EAST ARAPAHOE TRANSPORTATION PLAN
Alternatives Evaluation Report – Appendices A-H

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APPENDIX A VEHICLE OPERATIONS

This appendix provides detailed traffic operations analysis methodology and results to supplement the evaluation results that are provided in the East Arapahoe Transportation Plan Evaluation of Alternatives Report. The vehicle operations analysis area develops metrics related to current and projected traffic forecast for the Arapahoe corridor, and includes estimates of travel time, intersection level-of-service, auto vehicle-miles traveled, and freight impacts.

OVERALL ASSUMPTIONS AND DATA SOURCES

Travel forecasts from DRCOG for 2040 are one of the key inputs to the vehicle operations analysis. The base DRCOG projections indicate an approximately 20 to 30% increase in automobile traffic volumes along Arapahoe by 2040. An alternative 2040 scenario, grounded in historic trends over the past decade or more in Boulder, assumes that transit and land use policies included in the Boulder Valley Comprehensive Plan would reduce the projected increase in vehicle trips and that traffic volumes will be maintained near current levels (historic traffic trend). These scenarios will be used to provide bookends for evaluating the alternatives, i.e., the DRCOG 20% increase scenario would be used to develop high-end estimates of traffic volumes, travel times, etc., while the alternative transit/land use policy historic trends scenario would be used to develop low-end estimates of traffic volumes, travel times, etc.

INTERSECTION LOS FOR AUTOMOBILES

Analysis Overview

Intersection Level of Service (LOS) is an important metric used to compare the impacts of the multimodal improvement alternatives on automobile travel in the corridor. The number and type of automobile travel lanes, and the extent to which lanes are shared between through vehicles, right turning vehicles, and buses or BRT vehicles all have an impact on the LOS for automobiles.

The LOS metric calculates the amount of delay to motorists as they pass through an intersection. This analysis is typically focused on the AM and PM peak hours of the day when automobile traffic is highest and commuting patterns are most pronounced. The delay to motorists is calculated for each approaching movement to an intersection (left, through, right) and then averaged for the intersection overall. To help communicate the LOS concept, the delay to motorists is assigned a letter grade, much like a report card, with LOS A indicating a delay of less than 10 seconds, LOS B between 10 and 20 seconds, LOS C between 20 and 35 seconds, LOS D between 35 and 50 seconds, LOS E between 55 and 80 seconds, and LOS F more than 80 seconds.

The LOS calculation utilized analysis techniques from the Federal Highway Administration's Highway Capacity Manual (Synchro software) that was then applied to the projected peak hour traffic at the 13 signalized intersections in the corridor for each alternative. Traffic volumes incorporated into the analysis, key assumptions, and the resulting LOS findings are detailed below.

Figure A-1 Intersection Level of Service Analysis Summary Table

Peak Hour Auto Traffic Volumes and Level of Service	
Metric	AM and PM peak traffic volumes and Level of Service (LOS) - letter grade and average intersection delay (seconds/vehicle)
Purpose	Describe the impact of the alternatives on delay to vehicles at intersections along the corridor and the level of congestion that can be expected.
Analysis Methodology	Level of service is an output of the Synchro LOS model which uses Highway Capacity Manual procedures.
Data Source	Peak hour traffic volumes derived for signalized intersections from daily traffic volume estimates (adjusted DRCOG 2040 Travel Demand Model and historic trends data) and existing peak hour traffic patterns, then incorporated into Synchro LOS model

Assumptions

- Year 2040 Low traffic (+ 0% traffic growth) scenarios assume that BRT has been implemented along with additional TDM measures, allowing the traffic volume along East Arapahoe to remain approximately the same as today.
- Year 2040 High traffic (+ 20% traffic growth) scenarios are based on the DRCOG regional travel model which predicts a 20% growth in traffic in the corridor.
- Under peak hour traffic conditions, the saturation flow rate of traffic in the corridor is 2,100 vehicles per lane per hour.
- Side running BRT lanes are repurposed from the existing outside travel lane (typically) and this lane is shared between buses and right turning automobiles.
- Center running BRT lanes are repurposed from the inside travel lanes and are used exclusively by BRT vehicles. However, it is assumed that left turning automobiles cross over the BRT lanes upstream of the intersections to allow left turning traffic to do so from the center of the roadway.
- In the 2040 High traffic scenarios, it is assumed that BRT service will result in reducing daily traffic along Arapahoe by between 3,400 and 3,700 vehicles per day along the corridor. In the 2040 Low traffic scenarios, it is assumed that the automobile traffic has already been reduced as a means of achieving the 0% increase in traffic by 2040.

Evaluation Results

Key Findings

- There are 14 signalized intersections in the corridor. The “big five” (28th, 30th, Foothills, 55th, and 63rd) are the most influenced by geometric changes in the alternatives. The remaining nine intersections with smaller side street traffic loads are typically less impacted from a LOS perspective (except as noted).
- The traffic volumes at the five key intersections are illustrated on the attached Figures 1 – 4 for the different analysis horizons, alternative configurations, and low/high traffic volume forecasts. The attached Table 1 provides a summary of the LOS at the five key intersections.
- Without BRT in the future, if traffic grows by approximately 20% (as predicted by DRCOG models), the PM peak hour LOS at key intersections typically degrades by one to two letter grades (from C to D or E).

- With a lane repurposed for side running BRT in the 0% traffic growth scenario, the peak hour LOS is typically the same as today, except at Foothills where the PM peak degrades from D to E.
- With a lane repurposed for center running BRT in the 0% traffic growth scenario, the PM peak hour LOS at 4 of the 5 key intersections degrades by a letter grade.
- With a 20% increase in traffic, the addition of side running BRT results in a letter grade reduction in LOS at only the Foothills intersection, which degrades from E to F.
- With a 20% increase in traffic, the addition of center running BRT results in one or two letter degradation in LOS at the 30th, Foothills, and 55th intersections.

Figure A-2 PM Peak Hour LOS Results

Alternative	District A – 30th Street	District B – Foothills Parkway	District C 55th Street	District D 63rd Street	District E No Signals
Existing	LOS C	LOS D	LOS C	LOS C	N/A
Alt 1	High – LOS D	High – LOS E	High – LOS D	High – LOS E	N/A
Alt 2	Low – LOS C High – LOS D	Low – LOS D High – LOS E	Low – LOS C High – LOS D	Low – LOS C High – LOS E	N/A
Alt 3	Low – LOS C High – LOS D	Low – LOS E High – LOS F	Low – LOS C High – LOS D	Low – LOS C High – LOS C	N/A
Alt 4	Low – LOS D High – LOS E	Low – LOS E High – LOS F	Low – LOS D High – LOS F	Low – LOS C High – LOS C	N/A

Figure A-3 Auto Level of Service Evaluation Score

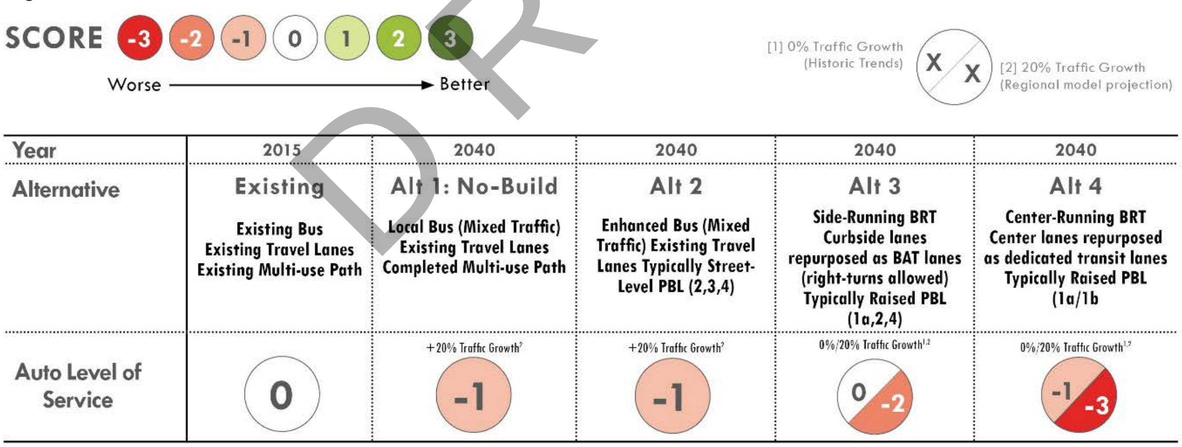


Figure A-4 Auto Level of Service, Peak Hour, All Directions, 2040

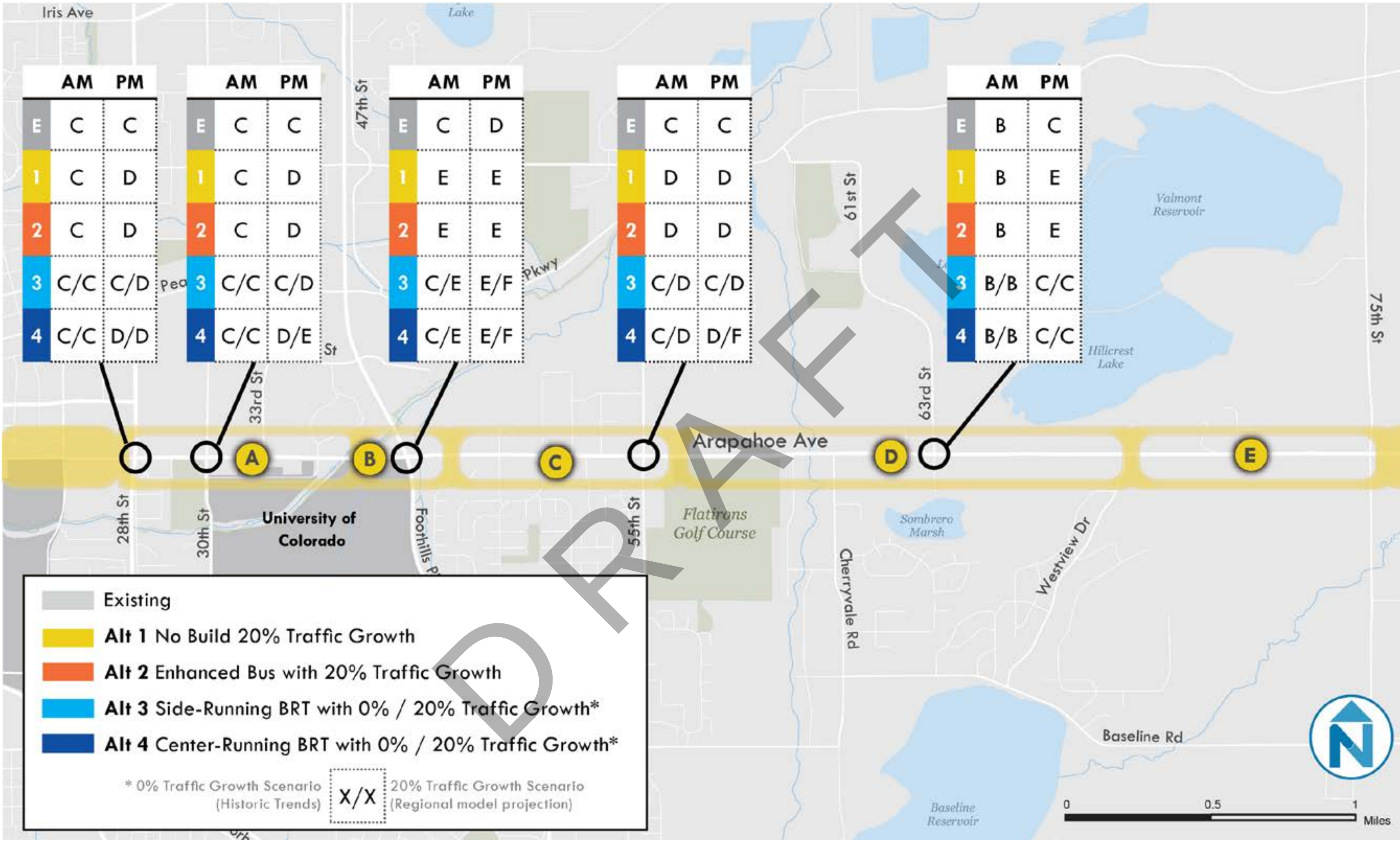


Figure A-5 Auto Level of Service, Peak Hour, East-West Peak Direction Only, 2040

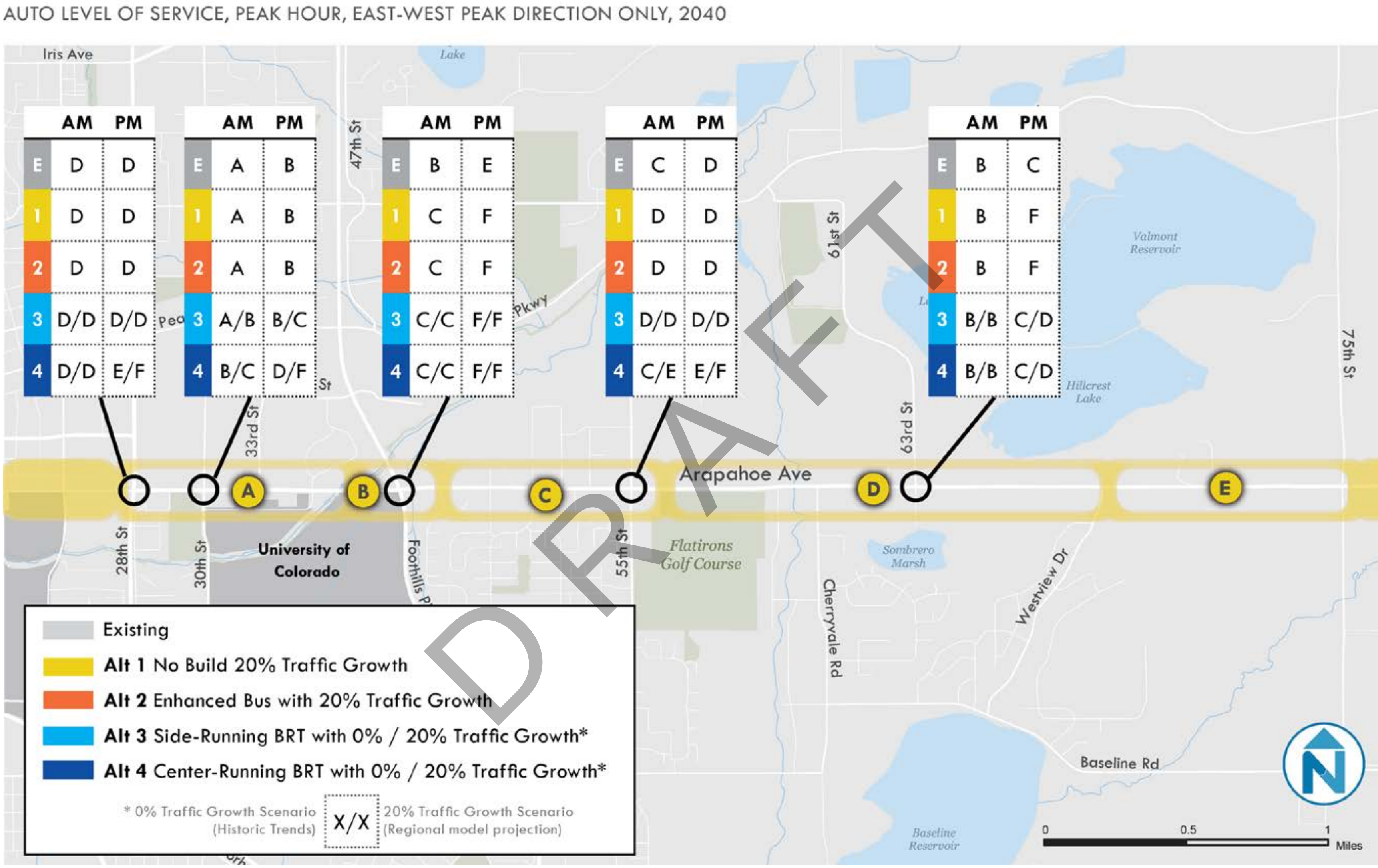


Figure A-6 Auto Volumes, Average Daily, Folsom to 75th Streets, 2040

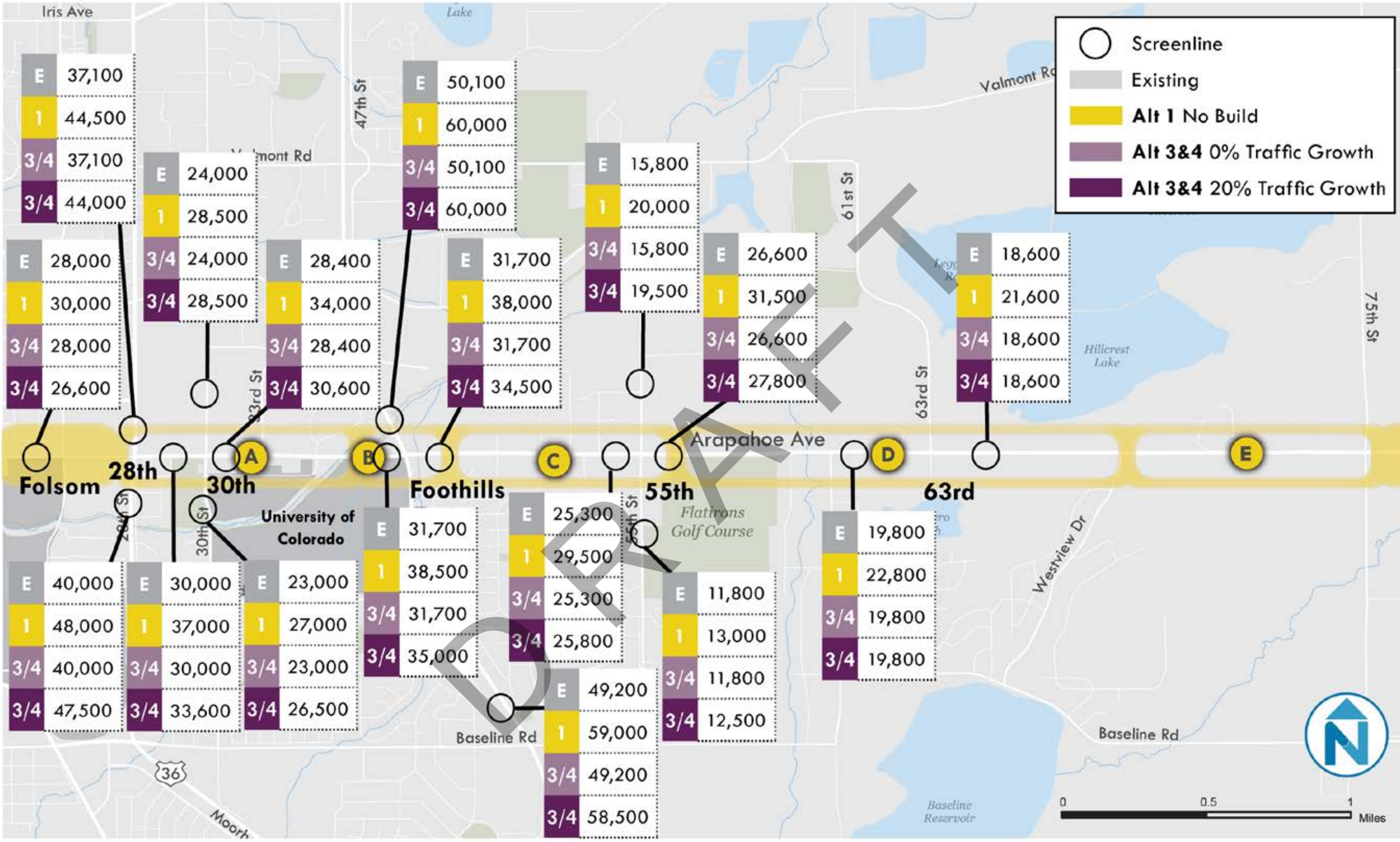


Figure A-7 Existing Vehicle Volumes and Level of Service at Key Intersections

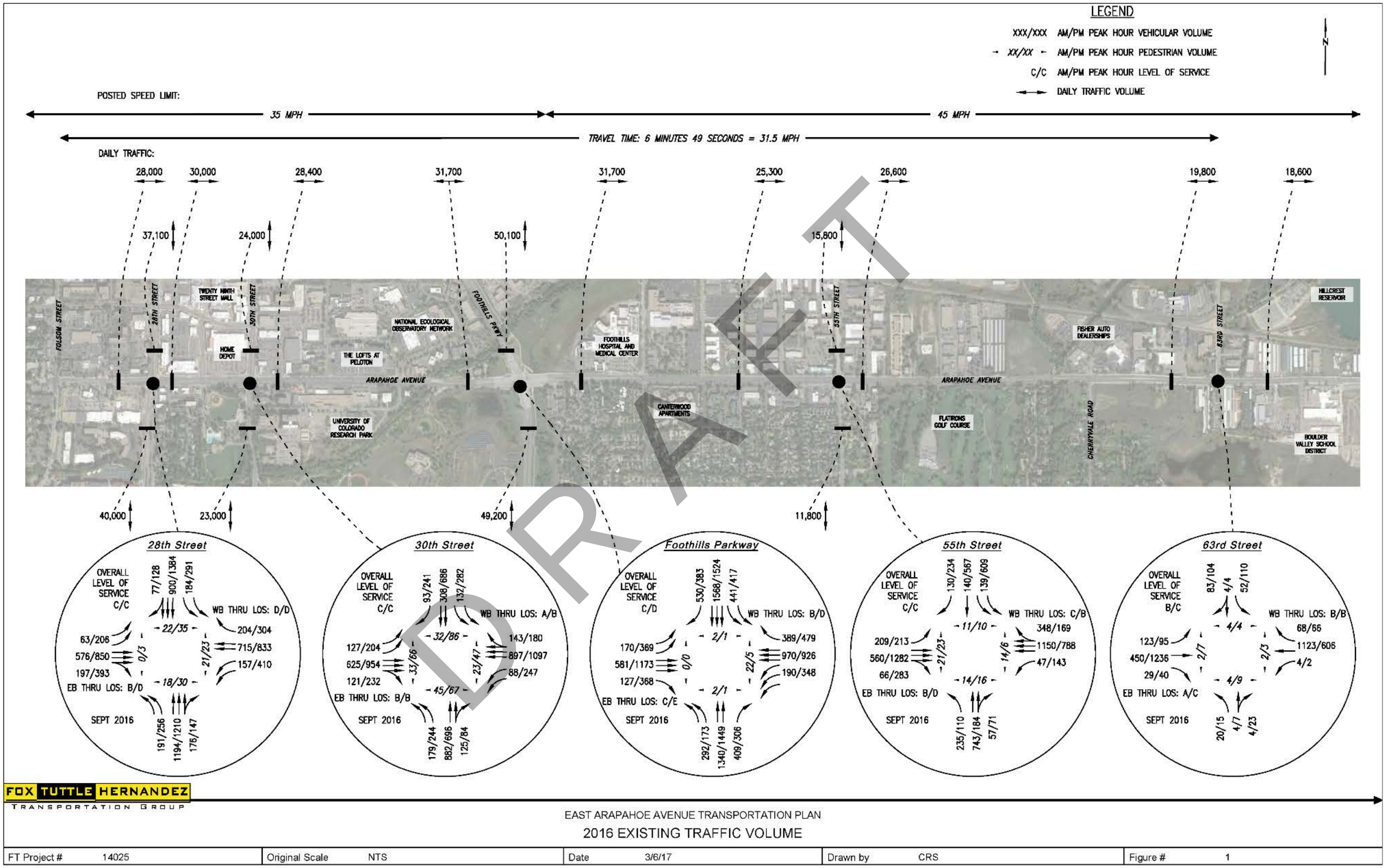


Figure A-8 No Build 2040 Vehicle Volumes and Level of Service at Key Intersections with 20% Traffic Growth

