available flowpaths. To determine if this situation exists and to evaluate potential impacts to vadose groundwater quality and quantity in the project area, surface topography, cave entrance elevations, and the deepest known point of 49 caves within a one-mile radius and four caves just beyond the one-mile radius of the project area ROW (total of 53 caves) were analyzed where these data were available.

Four caves protected as part of the Balcones Canyonlands Conservation Plan (BCCP) regional section 10(a)(1)(B) permit occur within 550 to 1,800 ft from the proposed MoPac Intersections ROW and five additional BCCP-protected caves are located between 3,000 and 5,800 ft from the MoPac Intersections Project ROW (Figure 3). No BCCP caves or their surface drainage basins are located within the project ROW (Figure 3). Topographic analysis of all nine BCCP caves near the project area is included in Table 2. When considering topography and cave entrance elevation, all of the BCCP caves analyzed could potentially be impacted by vadose groundwater flow from the proposed project area. Of the remaining 44 non-BCCP caves analyzed, only three could be ruled out from being impacted by vadose groundwater flows from the proposed project area, as their deepest elevations occur at higher elevations than the deepest proposed cut elevations in both intersection cuts (Table 3).

For the remaining 41 caves where topography and cave elevations could not be used to rule out potential shallow groundwater impacts to the caves hydraulic gradient was evaluated to determine if impacts were possible or likely. The hydraulic gradient between each cave was calculated from the highest point that rock cutting will take place at the underpass nearest to the cave, which represents the highest elevation from which construction phase vadose impacts could originate (Figure 4). For Slaughter Lane underpass near station 1029+00 (837 ft), and for La Crosse Lane underpass station 1068+00 (842 ft) (Plate 1- Plan and Profile Sheets). Note that construction fill was omitted from this analysis, as it does not contain karst features. The hydraulic gradient between each cave was also calculated from the highest point of the finished grade at the nearest underpass to the cave, which represents the highest elevation from which operational phase impacts could originate, because voids above the road grade (in the road cut) cannot be impacted by roadway runoff if they are at a higher elevation than the road grade adjacent to them. For Slaughter Lane underpass near station 1035+00 (824 ft), and for La Crosse Avenue underpass station 1068+00 (826 ft) (Plates 1 and 2). Gradients were calculated by first determining the difference between the cut or finished grade elevation and the lowest cave elevation and then dividing that number by the distance between the edge of the closest cut and the cave footprint (Figure 4). All gradients were calculated to the elevation of the lowest known point within the cave.

Previous groundwater tracing studies near the project area indicate that the hydraulic gradient in the vadose zone of the Grainstone and Kirschberg members ranges from 26% to 12%[11]; therefore, any cave where the lowest elevation is at a gradient of less than 12% from the closest underpass cut is unlikely to be impacted by vadose groundwater flow. Generally, the shallower the cave, and the further from the proposed cut, then the less likely that vadose zone impacts to groundwater quality and quantity will occur. Any cave with a negative hydraulic gradient would have no possibility to be impacted, as the cave is upgradient from the project. The results of these calculations are included in Table 4 and Table 5.

---

[11] Hauwert, N.M. and Cowan, B.D. 2013. Delineating source areas to cave drips and cave streams in Austin, Texas, USA, Proceedings of the Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Carlsbad, New Mexico, May 6-10, 2013.

Maps and other location data for caves and karst features were removed to protect the sensitive nature of these features and the species that may be harmed by unintentional human disturbance. These data may be available upon request.

Figure 3. BCCP-protected caves in the vicinity of the MoPac Intersections Project area.

Table 2. Topographic review of BCCP cave entrance and depth elevations relative to proposed cuts.

Feature Name	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Closest Cut (Slaughter/ La Crosse)	Topographic Review Comments
Arrow Cave	839	17.4	821.6	La Crosse	Halfway between the two cuts and west of the ROW; Cave is too deep for topographic separations to prevent impacts to vadose groundwater. Evaluate hydraulic gradient.
Blowing Sink Cave	775	260.0	515.0	Slaughter	East of the ROW. Cave is too deep for topographic separations to prevent impacts to vadose groundwater. Evaluate hydraulic gradient.
District Park Cave	766	43.0	723.0	Slaughter	Northwest of ROW and north of both cuts. Cave is too deep for topographic separations to prevent impacts to vadose groundwater. Evaluate hydraulic gradient.
Get Down Cave	795	48.3	746.7	Slaughter	East of ROW. Lower in elevation than deepest cuts. No topographic separation exists. Evaluate hydraulic gradient.
Goat Cave	765	43.0	722.0	Slaughter	West of ROW, but lower in elevation than deepest cuts. No topographic separation exists. Evaluate hydraulic gradient.
Maple Run Cave	783	105.0	678.0	Slaughter	East of ROW. Lower in elevation than deepest cuts. No topographic separation exists. Evaluate hydraulic gradient.
Midnight Cave	853	55.0	798.0	La Crosse	West of ROW, but lower in elevation than deepest cuts. No topographic separation exists. Evaluate hydraulic gradient.
Pipeline Cave	825	27.0	798.0	Slaughter	West of ROW, but lower in elevation than deepest cuts. No topographic separation exists. Evaluate hydraulic gradient.
Slaughter Creek Cave	822	40.7	781.3	La Crosse	West of ROW, but lower in elevation than deepest cuts. South of Slaughter Creek, so groundwater would daylight at Slaughter Creek (806 ft) before reaching this cave (781 ft) from Slaughter cut (826 ft); no topographic separation from La Crosse cut (826 ft). Evaluate hydraulic gradient.