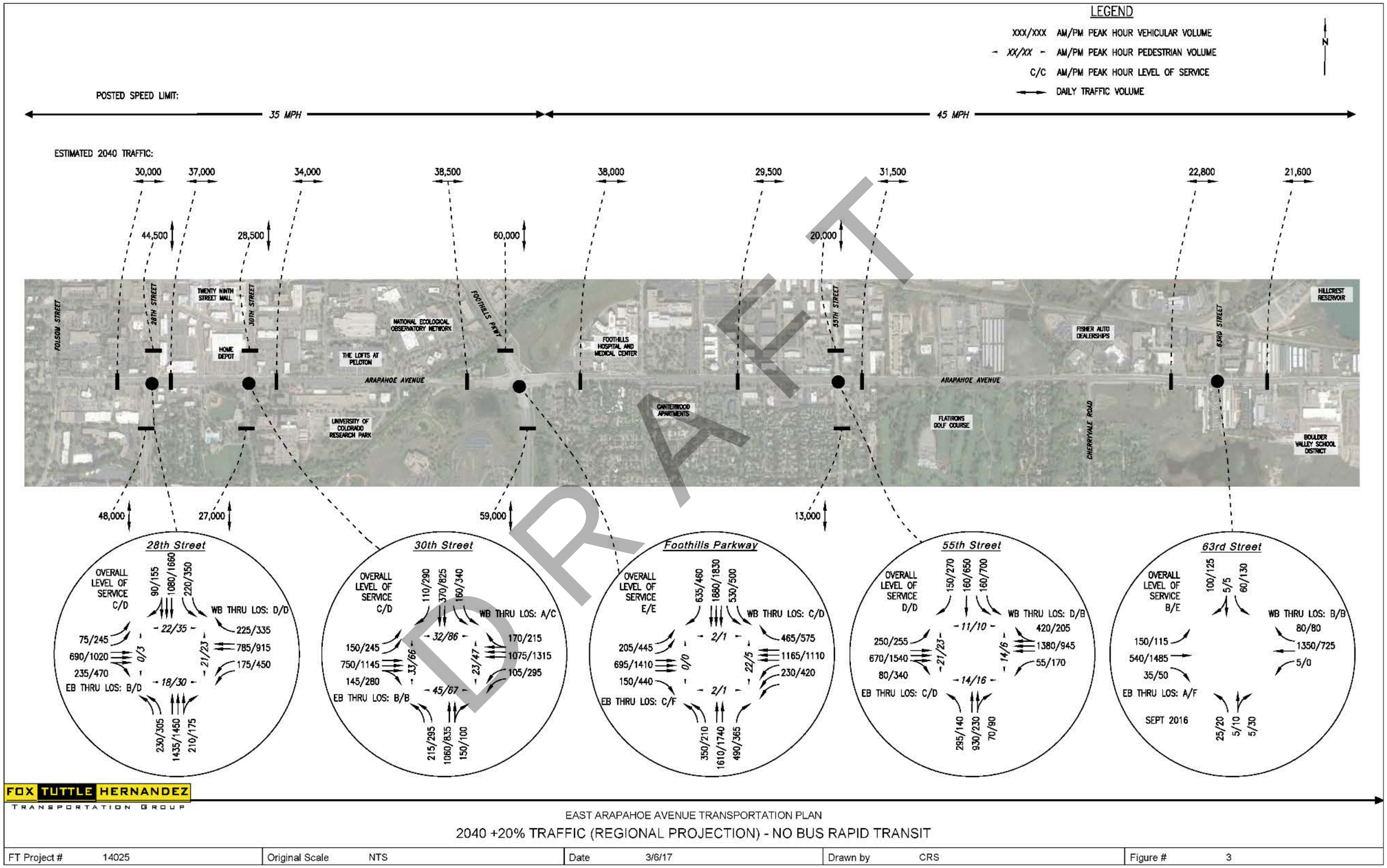


Figure A-9 Alts 3 and 4 (BRT) 2040 Vehicle Volumes and Level of Service at Key Intersections with 0% Traffic Growth

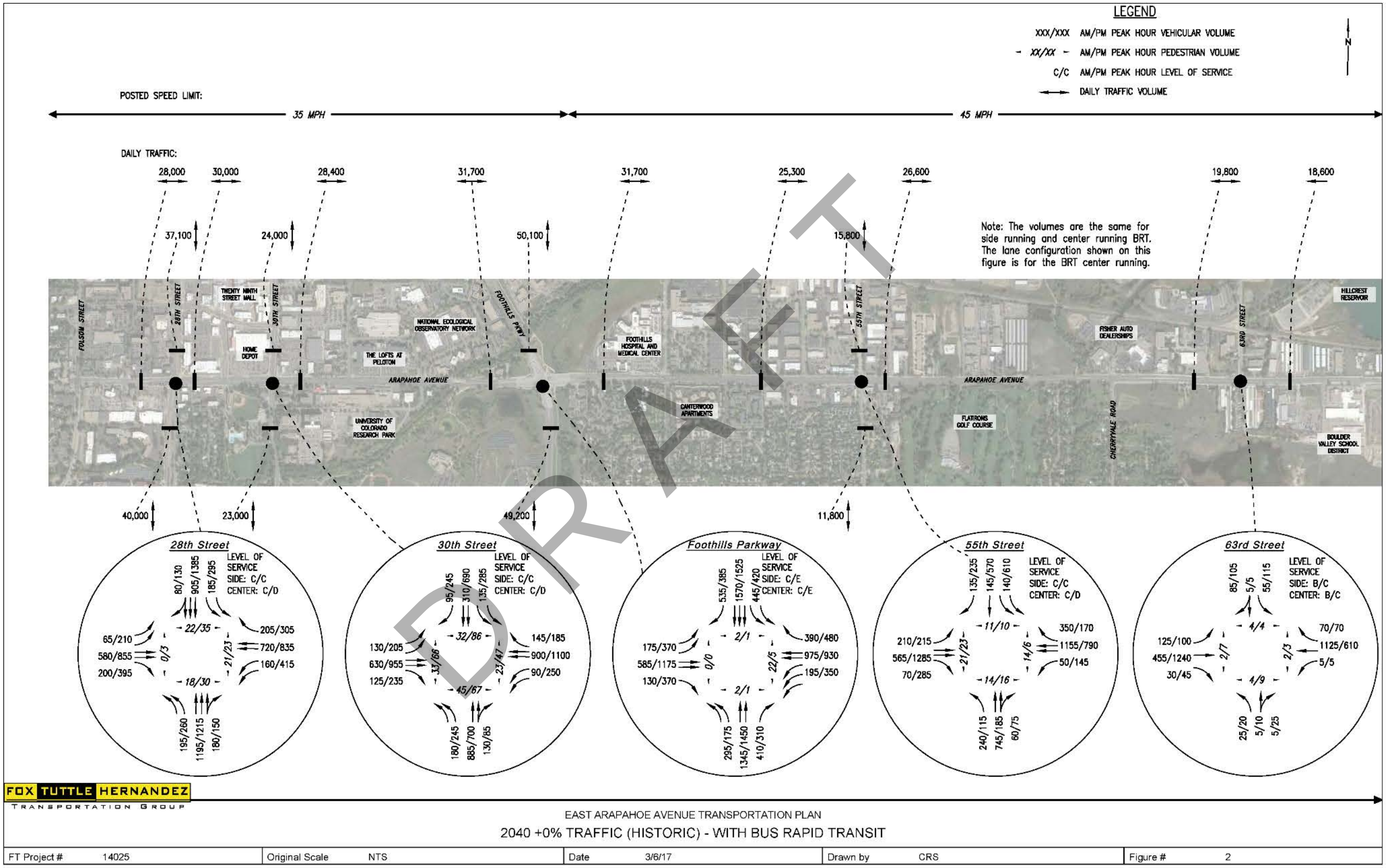


Figure A-10 Alts 3 and 4 (BRT) 2040 Vehicle Volumes and Level of Service at Key Intersections with 20% Traffic Growth

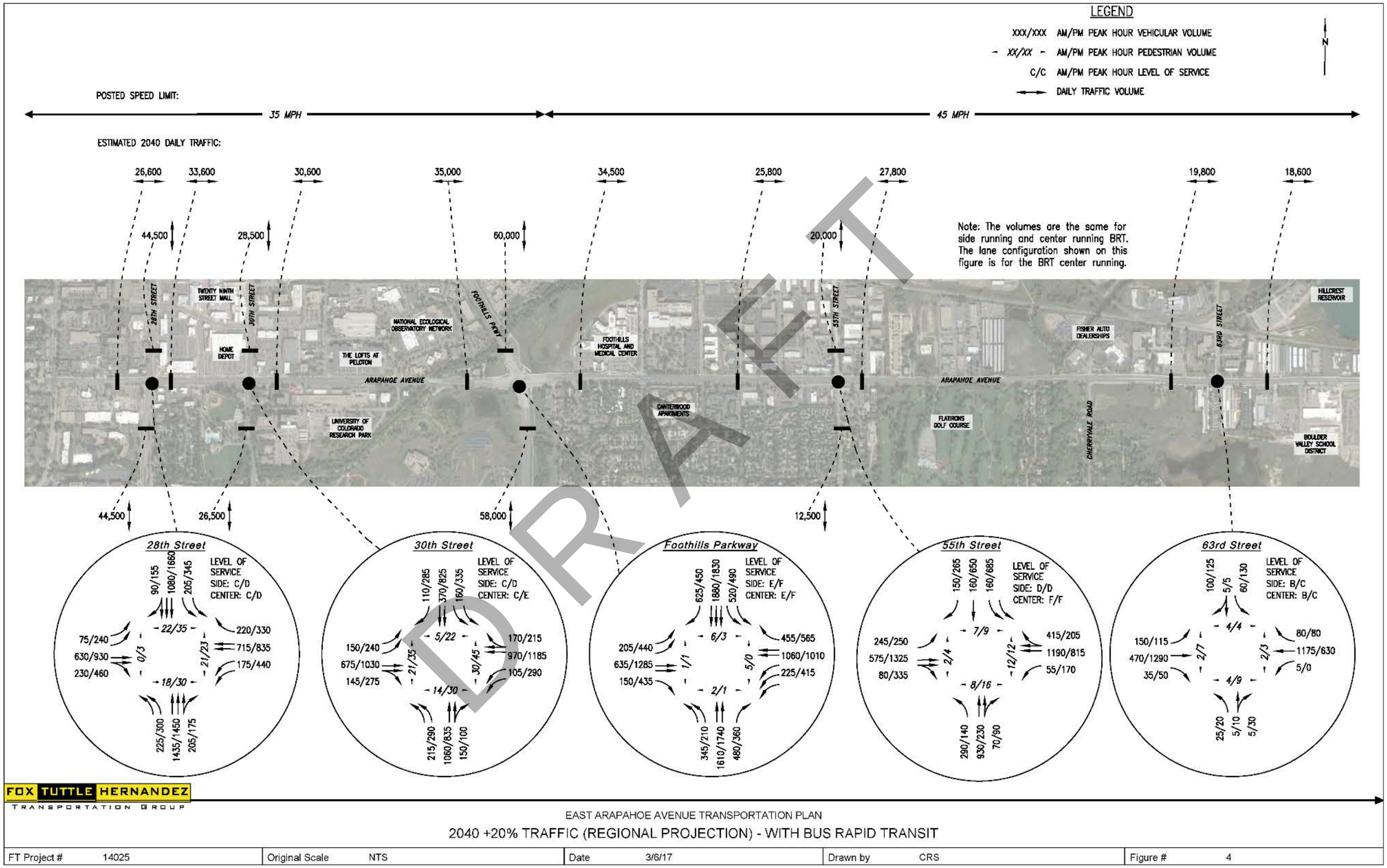


Figure A-11 Level of Service Summary for Key Intersections

Intersection and Lane Groups	Existing				2040 +0% Traffic (Historic) - with BRT (side running)				2040 +0% Traffic (Historic) - with BRT (center running)				2040 +20% Traffic (Regional Projection) - without BRT				2040 +20% Traffic (Reg. Proj.) - with BRT (side running)				2040 +20% Traffic (Reg. Proj.) - with BRT (center running)			
	AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak	
	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS
Arapahoe Avenue and 28th Street	23.3	C	33.8	C	22.6	C	33.5	C	23.6	C	38.9	D	26	C	43	D	24.5	C	43.1	D	25.8	C	53.6	D
Arapahoe Avenue and 30th Street	22.0	C	28.9	C	22.7	C	33.4	C	25.7	C	43.7	D	27.4	C	35.3	D	28.4	C	39.0	D	33.4	C	73.8	E
Arapahoe Avenue and Foothills Parkway	30.2	C	42.7	D	32.0	C	56.8	E	31.9	C	56.6	E	56.4	E	76.0	E	57.7	E	88.1	F	57.4	E	88.1	F
Arapahoe Avenue and 55th Street	28.3	C	32.6	C	32.0	C	34.7	C	32.3	C	47.3	D	37.8	D	43.0	D	36.8	D	39.8	D	48.8	D	90.1	F
Arapahoe Avenue and 63rd Street	12.9	B	22.2	C	13.1	B	22.6	C	13.1	B	22.5	C	18.3	B	61.0	E	17.1	B	32.2	C	17.1	B	32.0	C

Notes: Delay represented in average seconds per vehicle.

Figure A-12 Level of Service Details – Key Intersections

Intersection and Lane Groups	Existing				2040 +0% Traffic (Historic) - with BRT (side running)				2040 +0% Traffic (Historic) - with BRT (center running)				2040 +20% Traffic (Regional Projection) - without BRT				2040 +20% Traffic (Reg. Proj.) - with BRT (side running)				2040 +20% Traffic (Reg. Proj.) - with BRT (center running)			
	AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak	
	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS
SIGNAL CONTROL																								
Arapahoe Avenue and 28th Street	**23.3**	**C**	**33.8**	**C**	**22.6**	**C**	**33.5**	**C**	**23.6**	**C**	**38.9**	**D**	**26**	**C**	**43**	**D**	**24.5**	**C**	**43.1**	**D**	**25.8**	**C**	**53.6**	**D**
Eastbound Left	32.6	C	30.1	C	31.6	C	42.2	D	31.5	C	42.8	D	33	C	39	D	31.8	C	45.8	D	31.7	C	48.1	D
Eastbound Through+Right	15.2	B	35.1	D					19.2	B	62.8	E	17	B	40	D					21.5	C	116.0	F
Eastbound Through					16.6	B	36.4	D									17.3	B	43.3	D				
Eastbound Right*					2.6	A	33.0	C									3.1	A	41.9	D				
Westbound Left	35.6	D	55.1	E	34.7	C	53.1	D	34.7	C	51.1	D	35	D	65	E	35.1	D	58.2	E	35.0	C	55.1	E
Westbound Through	39.4	D	46.0	D	38.1	D	44.2	D	37.8	D	43.6	D	39	D	45	D	37.3	D	43.2	D	37.4	D	42.7	D
Westbound Right	37.3	D	32.7	C	34.6	C	30.9	C	34.3	C	30.1	C	35	C	30	C	34.6	C	30.7	C	34.3	C	30.4	C
Northbound Left	59.2	E	65.9	E	59.1	E	66.7	E	59.0	E	66.0	E	57	E	67	E	57.7	E	67.0	E	57.7	E	67.0	E
Northbound Through+Right	14.9	B	25.6	C	14.9	B	24.9	C	14.9	B	25.5	C	18	B	32	C	18.2	B	31.6	C	18.2	B	31.9	C
Southbound Left	40.1	D	35.8	D	40.4	D	36.5	D	40.4	D	36.4	D	56	E	50	D	49.0	D	49.0	D	49.0	D	49.0	D
Southbound Through+Right	13.9	B	22.4	C	14.2	B	21.5	C	14.2	B	22.6	C	19	B	48	D	19.1	B	46.8	D	19.1	B	47.5	D
Arapahoe Avenue and 30th Street	**22.0**	**C**	**28.9**	**C**	**22.7**	**C**	**33.4**	**C**	**25.7**	**C**	**43.7**	**D**	**27.4**	**C**	**35.3**	**D**	**28.4**	**C**	**39.0**	**D**	**33.4**	**C**	**73.8**	**E**
Eastbound Left	63.7	E	57.8	E	67.1	E	65.0	E	66.6	E	65.0	E	62.9	E	56.3	E	64.7	E	61.4	E	64.5	E	61.4	E
Eastbound Through+Right	13.3	B	14.4	B					14.6	B	42.1	D	16.9	B	18.6	B					17.2	B	103.5	F
Eastbound Through					12.9	B	16.9	B									14.5	B	22.8	C				
Eastbound Right*					0.8	A	4.3	A									0.8	A	7.2	A				
Westbound Left	19.2	B	21.1	C	20.5	C	33.5	C	27.1	C	38.9	D	19.5	B	31.5	C	23.0	C	37.5	D	31.4	C	40.2	D
Westbound Through+Right	4.1	A	18.5	B					15.1	B	47.8	D	6.6	A	29.5	C					25.1	C	108.4	F
Westbound Through					7.9	A	31.6	C									11.3	B	39.5	D				
Westbound Right*					3.7	A	42.0	D									7.4	A	45.0	D				
Northbound Left	62.7	E	50.4	D	62.7	E	50.3	D	62.7	E	50.3	D	63.3	E	54.6	D	63.3	E	54.2	D	63.3	E	54.2	D
Northbound Through+Right	31.3	C	37.2	D	31.5	C	37.3	D	31.5	C	37.3	D	48.3	D	46.9	D	48.3	D	46.9	D	48.3	D	46.9	D
Southbound Left	73.4	E	47.1	D	73.8	E	47.2	D	73.8	E	47.2	D	75.9	E	58.2	E	75.9	E	57.3	E	75.9	E	57.3	E
Southbound Through	9.4	A	31.0	C	9.4	A	31.0	C	9.4	A	31.0	C	8.9	A	32.3	C	8.9	A	36.2	D	8.9	A	36.2	D
Southbound Right	26.6	C	61.9	E	26.6	C	61.9	E	26.6	C	61.9	E	0.4	A	46.6	D	0.4	A	49.2	D	0.4	A	49.2	D
Arapahoe Avenue and Foothills Parkway	**30.2**	**C**	**42.7**	**D**	**32.0**	**C**	**56.8**	**E**	**31.9**	**C**	**56.6**	**E**	**56.4**	**E**	**76.0**	**E**	**57.7**	**E**	**88.1**	**F**	**57.4**	**E**	**88.1**	**F**
Eastbound Left	40.8	D	151.9	F	39.6	D	150.1	F	39.9	D	149.2	F	43.1	D	244.3	F	42.9	D	236.7	F	43.1	D	236.0	F
Eastbound Through	23.9	C	56.8	E	21.8	C	138.5	F	22.1	C	137.6	F	24.4	C	117.3	F	22.0	C	190.8	F	22.2	C	190.1	F
Eastbound Right	0.1	A	0.2	A	0.1	A	0.3	A	0.1	A	0.2	A	0.1	A	0.3	A	0.1	A	0.2	A	0.1	A	0.2	A
Westbound Left	49.1	D	46.2	D	48.3	D	48.1	D	46.7	D	52.1	D	45.9	D	61.5	E	47.3	D	58.6	E	46.5	D	62.2	E
Westbound Through	17.4	B	36.1	D	27.7	C	50.3	D	27.5	C	49.3	D	22.2	C	41.3	D	35.3	D	70.4	E	33.7	C	69.5	E
Westbound Right	0.3	A	0.3	A	0.2	A	0.4	A	0.1	A	0.3	A	0.3	A	0.4	A	0.2	A	0.4	A	0.2	A	0.4	A
Northbound Left	54.8	D	48.5	D	55.3	E	48.7	D	55.3	E	48.8	D	65.9	E	54.3	D	64.3	E	54.2	D	64.3	E	54.2	D
Northbound Through	31.8	C	40.4	D	32.5	C	40.5	D	32.5	C	40.5	D	106.4	F	106.8	F	106.4	F	106.8	F	106.3	F	106.8	F
Northbound Right	0.2	A	0.2	A	0.2	A	0.2	A	0.2	A	0.2	A	0.3	A	0.2	A	0.3	A	0.2	A	0.3	A	0.2	A
Southbound Left	160.9	F	162.2	F	166.3	F	166.7	F	166.3	F	166.7	F	272.2	F	265.4	F	259.7	F	253.8	F	259.7	F	253.8	F
Southbound Through	22.1	C	20.3	C	22.2	C	20.4	C	22.2	C	20.4	C	38.6	D	25.4	C	38.5	D	25.4	C	38.5	D	25.4	C
Southbound Right	0.3	A	0.1	A	0.3	A	0.2	A	0.3	A	0.1	A	0.5	A	0.2	A	0.5	A	0.2	A	0.5	A	0.2	A
Arapahoe Avenue and 55th Street	**28.3**	**C**	**32.6**	**C**	**32.0**	**C**	**34.7**	**C**	**32.3**	**C**	**47.3**	**D**	**37.8**	**D**	**43.0**	**D**	**36.8**	**D**	**39.8**	**D**	**48.8**	**D**	**90.1**	**F**
Eastbound Left	28.8	C	45.7	D	39.7	D	46.8	D	43.5	D	85.5	F	42.3	D	138.3	F	44.3	D	58.2	E	46.3	D	178.7	F
Eastbound Through+Right	18.0	B	39.0	D					27.5	C	73.6	E	24.6	C	45.3	D					27.8	C	182.0	F
Eastbound Through					24.8	C	47.2	D									25.8	C	51.3	D				
Eastbound Right*					13.9	B	27.3	C									17.1	B	26.5	C				
Westbound Left	19.8	B	39.2	D	25.4	C	38.9	D	26.6	C	38.7	D	23.3	C	45.4	D	26.0	C	44.0	D	27.0	C	43.9	D
Westbound Through+Right	29.9	C	17.7	B				A	33.8	C	21.9	C	40.7	D	18.8	B					68.0	E	23.2	C
Westbound Through					37.3	D	19.3	B									39.2	D	19.8	B				
Westbound Right*					28.9	C	16.9	B									32.6	C	16.9	B				
Northbound Left	26.9	C	37.1	D	27.4	C	38.5	D	27.4	C	38.5	D	33.1	C	57.5	E	32.5	C	57.5	E	32.5	C	57.5	E
Northbound Through+Right	36.1	D	27.0	C	36.2	D	27.2	C	36.2	D	27.2	C	49.3	D	29.3	C	49.4	D	29.3	C	49.4	D	29.3	C
Southbound Left	26.6	C	25.0	C	26.7	C	25.1	C	26.7	C	25.1	C	27.9	C	28.9	C	27.9	C	28.2	C	27.9	C	28.2	C
Southbound Through	29.1	C	47.2	D	29.2	C	48.3	D	29.2	C	48.3	D	29.4	C	67.5	E	29.4	C	67.5	E	29.4	C	67.5	E
Southbound Right	17.3	B	23.8	C	17.3	B	23.8	C	17.3	B	23.8	C	17.4	B	24.1	C	17.4	B	24.0	C	17.4	B	24.0	C
Arapahoe Avenue and 63rd Street	**12.9**	**B**	**22.2**	**C**	**13.1**	**B**	**22.6**	**C**	**13.1**	**B**	**22.5**	**C**	**18.3**	**B**	**61.0**	**E**	**17.1**	**B**	**32.2**	**C**	**17.1**	**B**	**32.0**	**C**
Eastbound Left	6.0	A	8.1	A	6.2	A	7.9	A	5.9	A	8.3	A	20.7	C	9.2	A	14.1	B	8.1	A	13.6	B	8.6	A
Eastbound Through	4.6	A	26.3	C	4.5	A	26.9	C	4.6	A	26.7	C	6.8	A	97.0	F	6.2	A	40.1	D	6.3	A	39.7	D
Eastbound Right	1.6	A	8.8	A	1.6	A	9.0	A	1.6	A	9.3	A	2.6	A	8.8	A	2.9	A	8.5	A	2.9	A	8.6	A
Westbound Left	10.2	B	9.4	A	9.8	A	10.6	B	9.8	A	10.6	B	14.1	B	0.0	A	13.0	B	0.0	A	13.1	B	0.0	A
Westbound Through+Right	13.1	B	10.1	B	13.2	B	10.2	B	13.2	B	10.2	B	18.5	B	11.0	B	16.9	B	10.6	B	17.0	B	10.6	B
Northbound Left	40.7	D	38.4	D	41.0	D	38.8	D	41.0	D	38.8	D	38.1	D	39.1	D	38.1	D	39.1	D	38.1	D	39.1	D
Northbound Through+Right	40.0	D	38.1	D	40.0	D	38.2	D	40.0	D	38.2	D	36.7	D	38.6	D	36.7	D	38.3	D	36.7	D	38.3	D
Southbound Left	42.1	D	44.5	D	42.2	D	44.9	D	42.2	D	44.9	D	40.7	D	69.7	E	40.7	D	69.7	E	40.7	D	69.7	E
Southbound Through+Right	40.4	D	38.6	D	40.4	D	38.7	D	40.4	D	38.7	D	38.5	D	38.8	D	38.1	D	38.8	D	38.1	D	38.8	D

Notes: Delay represented in average seconds per vehicle.

** With the BRT in the outside through travel lane, the right-turning vehicles will enter the BRT lane to turn; therefore, the Synchro analysis includes a right-turn lane to model this driving behavior.*

There are a few instances where the delay and LOS improves from the Existing/Background to the scenario with side running BRT. This is due to the traffic models overestimation of right-turn delay and impact on through vehicles. With a side running BRT, the right-turn vehicles will be able to enter the BRT lane to turn and will have minimal impact on the through vehicles, which in turn improves the through volume delay and LOS.

*** The bolded movement delay was adjusted to reflect observed delay and be more comparable to other intersections. Due to the updated movement delay, the overall delay was adjusted as: sum(mvmt vol*delay) / total intersection volume.*

Figure A-13 Level of Service Details – Minor Intersections

Intersection and Lane Groups	Existing				2040 +0% Traffic (Historic) - with BRT (side running)				2040 +0% Traffic (Historic) - with BRT (center running)				2040 +20% Traffic (Regional Projection) - without BRT				2040 +20% Traffic (Reg. Proj.) - with BRT (side running)				2040 +20% Traffic (Reg. Proj.) - with BRT (center running)			
	AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak		AM Peak		PM Peak	
	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS	Delay	LOS
SIGNAL CONTROL																								
Arapahoe Avenue and 26th Street	**7.4**	**A**	**16.5**	**B**	**8.1**	**A**	**18.6**	**B**	**8.2**	**A**	**19.5**	**B**	**7.8**	**A**	**17.6**	**B**	**8.6**	**A**	**20.0**	**B**	**8.7**	**A**	**21.3**	**C**
Eastbound Left	8.7	A	14.9	B	8.6	A	15.6	B	8.6	A	16.4	B	8.7	A	14.5	B	8.7	A	15.5	B	8.8	A	16.8	B
Eastbound Through+Right	9.7	A	20.8	C					10.8	B	25.5	C	10.0	A	21.7	C					11.3	B	26.7	C
Eastbound Through					10.7	B	24.6	C									11.0	B	25.5	C				
Eastbound Right*					13.8	B	27.5	C									14.7	B	27.7	C				
Westbound Left	1.7	A	5.7	A	1.7	A	10.5	B	1.8	A	15.4	B	2.0	A	22.5	C	2.0	A	26.1	C	2.0	A	36.4	D
Westbound Through+Right	1.5	A	3.3	A					1.7	A	4.7	A	1.5	A	3.6	A					1.8	A	5.9	A
Westbound Through					1.7	A	4.1	A									1.9	A	4.8	A				
Westbound Right*					0.0	A	0.2	A									0.2	A	0.4	A				
Northbound Left	32.4	C	35.8	D	32.4	C	35.9	D	32.4	C	35.9	D	32.8	C	36.9	D	32.8	C	36.9	D	32.8	C	36.9	D
Northbound Through	31.5	C	32.5	C	31.6	C	32.6	C	31.6	C	32.6	C	31.6	C	32.6	C	31.6	C	32.6	C	31.6	C	32.6	C
Northbound Right	31.3	C	32.7	C	31.3	C	32.7	C	31.3	C	32.7	C	31.3	C	32.7	C	31.3	C	32.7	C	31.3	C	32.7	C
Southbound Left	32.6	C	36.2	D	32.7	C	36.3	D	32.7	C	36.3	D	33.0	C	37.2	D	33.0	C	37.1	D	33.0	C	37.1	D
Southbound Through+Right	31.4	C	33.0	C	31.4	C	33.1	C	31.4	C	33.1	C	31.4	C	33.2	C	31.4	C	33.2	C	31.4	C	33.2	C
Arapahoe Avenue and 29th Street	**6.1**	**A**	**13.9**	**B**	**6.7**	**A**	**16.2**	**B**	**6.7**	**A**	**17.8**	**B**	**6.4**	**A**	**15.1**	**B**	**7.0**	**A**	**18.3**	**B**	**6.9**	**A**	**20.3**	**C**
Eastbound Left	8.9	A	29.0	C	8.4	A	38.4	D	8.5	A	42.7	D	14.9	B	36.3	D	11.1	B	45.8	D	11.1	B	40.7	D
Eastbound Through+Right	5.1	A	9.0	A					5.4	A	11.9	B	5.1	A	10.7	B					5.4	A	14.2	B
Eastbound Through					5.6	A	12.3	B									5.7	A	14.5	B				
Eastbound Right*					4.8	A	10.3	B									5.3	A	10.3	B				
Westbound Left	4.2	A	10.1	B	4.2	A	14.2	B	4.3	A	14.6	B	4.3	A	11.5	B	4.5	A	15.8	B	4.5	A	16.2	B
Westbound Through+Right	4.6	A	11.6	B				A	5.1	A	16.1	B	4.7	A	11.9	B					5.4	A	19.6	B
Westbound Through					4.9	A	13.1	B									5.3	A	15.0	B				
Westbound Right*					4.8	A	12.2	B									5.3	A	13.5	B				
Northbound Left+Through+Right	32.7	C	35.1	D	32.8	C	35.6	D	32.8	C	35.6	D	32.8	C	35.6	D	32.8	C	35.6	D	32.8	C	35.6	D
Southbound Left+Through	33.3	C	38.7	D	33.5	C	39.3	D	33.5	C	39.3	D	33.5	C	41.9	D	33.5	C	41.2	D	33.5	C	41.2	D
Southbound Right	32.7	C	35.1	D	32.7	C	35.2	D	32.7	C	35.2	D	32.7	C	35.8	D	32.7	C	35.7	D	32.7	C	35.7	D
Arapahoe Avenue and 33rd Street	**14.9**	**B**	**8.1**	**A**	**16.2**	**B**	**9.4**	**A**	**16.6**	**B**	**10.3**	**B**	**16.0**	**B**	**8.5**	**A**	**17.8**	**B**	**10.3**	**B**	**18.5**	**B**	**10.8**	**B**
Eastbound Left	6.0	A	14.2	B	5.7	A	26.1	C	10.4	B	45.0	D	17.5	B	36.2	D	9.8	A	46.9	D	25.0	C	49.2	D
Eastbound Through+Right	4.2	A	0.7	A					4.3	A	0.7	A	3.9	A	0.6	A					4.5	A	0.5	A
Eastbound Through					4.2	A	0.8	A									4.3	A	0.7	A				
Eastbound Right*					4.3	A	0.0	A									4.6	A	0.0	A				
Westbound Left	12.3	B	4.4	A	11.0	B	5.7	A	11.0	B	5.7	A	11.9	B	4.9	A	11.2	B	7.5	A	11.3	B	7.6	A
Westbound Through+Right	20.7	C	5.0	A				A	23.5	C	7.1	A	22.5	C	5.3	A					26.2	C	9.1	A
Westbound Through					20.6	C	6.5	A									22.5	C	7.9	A				
Westbound Right*					39.3	D	2.3	A									44.9	D	7.2	A				
Northbound Left+Through+Right	28.2	C	34.6	C	28.4	C	35.0	C	28.4	C	35.0	C	28.4	C	35.0	C	28.4	C	35.0	C	28.4	C	35.0	C
Southbound Left	30.6	C	41.8	D	30.6	C	43.8	D	30.6	C	43.8	D	30.6	C	43.8	D	30.6	C	43.1	D	30.6	C	43.1	D
Southbound Through+Right	28.6	C	35.8	D	28.9	C	36.1	D	28.9	C	36.1	D	28.9	C	36.4	D	28.9	C	36.1	D	28.9	C	36.1	D
Arapahoe Avenue and 38th Street	**10.9**	**B**	**13.5**	**B**	**13.2**	**B**	**15.4**	**B**	**11.4**	**B**	**15.4**	**B**	**10.7**	**B**	**13.3**	**B**	**14.1**	**B**	**15.8**	**B**	**11.6**	**B**	**15.8**	**B**
Eastbound Left	6.6	A	4.8	A	10.0	A	13.1	B	9.4	A	12.2	B	9.8	A	22.9	C	14.2	B	34.2	C	13.3	B	32.6	C
Eastbound Through+Right	7.7	A	3.8	A					8.7	A	4.5	A	7.6	A	3.6	A					8.4	A	4.6	A
Eastbound Through					9.3	A	4.5	A									9.4	A	4.5	A				
Eastbound Right*					6.2	A	1.6	A									6.9	A	1.4	A				
Westbound Left	9.8	A	7.1	A	9.5	A	8.6	A	9.6	A	9.2	A	11.7	B	14.1	B	10.4	B	11.9	B	10.6	B	12.7	B
Westbound Through	8.8	A	5.9	A	10.0	A	9.7	A	10.0	A	9.7	A	9.1	A	7.1	A	10.6	B	11.7	B	10.6	B	11.7	B
Westbound Right	13.2	B	3.4	A	20.7	C	4.7	A	10.7	B	3.3	A	11.4	B	3.4	A	23.4	C	5.7	A	11.0	B	3.7	A
Northbound Left	29.1	C	35.8	D	29.3	C	35.9	D	29.3	C	35.9	D	29.3	C	35.9	D	29.3	C	35.9	D	29.3	C	35.9	D
Northbound Through	29.1	C	34.6	C	29.2	C	34.7	C	29.2	C	34.7	C	29.2	C	34.7	C	29.2	C	34.7	C	29.2	C	34.7	C
Northbound Right	29.1	C	37.5	D	29.2	C	37.7	D	29.2	C	37.7	D	29.2	C	37.7	D	29.2	C	37.5	D	29.2	C	37.5	D
Southbound Left	30.2	C	47.1	D	30.3	C	47.6	D	30.3	C	47.6	D	30.3	C	47.6	D	30.3	C	46.6	D	30.3	C	46.6	D
Southbound Through+Right	29.0	C	36.4	D	29.1	C	36.4	D	29.1	C	36.4	D	29.1	C	36.8	D	29.1	C	36.6	D	29.1	C	36.6	D
Arapahoe Avenue and 48th Street	**13.9**	**B**	**9.0**	**A**	**33.1**	**C**	**13.4**	**B**	**35.9**	**D**	**15.6**	**B**	**29.2**	**C**	**12.0**	**B**	**32.6**	**C**	**14.3**	**B**	**37.8**	**D**	**16.2**	**B**
Eastbound Left	19.3	B	4.1	A	164.7	F	11.1	B	165.2	F	14.2	B	161.0	F	13.3	B	154.3	F	18.6	B	154.3	F	21.4	C
Eastbound Through+Right	15.8	B	5.9	A					20.9	C	14.1	B	18.2	B	8.9	A					22.2	C	15.3	B
Eastbound Through					18.6	B	11.5	B									19.9	B	12.8	B				
Eastbound Right*					34.8	C	1.5	A									38.1	D	1.3	A				
Westbound Left	8.4	A	6.3	A	9.3	A	21.5	C	9.8	A	52.7	D	9.5	A	55.2	E	9.1	A	50.4	D	9.4	A	52.4	D
Westbound Through+Right	9.6	A	4.6	A					19.6	B	6.4	A	12.1	B	4.9	A					27.1	C	7.0	A
Westbound Through					14.2	B	6.2	A									16.6	B	6.5	A				
Westbound Right*					7.0	A	1.3	A									6.5	A	1.1	A				
Northbound Left	31.2	C	36.2	D	34.9	C	36.6	D	34.9	C	36.6	D	34.9	C	36.6	D	34.4	C	36.6	D	34.4	C	36.6	D
Northbound Through+Right	28.4	C	34.0	C	28.7	C	34.3	C	28.7	C	34.3	C	28.7	C	34.6	C	28.7	C	34.4	C	28.7	C	34.4	C
Southbound Left	28.5	C	38.3	D	28.8	C	39.5	D	28.8	C	39.5	D	28.8	C	39.5	D	28.8	C	39.1	D	28.8	C	39.1	D
Southbound Through	28.2	C	34.0	C	28.5	C	34.2	C	28.5	C	34.2	C	28.5	C	34.2	C	28.5	C	34.2	C	28.5	C	34.2	C
Southbound Right	28.4	C	34.5	C	28.7	C	36.7	D	28.7	C	36.7	D	28.7	C	36.9	D	28.7	C	36.6	D	28.7	C	36.6	D
Arapahoe Avenue and Commerce St/Eisenhowe	**4.4**	**A**	**8.4**	**A**	**5.2**	**A**	**10.0**	**A**	**6.1**	**A**	**10.4**	**B**	**6.1**	**A**	**8.9**	**A**	**7.2**	**A**	**10.4**	**B**	**8.6**	**A**	**11.4**	**B**
Eastbound Left	10.3	B	3.1	A	17.0	B	4.1	A	32.6	C	4.2	A	43.8	D	3.4	A	53.1	D	4.2	A	55.5	E	5.1	A
Eastbound Through+Right	1.7	A	6.8	A					2.4	A	8.4	A	2.8	A	6.6	A					3.1	A	9.4	A
Eastbound Through					2.4	A	8.4	A									3.1	A	8.2	A				
Eastbound Right*					0.2	A	0.2	A									0.3	A	0.2	A				
Westbound Left	2.7	A	17.6	B	2.7	A	37.5	D	3.2	A	41.6	D	4.5	A	31.6	C	4.3	A	42.7	D	5.4	A	46.2	D
Westbound Through+Right	2.6	A	6.2	A					4.0	A	7.1	A	4.2	A	6.9	A		A			7.4	A	8.2	A
Westbound Through					3.3	A	7.0	A									5.5	A	8.0	A				
Westbound Right*					0.6	A	10.0	A									1.1	A	10.0	A				
Northbound Left	33.5	C	34.0	C	33.5	C	34.1	C	33.5	C	34.1	C	29.1	C	34.3	C	29.1	C	34.3	C	29.1	C	34.3	C
Northbound Through+Right	32.3	C	33.3	C	32.4	C	33.6	C	32.4	C	33.6	C	28.0	C	33.6	C	28.0	C	33.6	C	28.0	C	33.6	C
Southbound Left+Through	32.1	C	34.7	C	32.3	C	35.2	D	32.3	C	35.2	D	27.8	C	35.2	D	27.8	C	35.2	D	27.8	C	35.2	D
Southbound Right	32.0	C	33.3	C	32.0	C	33.3	C	32.0	C	33.3	C	27.6	C	33.3	C	27.6	C	33.3	C	27.6	C	33.3	C
Arapahoe Avenue and Conestoga Street	**9.0**	**A**	**7.3**	**A**	**12.5**	**B**	**9.9**	**A**	**15.6**	**B**	**12.0**	**B**	**30.3**	**C**	**11.0**	**B**	**23.5**	**C**	**13.7**	**B**	**35.0**	**C**	**15.1**	**B**
Eastbound Left	66.5	E	3.9	A	141.7	F	5.9	A	222.0	F	7.7	A	504.5	F	12.3	B	323.7	F	9.8	A	541.9	F	12.0	B
Eastbound Through+Right	3.2	A	2.6	A					4.0	A	6.7	A	3.7	A	3.5	A					4.4	A	10.0	A
Eastbound Through					4.0	A	5.0	A									4.1	A	7.3	A				
Eastbound Right*					0.3	A	4.3	A									0.3	A	6.9	A				
Westbound Left	5.2	A	31.1	C	5.0	A	81.5	F	4.6	A	132.2	F	5.5	A	175.6	F	5.7	A	176.5	F	5.0	A	168.5	F
Westbound Through+Right	5.6	A	5.4	A		A			6.0	A	5.9	A	5.4	A	5.8	A					6.7	A	6.7	A
Westbound Through					6.3	A	5.8	A									6.5	A	6.5	A				
Westbound Right*					0.9	A	2.0	A									0.4	A	3.0	A				
Northbound Left+Through	25.7	C	31.0	C	25.8	C	31.2	C	25.8	C	31.2	C	25.5	C	31.4	C	25.5	C	31.4	C	25.5	C	31.4	C
Northbound Right	24.3	C	30.7	C	24.3	C	30.8	C	24.3	C	30.8	C	24.2	C	31.0	C	24.2	C	31.0	C	24.2	C	31.0	C
Southbound Left+Through	24.5	C	31.4	C	24.7	C	31.6	C	24.7	C	31.6	C	24.8	C	32.7	C	24.8	C	32.7	C	24.8	C	32.7	C
Southbound Right	24.8	C	31.1	C	24.8	C	31.1	C	24.8	C	31.1	C	25.7	C	32.6	C	25.6	C	32.1	C	25.6	C	32.1	C
Arapahoe Avenue and Cherryvale Road	**15.4**	**B**	**11.1**	**B**	**15.6**	**B**	**11.4**	**B**	**15.4**	**B**	**11.3**	**B**	**16.2**	**B**	**12.0**	**B**	**16.7**	**B**	**12.3**	**B**	**16.6**	**B**	**12.1**	**B**
Eastbound Left	17.9	B	5.9	A	19.3	B	5.8	A	20.1	C	5.8	A	37.8	D	6.0	A	28.1	C	6.4	A	30.7	C	6.2	A
Eastbound Through	12.9	B	6.6	A	11.8	B	6.5	A	11.1	B	6.4	A	14.7	B	7.2	A	12.9	B	7.4	A	12.2	B	7.1	A
Eastbound Right	25.2	C	5.7	A	19.8	B	5.4	A	16.8	B	5.4	A	24.8	C	6.2	A	19.3	B	6.8	A	16.2	B	6.5	A
Westbound Left	2.3	A	16.5	B	2.4	A	18.2	B	2.4	A	18.2	B	3.5	A	48.0	D	3.6	A	22.8	C	3.6	A	22.8	C
Westbound Through+Right	3.2	A	9.7	A					4.6	A	10.4	B	3.6	A	9.3	A					5.4	A	10.2	B
Westbound Through					4.5	A	10.3	B									5.3	A	10.2	B				
Westbound Right*					0.6	A	13.5	B									1.0	A	15.1	B				
Northbound Left	35.5	D	36.0	D	35.6	D	36.1	D	35.6	D	36.1	D	35.2	D	37.0	D	35.4	D	36.9	D	35.4	D	36.9	D
Northbound Through+Right	27.2	C	33.8	C	27.0	C	34.0	C	27.0	C	34.0	C	25.0	C	34.5	C	25.3	C	34.1	C	25.3	C	34.1	C
Southbound Left+Through	26.4	C	37.3	D	26.4	C	37.6	D	26.4	C	37.6	D	24.0	C	38.2	D	24.4	C	38.2	D	24.4	C	38.2	D
Southbound Right	26.2	C	34.1	C	26.1	C	34.2	C	26.1	C	34.2	C	24.1	C	34.5	C	24.3	C	34.5	C	24.3	C	34.5	C
Arapahoe Avenue and 65th Street	**17.4**	**B**	**57.0**	**E**	**17.4**	**B**	**62.2**	**E**	**17.4**	**B**	**61.8**	**E**	**45.9**	**D**	**126.5**	**F**	**21.1**	**C**	**74.2**	**E**	**21.1**	**C**	**74.2**	**E**
Eastbound Left	10.0	A	7.9	A	10.0	A	8.0	A	10.1	B	8.0	A	16.6	B	7.6	A	15.7	B	7.6	A	15.7	B	7.6	A
Eastbound Through	10.1	B	80.7	F	10.0	A	89.5	F	9.9	A	88.9	F	11.1	B	187.2	F	9.6	A	107.8	F	9.5	A	107.8	F
Eastbound Right	14.6	B	5.9	A	11.0	B	6.3	A	11.4	B	6.3	A	9.5	A	6.3	A	7.1	A	6.3	A	7.0	A	6.3	A
Westbound Left	4.9	A	33.6	C	5.0	A	32.7	C	5.0	A	32.7	C	5.9	A	32.7	C	5.5	A	32.7	C	5.5	A	32.7	C
Westbound Through+Right	18.9	B	6.9	A	19.0	B	7.0	A	19.0	B	7.0	A	62.6	E	8.0	A	25.8	C	7.1	A	25.8	C	7.1	A
Northbound Left	37.1	D	44.2	D	37.1	D	44.6	D	37.1	D	44.6	D	37.6	D	44.6	D	37.6	D	44.6	D	37.6	D	44.6	D
Northbound Through+Right	36.0	D	42.0	D	36.0	D	42.0	D	36.0	D	42.0	D	36.0	D	42.0	D	36.0	D	42.0	D	36.0	D	42.0	D
Southbound Left+Through+Right	35.9	D	41.7	D	35.9	D	41.7	D	35.9	D	41.7	D	35.9	D	41.7	D	35.9	D	41.7	D	35.9	D	41.7	D

Notes: Delay represented in average seconds per vehicle.

** With the BRT in the outside through travel lane, the right-turning vehicles will enter the BRT lane to turn; therefore, the Synchro analysis includes a right-turn lane to model this driving behavior.*

There are a few instances where the delay and LOS improves from the Existing/Background to the scenario with side running BRT. This is due to the traffic models overestimation of right-turn delay and impact on through vehicles. With a side running BRT, the right-turn vehicles will be able to enter the BRT lane to turn and will have minimal impact on the through vehicles, which in turn improves the through volume delay and LOS.

CORRIDOR TRAVEL TIME BY AUTOMOBILE

Analysis Overview

The City of Boulder has been monitoring travel time across town in the Arapahoe corridor for many years. This historic data has illustrated that the travel time on Arapahoe has been relatively constant over time. The existing travel time in the corridor has been used as the basis for projecting future travel times. The calculated increase or decrease in intersection delay in the future from the Level of Service (LOS) model for each alternative has been utilized to project changes in future travel time in the corridor.

Figure A-14 Automobile Travel Time Analysis Summary Table

Auto Travel Times	
Metric	Auto travel time along Arapahoe, AM and PM peak periods by direction
Purpose	Describe how the alternatives would affect the time required to travel through the corridor during peak hour conditions.
Analysis Methodology	Folsom Street to 65th Street end-to-end auto travel time along Arapahoe and travel time for sample origin-destination subsets. AM Peak is defined as 7:30 to 8:30 AM and PM Peak is defined as 4:30 to 5:30 PM.
Data Source	Historic City of Boulder travel time runs by direction in the corridor, used in conjunction with projected intersection delay calculated for each alternative by the Synchro LOS model.

Assumptions

- Automobile travel times will be impacted by future increases in traffic volume and congestion, and by any potential lane utilization changes at signalized intersections for BRT.
- Alternative 1 (No Build) and Alternative 2 (Enhanced Bus) will likely function the same with travel times determined by the projected 20% increase in traffic in the corridor.
- BRT scenarios include lane repurposing, which takes away some of the automobile through capacity at intersections, but BRT ridership causes a reduction in automobile traffic, which can have a balancing effect on travel time.

Evaluation Results

Key Findings

- Travel times are projected to increase in the future in the Alternative 1 (No Build) scenario where corridor traffic increases by approximately 2o% (see Table 5 below)
- In the future 0% traffic growth scenario with side running BRT, the travel times are higher than today, but typically lower than the high growth future without any BRT, particularly in the direction of peak flows (westbound in the AM and eastbound in the PM).
- Center running BRT in the 0% growth scenario is also projected to result in shorter automobile travel times in peak hour peak directional flows when compared to the high volume scenario with no BRT (Alt.1).
- In the high growth scenario (+20%), the peak direction travel times with side running BRT are also less than the No Build scenario without BRT.

- The influence of center running BRT operation in the high growth scenario does result in automobile travel time that is longer in all cases.

Figure A-15 Automobile Travel Time Folsom to 75th by Direction and Peak Hour

Scenario	Eastbound AM	Eastbound PM	Westbound AM	Westbound PM
2014 Existing	7.92	11.22	10.15	10.08
Alt. 1 - High No Build	8.39	16.94	11.54	10.47
Alt. 2 - High with Enhanced Bus	8.39	16.94	11.54	10.47
Alt. 3 - Low with BRT (side running)	8.13	13.07	10.61	10.71
Alt. 3 - High with BRT (side running)	8.39	15.78	11.33	11.34
Alt. 4 - Low with BRT (center running)	8.29	14.43	10.82	11.07
Alt. 4 - High with BRT (center running)	8.56	20.61	12.29	12.65

Figure A-16 Auto Travel Time Evaluation Score

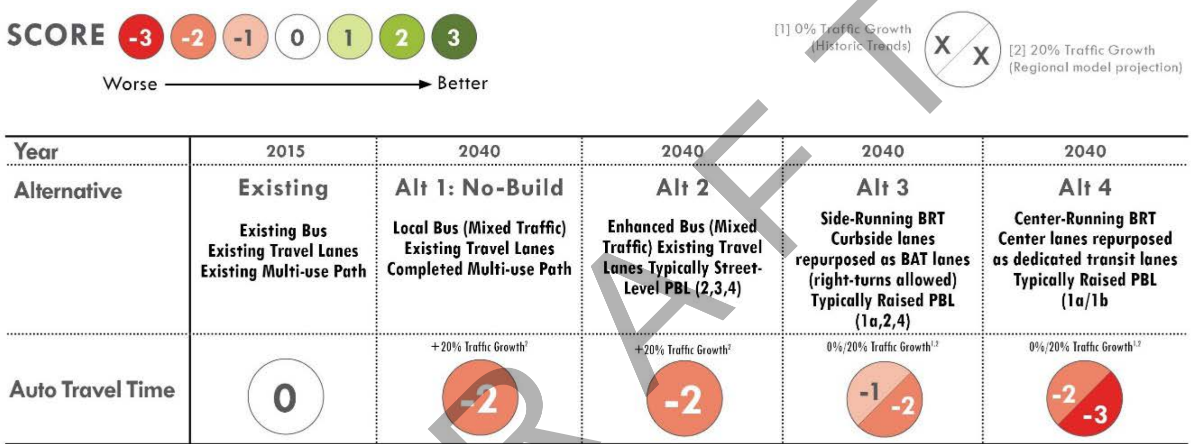


Figure A-17 Automobile Travel Time Comparison

Scenario	Folsom Street	26th Street	28th Street	29th Street	30th Street	33rd Street	38th Street	Foothills Parkway	48th Street	Commerce Street	Conestoga Street	55th Street	Cherryvale Road	63rd Street	65th Street	Westview Drive	75th Street	Total Travel Time (seconds)	Total Travel Time (minutes)	Total Increase Relative to Existing (minutes)
	Change in Through Delay on Arapahoe Avenue (seconds, relative to existing)																			
Eastbound - AM Peak Hour																				
2014 Existing	0	14	14	13	12	20	20	26	32	14	19	58	54	27	28	55	69	475	7.92	-
2040 +0% Traffic (Historical) with BRT (side running)	0	1	1.4	0.5	-0.4	0	1.6	-2.1	2.8	0.7	0.8	6.8	0	-0.1	0	0	0	488	8.13	0.22
2040 +0% Traffic (Historical) with BRT (center running)	0	1.1	4	0.3	1.3	0.1	1	-1.8	5.1	0.7	0.8	9.5	0	0	0	0	0	497	8.29	0.37
2040 +20% Traffic (Regional Projection) without BRT	0	0.3	1.5	0	3.6	-0.3	-0.1	0.5	2.4	1.1	0.5	6.6	1.8	2.2	1	0	7	503	8.39	0.47
2040 +20% Traffic (Regional Projection) with BRT (side running)	0	1.3	2.1	1.3	1.2	0.1	1.7	-1.9	4.1	1.4	0.9	7.8	0	1.6	-0.5	0	7	503	8.39	0.47
2040 +20% Traffic (Regional Projection) with BRT (center running)	0	1.6	6.3	1.5	3.9	0.3	0.7	-1.7	6.4	1.4	1.2	9.8	-0.7	1.7	-0.6	0	7	514	8.56	0.65
Eastbound - PM Peak Hour																				
2014 Existing	0	15	74	18	15	21	26	76	31	17	24	87	63	50	41	50	65	673	11.22	-
2040 +0% Traffic (Historical) with BRT (side running)	0	3.8	1.3	3.3	2.5	0.1	0.7	81.7	5.6	1.6	2.4	8.2	0	0	0	0	0	784	13.07	1.85
2040 +0% Traffic (Historical) with BRT (center running)	0	4.7	27.7	2.9	27.7	0	0.7	80.8	8.2	1.6	4.1	34.6	0	0	0	0	0	866	14.43	3.22
2040 +20% Traffic (Regional Projection) without BRT	0	0.9	4.4	1.7	4.2	-0.1	-0.2	60.5	3	-0.2	0.9	45.3	0.6	70.7	106.5	0	45	1016	16.94	5.72
2040 +20% Traffic (Regional Projection) with BRT (side running)	0	4.7	8.2	5.5	8.4	0	0.7	134	6.9	1.4	4.7	12.3	0.8	13.8	27.1	0	45	947	15.78	4.56
2040 +20% Traffic (Regional Projection) with BRT (center running)	0	5.9	80.9	5.2	89.1	-0.2	0.8	133.3	9.4	2.6	7.4	143	0.5	13.8	27.1	0	45	1237	20.61	9.40