Table 3. Other non-BCCP caves ruled out based on topography, cave entrance, and depth elevations relative to proposed cuts.

Feature Name	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Closest Cut (Slaughter/ La Crosse)	Topographic Review Comments
Ballenton Cave	864	15.0	849.0	La Crosse	Cave depth is higher in elevation than closest maximum cut elevation (816 ft)
Y2Kave	899	14.0	885.0	Slaughter	Cave depth is higher in elevation than closest maximum cut elevation (800 ft)
South Fence Sink	876	8.0	868.0	La Crosse	Cave depth is higher in elevation than closest maximum cut elevation (816 ft)

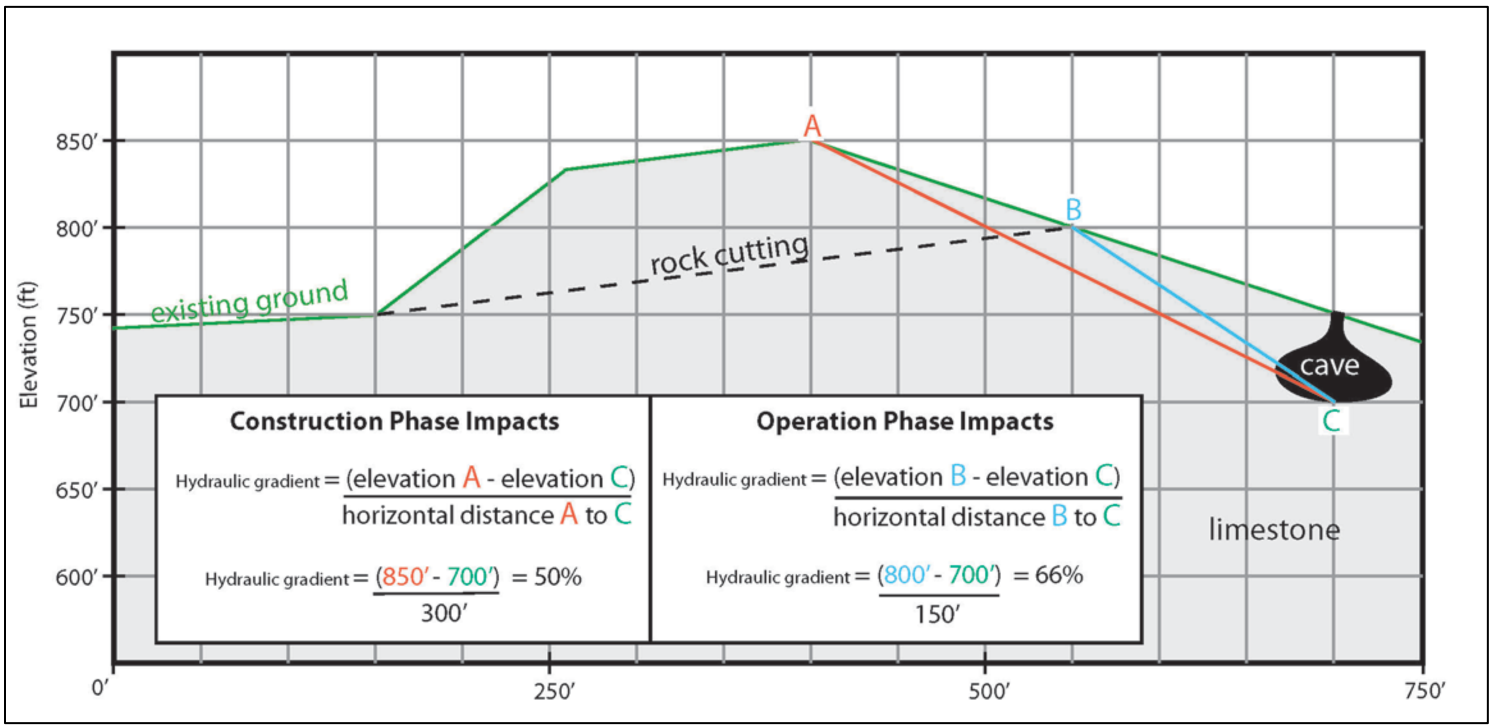


Figure 4. Explanation of hydraulic gradient calculations.

Table 4. Hydraulic gradient from finished grade for caves and sinkholes within one-mile of the project ROW and BCCP caves near the project area. This represents construction phase impacts. BCCP-protected caves are shown in ***bold italics***. * - Caves with a modifying 'north' or 'south' are beyond the northern or southern limits of the proposed MoPac Intersections Project.

Feature Name	Direction of Cave Relative to ROW	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Distance from Cutting (ft)	Difference in Elevation (Cut-Cave)	High Cut Hydraulic Gradient (%)	Closest to Cut (Slaughter/ La Crosse)
Caves that may be impacted by shallow groundwater (>12% gradient)								
Baby Fox Cave	east	782	3.7	778.3	110	58.7	53.3	Slaughter
Buddy's Vault	east	832	27.0	805.0	170	32.0	18.8	Slaughter
Another Cave	west	823	20.0	803.0	247	39.0	15.8	La Crosse
Slaughter Creek Cave	***west***	***822***	***40.7***	***781.3***	***500***	***60.7***	***12.1***	***La Crosse***
Caves that are not likely to be impacted by shallow groundwater (1 to 12% gradient)								
Millennium Cave	west	792	31.5	760.5	925	76.5	8.3	Slaughter
Get Down Cave	***west***	***795***	***48.3***	***746.7***	***1,140***	***90.3***	***7.9***	***Slaughter***
La Crosse Cave	east	815	22.0	793.0	680	49.0	7.2	La Crosse
Equinox Cave	west	789	28.7	760.3	1,090	76.7	7.0	Slaughter
Pipeline Cave	***west***	***825***	***27.0***	***798.0***	***568***	***39.0***	***6.9***	***Slaughter***
Confusion Cave	west	820	16.4	803.6	518	33.4	6.4	Slaughter
Wildflower Cave	east	805	12.1	792.9	858	49.1	5.7	La Crosse
Blowing Sink Cave	***east***	***775***	***260.0***	***515.0***	***5,800***	***322***	***5.6***	***Slaughter***
Live Oak Cave	west	792	12.1	779.9	1,050	57.1	5.4	Slaughter
Big Oak Cave	east	788	5.9	782.1	1,110	54.9	4.9	Slaughter
Recharge Cave	east	800	5.9	794.1	990	47.9	4.8	La Crosse
Senatorial Sink	west	794	3.9	790.1	1,040	46.9	4.5	Slaughter
Chinese Puzzle Cave	east	810	12.1	797.9	1,000	44.1	4.4	La Crosse
District Park Cave	***northwest***	***766***	***43.0***	***723.0***	***3,130***	***114.0***	***3.6***	***Slaughter***
Salamander Mountain Cave	west	854	37.1	816.9	573	20.1	3.5	Slaughter

Feature Name	Direction of Cave Relative to ROW	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Distance from Cutting (ft)	Difference in Elevation (Cut-Cave)	High Cut Hydraulic Gradient (%)	Closest to Cut (Slaughter/ La Crosse)
Slaughter Crack	west	818	3.0	815.1	785	27.0	3.4	La Crosse
Survey Line Cave	west	802	5.9	796.1	1,215	40.9	3.4	Slaughter
Grapevine Cave	east	806	15.1	790.9	1,400	46.1	3.3	Slaughter
Maple Run Cave	***east***	***783***	***105.0***	***678.0***	***5,300***	***159***	***3.0***	***Slaughter***
Shops Culvert Crawl	east	827	3.9	823.1	483	13.9	2.9	Slaughter
Sendero Sink Cave	east	792	18.0	774.0	2,470	63.0	2.6	Slaughter
Sunspot Cave	east	795	63.0	732.0	4,350	105.0	2.4	Slaughter
Headquarters Flat Cave	southeast	785	37.0	748.0	4,040	94.0	2.3	La Crosse
Beckett's Cave	northeast	761	34.0	727.0	5,150	110.0	2.1	Slaughter
Goat Cave	***east***	***765***	***43.0***	***722.0***	***5,400***	***115***	***2.1***	***Slaughter***
Locus Cave	northwest	766	9.8	756.2	4,100	80.8	2.0	Slaughter
Bowie High School Sink	east	790	40.0	750.0	4,700	92.0	2.0	La Crosse
Construction Destruction Cave No. 1	northeast	779	4.9	774.1	3,375	62.9	1.9	Slaughter
Beckett's New Cave - Filled	northeast	746	15.1	730.9	5,700	106.1	1.9	Slaughter
Broken Hammer Cave	northwest	765	3.3	761.7	4,225	75.3	1.8	Slaughter
Boney Cave	east	775	4.9	770.1	4,100	71.9	1.8	La Crosse
Construction Destruction Cave No. 2	northeast	781	3.0	778.0	3,375	59.0	1.7	Slaughter
Cacto Malvato Cave	southeast	780	7.9	772.1	5,100	69.9	1.4	La Crosse
Cueva del Ventana	southeast	806	27.9	778.1	4,870	63.9	1.3	La Crosse
Grassy Cove Cave	west	838	44.1	793.9	3,370	43.1	1.3	Slaughter
Arrow Cave	***west***	***839***	***17.4***	***821.6***	***1,821***	***20.4***	***1.1***	***La Crosse***