Scenario	75th Street	Westview Drive	65th Street	63rd Street	Cherryvale Road	55th Street	Conestoga Street	Commerce Street	48th Street	Foothills Parkway	38th Street	33rd Street	30th Street	29th Street	28th Street	26th Street	Folsom Street	Total Travel Time (seconds)	Total Travel Time (minutes)	Total Increase Relative to Existing (minutes)
	Change in Through Delay on Arapahoe Avenue (seconds, relative to existing)																			
Westbound - AM Peak Hour																				
2014 Existing	0	80	120	33	34	71	15	18	12	46	28	22	23	13	40	16	38	609	10.15	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	0	0	0	7.4	0.7	0.7	4.6	10.3	1.2	-0.1	3.8	0.3	-1.3	0.2	0	637	10.61	0.46
2040 +0% Traffic (Historical) with BRT (center running)	0	0	0	0	0	3.9	0.4	1.4	10.0	10.1	1.2	2.8	11.0	0.5	-1.6	0.2	0	649	10.82	0.66
2040 +20% Traffic (Regional Projection) without BRT	10	0	43.7	5.4	0.4	10.8	-0.2	1.6	2.5	4.8	0.3	1.8	2.5	0.1	-0.2	0	0	693	11.54	1.39
2040 +20% Traffic (Regional Projection) with BRT (side running)	10	0	6.9	3.8	2.1	9.3	0.9	2.9	7.0	17.9	1.8	1.8	7.2	0.7	-2.1	0.4	0	680	11.33	1.18
2040 +20% Traffic (Regional Projection) with BRT (center running)	10	0	6.9	3.9	2.2	38.1	1.1	4.8	17.5	16.3	1.8	5.5	21.0	0.8	-2.0	0.3	0	737	12.29	2.14
Westbound - PM Peak Hour																				
2014 Existing	0	50	53	28	29	109	17	19	13	32	28	23	73	24	53	16	38	605	10.08	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	0	0	0	1.6	0.4	0.8	1.6	14.2	3.8	1.5	13.1	1.5	-1.8	0.8	0	643	10.71	0.63
2040 +0% Traffic (Historical) with BRT (center running)	0	0	0	0	0	4.2	0.5	0.9	1.8	13.2	3.8	2.1	29.3	4.5	-2.4	1.4	0	664	11.07	0.99
2040 +20% Traffic (Regional Projection) without BRT	1	0	1.1	0.9	0	1.1	0.4	0.7	0.3	5.2	1.2	0.3	11.0	0.3	-0.6	0.3	0	628	10.47	0.39
2040 +20% Traffic (Regional Projection) with BRT (side running)	1	0	0.2	0.5	0.5	2.1	1.1	1.8	1.9	34.3	5.8	2.9	21.0	3.4	-2.8	1.5	0	680	11.34	1.25
2040 +20% Traffic (Regional Projection) with BRT (center running)	1	0	0.2	0.5	0.5	5.5	1.3	2.0	2.4	33.4	5.8	4.1	89.9	8.0	-3.3	2.6	0	759	12.65	2.57

Figure A-18 Bus Travel Time Compared to Existing Automobile Travel Time

Scenario	Change in Through Delay on Arapahoe Avenue (seconds, relative to existing)																	Total Travel Time (seconds)	Total Travel Time (minutes)	Total Increase Relative to Existing (minutes)
	Folsom Street	26th Street	28th Street	29th Street	30th Street	33rd Street	38th Street	Foothills Parkway	48th Street	Commerce Street	Conestoga Street	55th Street	Cherryvale Road	63rd Street	65th Street	Westview Drive	75th Street			
Eastbound - AM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*14*	*14*	*13*	*12*	*20*	*20*	*26*	*32*	*14*	*19*	*58*	*54*	*27*	*28*	*55*	*69*	*475*	*7.92*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	-0.9	-0.2	0.1	0.0	-0.8	-11.9	9.5	7.4	-1.5	1.0	0	0	0	0	0	478	7.96	0.05
2040 +0% Traffic (Historical) with BRT (center running)	0	0	-2.2	-2.6	-0.3	-2.1	-3.9	-11.9	-7.9	7.3	-1.6	-6.0	0	0	0	0	0	444	7.40	-0.52
2040 +20% Traffic (Regional Projection) without BRT	0	0.3	1.5	0.0	3.6	-0.3	-0.1	0.5	2.4	1.1	0.5	6.6	1.8	2.2	1.0	0	7.0	503	8.39	0.47
2040 +20% Traffic (Regional Projection) with BRT (side running)	0	7.7	-0.6	0.1	0.1	0.2	-0.4	-11.9	11.2	7.5	-1.5	2.6	0	1.6	-0.5	0	7.0	498	8.30	0.38
2040 +20% Traffic (Regional Projection) with BRT (center running)	0	0.3	-2.2	-2.6	-0.3	-2.1	-3.9	-11.9	-7.9	7.3	-1.6	-6.0	-0.7	1.7	-0.6	0	7.0	452	7.53	-0.39
Eastbound - PM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*15*	*74*	*18*	*15*	*21*	*26*	*76*	*31*	*17*	*24*	*87*	*63*	*50*	*41*	*50*	*65*	*673*	*11.22*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	-5.6	0.7	0.8	-0.4	-1.1	-44.8	-2.2	-3.3	0.9	-13.4	0	0	0	0	0	605	10.08	-1.14
2040 +0% Traffic (Historical) with BRT (center running)	0	0	-22.1	-4.5	-1.4	-0.4	-1.9	-44.8	-3.0	-3.4	-1.3	-27.0	0	0	0	0	0	563	9.39	-1.83
2040 +20% Traffic (Regional Projection) without BRT	0	0.9	4.4	1.7	4.2	-0.1	-0.2	60.5	3.0	-0.2	0.9	45.3	0.6	70.7	106.5	0	45.0	1016	16.94	5.72
2040 +20% Traffic (Regional Projection) with BRT (side running)	0	14.8	-1.2	0.7	2.2	-0.4	-1.2	-44.8	-2.3	-3.3	2.2	-13.8	0.8	13.8	27.1	0	45.0	713	11.88	0.66
2040 +20% Traffic (Regional Projection) with BRT (center running)	0	0.9	-22.1	-4.5	-1.4	-0.4	-1.9	-44.8	-3.0	-3.4	-1.3	-27.0	0.5	13.8	27.1	0	45.0	651	10.84	-0.37

Scenario	Change in Through Delay on Arapahoe Avenue (seconds, relative to existing)																	Total Travel Time (seconds)	Total Travel Time (minutes)	Total Increase Relative to Existing (minutes)
	75th Street	Westview Drive	65th Street	63rd Street	Cherryvale Road	55th Street	Conestoga Street	Commerce Street	48th Street	Foothills Parkway	38th Street	33rd Street	30th Street	29th Street	28th Street	26th Street	Folsom Street			
Westbound - AM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*80*	*120*	*33*	*34*	*71*	*15*	*18*	*12*	*46*	*28*	*22*	*23*	*13*	*40*	*16*	*38*	*609*	*10.15*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	0	0	-1.0	-0.4	3.9	-1.0	-1.3	-4.4	-4.4	8.0	12.8	0.1	-1.3	0	0	620	10.33	0.18
2040 +0% Traffic (Historical) with BRT (center running)	0	0	0	-6.6	-1.6	-14.9	3.4	-1.3	-4.8	-4.4	-4.4	-11.7	10.9	-2.3	-1.6	0	0	570	9.50	-0.65
2040 +20% Traffic (Regional Projection) without BRT	10.0	0	43.7	5.4	0.4	10.8	-0.2	1.6	2.5	4.8	0.3	1.8	2.5	0.1	-0.2	0	0	693	11.54	1.39
2040 +20% Traffic (Regional Projection) with BRT (side running)	10.0	0	6.9	3.8	-0.7	1.4	3.6	-0.8	-1.6	-4.4	-4.4	10.8	14.6	0.4	-2.1	0.4	0	647	10.78	0.63
2040 +20% Traffic (Regional Projection) with BRT (center running)	10.0	0	6.9	3.9	-1.6	-14.9	3.4	-1.3	-4.8	-4.4	-4.4	-11.7	10.9	-2.3	-2.0	0.3	0	597	9.95	-0.20
Westbound - PM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*50*	*0*	*28*	*29*	*109*	*17*	*19*	*13*	*32*	*28*	*23*	*73*	*24*	*53*	*16*	*38*	*552*	*9.20*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	0	0	3.5	5.8	4.6	1.9	-1.7	-23.1	-3.0	5.2	17.5	0.3	-1.8	0	0	561	9.35	0.15
2040 +0% Traffic (Historical) with BRT (center running)	0	0	0	-2.0	-4.9	-2.7	3.6	-3.1	-2.3	-23.1	-3.0	4.0	-3.5	-5.8	-2.4	0	0	507	8.45	-0.75
2040 +20% Traffic (Regional Projection) without BRT	1.0	0	1.1	0.9	0.0	1.1	0.4	0.7	0.3	5.2	1.2	0.3	11.0	0.3	-0.6	0.3	0	575	9.59	0.39
2040 +20% Traffic (Regional Projection) with BRT (side running)	1.0	0	0.2	0.5	2.8	5.8	5.1	1.9	-1.8	-23.1	-3.0	7.6	19.0	1.0	-2.8	2.8	0	569	9.48	0.28
2040 +20% Traffic (Regional Projection) with BRT (center running)	1.0	0	0.2	0.5	-4.9	-2.7	3.6	-3.1	-2.3	-23.1	-3.0	4.0	-3.5	-5.8	-2.4	3	0	513	8.55	-0.65

VEHICLE MILES OF TRAVEL

Analysis Overview

Vehicle miles of travel by automobile is a useful measure in determining corridor mobility and differences between alternatives, impacts on air quality, success toward TMP goals, etc. Person miles of travel by automobile also allows a measure of total person trip mobility in the corridor when combined with estimates of travel by transit, bicycle and as pedestrians.

Figure A-19 Vehicle Mile Traveled Analysis Summary Table

Vehicle Miles Traveled	
Metric	Daily vehicle miles traveled (VMT)
Purpose	Describe the impact of the alternatives on the amount of vehicle travel in the corridor
Analysis Methodology	VMT is calculated based on the average daily traffic output of the travel demand modeling (described above). It is calculated as the number of daily vehicle trips in each corridor segment multiplied by the average distance of each segment and summed for all segments.
Data Source	DRCOG 2040 Travel Demand Model (adjusted with local model refinement) and historic traffic trends, coupled with physical roadway segment lengths

Key Assumptions

- Low growth traffic projections are similar to today by definition.
- An auto occupancy factor of 1.15 was used to convert from auto miles of travel to person miles of travel in automobiles.

Evaluation Results

Key Findings

- Future no-build High traffic projections (Alts. 1 & 2) result in VMT estimates that are approximately 18% higher than existing.
- As expected, the future year low growth scenarios with BRT result in VMT that is approximately equal to today's corridor VMT.
- BRT ridership in the High traffic scenarios is successful in reducing VMT growth such that the corridor VMT is only 5% more than existing.

Figure A-20 Vehicle Miles of Travel and Person Miles of Travel in Automobiles – Folsom to 75th, both directions

Alternative	Development Scenario	Vehicle Miles of Travel (VMT)	Average Auto Occupancy**	Person Miles of Travel in Automobiles (APMT)	Automobile Person Miles of Travel Comparison to Existing (% increase)
Existing	Existing	110,500	1.15	127,075	n/a
1	2040 + 20% Traffic (Regional Projection) Without BRT	130,100	1.15	149,615	17.7%
2	2040 + 20% Enhanced Transit	130,100	1.15	149,615	17.7%
3&4 Low	2040 + 0% Traffic (Historic Trend) With BRT	111,300	1.15	127,995	0.7%
3&4 High	2040 + 20% Traffic (Regional Projection) With BRT	116,000	1.15	133,400	5.0%

** Source: Estimate based on FTA data and tendency for commuting trips in this corridor

FREIGHT IMPACTS

Analysis Overview

Arapahoe Avenue is an important east-west vehicle travel corridor serving downtown Boulder, CU, Boulder Community Health, other major employers, and adjacent neighborhoods. Because there are only a few major east-west and north-south roads in East Boulder, there are limited alternative routes for trucks serving businesses in the corridor, and/or carrying freight between Boulder and the communities to the east. This measure provides a qualitative assessment of considerations for freight using the corridor.

Figure A-21 Freight Analysis Summary Table

Freight	
Metric	Anticipated impacts on freight
Purpose	Describe the impact of the alternatives on freight movements along the corridor
Analysis Methodology	Qualitative assessment based on traffic analysis, existing and forecast freight volumes, likely freight access routes, and anticipated geometric design. The analysis will identify any geometric design impacts that would affect freight movements.
Data Source	CDOT vehicle classification information and projected traffic volumes

Key Assumptions

- It is likely that multi-modal improvements and traffic access control measures will result in continuous medians between signalized intersections, which will restrict unsignalized left turn access.
- Driveway consolidation between adjacent parcels is likely to minimize motorized crossings of bicycle and pedestrian facilities.
- Access control measures will minimize crashes and enhance safety in the corridor.
- Side running BRT will allow right turning trucks to access driveways from the outside BRT lane with less interaction with through traffic but buses and trucks will have to mix in the outside lane.
- Center running BRT will allow buses to avoid most interaction with trucks in the corridor. However, now trucks will need to interact with through traffic in the busy outside through-right turn lanes.

Evaluation Results

Key Findings

- The East Arapahoe corridor serves much of Boulder's service commercial and light industrial uses. In this context freight access by truck is important.
- Trucks on Arapahoe typically represent only 3%to 4% of the daily traffic according to CDOT data
- Traffic access control will be a key component of implementing multi-modal improvements in the corridor. Access control measures will need to consider maintaining efficient truck access.

- In this context, it will be important to still allow efficient truck access to the businesses along the East Arapahoe corridor. Intersections and driveways will need to be designed to accommodate the turning paths of the truck traffic serving the corridor.

Figure A-22 Freight Access Evaluation Results

Measure	District A	District B	District C	District D	District E	Overall
Existing						
Alt 1	Freight access similar to today	Freight access similar to today	Freight access similar to today	Freight access similar to today	Freight access similar to today	Little change in freight access.
Alt 2	Freight access similar to today	Freight access similar to today	Freight access similar to today	Freight access similar to today	Freight access similar to today	Little change in freight access unless access control measures are implemented
Alt 3	Trucks will make right turning access from BRT lane. Will need to mix with buses.	Trucks will make right turning access from BRT lane. Will need to mix with buses.	Trucks will make right turning access from BRT lane. Will need to mix with buses.	Trucks will make right turning access from BRT lane. Will need to mix with buses.	Trucks will make right turning access from BRT lane. Will need to mix with buses.	Less friction with turning trucks than today.
Alt 4	Trucks will make right turns from congested through-right turn lanes, but interaction with buses is minimized.	Trucks will make right turns from congested through-right turn lanes, but interaction with buses is minimized.	Trucks will make right turns from congested through-right turn lanes, but interaction with buses is minimized.	Trucks will make right turns from congested through-right turn lanes, but interaction with buses is minimized.	Trucks will make right turns from congested through-right turn lanes, but interaction with buses is minimized.	Most congested access for right turning trucks in to driveways along the corridor.

APPENDIX B TRANSIT OPERATIONS

This appendix provides detailed transit operations analysis methodology and results to supplement the evaluation results that are provided in the East Arapahoe Transportation Plan Evaluation of Alternatives Report.

OVERALL ASSUMPTIONS AND DATA SOURCES

Station Locations

Six conceptual Enhanced Bus or BRT station locations were assumed in Boulder, between 28th Street and 75th Street. These station locations were based on a station spacing scenario targeting a minimum distance of approximately a half-mile between stations. The scenarios were identified based on past City of Boulder staff discussions, internal workshops, and public and stakeholder outreach, and include potential station locations assumed in the Northwest Area Mobility Study (NAMS). Conceptual stations locations were identified based on major generators, important transit and multimodal connections, land use, right-of-way feasibility, existing ridership and stop spacing considerations. Figure B-1 lists the station locations and the approximate distance from the previous station. Figure B-2 is a map of the station locations.

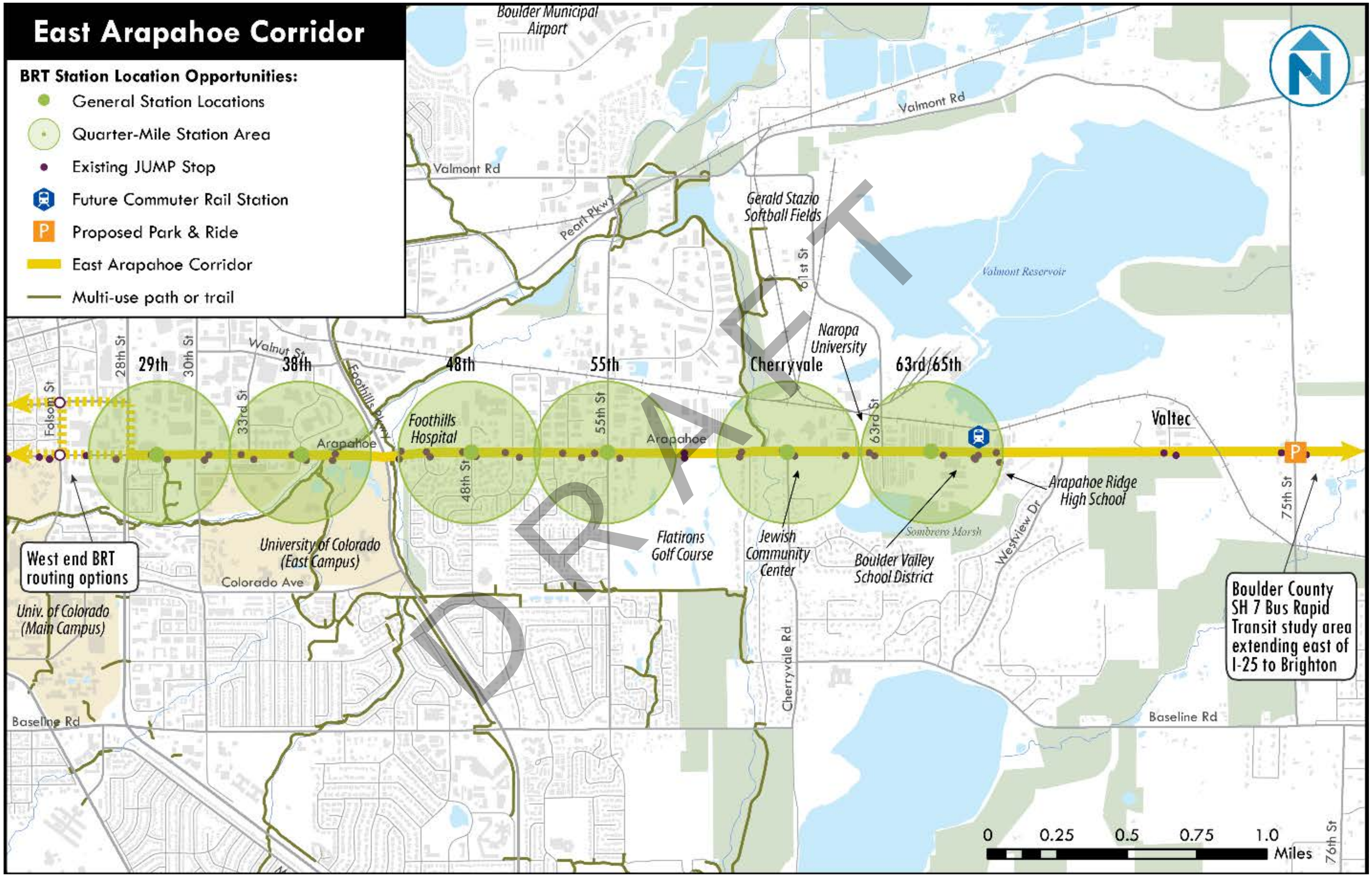
Figure B-1 Conceptual Station Locations within City of Boulder Study Area, Folsom – 63rd/65th Streets

Assumed Station Location	Approximate Station Spacing (Miles)
29th St	-
38th St	0.50
48th St	0.62
55th St	0.50
Cherryvale Rd	0.65
63rd/65th St	0.34 to 0.65 *

* Depends on final location

Appendix B.1 provides additional background on station spacing and scenarios.

Figure B-2 Conceptual Station Locations



"West End" Alignment and Station Location Options

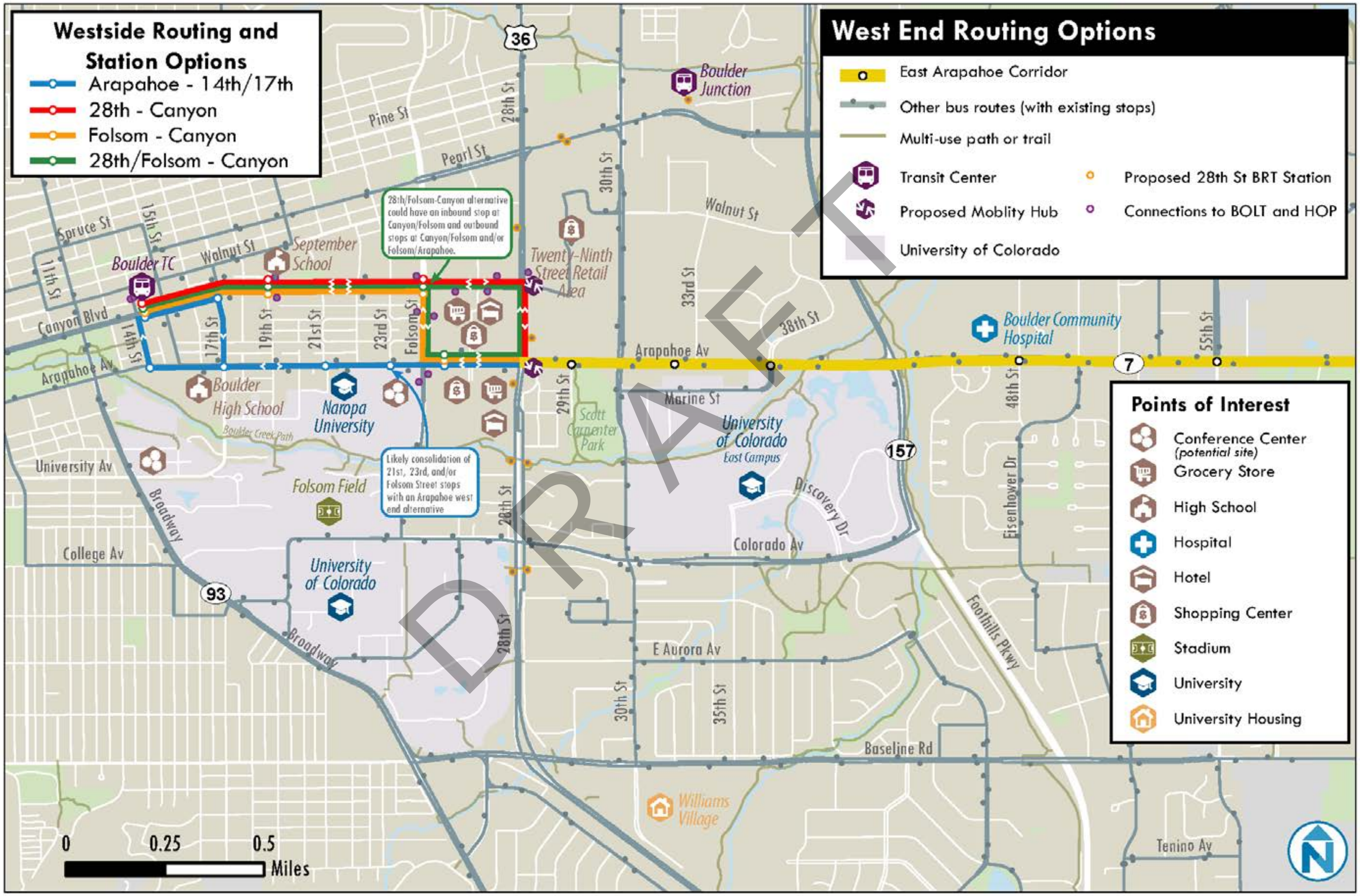
A high level assessment of alignment and stop location options was conducted for the West End of the East Arapahoe corridor (defined as areas west of 28th Street), where multiple alignments could be selected for BRT or Enhanced Bus service. Figure B-3 identifies four potential West End alignments that were identified for BRT or Enhanced Bus service on the Arapahoe corridor:

- **Arapahoe:** Arapahoe Avenue, 14th Street (inbound), and 17th Street (outbound)
- **Canyon via 28th**: 28th Street and Canyon Boulevard
- **Canyon via Folsom:** Folsom Street and Canyon Boulevard
- **Canyon via 28th/Folsom:** 28th Street (inbound), Canyon Boulevard, and Folsom Street (outbound)

Based on a high-level evaluation of these options (summarized in Appendix B.2), the East Arapahoe Transportation Plan includes preliminary assumptions about the West End (e.g., transit travel time), but does not recommend a specific West End alignment or station locations. It also assumes that the Downtown Boulder Transit Center (TC) will be the western terminus of the Arapahoe Corridor BRT, recognizing that an alternate terminus may be desirable based on a future, detailed assessment of transit markets. Terminal options and detailed routing, facility capacity, and costs, etc., would need to be developed during a later study phase, and coordinated with other studies including the Canyon Boulevard Complete Street Study and future studies of BRT service between Longmont and Boulder.

Appendix B.2 provides additional background on "west end" alignment and station location options.

Figure B-3 West End Alignment Options



Service Span and Frequency

Service along Arapahoe will operate at different frequencies based on the time of day, day of the week, and whether it is BRT or local service. Figure B-4 lists the headway by hour and day of the week. Local service frequency is for service within Boulder (west of 65th Street). BRT and local service combine for an effective frequency of up to every five minutes (peak) and 7.5 minutes (off-peak) at common stops.

Figure B-4 BRT and Local Bus Headway Assumptions by Hour and Day of the Week, 2040

Hour	BRT Weekday	Local Weekday	BRT Saturday	Local Saturday	BRT Sunday	Local Sunday
4 AM	-	-	-	-	-	-
5 AM	30	10	-	-	-	-
6 AM	10	10	30	15	30	15
7 AM	10	10	15	15	30-	15
8 AM -	10	10	15	15	15	15
9 AM	15	15	15	15	15	15
10 AM	15	15	15	15	15	15
11 AM	15	15	15	15	15	15
12 PM	15	15	15	15	15	15
1 PM	15	15	15	15	15	15
2 PM	15	15	15	15	15	15
3 PM	10	10	15	15	15	15
4 PM	10	10	15	15	15	15
5 PM	10	10	15	15	15	15
6 PM	10	10	15	15	30	15
7 PM	30	30	30	30	30	30
8 PM	30	30	30	30	30	30
9 PM	30	30	30	30	30	30
10 PM	30	30	30	30	30	30
11 PM	30	30	30	30	30	30
12 AM	30	-	30	30	30	-
1 AM	-	-	-	-	-	-

TRAVEL TIME AND RELIABILITY

This section describes the evaluation methodology, assumptions, and additional results for the travel time results provided on pages 31-32 of the Evaluation of Alternatives Summary Report.

Analysis Overview

Figure B-5 Transit Travel Time Analysis Summary Table

Transit Travel Time	
Metric	Transit travel time along Arapahoe, AM and PM peak periods, average of both directions
Purpose	Describe how the alternatives would affect the speed of transit travel in the corridor, and how transit travel time compares to driving
Analysis Methodology	Transit travel times include the base time for a bus to travel along the corridor and the time needed to make stops. Time at stops will be based on a single set of conceptual stop locations that would be developed for each alternative, industry-standard parameters for boarding/alighting time based on the type of transit vehicle, BRT features, and boarding policies, and estimated ridership at each stop. End-to-end transit travel time along Arapahoe and travel time for sample origin-destination pairs Transit travel time assumptions and data sources for 2040 outside of the Folsom – 65th traffic analysis area to be based on the SH 7 BRT Study.
Data Source	Base transit travel time from traffic operations analysis, for AM and PM peak periods, by direction.

Figure B-6 Service Reliability Analysis Summary Table

Service Reliability	
Metric	Reliability of transit travel times
Purpose	Describe how the alternatives would affect the variability or consistency of transit travel times along the corridor
Analysis Methodology	Qualitative assessment based on transit priority features included in each alternative. (It is assumed that a traffic simulation model such as VISSIM will not be used in this phase of analysis for the East Arapahoe Transportation Plan; in a future phase, such a model could be used to develop a quantitative measure of transit travel time reliability.)
Data Source	Transit travel time analysis, based on travel demand model

Methods and Input Data

Automobile travel time estimates from FTH from the study traffic analysis were used as the basis for transit travel time estimates. These estimates were developed by scenario, direction, segment and time of day. To estimate travel time for transit, estimates for dwell time, acceleration, deceleration, savings from transit signal priority (TSP), and/or savings from queue jumps were added to the vehicular travel times. The total corridor transit travel time is the sum of travel times for each segment within a single time period, direction and scenario.

Figure B-7 FTH Travel Time Outputs (Hourly Bus), in seconds

Table 4 - Bus Travel Time Comparison To Exsiting Automobile Travel Time (no bus stops)

Scenario	Change in Through Delay on Arapahoe Avenue (seconds, relative to existing)																	Total Travel Time (seconds)	Total Travel Time (minutes)	Total Increase Relative to Existing (minutes)
	Folsom Street	26th Street	28th Street	29th Street	30th Street	33rd Street	38th Street	Foothills Parkway	48th Street	Commerce Street	Conestoga Street	55th Street	Cherryvale Road	63rd Street	65th Street	Westview Drive	75th Street			
Eastbound - AM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*14*	*14*	*13*	*12*	*20*	*20*	*26*	*32*	*14*	*19*	*58*	*54*	*27*	*28*	*55*	*69*	*475*	*7.92*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	-0.9	-0.2	0.1	0.0	-0.8	-11.9	9.5	7.4	-1.5	1.0	0	0	0	0	0	478	7.96	0.05
2040 +0% Traffic (Historical) with BRT (center running)	0	0	-2.2	-2.6	-0.3	-2.1	-3.9	-11.9	-7.9	7.3	-1.6	-6.0	0	0	0	0	0	444	7.40	-0.52
2040 +20% Traffic (Regional Projection) without BRT	0	0.3	1.5	0.0	3.6	-0.3	-0.1	0.5	2.4	1.1	0.5	6.6	1.8	0	0	0	7.0	500	8.33	0.42
2040 +20% Traffic (Regional Projection) with BRT (side running)	0	7.7	-0.6	0.1	0.1	0.2	-0.4	-11.9	11.2	7.5	-1.5	2.6	0	0	0	0	7.0	497	8.28	0.36
2040 +20% Traffic (Regional Projection) with BRT (center running)	0	0.3	-2.2	-2.6	-0.3	-2.1	-3.9	-11.9	-7.9	7.3	-1.6	-6.0	-0.7	0	0	0	7.0	451	7.51	-0.41
Eastbound - PM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*15*	*74*	*18*	*15*	*21*	*26*	*76*	*31*	*17*	*24*	*87*	*63*	*50*	*41*	*50*	*65*	*673*	*11.22*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	-5.6	0.7	0.8	-0.4	-1.1	-44.8	-2.2	-3.3	0.9	-13.4	0	0	0	0	0	605	10.08	-1.14
2040 +0% Traffic (Historical) with BRT (center running)	0	0	-22.1	-4.5	-1.4	-0.4	-1.9	-44.8	-3.0	-3.4	-1.3	-27.0	0	0	0	0	0	563	9.39	-1.83
2040 +20% Traffic (Regional Projection) without BRT	0	0.9	4.4	1.7	4.2	-0.1	-0.2	60.5	3.0	-0.2	0.9	45.3	0.6	0	0	0	45.0	839	13.98	2.77
2040 +20% Traffic (Regional Projection) with BRT (side running)	0	14.8	-1.2	0.7	2.2	-0.4	-1.2	-44.8	-2.3	-3.3	2.2	-13.8	0.8	0	0	0	45.0	672	11.20	-0.02
2040 +20% Traffic (Regional Projection) with BRT (center running)	0	0.9	-22.1	-4.5	-1.4	-0.4	-1.9	-44.8	-3.0	-3.4	-1.3	-27.0	0.5	0	0	0	45.0	610	10.16	-1.06

Scenario	Change in Through Delay on Arapahoe Avenue (seconds, relative to existing)																	Total Travel Time (seconds)	Total Travel Time (minutes)	Total Increase Relative to Existing (minutes)
	75th Street	Westview Drive	65th Street	63rd Street	Cherryvale Road	55th Street	Conestoga Street	Commerce Street	48th Street	Foothills Parkway	38th Street	33rd Street	30th Street	29th Street	28th Street	26th Street	Folsom Street			
Westbound - AM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*80*	*120*	*33*	*34*	*71*	*15*	*18*	*12*	*46*	*28*	*22*	*23*	*13*	*40*	*16*	*38*	*609*	*10.15*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	0	0	-1.0	-0.4	3.9	-1.0	-1.3	-4.4	-4.4	8.0	12.8	0.1	-1.3	0	0	620	10.33	0.18
2040 +0% Traffic (Historical) with BRT (center running)	0	0	0	-6.6	-1.6	-14.9	3.4	-1.3	-4.8	-4.4	-4.4	-11.7	10.9	-2.3	-1.6	0	0	570	9.50	-0.65
2040 +20% Traffic (Regional Projection) without BRT	10.0	0	43.7	5.4	0.4	10.8	-0.2	1.6	2.5	4.8	0.3	1.8	2.5	0.1	-0.2	0	0	693	11.54	1.39
2040 +20% Traffic (Regional Projection) with BRT (side running)	10.0	0	6.9	3.8	-0.7	1.4	3.6	-0.8	-1.6	-4.4	-4.4	10.8	14.6	0.4	-2.1	0.4	0	647	10.78	0.63
2040 +20% Traffic (Regional Projection) with BRT (center running)	10.0	0	6.9	3.9	-1.6	-14.9	3.4	-1.3	-4.8	-4.4	-4.4	-11.7	10.9	-2.3	-2.0	0.3	0	597	9.95	-0.20
Westbound - PM Peak Hour																				
2014 Existing (AUTOMOBILE TRAVEL TIME)	*0*	*50*	*0*	*28*	*29*	*109*	*17*	*19*	*13*	*32*	*28*	*23*	*73*	*24*	*53*	*16*	*38*	*552*	*9.20*	-
2040 +0% Traffic (Historical) with BRT (side running)	0	0	0	0	3.5	5.8	4.6	1.9	-1.7	-23.1	-3.0	5.2	17.5	0.3	-1.8	0	0	561	9.35	0.15
2040 +0% Traffic (Historical) with BRT (center running)	0	0	0	-2.0	-4.9	-2.7	3.6	-3.1	-2.3	-23.1	-3.0	4.0	-3.5	-5.8	-2.4	0	0	507	8.45	-0.75
2040 +20% Traffic (Regional Projection) without BRT	1.0	0	1.1	0.9	0.0	1.1	0.4	0.7	0.3	5.2	1.2	0.3	11.0	0.3	-0.6	0.3	0	575	9.59	0.39
2040 +20% Traffic (Regional Projection) with BRT (side running)	1.0	0	0.2	0.5	2.8	5.8	5.1	1.9	-1.8	-23.1	-3.0	7.6	19.0	1.0	-2.8	2.8	0	569	9.48	0.28
2040 +20% Traffic (Regional Projection) with BRT (center running)	1.0	0	0.2	0.5	-4.9	-2.7	3.6	-3.1	-2.3	-23.1	-3.0	4.0	-3.5	-5.8	-2.4	3	0	513	8.55	-0.65

Source: Fox Tuttle Hernandez

Assumptions used to adjust the base bus travel times to include stops and other elements included:

Figure B-8 Additional Travel Time Assumptions

Assumption	Value	Source/Notes
Dwell time – standard	30 seconds	SH 7 BRT Study. Applied to Enhanced Bus and BRT. In future work, this could also be adjusted based on projected passenger volumes at stations.
Dwell time with off-board fare collection	18.6 seconds	
Transit Signal Priority	10 seconds	Consistent with SH7 BRT Study. Applied at signalized intersections for BRT alternatives. This could be refined based on more detailed study.

For travel time estimates east of 75th, the project team used travel times from the SH 7 BRT study. Base travel times for existing and No Build were derived from the "Auto" scenario, side-running BRT with low traffic increase used the "Managed Lane" scenario, Center-running BRT with low traffic increase used the "Dedicated Lane" scenario, and both side- and center-running BRT with high traffic increases used the "Managed Lane" scenario. Figure B-7 shows the travel time outputs for segments west of 75th Avenue. Figure B-9 shows the travel time outputs for segments east of 75th Avenue.

Figure B-9 SH 7 BRT Travel Times by Segment, in minutes

SH 7 BRT Segment	Boundaries	Auto	Mixed Traffic	Dedicated Lane	Managed Lane	Standard Bus
1	Arapahoe from 75th to US 287	16.1	15.4	6.3	7.5	17.2
2	US 287 from Arapahoe to Baseline	2.3	2.2	1.9	2.1	2.4
3	Baseline from US 287 to Public	3.5	3.4	1.8	2.2	3.8
4	Baseline from Public to 119th	4.6	4.4	2.1	2.6	5.0
5	Baseline from 119th to County Line	2.6	2.5	1.4	1.7	2.8
6	Baseline from County Line to Sheridan	5.3	5.1	4.5	5.0	5.7
7	Baseline from Sheridan to York	7.0	6.7	6.1	6.5	7.5
8	160th from York to Holly	3.6	3.4	3.1	3.2	3.8
9	160th from Holly to Riverdale	8.0	7.7	6.7	7.1	8.6
10	160th from Riverdale to US 85	1.7	2.0	1.8	2.0	2.0
11	Bridge from US 85 to 27th	3.1	3.5	3.0	3.3	3.5
	Full Corridor - Processed	79.5	76.4	53.9	63.7	85.3
	Full Corridor - Pre-Processed	74.8	74.8	41.3	49.6	74.8

Source: SH7 Bus Rapid Transit Study, 2017

Evaluation Results

Figure B-10 shows the estimated total travel times for transit in each Character District by direction, time-of-day, and scenario.

Figure B-11 compares the automobile and transit travel times for travel between Folsom and 75th by direction and time-of-day in each scenario to the travel times in Alt 1 – No Build. The final two columns show the ratio of transit to automobile travel times and the change from Alt 1 – No Build....

Figure B-10 Transit Travel Time (in minutes), by District

Scenario	West of Folsom	A	B	C	D	E	East of 75th	Boulder [A]
AM Peak (Eastbound)								
2015 Existing	5.6	3.9	1.2	3.8	5.4	2.0	-	21.92
Alt 1 - No Build	5.6	4.0	1.2	4.0	5.4	2.1	62.2	22.33
Alt 2 - Enhanced Bus	5.2	3.4	1.0	3.6	4.8	2.0	61.0	20.05
Alt 3 - Side Running BRT (+0% Traffic)	4.7	3.3	0.7	3.7	4.8	1.7	43.1	18.85
Alt 3 - Side Running BRT (+20% Traffic)	4.7	3.5	0.7	3.7	4.8	1.8	43.1	19.17
Alt 4 - Center Running BRT (+0% Traffic)	4.7	3.2	0.7	3.3	4.8	1.7	38.7	18.29
Alt 4 - Center Running BRT (+20% Traffic)	4.7	3.2	0.7	3.3	4.8	1.8	38.7	18.40
AM Peak (Westbound)								
2015 Existing	5.6	4.9	1.3	3.3	6.9	2.2	-	24.15
Alt 1 - No Build	5.6	5.0	1.3	3.4	7.9	2.2	62.2	25.38
Alt 2 - Enhanced Bus	5.2	4.4	1.1	3.0	7.4	2.0	61.0	23.10
Alt 3 - Side Running BRT (+0% Traffic)	4.7	4.7	0.8	2.8	6.3	1.9	43.1	21.22
Alt 3 - Side Running BRT (+20% Traffic)	4.7	5.1	0.8	2.8	6.5	1.9	43.1	21.68
Alt 4 - Center Running BRT (+0% Traffic)	4.7	4.3	0.8	2.8	6.0	1.9	38.7	20.38
Alt 4 - Center Running BRT (+20% Traffic)	4.7	4.2	0.8	2.7	5.9	1.9	38.7	20.02
PM Peak (Eastbound)								
2015 Existing	6.6	5.2	2.1	4.4	6.0	2.0	-	26.22
Alt 1 - No Build	6.6	5.4	3.1	5.2	6.0	2.7	62.2	28.98
Alt 2 - Enhanced Bus	6.2	4.8	2.9	4.8	6.0	2.5	61.0	27.20
Alt 3 - Side Running BRT (+0% Traffic)	5.7	4.5	1.0	3.7	5.5	1.6	43.1	21.96
Alt 3 - Side Running BRT (+20% Traffic)	5.7	4.9	1.0	3.7	5.5	2.4	43.1	23.08
Alt 4 - Center Running BRT (+0% Traffic)	5.7	4.1	1.0	3.4	5.5	1.6	38.7	21.28
Alt 4 - Center Running BRT (+20% Traffic)	5.7	4.1	1.0	3.4	5.5	2.4	38.7	22.05
PM Peak (Westbound)								
2015 Existing	6.6	6.2	1.3	3.1	5.4	1.7	-	24.20
Alt 1 - No Build	6.6	6.3	1.3	3.2	5.4	1.7	62.2	24.59
Alt 2 - Enhanced Bus	6.2	5.8	1.1	2.8	4.9	1.5	61.0	22.31
Alt 3 - Side Running BRT (+0% Traffic)	5.7	5.9	0.9	2.4	5.0	1.4	43.1	21.24
Alt 3 - Side Running BRT (+20% Traffic)	5.7	6.0	0.9	2.4	5.0	1.4	43.1	21.37
Alt 4 - Center Running BRT (+0% Traffic)	5.7	5.5	0.9	2.3	4.7	1.4	38.7	20.33
Alt 4 - Center Running BRT (+20% Traffic)	5.7	5.5	0.9	2.3	4.7	1.4	38.7	20.44

Notes: [A] Boulder includes Districts A through E and West of Folsom.

Figure B-11 Travel Time Comparison, Folsom to 75th

Scenario	Auto Travel Time (min)	% Change [A]	Transit Travel Time (min)	% Change [A]	Transit- to-Auto Travel Time Ratio	% Change [A]
AM Peak (Eastbound)						
2015 Existing	7.9		16.3		2.1	
Alt 1 - No Build	8.4	6%	16.7	3%	2.0	-3%
Alt 2 - Enhanced Bus	8.4	0%	14.8	-11%	1.8	-11%
Alt 3 - Side Running BRT (+0% Traffic)	8.1	-3%	14.1	-16%	1.7	-13%
Alt 3 - Side Running BRT (+20% Traffic)	8.4	0%	14.5	-14%	1.7	-14%
Alt 4 - Center Running BRT (+0% Traffic)	8.3	-1%	13.6	-19%	1.6	-18%
Alt 4 - Center Running BRT (+20% Traffic)	8.6	2%	13.7	-18%	1.6	-20%
AM Peak (Westbound)						
2015 Existing	10.2		18.6		1.8	
Alt 1 - No Build	11.4	15%	19.8	8%	1.7	-4%
Alt 2 - Enhanced Bus	11.4	0%	17.9	-10%	1.6	-10%
Alt 3 - Side Running BRT (+0% Traffic)	10.6	-7%	16.5	-17%	1.6	-11%
Alt 3 - Side Running BRT (+20% Traffic)	11.6	2%	17.0	-14%	1.5	-16%
Alt 4 - Center Running BRT (+0% Traffic)	10.8	-5%	15.7	-21%	1.4	-17%
Alt 4 - Center Running BRT (+20% Traffic)	12.8	12%	15.3	-23%	1.2	-31%
PM Peak (Eastbound)						
2015 Existing	11.2		19.6		1.8	
Alt 1 - No Build	16.9	72%	22.4	17%	1.3	-21%
Alt 2 - Enhanced Bus	16.9	0%	21.0	-6%	1.2	-6%
Alt 3 - Side Running BRT (+0% Traffic)	13.1	-23%	16.3	-27%	1.2	-6%
Alt 3 - Side Running BRT (+20% Traffic)	15.8	-7%	17.4	-22%	1.1	-17%
Alt 4 - Center Running BRT (+0% Traffic)	14.4	-15%	15.6	-30%	1.1	-18%
Alt 4 - Center Running BRT (+20% Traffic)	20.6	22%	16.3	-27%	0.8	-40%
PM Peak (Westbound)						
2015 Existing	10.1		17.6		1.7	
Alt 1 - No Build	10.5	5%	18.0	2%	1.7	-1%
Alt 2 - Enhanced Bus	10.5	0%	16.1	-11%	1.5	-11%
Alt 3 - Side Running BRT (+0% Traffic)	10.7	2%	15.5	-14%	1.5	-16%
Alt 3 - Side Running BRT (+20% Traffic)	11.3	8%	15.7	-13%	1.4	-20%
Alt 4 - Center Running BRT (+0% Traffic)	11.1	6%	14.6	-19%	1.3	-23%
Alt 4 - Center Running BRT (+20% Traffic)	12.6	21%	14.7	-18%	1.2	-32%

Notes: [A] Percent change in travel time from Alt 1 – No Build. For Alt 1 – No Build, values represent percent change from 2015 Existing

Figure B-12 Transit Travel Time Evaluation Score

SCORE -3 -2 -1 0 1 2 3
Worse → Better

[1] 0% Traffic Growth (Historic Trends) X/X [2] 20% Traffic Growth (Regional model projection)

Year	2015	2040	2040	2040	2040
Alternative	Existing Existing Bus Existing Travel Lanes Existing Multi-use Path	Alt 1: No-Build Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	Alt 2 Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	Alt 3 Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	Alt 4 Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
		+20% Traffic Growth[2]	20% Traffic Growth[2]	0%/20% Traffic Growth[1,2]	0%/20% Traffic Growth[1,2]
Transit Travel Time	0	-1	1	2 / 2	3 / 2

RIDERSHIP IN CORRIDOR

This section describes the evaluation methodology, assumptions, and additional results for the ridership results provided on page 33 of the Evaluation of Alternatives Summary Report.

Analysis Overview

Figure B-13 Ridership Analysis Summary Table

Ridership and New Transit Trips	
Metric	Total and new weekday daily boardings
Purpose	Describe how the alternatives would affect total transit ridership along the corridor and estimate the anticipated increase in transit ridership, relative to the baseline alternative
Analysis Methodology	Ridership was estimated using a localized transit ridership model (see next row), incorporating estimated travel times for each alternative (see Travel Time metric) and a conceptual operating plan with a single set of conceptual stop locations (see overall .assumptions section above).
Data Source	Localized transit ridership model based on existing JUMP ridership (Spring 2015, stop-level, from RTD) and industry-standard adjustments for service quality improvements. Future ridership growth will incorporate the projected change in future population/employment, from the DRCOG regional model from 2013 to 2035 (2035 and 2040 are assumed to be comparable for the purposes of this analysis). East of existing JUMP service, between approximately US 287 and Brighton, ridership is estimated based on transit mode share assumptions applied to total projected trips to/from Boulder from the DRCOG travel demand model. The mode share assumptions are based on the existing transit mode share, adjusted for the type of transit included in each alternative.

Ridership along Existing Arapahoe Transit Corridor (Boulder-Erie/Lafayette)

Sketch-level ridership estimates were based on existing stop-level ridership data from RTD. The analysis pivots on existing stop-level ridership (or ridership generated by similar land use conditions where no current service exists), adjusted for population and employment growth and adjustments to service type and quality (e.g., service levels, travel times, etc.) between the No-Build and Build scenarios. The key adjustments were:

- Changes in projected land use between 2015 and 2040.
- Service levels for each alternative based on the operating plan assumptions.
- Travel times for each alternative based on the traffic analysis and transit travel time assumptions.

Figure B-14 describes elasticity of ridership and other assumptions used.

Figure B-14 Elasticity and Other Ridership Estimation Assumptions

Variable	Data Value or Adjustment Factor/Range	Source and Methodology Notes
Base Ridership	▪ Route and Stop-Level	▪ Stop-level ons and offs by route within four daily periods (AM, PM, Midday, and Evening). Evening is not in the base data but is calculated as total ons and offs minus the sum of AM, PM, and Midday ons and offs.
Network Buffer Size	▪ 3/8 mile (walking distance)	▪ Used for calculating population and employment (total and density) for each corridor. ▪ A 3/8 mile (straight-line distance) catchment area was assumed for the Boulder TMP analysis. (This varies by application – in some cases a ½ mile buffer is assumed for BRT or rail stations and a ¼ mile (straight-line) catchment is assumed as a minimum catchment area for local bus service.)
Population and Employment Growth and Population Density	▪ 0.23 (base elasticity) ▪ Up to 1	▪ Based on elasticities developed for MTC and SACOG (2004) for direct ridership modeling approaches, applied to the sum of population and employment growth. ▪ This factor is applied to base ridership at the stop-level, based on growth in the surrounding Transportation Analysis Zones (TAZs). ▪ The base factor implies that for a 100% change in population and employment, existing transit ridership grows by 23%, i.e., a *decrease* in transit trips per population and employment. However, in some areas a higher response could be expected. For local TAZs, up to constant growth in ridership per capita was assumed (elasticity of 1).
	▪ Additional 0.04 to 0.34 based on changes in population density	▪ In addition, research and surveys indicate non-linear increases in transit use as population density increases. The assumptions used in this analysis are based on Seattle region household travel survey data, which indicated greater rates of transit use in areas of higher population density. This relationship is similar to the one found in the San Francisco Bay Area, analysis of the National Personal Transportation Survey, and other research/data. ▪ In the Boulder application the maximum bonus was 13%.
Service Level – Service Hours	▪ -0.5	▪ Based on national research, the elasticity of transit use with respect to headway averages 0.5.
Travel Time (and Reliability), including User Experience Benefits (Real-Time Information, etc.)	▪ 10% to 45% benefit (varied by service type and corridor) ▪ Elasticity of -0.5 to -0.7 (-0.7 was used)	▪ Constrained by national data and specific case studies.
Urban Form / Accessbility	▪ Up to 10% adjustment	▪ Recent national meta-analysis (Ewing and Cervero)[5] shows that destination accessibility or the ability for direct access to destinations (including transit stations) has the highest correlation to reduced SOV trip making of a number of factors related to transportation services, design, and built form. The model could use either intersection density or another measure of network quality to represent this factor. The Ewing and Cervero meta-analysis found that intersection density is a more significant variable than street connectivity.
Transit Use Propensity	▪ Up to 10% adjustment	▪ Demographic groups including low-income and carless households along with seniors and youth have higher rates of transit use. ▪ An index of demographic groups is used to assume a greater ridership response based on concentrations of these groups.