Feature Name	Direction of Cave Relative to ROW	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Distance from Cutting (ft)	Difference in Elevation (Cut-Cave)	High Cut Hydraulic Gradient (%)	Closest to Cut (Slaughter/ La Crosse)
Deer Park Cave	east	808	11.0	797.0	3,650	40.0	1.1	Slaughter
Calypso Cave	southeast	824	20.0	804.0	3,872	38.0	1.0	La Crosse
Tres Amigos Cave	southeast	815	20.5	794.5	5,000	47.5	1.0	La Crosse
Caves that will not be impacted by shallow groundwater (<1% gradient)								
Midnight Cave	***west***	***853***	***55.0***	***798.0***	***5,660***	***44***	***0.8***	***La Crosse***
Snake Bed Cave	southeast	813	6.9	806.1	4,800	35.9	0.7	La Crosse
Boarded Cave	southwest	815	9.8	805.2	6,500	36.8	0.6	La Crosse
Hackberry Hole	southeast	825	15.1	809.9	5,800	32.1	0.6	La Crosse
Possum Pit	southeast	830	9.8	820.2	7,000	21.8	0.3	La Crosse
Pocahontas Cave	southeast	831	9.8	821.2	6,990	20.8	0.3	La Crosse
Smith Hole	southeast	831	3.1	827.9	6,980	14.1	0.2	La Crosse
Hannon Hillside Cave	southwest	855	18.0	837.0	4,400	5.0	0.1	La Crosse
Ballenton Cave	west	864	15.0	849.0	1,296	-7.0	-0.5	La Crosse
South Fence Sink	southeast	876	8.0	868.0	4,075	-26.0	-0.6	La Crosse
Y2Kave	west	899	14.0	885.0	5,035	-48.0	-1.0	Slaughter

Table 5. Hydraulic gradient calculations from high cut elevations for caves and sinkholes within one-mile of the project ROW and BCCP caves near the project area. This represents operation phase impacts. BCCP-protected caves are shown in ***bold italics***. * - Caves with a modifying 'north' or 'south' are beyond the northern or southern limits of the proposed MoPac Intersections Project.

Feature Name	Direction of Cave Relative to ROW	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Distance from Cutting (ft)	Difference in Elevation (Cut-Cave)	High Cut Hydraulic Gradient (%)	Closest to Cut (Slaughter/ La Crosse)
Caves that may be impacted by shallow groundwater (>12% gradient)								
Baby Fox Cave	east	782	3.7	778.3	110	45.7	41.5	Slaughter
Caves that are not likely to be impacted by shallow groundwater (1 to 12% gradient)								
Buddy's Vault	east	832	27.0	805.0	170	19.0	11.2	Slaughter
Another Cave	west	823	20.0	803.0	247	23.0	9.3	La Crosse
Slaughter Creek Cave	***west***	***822***	***40.7***	***781.3***	***500***	***44.7***	***8.9***	***La Crosse***
Millennium Cave	west	792	31.5	760.5	925	63.5	6.9	Slaughter
Get Down Cave	***west***	***795***	***48.3***	***746.7***	***1,140***	***77.3***	***6.8***	***Slaughter***
Equinox Cave	west	789	28.7	760.3	1,090	63.7	5.8	Slaughter
Blowing Sink Cave	***east***	***775***	***260.0***	***515.0***	***5,800***	***309.0***	***5.3***	***Slaughter***
La Crosse Cave	east	815	22.0	793.0	680	33.0	4.9	La Crosse
Pipeline Cave	***west***	***825***	***27.0***	***798.0***	***568***	***26.0***	***4.6***	***Slaughter***
Live Oak Cave	west	792	12.1	779.9	1,050	44.1	4.2	Slaughter
Confusion Cave	west	820	16.4	803.6	518	20.4	3.9	Slaughter
Wildflower Cave	east	805	12.1	792.9	858	33.1	3.9	La Crosse
Big Oak Cave	east	788	5.9	782.1	1,110	41.9	3.8	Slaughter
Senatorial Sink	west	794	3.9	790.1	1,040	33.9	3.3	Slaughter
District Park Cave	***northwest***	***766***	***43.0***	***723.0***	***3,130***	***101.0***	***3.2***	***Slaughter***
Recharge Cave	east	800	5.9	794.1	990	31.9	3.2	La Crosse
Chinese Puzzle Cave	east	810	12.1	797.9	1,000	28.1	2.8	La Crosse
Maple Run Cave	***east***	***783***	***105.0***	***678.0***	***5,300***	***135.0***	***2.5***	***Slaughter***
Grapevine Cave	east	806	15.1	790.9	1,400	33.1	2.4	Slaughter