Variable	Data Value or Adjustment Factor/Range	Source and Methodology Notes
Transit in areas with new service	▪ Generally, based on route segments with comparable land use and density. East of existing service along Arapahoe, additional data analysis was used to generate an estimate (see next section).	▪ As a minimum value, new service in a community with no previous service is considered to achieve 3 to 5 annual rides per capita. ▪ Where local comparisons are available, base ridership levels applied based on peer productivity given local comparisons of land use and service level. ▪ Alternatively mode capture assumptions can be used to estimate new riders.

Notes/Sources:

1. The Factors Influencing Transit Ridership: A Review and Analysis of the Ridership Literature, Brian D. Taylor and Camille N.Y. Fink. UCLA.
2. Portland Metro Primary Transit Network Study, Nelson\Nygaard
3. Direct Ridership Forecasting, Fehr and Peers
4. California Air Quality Resource Board Urban Air Quality Emissions Model Trip Generational Element, Nelson\Nygaard
5. Travel and the Built Environment: A Meta-Analysis, Ewing and Cervero. JAPA 2010.
6. TCRP Report 95: Traveler Responses to Transportation System Changes
7. MTC, Bay Area Transit Oriented Development (TOD) Study
8. VTPI, Transportation/Transit Elasticities

Base Ridership Estimate

Figure B-15 summarizes the resulting ridership estimate for the portion of the corridor with existing transit service (downtown Boulder TC to Erie/Lafayette). *These results do not include assumptions for the extension of the corridor beyond the eastern edge of existing service – to Brighton – described in more detail below and added into the final estimate.*

- In the No-Build alternative (Alt 1), there would be an estimated 42% increase in ridership on the JUMP route based on population and employment growth, and minor enhancements to service hours.
- The Enhanced Bus alternative (Alt 2) is estimated to increase ridership by approximately 65% of the estimated BRT ridership in Alt 3 and 4.
- Modeling of the BRT options (Alts 3 and 4) varied primarily based on differences in transit travel time, related to the underlying traffic scenarios (including assumptions for 0% to 20% growth in future traffic) and likely differences in transit service reliability with a side-running or center-running BRT alignment. The differences in ridership are estimated at +/- 10%.

Figure B-15 Base Ridership Estimate, Existing Arapahoe Transit Service Corridors

Scenario	Avg Weekday Daily Boardings	
	Low	High
Existing (2015)	2,400	
Alt 1 – No Build (2040)	3,400	
Alt 2 – Enhanced Bus (2040)	4,500	
Alt 3/4 – Side-Running BRT with 0% or 20% Traffic Growth (2040)	7,000	7,800

Travel Patterns at Screenline

Figure B-16 describes the existing travel patterns of JUMP riders across four screenlines along the corridor. For example, over 70% of trips on the JUMP either crossed or got off/on the bus at 30th Street. The patterns of existing riders were the basis for assumptions about future transit travel patterns.

Figure B-16 Distribution of Transit Trips at Screenlines

Scenario	28th	30th	Foothills	55th
Existing (2015)	63%	70%	59%	49%

Land Use Sensitivity Analysis

In 2014, existing and future land use scenarios were analyzed with and without the addition of arterial BRT service in the Arapahoe corridor. Results indicated an increase in the number of people moving through the corridor and within the area around the corridor using all modes, particularly increasing use of transit, walking, and biking modes. The results of this analysis was used to inform the high-end of the ridership estimate range:

- 2,300 additional transit trips were assumed on BRT (Alts 3 and 4).
- 1,500 additional transit trips were assumed for Enhanced Bus (Alt 2), 65% of the Alt 3/4 level, based on the overall ratio of estimated ridership for Alt 2 compared to Alt 3/4.

Travel patterns were assumed to be similar to the existing JUMP.

East End Ridership

The localized transit ridership model described above pivots off of existing transit ridership and was used to estimate ridership along the existing JUMP route. This method is not possible east of existing JUMP service between Boulder and Erie/Lafayette. This section describes the analysis used to develop a high-level estimate of potential ridership into Boulder from the eastern SH 7 corridor, extending out to Brighton as is currently being considered in the Boulder County SH 7 BRT Study. The analysis utilizes regional model travel pattern data and Census employment data and assumptions for mode shift to new/extended regional service.

Figure B-19 illustrates zones that were defined to represent the catchment area for BRT or other enhanced transit service between Boulder and areas east of Boulder for this analysis. They represent a half-mile walking distance around BRT stations and a three-mile distance around potential BRT park-n-ride facilities outside of Boulder; these stations and park-n-ride locations were based on the conceptual locations identified in the RTD Northwest Area Mobility Study (NAMS) completed in 2013. Key findings include:

- Existing (2015) JUMP ridership to existing stops east of Boulder is approximately 700 transit trips. This represents approximately 7% of all trips between a half-mile walking buffer of those existing stops and a half-mile walking distance of the Arapahoe corridor in Boulder (Downtown Boulder TC – 75th Street). The percentages is based on trips by all modes and purposes, in the current year (2015) travel demand projections from DRCOG.
- There are approximately projected 25,000 trips (all trip purposes) in 2035 between the assumed transit catchment area in the east end of the SH 7 corridor (based on a half-mile walking distance around BRT stations and a three-mile distance around potential BRT park-n-ride facilities) and within a half-mile walking distance of the Arapahoe corridor in Boulder (Downtown Boulder TC – 75th Street).

- Given an assumption that future transit service (e.g., BRT) captures the same share of all future trips as today (7%), approximately 1,750 trips would be attracted to this service from locations in the station and park-n-ride catchment area. Subtracting the estimate of existing trips there would be **1,050** new daily trips into Boulder from the east end of the corridor.

An additional analysis was conduct to estimate the numbers of work trips between Boulder and the far end of the corridor (I-25/Brighton), based on US Census Bureau LEHD data from 2013, and develop an order-of-magnitude assumption for number of these trips that could be attracted to a BRT-type service to/from Boulder. Key findings include:

- There are approximately 4,000 current total work trips between the far east zones shown in Figure B-19 (zones 6-11), a zone covering the corridor between I-25 and 75th Street (zone 4), and the zones in Boulder (zones 1, 2, 3, and 5).
- Assumptions were made to account for the additional share of these trips that would be attracted to BRT service to/from the far east end of the corridor, including a park-n-ride in Brighton. The assumed mode share ranged from 2% for outlying areas (zone 10), 5% (zones 8, 9, and 11), and 10% (zones 6 and 7). The assumptions were scaled based on distance and travel time to access service in the corridor.
- A rough assumption of 1% average annual growth was used to account for future employment.
- The resulting estimate was for an approximately 450 trips between the far east end zones (zones 6-11) and Boulder (zones 1, 2, 3, and 5) and approximately 200 additional trips between the 75th Street – I-25 portion of the corridor (zone 4), a total of **650** new transit trips.

Based on the results of both analyses, a total **1,700** new transit trips were assumed. Figure B-17 summarizes the analysis.

Figure B-17 Order-of-Magnitude Ridership Analysis for East of End of Arapahoe Corridor

Portion of Corridor* (Analysis Zone)	Potential Trips	Mode Capture Assumption	Total Trips Assumed	Existing Transit Trips (on JUMP)	Net New Trips
I-25 - 95th Street (4)	All Trips - 25,000 [1]	7%	1,750	700	1,050
Brighton – I-25 (6-11)	Work Trips - 4,000 [2]	2% to 10%**	450	-	450
I-25 – 95th Street (4)		10%	200	-	200
Total			2,400	700	1,700

Notes: * ½ mile walking distance or 3 mile park-n-ride access distance. ** Scaled based on distance & travel time.

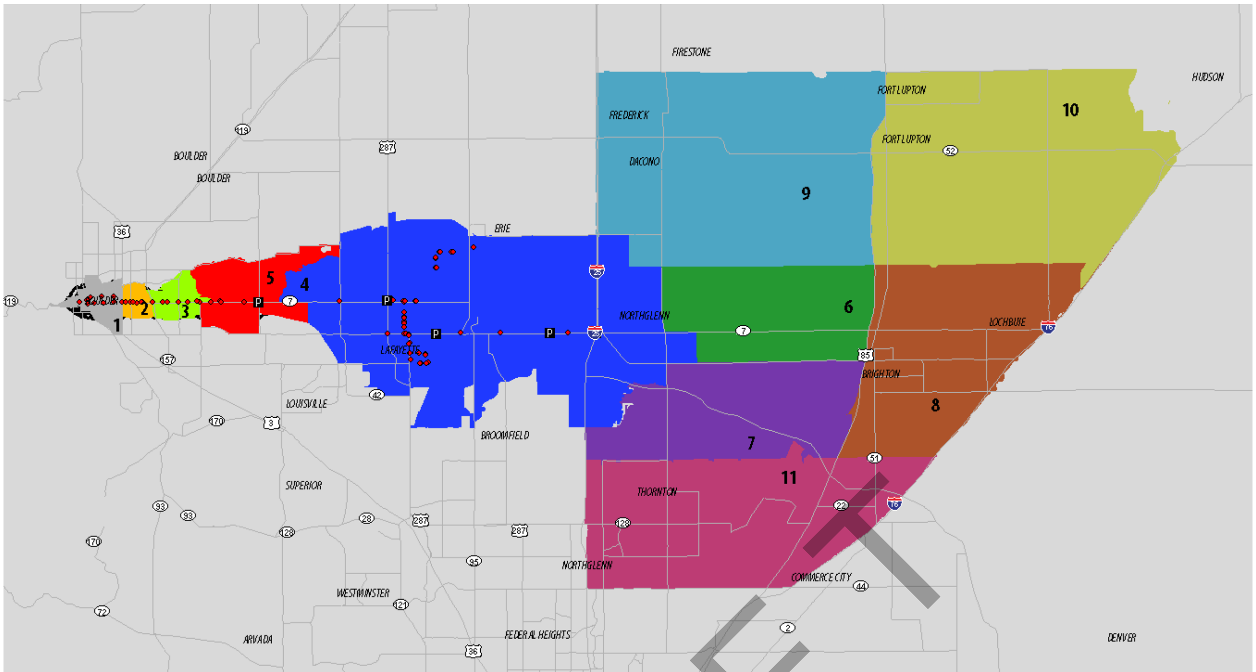
Sources: [1] DRCOG Travel Demand Model, 2035. [2] US Census Bureau, LEHD, 2013 (latest data as of 2015).

These trips were assigned to screenlines along the corridor based on the analysis zones shown in Figure B-19. The screenlines are used in developing mode share estimates at these locations.

Figure B-18 East End Ridership, Assigned to Screenlines

28th	30th	Foothills	55th
520	520	700	1,110

Figure B-19 Analysis Zones for East End Ridership Analysis



Modal Distribution of Trips

Order-of-magnitude estimates were developed for the distribution of ridership between BRT or Enhanced Bus and local bus service on Arapahoe based on analysis of existing stop boarding patterns and proximity of conceptual BRT stations locations to existing stops; this was done primarily to inform a passenger load analysis (described below). Slightly less than two-third of boarding would be expected to occur at the BRT or Enhanced Bus stations while approximately one-third of boardings would occur at local stops. Transit riders are typically assumed to walk up to approximately a half-mile to access high quality service.

Although any possible effects were not quantified, Enhanced Bus and Side-Running BRT service would share curb-side stops with local buses; while center-running BRT would stop in the median and it may not be feasible for local service to share the median stops. This would depend on final transit designs for the corridor and whether there are local stops between potential center-running BRT stations. If center-running BRT and local buses do not share stops, at common stop locations passengers who could use either service would need to decide whether to wait for the bus at the median or curb-side station (e.g., based on real-time arrival information at both sets of stops).

Time Distribution of Trips

Figure B-20 summarizes the time distribution of existing ridership patterns on the JUMP. Future service is assumed to have similar characteristics. Key findings include:

- Westbound ridership comprises nearly 60% of the AM peak period, while eastbound ridership comprises nearly 55% of the PM peak period.
- The maximum average ridership by time period occurs in the eastbound PM peak (10%).
- A peak hour factor was calculated (ratio of average to maximum ridership) for purposes of assessing capacity of vehicles to accommodate estimated ridership. This resulted in an adjusted peak ridership percentage of 14% in the eastbound PM peak.

Figure B-20 Assumed Time Distribution, Percentages Based on Existing JUMP Ridership, January 2015

Time Period		By Direction		% in Period		Per Hour		Average % in Hour			Peak hour factors [1]	Adjusted Peak Hour			
Category	Hours	WB	EB	WB	EB	WB	EB	WB	EB	TOTAL		WB	EB	WB	EB
All-Day	17	1,184	1,186	50%	50%	-	-	-	-	-	-	-	-	-	-
AM Peak	3	290	205	59%	41%	96.7	68.3	8%	6%	14%	161%	155	110	13%	9%
Midday	6	433	461	48%	52%	72.2	76.8	6%	6%	13%	-	-	-	-	-
PM Peak	3	308	366	46%	54%	102.7	122.1	9%	10%	19%	138%	142	169	12%	14%
Evening	5	153	154	50%	50%	30.5	30.8	3%	3%	5%	-	-	-	-	-

Notes: Calculated as the ratio of maximum to average load in the AM and PM Peak periods, to account for variation in average daily ridership.

Source: Analysis of RTD Ridership Data, January 2015

Passenger Loading Analysis

A high-level analysis of passenger demand was conducted. Key assumptions and findings include:

- It is assumed articulated buses are not feasible, based on operational constraints in downtown Boulder.
- Assuming vehicle capacity of 75 people in a 40-foot BRT-style vehicle, the conceptual frequency and vehicles could support projected daily ridership is in the lower end of ridership estimate range (7,000 – 10,000 daily boardings) and peak-hour distribution of daily ridership, but depending on factors including the number of riders trying to use the line in the peak hour and the share of ridership demand met by BRT (as opposed to local) service, additional peak frequency and vehicles could be needed to support the future passenger load. Figure B-21 provide results of the calculations for several different scenarios.
- This analysis should be updated and refined in later stages of planning and design.

Figure B-21 Passenger Loading Sensitivity Analysis

Average Weekday Daily Ridership		Peak-Hour and Peak-Direction Boardings		% using BRT (vs. Local)	Current Peak Frequency Assumption		With Additional Peak Frequency	
		% Daily Boardings	Peak Hour Boardings		BRT Headway (Vehicles / Direction / Hour)	Persons / Vehicle	BRT Headway (Vehicles / Direction / Hour)	Persons / Vehicle
Low-End of Range	7,000	10%	700	60%	6	70	8	53
Median	8,500	12%	1,020	60%	6	102	8	77
High-End of Range	10,000	14%	1,400	65%	6	152	8	114

Evaluation Results

Figure B-22 provides the overall ridership estimate, which includes both the base ridership estimate (pivoting off of existing stop-level transit ridership) and the additional east end ridership estimate (east of existing JUMP service). The high-end of the estimate range for the Build scenarios accounts for both the variability of different BRT options and traffic growth scenarios, and the potential of transportation and land use policy changes to reduce vehicle trips and attract new riders (e.g., providing transit passes, parking management, etc.). Key findings include:

- Side and center-running BRT ridership is projected to be from 7,000 to 10,000 daily boardings (combined BRT and local), with either Alt 3 or 4 within in a +/– 10% margin, regardless of the traffic growth scenario.
- Ridership would be lower in the Enhanced Bus scenario (4,500 to 6,000 daily boardings), with limited stop service and enhanced vehicles, stations, and amenities, but without exclusive right-of-way.
- The primary factors that differentiate between the Enhanced Bus alternative (Alt 2) and the Side and Center-Running BRT alternatives (Alts 3 & 4) are travel time, travel time reliability, and the increased visibility of transit service.

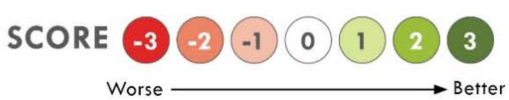
Figure B-22 Ridership Estimate, Weekday Average Daily Boardings, Downtown Boulder - Brighton

Scenario	Total Boardings	
	Low	High
Existing (2015)	2,400	
Alt 1 – No Build (2040)	3,400	
Alt 2 – Enhanced Bus (2040)	4,500	6,000
Alt 3/4 – Side-Running BRT with 0% or 20% Traffic Growth (2040)	7,000	10,000

Notes: Ridership estimates for Alternatives 2, 3, and 4 are from Downtown Boulder to Brighton and include local JUMP service. Alternative 1 (No-Build) ridership is based on the existing JUMP route between Downtown Boulder and Lafayette/Erie.

Source: Sketch-level local ridership model. RTD ridership data for JUMP, January 2015. DRCOG Regional Travel Demand Model data, 2013/2035. US Census Longitudinal Employer-Household Dynamics (LEHD), 2014.

Figure B-23 Transit Ridership Evaluation Score



Year	2015	2040	2040	2040	2040
Alternative	Existing Existing Bus Existing Travel Lanes Existing Multi-use Path	Alt 1: No-Build Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	Alt 2 Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	Alt 3 Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	Alt 4 Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
Transit Ridership	0	1	2	3	3

OPERATING COST

This section describes the evaluation methodology, assumptions, and additional results for the ridership results provided on page 38 of the Evaluation of Alternatives Summary Report.

Analysis Overview

Figure B-24 provides an overview of the operating cost analysis, including the methodology and data sources.

Figure B-24 Operating Cost Analysis Summary Table

Operating Cost	
Metric	Total and new transit operating costs, annual
Purpose	Describe the ongoing cost of operating transit service in the Arapahoe corridor under each alternative
Analysis Methodology	Develop a conceptual operating plan for transit service in the Arapahoe corridor in each alternative, including the frequency and hours of operation. Calculate the annual vehicle hours required to operate each alternative, based on the estimated travel times and a single set of conceptual transit stop locations (average 1/3 to ½ mile spacing). Multiply service hours by the average hourly transit operating cost.
Data Source	Base service cost of $123.96 (2015) from RTD for Boulder Regional service. Adjustments for BRT, if applicable, based on peer data or industry standard factors.

Figure B-25 provides the total annual operating hours for BRT and JUMP services in each of the scenarios. The values are based on the operating plan above.

Figure B-25 Annual Operating Hours

Scenario	BRT	JUMP			Total
		Erie	Lafayette	To 65th	
Existing (2015)	0	NA	NA	NA	33,100
Alt 1 – No Build (2040)	0	19,264	20,694	7,140	47,100
Alt 2 – Enhanced Bus (2040)	88,400	19,264	20,694	-	128,400
Alt 3 – Side-Running BRT with 0% Traffic Growth (2040)	66,900	19,264	20,694	-	106,900
Alt 3 – Side-Running BRT with 20% Traffic Growth (2040)	67,900	19,264	20,694	-	107,900
Alt 4 – Center-Running BRT with 0% Traffic Growth (2040)	62,400	19,264	21,714	-	103,400
Alt 4 – Center-Running BRT with 20% Traffic Growth (2040)	62,400	20,284	21,714	-	104,400

Figure B-26 lists the number of vehicles that would be required for BRT and JUMP services in each scenario, based on the operating plan peak headway and travel time estimates. A spare ratio of 20% was assumed for BRT vehicles. BRT vehicle requirements are for Boulder-Brighton service, while JUMP vehicle requirements are for the JUMP alignment from Boulder to Erie and Lafayette.

Figure B-26 Vehicle Requirements

	BRT		JUMP			Total Vehicles
Scenario	Base	Spares	Erie	Lafayette	To 65th	
Existing (2015)	0	0	NA	NA	0	10
Alt 1 – No Build (2040)	0	0	4	4	2	10
Alt 2 – Enhanced Bus (2040)	20	4	4	4	0	32
Alt 3 – Side-Running BRT with 0% Traffic Growth (2040)	15	3	4	4	0	26
Alt 3 – Side-Running BRT with 20% Traffic Growth (2040)	16	3	4	4	0	27
Alt 4 – Center-Running BRT with 0% Traffic Growth (2040)	14	3	4	5	0	26
Alt 4 – Center-Running BRT with 20% Traffic Growth (2040)	14	3	5	5	0	27

Figure B-27 lists the operating cost assumptions for cost per hour, and BRT station maintenance costs.

Figure B-27 Operating Cost Assumptions

Assumption	Value
BRT operating cost per hour	$151
Local operating cost per hour	$104
BRT station maintenance cost	$21,000

Note: The hourly operating cost assumption for Enhanced Bus or BRT service was based on the hourly operating costs for Boulder regional service from RTD in 2016 (provided by RTD in January 2017). As of January 2017, RTD does not have a comparable service cost for arterial BRT. Therefore, the total assumed hourly operating cost includes an additional cost assumption for security/fare enforcement (on a per-hour basis), based on a 2012 Arterial Transitway Corridor Study from Metro Transit in Minneapolis-St. Paul. A maintenance cost assumption per station was also assumed based on the Metro Transit study. All costs were escalated to 2017 dollars assuming a 3% inflation rate.

Evaluation Results

The estimated operating costs provided in Figure B-28 and Figure B-29 are the basis for the operating costs reported in the Evaluation of Alternatives Summary Report.

Figure B-28 Annual Operating Cost, Boulder-Brighton, 2017 Dollars

Scenario	BRT	JUMP			Total
		Erie	Lafayette	To 65th	
Existing (2015)	0	NA	NA	NA	$3.2 M
Alt 1 – No Build (2040)	$0.0 M	$2.0 M	$2.2 M	$0.7 M	$4.9 M
Alt 2 – Enhanced Bus (2040)	$13.3 M	$2.0 M	$2.2 M	-	$17.5 M
Alt 3 – Side-Running BRT with 0% Traffic Growth (2040)	$10.1 M	$2.0 M	$2.2 M	-	$14.3 M
Alt 3 – Side-Running BRT with 20% Traffic Growth (2040)	$10.3 M	$2.0 M	$2.2 M	-	$14.4 M
Alt 4 – Center-Running BRT with 0% Traffic Growth (2040)	$9.4 M	$2.0 M	$2.3 M	-	$13.7 M
Alt 4 – Center-Running BRT with 20% Traffic Growth (2040)	$9.4 M	$2.1 M	$2.3 M	-	$13.8 M

Figure B-29 Total Annual Operations & Maintenance and Vehicle Capital Costs, Boulder-Brighton, 2017 Dollars

Scenario	Annual Local Bus O&M	Annual BRT O&M	Annual Station O&M	Annual TSP O&M	Total Annual O&M	Vehicle Capital Costs
Existing (2015)	$3.2 M	$0.0 M	$0	$0	$3.2 M	$4.7 M
Alt 1 – No Build (2040)	$4.9 M	$0.0 M	$0	$0	$4.9 M	$4.7 M
Alt 2 – Enhanced Bus (2040)	$4.2 M	$13.3 M	$340,000	$0	$17.9 M	$21.6 M
Alt 3 – Side-Running BRT with 0% Traffic Growth (2040)	$4.2 M	$10.1 M	$340,000	$102,000	$14.7 M	$17.2 M
Alt 3 – Side-Running BRT with 20% Traffic Growth (2040)	$4.2 M	$10.3 M	$340,000	$102,000	$14.9 M	$17.9 M
Alt 4 – Center-Running BRT with 0% Traffic Growth (2040)	$4.3 M	$9.4 M	$340,000	$102,000	$14.1 M	$16.9 M
Alt 4 – Center-Running BRT with 20% Traffic Growth (2040)	$4.4 M	$9.4 M	$340,000	$102,000	$14.2 M	$17.4 M

Figure B-30 Operating Cost Evaluation Score

Year	2015	2040	2040	2040	2040
Alternative	**Existing** Existing Bus Existing Travel Lanes Existing Multi-use Path	**Alt 1: No-Build** Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	**Alt 2** Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	**Alt 3** Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	**Alt 4** Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b)
Operating Cost	0	$	$$$	$$$	$$$

COST-EFFECTIVENESS (LIFECYCLE OPERATING AND CAPITAL COSTS PER RIDER)

This section describes the evaluation methodology, assumptions, and additional results for the cost-effectiveness results provided on page 39 of the Evaluation of Alternatives Summary Report.

Analysis Overview

Figure B-31 Cost-Effectiveness Analysis Summary Table

Cost-Effectiveness	
Metric	Lifecycle operating and capital cost per user
Purpose	Describe the return on operating and capital investment in terms of transit riders using the facilities and services provided.
Analysis Methodology	Calculated from transit operating costs, capital costs, and ridership
Data Source	See Operating Costs, Capital Costs, and Ridership

Assumptions

- Transit capital costs are only for Enhanced Bus or BRT in the City of Boulder portion of the Arapahoe Corridor (Districts A-E). This calculation includes only costs that are directly transit-related. For this measure, costs are spread over a 30-year period, except for vehicles (12 years). Figure B-32 lists assumptions for years of useful life.
- Annual transit operating and maintenance costs and vehicle capital costs are for a share of the end-end Enhanced Bus or BRT service in Alts 2, 3, and 4 (estimated based on the proportion of service hours in Boulder).
- Ridership is end-end for a transit project operating between Boulder TC and Brighton.

Figure B-32 Years of Useful Life for Capital Elements

Capital Cost Element	Years of Useful Life
Transit Facility	30
Transit Facility - Station	30
Traffic Signals/Communications	30
Vehicles	12
Administration/Services	30

Methods

Lifecycle costs were calculated as the sum of annual operating costs and annualized capital costs (i.e., total cost for each element divided by years of useful life), divided by the total number of transit riders.

Evaluation Results

Figure B-33 provides the cost-effectiveness measure results provided in the Evaluation of Alternatives Summary Report, along with intermediate calculations.