Feature Name	Direction of Cave Relative to ROW	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Distance from Cutting (ft)	Difference in Elevation (Cut-Cave)	High Cut Hydraulic Gradient (%)	Closest to Cut (Slaughter/ La Crosse)
Survey Line Cave	west	802	5.9	796.1	1,215	27.9	2.3	Slaughter
Sunspot Cave	east	795	63.0	732.0	4,350	92.0	2.1	Slaughter
Sendero Sink Cave	east	792	18.0	774.0	2,470	50.0	2.0	Slaughter
Headquarters Flat Cave	southeast	785	37.0	748.0	4,040	78.0	1.9	La Crosse
Beckett's Cave	northeast	761	34.0	727.0	5,150	97.0	1.9	Slaughter
Goat Cave	***east***	***765***	***43.0***	***722.0***	***5,400***	***91.0***	***1.7***	***Slaughter***
Locus Cave	northwest	766	9.8	756.2	4,100	67.8	1.7	Slaughter
Beckett's New Cave - Filled	northeast	746	15.1	730.9	5,700	93.1	1.6	Slaughter
Bowie High School Sink	east	790	40.0	750.0	4,700	76.0	1.6	La Crosse
Construction Destruction Cave No. 1	northeast	779	4.9	774.1	3,375	49.9	1.5	Slaughter
Broken Hammer Cave	northwest	765	3.3	761.7	4,225	62.3	1.5	Slaughter
Slaughter Crack	west	818	3.0	815.1	785	11.0	1.4	La Crosse
Boney Cave	east	775	4.9	770.1	4,100	55.9	1.4	La Crosse
Construction Destruction Cave No. 2	northeast	781	3.0	778.0	3,375	46.0	1.4	Slaughter
Salamander Mountain Cave	west	854	37.1	816.9	573	7.1	1.2	Slaughter
Cacto Malvato Cave	southeast	780	7.9	772.1	5,100	53.9	1.1	La Crosse
Cueva del Ventana	southeast	806	27.9	778.1	4,870	47.9	1.0	La Crosse
Caves that will not be impacted by shallow groundwater (<1% gradient)								
Grassy Cove Cave	west	838	44.1	793.9	3,370	30.1	0.9	Slaughter
Deer Park Cave	east	808	11.0	797.0	3,650	27.0	0.7	Slaughter
Tres Amigos Cave	southeast	815	20.5	794.5	5,000	31.5	0.6	La Crosse

Feature Name	Direction of Cave Relative to ROW	Entrance Elevation (ft)	Depth (ft bgs)	Deepest Elevation (ft)	Distance from Cutting (ft)	Difference in Elevation (Cut-Cave)	High Cut Hydraulic Gradient (%)	Closest to Cut (Slaughter/ La Crosse)
Calypso Cave	southeast	824	20.0	804.0	3,872	22.0	0.6	La Crosse
Snake Bed Cave	southeast	813	6.9	806.1	4,800	19.9	0.4	La Crosse
Boarded Cave	southwest	815	9.8	805.2	6,500	20.8	0.3	La Crosse
Hackberry Hole	southeast	825	15.1	809.9	5,800	16.1	0.3	La Crosse
Midnight Cave	***west***	***853***	***55.0***	***798.0***	***5,660***	***15.0***	***0.3***	***La Crosse***
Arrow Cave	***west***	***839***	***17.4***	***821.6***	***1,821***	***4.4***	***0.2***	***La Crosse***
Shops Culvert Crawl	east	827	3.9	823.1	483	0.9	0.2	Slaughter
Possum Pit	southeast	830	9.8	820.2	7,000	5.8	0.1	La Crosse
Pocahontas Cave	southeast	831	9.8	821.2	6,990	4.8	0.1	La Crosse
Smith Hole	southeast	831	3.1	827.9	6,980	-1.9	0.0	La Crosse
Hannon Hillside Cave	southwest	855	18.0	837.0	4,400	-11.0	-0.3	La Crosse
South Fence Sink	southeast	876	8.0	868.0	4,075	-42.0	-1.0	La Crosse
Y2Kave	west	899	14.0	885.0	5,035	-59.0	-1.2	Slaughter
Ballenton Cave	west	864	15.0	849.0	1,296	-23.0	-1.8	La Crosse

An analysis of hydraulic gradients between the proposed cuts and nearby BCCP-protected caves suggests that only Slaughter Creek Cave could be impacted by vadose flow from the project and only during the construction phase when cutting is occurring at the higher elevations. Another important consideration is that the three BCCP caves closest to the proposed project are all located to the west of the ROW, while groundwater flow in this area is generally to the east. The surface drainage basin for Slaughter Creek Cave is located outside of the ROW; therefore, impacts to this cave are unlikely, even though its hydraulic gradient is greater than 12% (Figure 5). The hydraulic gradient from the highest cutting elevation at La Crosse Avenue to Slaughter Creek Cave is 12.1% based on a maximum cut elevation of 842 ft, indicating it could be impacted during the construction phase (Table 4). The hydraulic gradient to Slaughter Creek Cave from an elevation of 841 ft is 11.9%, which indicates that the cave is unlikely to be impacted by construction phase activities except for when the upper 1 foot of bedrock is cut at La Crosse Avenue. During the operation phase, the hydraulic gradient to the cave will be 8.9%, which is significantly lower (Table 5).

Because Blowing Sink Cave intersects the phreatic (saturated, regional water table) zone, it is possible that the project could impact the phreatic portion of the cave, but unlikely that portions of the cave within the vadose (unsaturated) zone will be impacted. Near La Crosse Avenue, Wildflower Cave, which is not BCCP cave, but has been dye traced to connect to Blowing Sink Cave, is at approximately 2% gradient from the closest intersection cut at La Crosse Avenue, and is therefore unlikely to be impacted by the project. Due to the relatively small footprint and drainage area of the proposed project relative to the potential subsurface drainage areas of Blowing Sink Cave, it is unlikely that the proposed project would impact the quantity of water reaching Blowing Sink Cave in either the vadose or phreatic zones. Additionally, all water leaving the site will be treated by water quality Best Management Practices (BMPs) once operational; therefore, it is unlikely that the proposed project would impact the quality of water flowing into or through Blowing Sink Cave.

Other non-BCCP caves within a one-mile radius of the project area were evaluated similarly and the results are presented in Table 4 and Table 5. Of those evaluated, Baby Fox Cave, Buddy's Vault, and Another Cave occur at a hydraulic gradient greater than 12% from the nearest proposed rock cutting (Slaughter Lane) (Figure 5). Another Cave is west of the project area in City of Austin-owned parkland. The surface drainage basin of Another Cave is located outside of the ROW and as discussed above, groundwater flow in this area is generally to the east; therefore, impacts to this cave are less likely. Buddy's Vault is a previously entranceless cave encountered during the construction of a bank on the southeast corner of MoPac and Slaughter Lane. This was evaluated, found not to be potential habitat for karst invertebrates and was sealed from the surface; therefore it has no surface drainage basin. The remaining cave, Baby Fox Cave is a 3.66 ft deep and is located in a City of Austin-owned preserve, east of the ROW and its surface drainage basin is mapped outside of the ROW (Figure 5).

The hydraulic gradients of the caves previously ruled out previously were also analyzed to further prove these would not be impacted by shallow groundwater flows and those results are also included at the end of Table 4 and Table 5. Negative values for hydraulic gradient indicate that the cave is situated above the closest cut.

Maps and other location data for caves and karst features were removed to protect the sensitive nature of these features and the species that may be harmed by unintentional human disturbance. These data may be available upon request.

Figure 5. Caves near the project area that may potentially be impacted by changes in vadose hydrology.

Surface Drainage Basins *- Describe and depict surface catchments for the caves and sinks within the project area including Wildflower Cave and La Crosse Cave.*

The surface drainage basins for three caves mapped by the City of Austin that extend into the MoPac Intersections ROW were reviewed. An assessment of the Wildflower Cave and Windmill Flat Sink surface drainage basin indicates that these are mapped correctly; however, refinements to the surface drainage basin for La Crosse Cave are suggested. The refinements to the La Crosse Cave surface drainage basin (i.e., trimming off the portions along La Crosse Avenue) are based on the presence of curb and gutter directing runoff to a water quality structure and away from the cave. Additionally, there was no evidence of surface flows that would suggest that the surface drainage basin for La Crosse Cave should extend into the intersection of MoPac and La Crosse Avenue (Figure 6).