Figure B-33 Annual Lifecycle Cost with Intermediate Costs and Calculations

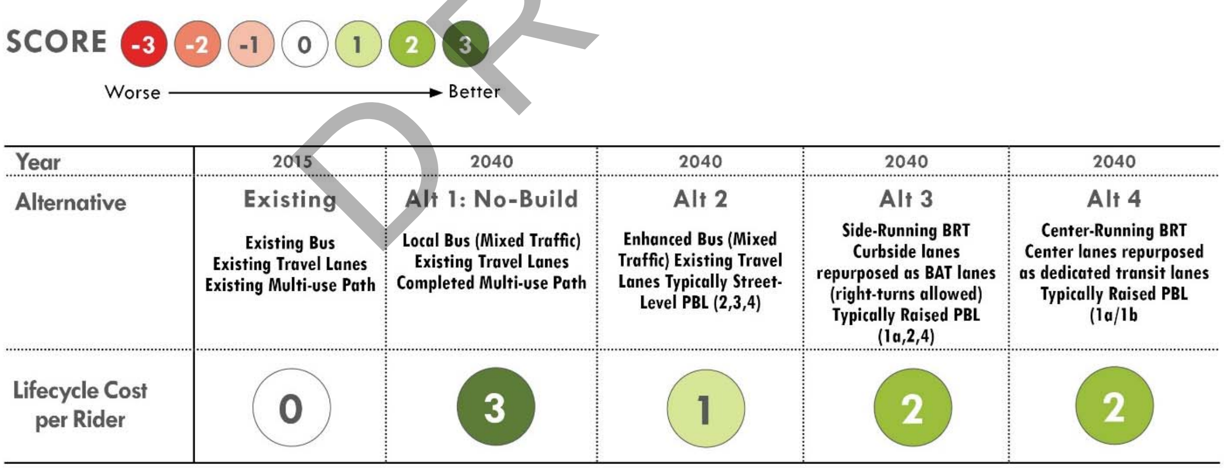
Measure	Annualized Capital Cost [1]	Annual Transit O&M Cost [1]	Total Annualized Cost [1]	Daily Riders [2]	Annual Riders [2]	Annual Lifecycle Cost per User [3]
Existing (2015)	$0.0 M	$0.0 M	$0.0 M	2,400	720,000	$0.00
Alt 1 – No-Build	$0.0 M	$0.0 M	$0.0 M	3,400	1,020,000	$0.00
Alt 2 – Enhanced Bus	$0.8 M	$5.2 M	$6.0 M	5,250	1,575,000	$3.81
Alt 3 – Side-Running BRT	$0.9 M	$5.0 M	$5.8 M	8,500	2,550,000	$2.29
Alt 4 – Center-running BRT	$1.3 M	$5.0 M	$6.2 M	8,500	2,550,000	$2.44

Note: [1] Costs are in 2017 dollars.
[2] Ridership estimates are for 2035/2040.
[3] Users are transit riders; currently does not include people walking or bicycling.

Key Findings

- Alt 2 has a higher lifecycle cost compared to side-running and center-running BRT (Alts 3 and 4) due to higher operating costs (see transit travel time measure), and the higher number of vehicles required.

Figure B-34 Lifecycle Cost per Rider Evaluation Score



TRANSIT SERVICE QUALITY

This section describes the evaluation methodology, assumptions, and additional results for an analysis of transit service quality (not included in the Evaluation of Alternatives Summary Report). The purpose of calculating this measure was to provide a complementary evaluation for transit to the evaluation of vehicle, pedestrian, and bicycle level of service.

Analysis Overview

The Transit Service Quality measure is based on a transit Level of Service (LOS) measure. This is calculated based on a methodology adapted from the Transit Capacity and Quality of Service Manual, 3rd Edition (TCRP Report 165). The inputs to the transit LOS address various factors related to transit service quality such as frequency, level of amenities, and quality of the pedestrian environment:

- Transit frequency by alternative, including local bus, Enhanced Bus, and/or BRT trips.
- Factors that affect perceived travel time, including:
  - Presence of existing shelters and benches, and new shelters/benches at Enhanced Bus and BRT stations
  - Transit travel speed by street segment
  - Excess waiting time, based on RTD data for scheduled and actual bus departure times and transit priority assumptions for each alternative
- Pedestrian environment factors including peak-direction, mid-block vehicle volume in the outside lane for each alternative and vehicular travel speeds. In Alt 3, the curbside BAT lane carries only buses and right-turning vehicles.

Figure B-35 Service Quality Analysis Summary Table

Service Quality	
Metric	Quality of transit (Transit Level of Service)
Purpose	Describe how the alternatives would affect the quality of all aspects of a transit trip. This includes quality of the pedestrian environment for access to the stop, measures of the wait at a transit stop (service frequency and reliability and amenities), and the on-board satisfaction (crowding and speed).
Analysis Methodology	Qualitative assessment based on GIS analysis and calculations source from TCRP Report 165.
Data Source	Travel time and volume estimates from FTH; RTD; City of Boulder; Google Earth and Google Street View;

Assumptions

- All BRT stops would have benches and shelters. Local stops without benches and shelters would remain that way in all scenarios.
- Transit travel time was adjusted from base transit travel times for each scenario, estimated as part of the traffic analysis for this study data: No-Build increased by 10%, Enhanced Bus reduced by 5%, Side-Running BRT reduced by 10%, Center-Running BRT reduced by 20%.
- Center and Side BRT scenarios assumed two vehicle lanes in each direction in Districts A, B and C, and one lane in each direction in Districts D and E. The Enhanced Bus scenario assumed three lanes in each direction in Districts A, B, and C, two lanes in District D, and one lane in District E. (The actual number of lanes transitions through District D.)
- Bike lanes would range between 6 and 10.5 feet and sidewalks would range between 6 and 12 feet in the Enhanced Bus and BRT scenarios.
- Volume per lane is based on the peak hour volume in the outside lane (see Figure B-36). For segments where there was no data, the average of the two closest data points were used.

Figure B-36 Peak-Hour Traffic Volume in Outside Lane

Between		2016 Existing	2040 Low with BRT (Side Running)	2040 Low with BRT (Center Running)	2040 High without BRT (Background)	2040 High with BRT (Side Running)	2040 High with BRT (Center Running)
AM Peak (Eastbound)							
Folsom Street	26th Street	363	365	365	435	398	398
26th Street	28th Street	272	200	390	325	230	430
28th Street	29th Street	97	10	360	115	5	383
29th Street	30th Street	196	125	378	235	145	410
30th Street	33rd Street	93	5	390	116	5	420
33rd Street	38th Street	105	20	383	127	20	415
38th Street	Foothills Parkway	220	130	358	261	150	393
Foothills Parkway	48th Street	252	95	543	284	95	578
48th Street	Commerce Street	159	25	438	193	30	465
Commerce Street	Conestoga Street	170	45	425	204	50	443
Conestoga Street	55th Street	139	70	318	167	80	328
55th Street	Cherryvale Road	257	260	260	308	275	275
Cherryvale Road	63rd Street	479	485	485	575	505	505
63rd Street	65th Street	401	405	405	480	425	425
AM Peak (Westbound)							
Folsom Street	26th Street	413	418	418	498	455	455
26th Street	28th Street	406	40	408	488	45	445
28th Street	29th Street	204	205	205	225	220	220
29th Street	30th Street	568	60	555	680	65	598
30th Street	33rd Street	340	145	523	407	170	570
33rd Street	38th Street	368	145	583	443	170	635

Between		2016 Existing	2040 Low with BRT (Side Running)	2040 Low with BRT (Center Running)	2040 High without BRT (Background)	2040 High with BRT (Side Running)	2040 High with BRT (Center Running)
38th Street	Foothills Parkway	752	485	863	901	565	955
Foothills Parkway	48th Street	651	390	683	780	455	758
48th Street	Commerce Street	509	134	782	598	130	838
Commerce Street	Conestoga Street	462	90	743	556	105	788
Conestoga Street	55th Street	448	65	745	537	75	783
55th Street	Cherryvale Road	555	350	271	668	415	289
Cherryvale Road	63rd Street	1,077	30	1,085	1,290	30	1,125
63rd Street	65th Street	1,191	1,195	1,195	1,430	1,255	1,255
PM Peak (Eastbound)							
Folsom Street	26th Street	601	603	603	723	660	660
26th Street	28th Street	478	395	625	572	460	695
28th Street	29th Street	128	10	603	153	10	648
29th Street	30th Street	366	235	595	440	275	653
30th Street	33rd Street	175	15	600	214	15	648
33rd Street	38th Street	203	20	685	246	20	745
38th Street	Foothills Parkway	638	370	773	764	435	860
Foothills Parkway	48th Street	517	140	898	595	135	958
48th Street	Commerce Street	455	85	853	547	100	905
Commerce Street	Conestoga Street	462	85	868	554	100	910
Conestoga Street	55th Street	462	285	785	556	335	830
55th Street	Cherryvale Road	928	933	933	1,113	1,003	1,003
Cherryvale Road	63rd Street	1,276	1,285	1,285	1,535	1,340	1,340
63rd Street	65th Street	1,446	1,450	1,450	1,735	1,510	1,510

Between		2016 Existing	2040 Low with BRT (Side Running)	2040 Low with BRT (Center Running)	2040 High without BRT (Background)	2040 High with BRT (Side Running)	2040 High with BRT (Center Running)
PM Peak (Westbound)							
Folsom Street	26th Street	486	490	490	583	538	538
26th Street	28th Street	468	120	470	560	135	513
28th Street	29th Street	304	305	305	335	330	330
29th Street	30th Street	954	195	860	1143	225	935
30th Street	33rd Street	454	185	643	544	215	700
33rd Street	38th Street	467	140	735	559	155	795
38th Street	Foothills Parkway	435	105	720	520	120	788
Foothills Parkway	48th Street	720	480	705	864	565	788
48th Street	Commerce Street	362	26	681	440	25	730
Commerce Street	Conestoga Street	336	10	640	405	10	675
Conestoga Street	55th Street	282	25	518	340	25	540
55th Street	Cherryvale Road	350	170	221	422	205	235
Cherryvale Road	63rd Street	643	15	650	770	10	670
63rd Street	65th Street	672	680	680	805	710	710

- Excess wait time is based on the average time that JUMP buses arrived at a stop late based on RTD's ridership report (see Figure B-37) . This value was increased by 20% for No Build and 15% for Enhanced Bus. BRT was assumed to have no excess wait time. However in scenarios where the JUMP was assumed to still operate in mixed traffic, the transit LOS accounts for the excess wait times of both services. In Side-Running BRT there is no excess wait time because both JUMP and BRT vehicles use transit lanes. But in Center-Running BRT, only BRT vehicles have a dedicated transit lane, while JUMP vehicles continue to use the curb lane. Therefore the overall excess wait time for the Center BRT scenario is higher than Side-Running scenario.

Figure B-37 Excess Wait Time (minutes)

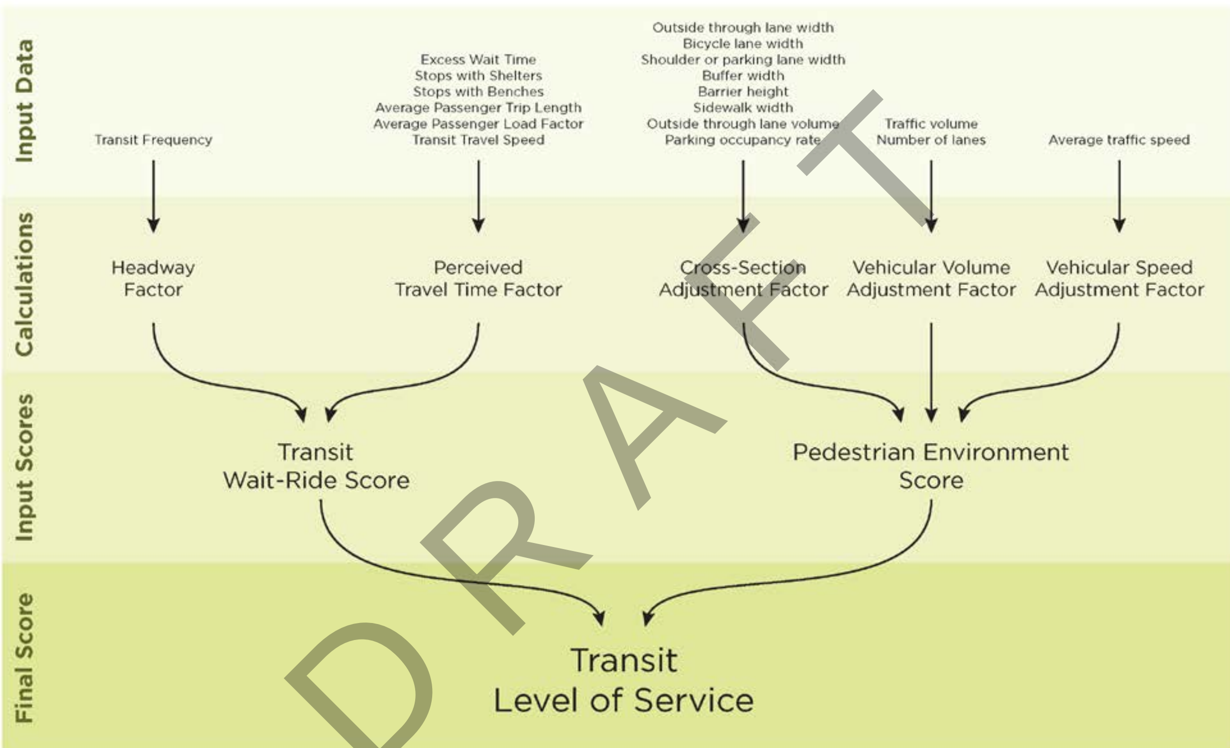
Segment	AM Early	AM Peak	Midday	PM Peak	PM Evening	PM Late	Other
Eastbound							
Boulder Station to Arapahoe Ave/30th St	NA	-	-	-	-	-	NA
Arapahoe Ave/30th St to Arapahoe Ave/Marine St	NA	-	-	-	-	-	NA
Arapahoe Ave/Marine St to Arapahoe Ave/55th St	NA	-	-	-	-	-	NA
Arapahoe Ave/55th St to Arapahoe Ave/63rd St	NA	0.8	0.1	-	-	0.2	NA
Arapahoe Ave/63rd St to VoTech	NA	0.8	0.1	-	-	0.2	NA
Arapahoe Ave/63rd St to Arapahoe/65th St	NA	0.5	-	-	-	-	NA
Arapahoe Ave/65th St to Arapahoe Rd/Dagny Way	NA	-	-	-	-	-	NA
Westbound							
Boulder Station to Arapahoe Ave/30th St	0.6	1.9	0.6	2.0	-	-	-
Arapahoe Ave/30th St to Arapahoe Ave/Marine St	-	2.7	0.5	1.7	-	-	-
Arapahoe Ave/Marine St to Arapahoe Ave/55th St	-	1.5	-	1.2	-	-	-
Arapahoe Ave/55th St to Arapahoe Ave/63rd St	-	1.5	-	1.2	-	-	0.3
Arapahoe Ave/63rd St to VoTech	-	1.7	-	1.2	-	-	0.3
Arapahoe Ave/63rd St to Arapahoe/65th St	-	2.3	0.5	1.4	-	-	-
Arapahoe Ave/65th St to Arapahoe Rd/Dagny Way	-	1.6	-	1.2	-	-	-

- Travel times are based on peak travel directions (eastbound during PM peak, and westbound during AM peak). See the Travel Time and Reliability Section.

Methods

Using a combination of GIS and Excel, the transit LOS score for each district in each scenario was calculated by combining two different scores: the transit wait-ride score and the pedestrian environment score. The transit wait-ride score is a measure of headway and perceived travel time. The pedestrian environment score is a measure of the quality of the pedestrian environment in proximity to the stops. The analysis was completed for each roadway segment in each direction. The scores were aggregated to get individual scores at each station location.

Figure B-38 Transit Level of Service Methodology



Evaluation Results

Overall Results and Key Findings

Figure B-39 Transit LOS, by Segment and Scenario

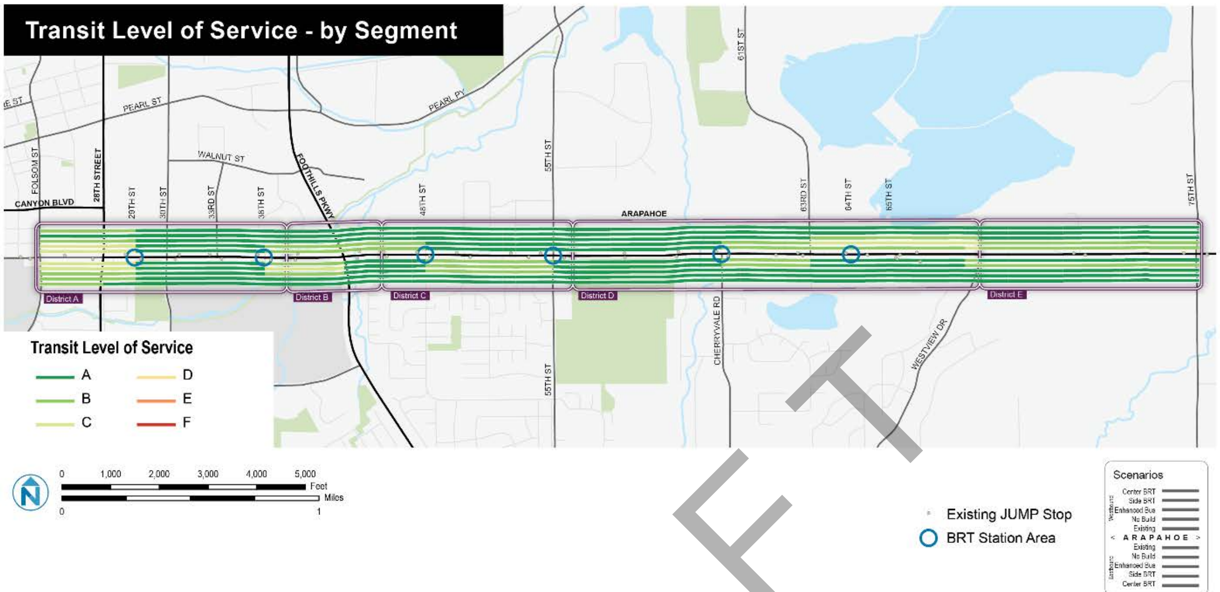


Figure B-40 Transit LOS, by Sub District and Scenario

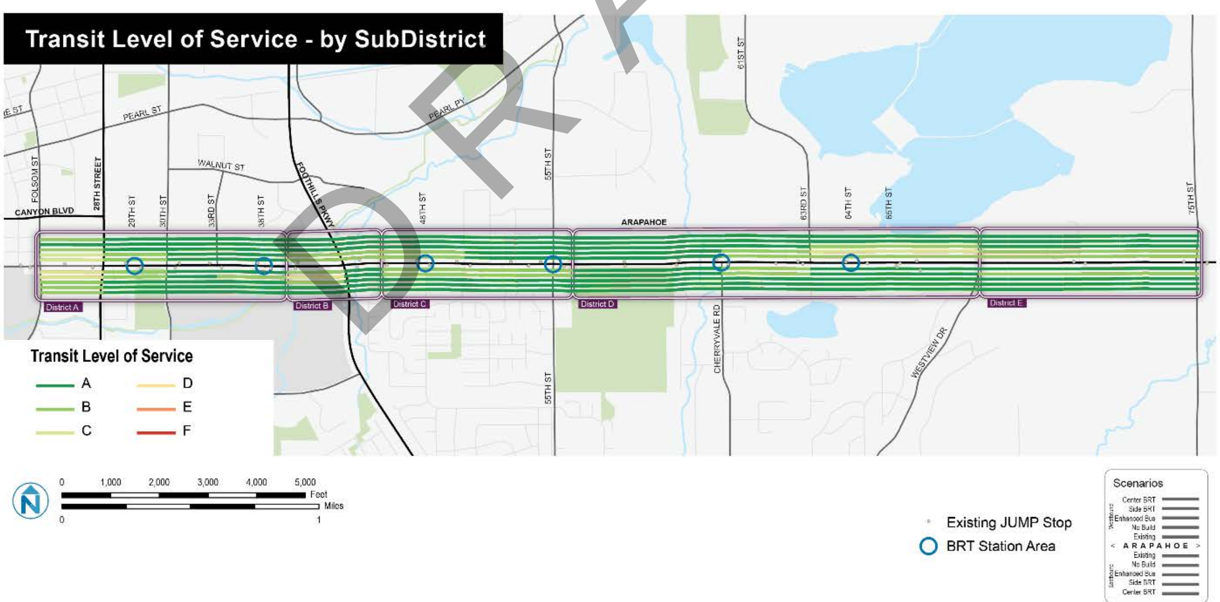
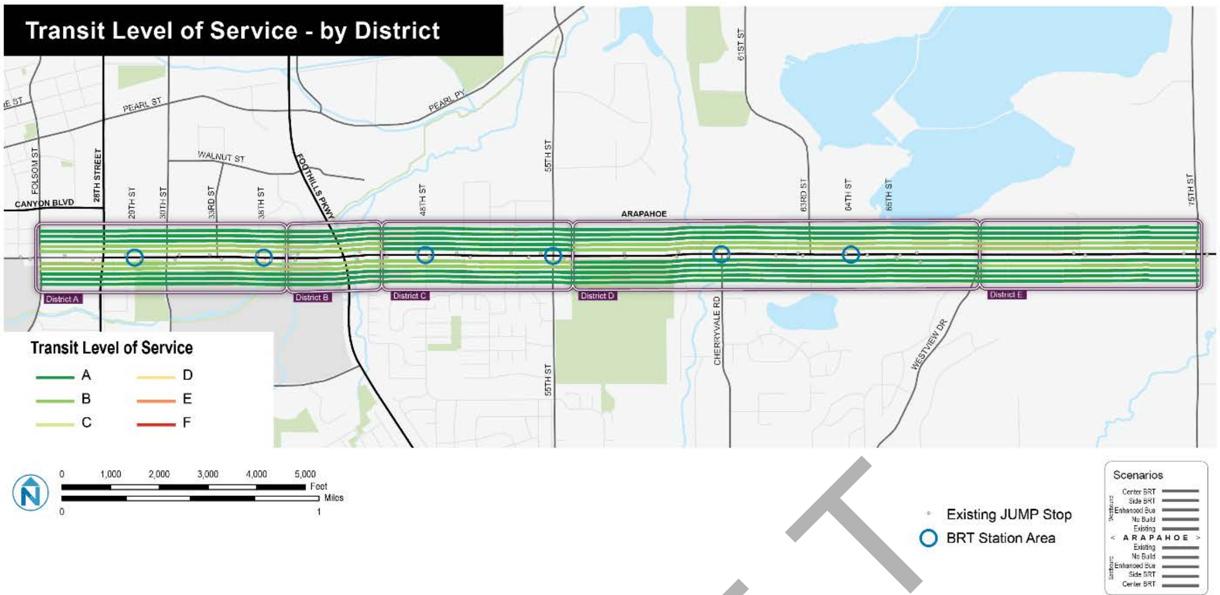


Figure B-41 Transit LOS, by District and Scenario



Key Findings

- Existing transit service along the East Arapahoe corridor is very frequent (every 10 minutes during the day). As a result, overall service quality is rated all segments in all alternatives score "C" or better.
- The No-Build score is slightly lower in some cases, e.g., due to higher future traffic volumes.
- Enhanced Bus increases quality of service and facilities to a "B" or better.
- Both BRT alternatives score "A" along the full corridor.