The surface drainage basin delineations for all three of these caves excludes the lanes of MoPac south of La Crosse Avenue because 1) the MoPac northbound lanes are graded to the west where all runoff would be directed to the center median, 2) in portions of the northbound MoPac lanes that are not graded away from the caves there is a curb that prevents flow to the caves, and 3) in portions of the road not graded in either direction and lacking a curb, an existing grassy swale would convey runoff to the closest creek. The current drainage patterns will remain the same along the ROW adjacent to the caves surface drainage basins[12]; therefore, no impacts to the surface drainage basins of La Crosse Cave, Wildflower Cave, or Windmill Flat Sink are anticipated.

[12] K. Friese & Associates. 2014. MoPac Intersections Environmental Study Preliminary Drainage Analysis and Design. For Central Texas Regional Mobility Authority and Texas Department of Transportation.

Maps and other location data for caves and karst features were removed to protect the sensitive nature of these features and the species that may be harmed by unintentional human disturbance. These data may be available upon request.

Figure 6. Caves with drainage basins mapped within the MoPac Intersections ROW and suggested refinements to La Crosse Cave surface drainage basin.

Water Availability – *Develop water balance to evaluate the impacts of the project on aquifer recharge volumes*

Provided by Michael Barrett, Ph.D., P.E., D.WRE, Center for Research in Water Resources: One concern related to the creation of new impervious surfaces on the Edwards Aquifer recharge zone is a reduction in the amount of aquifer recharge. A recent study by Hauwert and Sharp[13] documented that most rainfall that falls on the Edwards recharge zone is lost to evapotranspiration (ET). The amount returned to the atmosphere through ET is a function of precipitation, but appears to average about 70%. About 5% of rainfall becomes surface runoff to creeks and upland recharge features, while only about 25% enters the aquifer through diffuse recharge[14].

The proposed improvements to the Slaughter and La Crosse intersections will add about eight acres of new impervious cover on the recharge zone. The long term average discharge at Barton Springs is approximately 51 f^3/sec (cfs)[15]. Assuming an annual rainfall of 32 inches, the expanded roadway will reduce diffuse recharge by about 232,000 ft^3/yr. Although this is a substantial amount of water, it represents only 0.015 % of the average annual flow at Barton Springs.

A more important fact is that adding impervious cover largely eliminates ET, which is the fate of the largest fraction of rainfall. Assuming a runoff coefficient of 0.9, the additional pavement at these two intersections will generate about 837,000 ft^3/yr of runoff in an average year, which will be discharged to Slaughter Creek and its tributaries after treatment. It is in the beds of these and other creeks where a majority of Edwards Aquifer recharge occurs.

Historical flow data from many of the creeks crossing the Barton Springs portion of the Edwards Aquifer demonstrates that isolated, small to moderate sized rain events generally do not result in creek flow. This is especially true for periods of extended dry weather when soil moisture is low prior to rain events. This low soil moisture also increases ET and reduces diffuse infiltration, further reducing the volumes available for recharge. Conversely, impervious cover generates runoff from virtually all rainfall events, even during drought, and this flow will recharge the aquifer in the beds of the creeks. During droughts there is little to no flow in the creeks, which means that virtually all of this runoff is likely to infiltrate. Consequently, the proposed roadway improvements will actually help sustain flow during droughts to a greater degree than the no-build alternative.

---

[13] Hauwert, N. and Sharp, J. 2014. Measuring Autogenic Recharge over a Karst Aquifer Utilizing Eddy Covariance Evapotranspiration. *Journal of Water Resource and Protection*, 6, 869-879. doi: 10.4236/jwarp.2014.69081.

[14] Slade, Jr. R.M. 2014. Documentation of a recharge-discharge water budget and main streambed recharge volumes, and fundamental evaluation of groundwater tracer studies for the Barton Springs segment of the Edwards Aquifer. *Texas Water Journal*, Volume 5, Number 1. ISSN 2160-5319, 12-23. Available at: https://journals.tdl.org/twj/index.php/twj/article/view/6988/6091.

[15] Slade, Jr. R.M. 2014 (see footnote 14).

Conclusions

Based on available data and the current design, the proposed MoPac Intersections Project poses a low risk for significant hydrogeological connections to sensitive caves, karst features, and groundwater resources that could affect water quality, quantity, and protected species for the following reasons:

- Risk of cave and karst feature encounters:
  - Caves and karst features are known occur in the geologic units present in the project area; therefore, it is possible that karst voids will be intersected anywhere grading or downcutting into bedrock occurs.
  - The proposed cut at Slaughter Lane occurs in the Grainstone member where laterally extensive caves are not normally found; however, the contact between the Grainstone and Kirschberg members occurs within 4 ft. of the proposed cut. The Grainstone/Kirschberg contact is known for some of the most laterally extensive cavernous zones within the Barton Springs Segment.
  - More extensive caves may be encountered at the La Crosse Avenue cut, as it is in the Kirschberg member, which is known for laterally extensive caves.
  - Based on analysis of cave dimensions near the project area, the majority of known caves are less than 100 ft in their longest segment and likely would not extend across the full width of either of the cut areas.

- Water quality:
  - The limits of construction of the proposed project are not located within the surface drainage basin of any known cave. While the surface drainage basins of three caves, La Crosse Cave, Wildflower Cave, and Windmill Flat Sink, are mapped within the ROW, current drainage patterns within the ROW direct runoff from the ROW away from these cave entrances. The current drainage patterns will remain the same along the ROW adjacent to the caves surface drainage basins, so there will be no impacts to the surface drainage entering these caves from the ROW.
  - Analysis of topography and hydrologic gradients to caves in the project area indicates that, with the exception of Baby Fox Cave, Buddy's Vault, Another Cave, and Slaughter Creek Cave, known caves are unlikely to be impacted by vadose groundwater flows from the project area. Of these caves, only Baby Fox Cave is east of the ROW in the general direction of groundwater flow.
  - Any impacts to the phreatic groundwater within Blowing Sink Cave would be mitigated by water quality BMPs that would treat all flows leaving the ROW once the proposed project is operational.

- Water quantity:
  - Engineered solutions will be implemented for subsurface voids encountered with evidence of significant groundwater flow.

  - While the project will add approximately eight acres of new impervious cover over the Recharge zone, proposed roadway improvements may help to sustain flow during droughts due to an overall increase in treated runoff released from water quality structures compared with existing conditions.
  - Water quality BMPs are designed to create hydrographs with an extended period of discharge, which will benefit downstream recharge opportunities in the receiving waterways.[16]

- Protected Species:
  - No federally-listed karst invertebrate species are known from any caves or karst features within the proposed project ROW or within 1 mile of the proposed project[17].
  - No BCCP-protected caves containing species of concern are within the ROW.
  - Analysis of topography and hydraulic gradient from the cut areas to the nine closest BCCP-protected caves (within ~1 mile) indicates that it is unlikely that there will be vadose flow impacts to any BCCP-protected caves except Slaughter Creek Cave, which has a slight risk of being impacted during cutting of the upper 1 ft of bedrock at La Crosse Avenue based on the hydraulic gradient (12.1%). During the operation phase, Slaughter Creek Cave is unlikely to be impacted, as the hydraulic gradient will be reduced to 8.9%. It is important to note that Slaughter Creek Cave is west of the project area and groundwater flow is generally to the east. Based on the hydraulic gradient and location of Slaughter Creek Cave in relation to the La Crosse Avenue cut, it is very unlikely that the cave will be impacted by the proposed project. Based on the hydraulic gradients, no impacts to species of concern are anticipated in any other BCCP caves.
  - Potential impacts to federally-listed *Eurycea* sp. salamanders in Blowing Sink Cave or Barton Springs are highly unlikely due to existing and proposed water quality BMPs that will treat any surface water flowing from the project area before it recharges the Barton Springs Segment of the Edwards Aquifer.

---

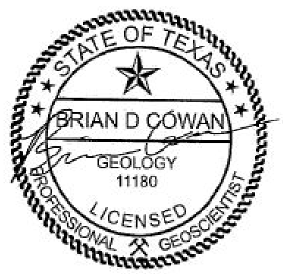
[16] K. Friese & Associates. 2014. MoPac Intersections Environmental Study Preliminary Water Quality Analysis and Design. Prepared for Central Texas Regional Mobility Authority and Texas Department of Transportation.

[17] Zara Environmental LLC. 2014. Draft: Karst Invertebrate and Salamander technical Report MoPac Intersections Environmental Study, Austin, Travis County, Texas. Prepared for Jacobs Engineering, Inc. 17 June 2014.

Geologist Certification

In accordance with the Texas Board of Professional Geologists rules at 22 Texas Administrative Code, Part 39, Chapter 851, Subchapter C, §851.156, this report is signed and sealed on the title page to assure the user that the work has been performed by or directly supervised by the following professional geologist who takes full responsibility for this work.

The computer generated seal appearing on this document was authorized by Brian Cowan, P.G. 11180, on 29 October 2014.



29 October 2014
Brian Cowan, Texas Professional Geologist No. 11180

This page left intentionally blank.