Individual Components

Figure B-42 Pedestrian Environment Score and Transit Wait-Ride Score

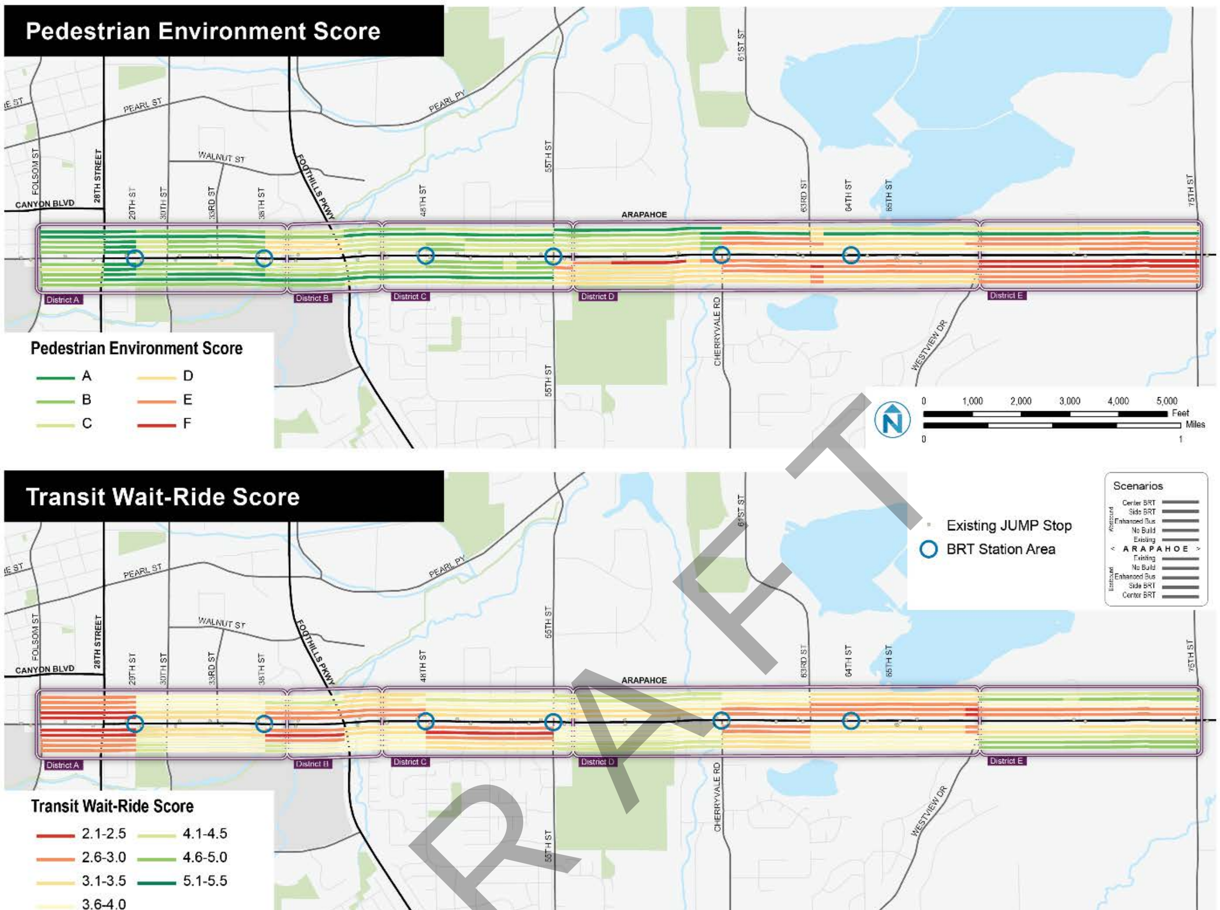


Figure B-43 Transit Frequency and Perceived Travel Time

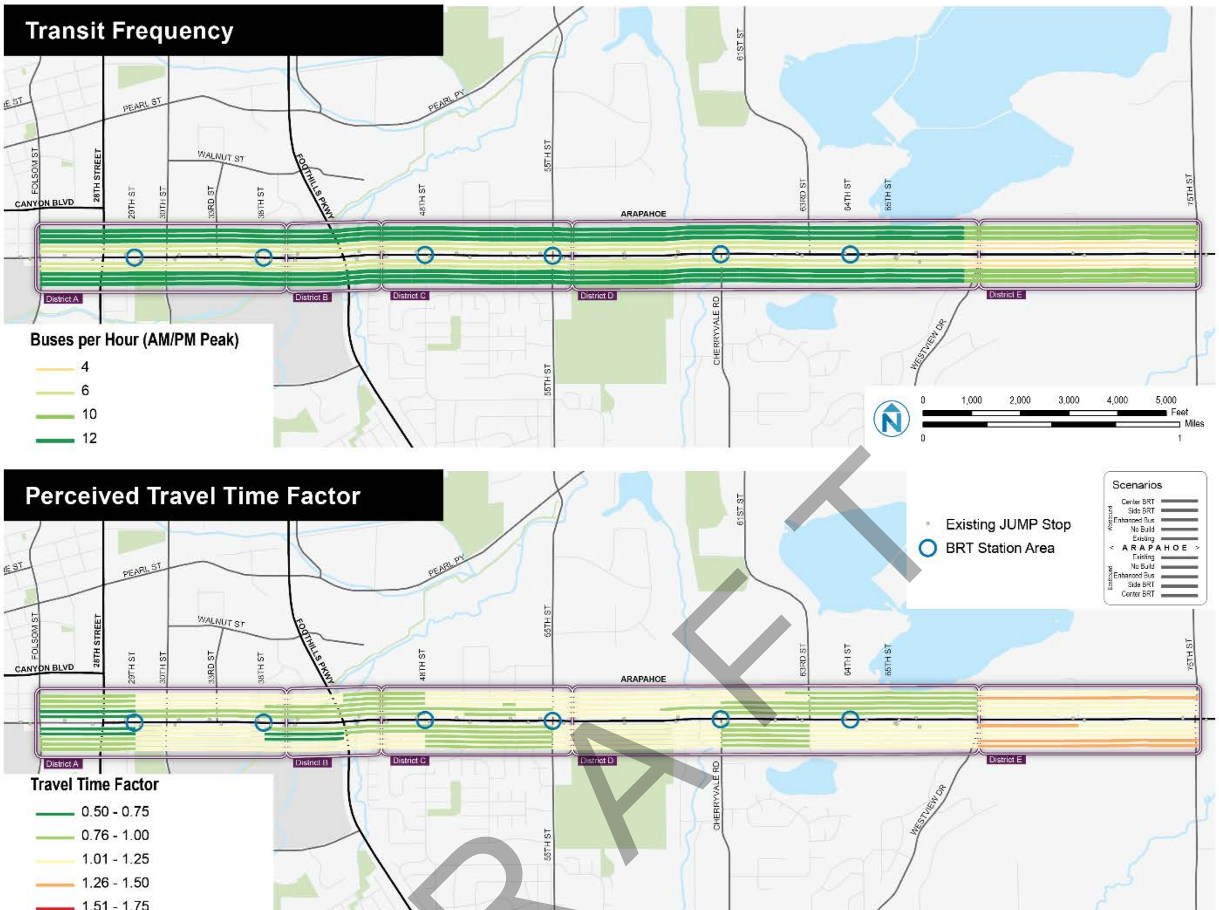


Figure B-44 Cross-Section Adjustment Factor and Vehicular Volume Adjustment Factor

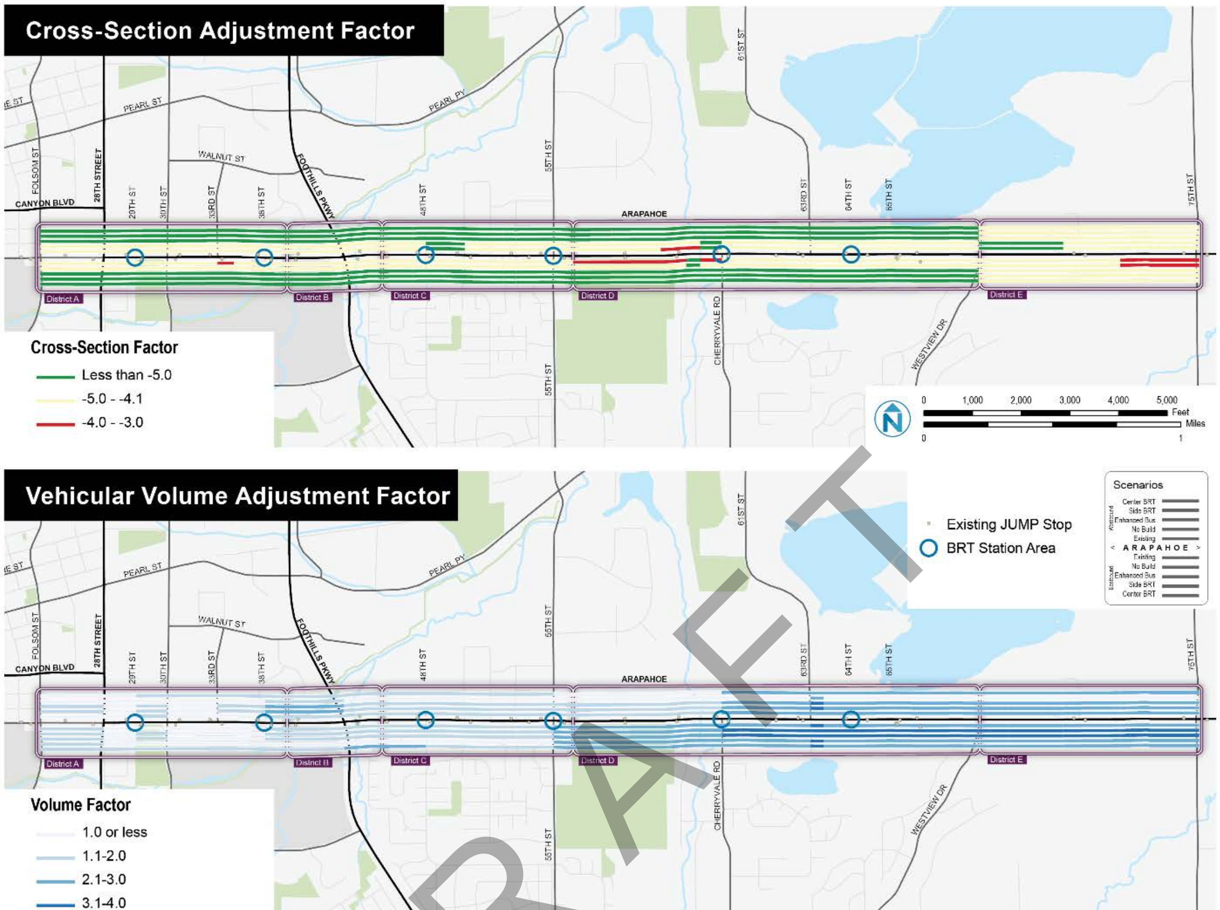


Figure B-45 Average Traffic Speed and Bus Stops with Benches

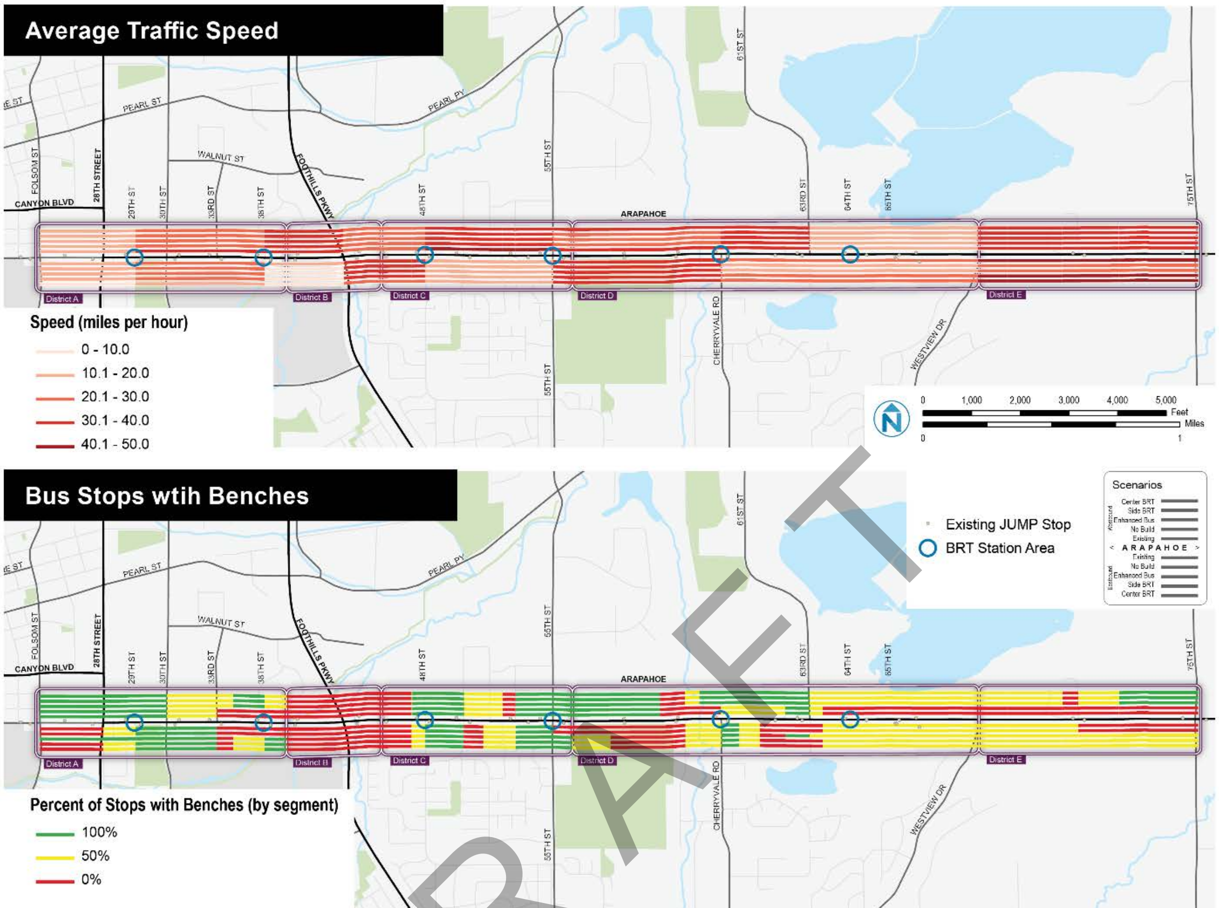
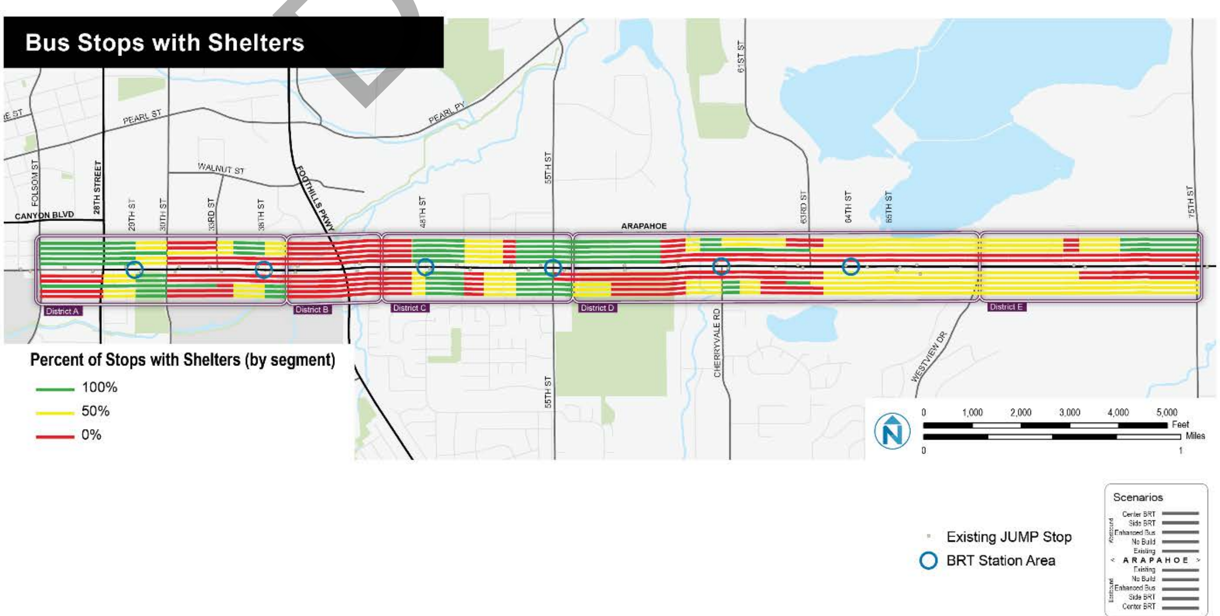


Figure B-46 Bus Stops with Shelters



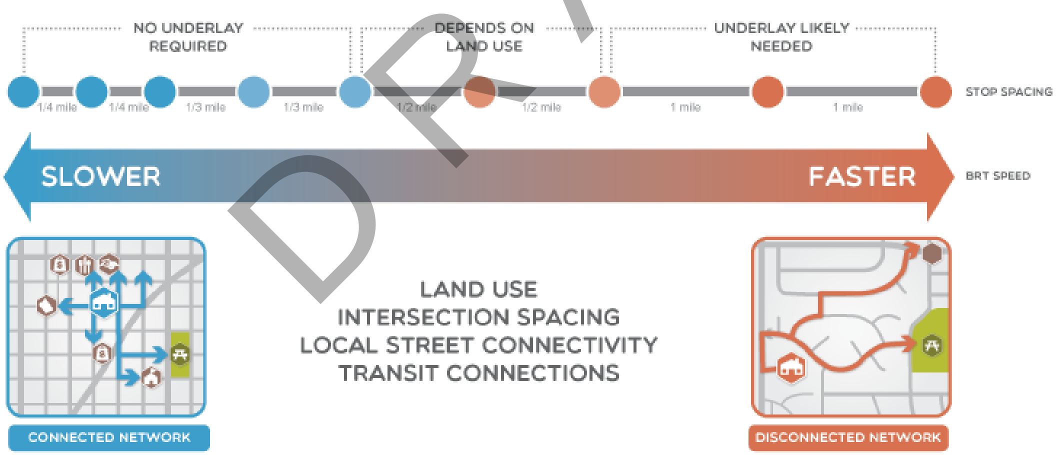
APPENDIX B.1 TRANSIT OPERATIONS: STATION LOCATION BEST PRACTICES AND ANALYSIS

This appendix provides additional detail on station location assumptions.

STATION SPACING BEST PRACTICES

BRT station locations are typically determined based on existing transit ridership, potential transit markets, corridor land use, and transfer opportunities. Stations provide access to residential and employment areas, major demand generators, and connecting transit services. A half-mile is commonly considered the distance people will walk to a BRT or rail station. As illustrated in Figure B-1.1, closely spaced intersections and a well-connected local street network increase the catchment area of a BRT station.

Figure B.1-1 Stop Spacing Factors



Source: Nelson\Nygaard

There are tradeoffs between station spacing, land use access, and BRT speed. Closer spacing reduces BRT travel speed but increases access, while wider spacing increases BRT speed but reduces access.

Station spacing helps determine whether underlying local bus service will be required along the BRT corridor. Stations a quarter to a third of a mile apart may not need a local underlay, assuming a well-connected street network. BRT stations spaced greater than a half-mile apart would typically require a local route to serve stops between BRT stations. With station spacing between a third of a mile and a half-mile, the need for local service depends on land use, specifically the level of density and number of demand generators, and spacing of streets and pedestrian facilities providing access to the corridor.

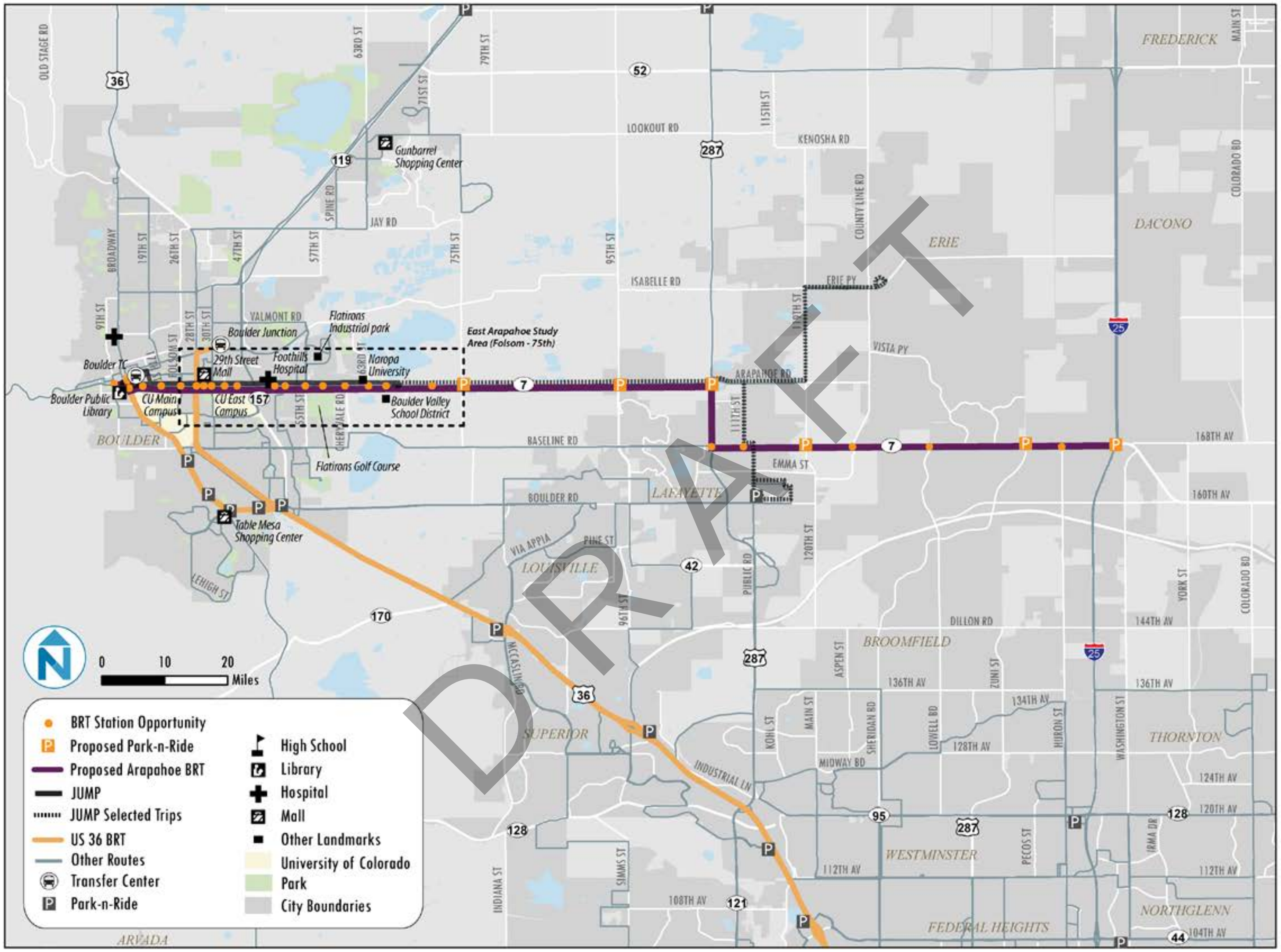
BRT station spacing is flexible and may vary by segment of a BRT corridor. A BRT line serving regional travel needs (i.e., longer trip distances between cities) could be designed with wider station spacing and local underlay service that serves local stops between stations. A BRT line serving travel needs in more urbanized corridor (i.e., shorter, more localized trips to/from activity centers) may warrant closer station spacing and local underlay service may not be necessary. Some transit corridors, including Arapahoe Avenue, are comprised of both urbanized and less urban segments, and serve both regional and more localized travel markets. In this case, a mix of wider and shorter stop spacing could be employed for different corridor segments.

ANALYSIS OF POTENTIAL STATION LOCATIONS IN BOULDER

This section provides an assessment of potential BRT station locations for the Arapahoe corridor. This assessment will be used to identify alternative station spacing scenarios. These scenarios will be incorporated into operating alternatives that will be evaluated for a range of metrics. The evaluation of these alternatives will help staff, elected officials, stakeholders, and the public evaluate tradeoffs between station spacing and BRT speed, access, and cost, and shape a BRT alternative for the Arapahoe Corridor that best meets Boulder's goals and objectives.

Figure B.1-2 illustrates the proposed Arapahoe BRT corridor, between Boulder Transit Center and I-25, along with potential station locations identified along the alignment. These station locations include those assumed in the Northwest Area Mobility Study (NAMS) as well as those identified by the City of Boulder project team based on staff discussions and internal workshops.

Figure B.1-2 Arapahoe Corridor Extent



Station Location Assessment

The left portion of Figure B.1-3 provides a high-level assessment of potential station locations. This assessment includes major ridership generators, land use, right-of-way constraints, connectivity and access for people walking and riding bicycles to/from BRT stations, connections to other transit routes, and planned Mobility Hub locations.[1] The assessment informed the development of several stop spacing scenarios, identified in the right portion of Figure B.1-3. The following section describes these scenarios and the iterative process by which they were developed.

Station Selection Process and Spacing Scenarios

The selection process resulted in three stop spacing scenarios, with stations preferably located no closer than a quarter-mile and between a third of a mile and a half-mile from adjacent stops. The process for selecting station locations was iterative. The project team first identified general station areas along the corridor that would be important to serve based on the presence of major generators (such as the 29th Street Mall) and important transit and multimodal connections (such as US 36 BRT). The team then identified more specific station locations considering factors including land use, right-of-way feasibility, existing ridership, and stop spacing considerations.

The right portion of Figure B.1-3 identifies the station locations included in each scenario.

- **Scenario 1: Longer spacing targeting a minimum approximately half-mile distance between stations.** Figure B.1-4 illustrates this scenario, which includes six stops between Folsom and 75th: 29th, 38th, 48th, 55th, Cherryvale, and either 63rd or 65th. Compared to Scenario 2, it does not include a station at 32nd Street (between 29th and 38th Streets) and includes only one station at 63rd or 65th.
- **Scenario 2: Moderate spacing – average of about 0.4 miles.** Figure B.1-5 illustrates this scenario, which includes two additional stations relative to Scenario 1 (nine total): 29th, *32nd*, 38th, 48th, 55th, Cherryvale, and both 63rd and 65th.
- **Scenario 3: Shorter spacing – average of about a third of a mile.** Figure B.1-6 illustrates this scenario, which includes three additional stops relative to Scenario 2 (12 total): 29th, 32nd, 38th, 48th, *Eisenhower/Commerce,* 55th, Cherryvale, both 63rd and 65th, and Valtec Drive.

Additional details on the station selection considerations are provided below Figure B.1-3.

Figure B.1-7 provides a more detailed listing of all existing stops (including existing ridership) and proposed stations. It includes the BRT stations proposed in the NAMS study and provides the distance between stops. Figure B.1-8 illustrates existing ridership on a map.

[1] Mobility hubs are a concept included in the City of Boulder TMP. Mobility hubs facilitate transit connections outside of the primary transit centers and include pedestrian and bicycle improvements and other sustainable modes (e.g., car or bike sharing) designed to connect transit passengers to adjacent neighborhoods and nearby land uses.

Figure B.1-3 Station Location Assessment and Spacing Scenarios (within City of Boulder)

Location	Station Assessment						Recommended BRT Station Scenario				
	Major Generators	Land Use Environment	Right-of-Way Constraints	Ped/Bike Connections	Transit Connections	Mobility Hub	Long	Moderate	Shorter	Primary Rationale	Notes
28th	29th Street Mall	Urban, Mixed Use	Dual left-turn lanes in both directions	Multi-Use Path	US 36 BRT	Proposed	-	-	-	Constrained ROW	A
29th	29th Street Mall	Urban, Mixed Use		N: Bike Lanes S: Bike Route	S (EB); 1 block from US 36 BRT, S (SB), BOUND	-	X	X	X	Proximity to both 28th Street and US 36 BRT, and 30th Street and BOUND	A
30th	29th Street Mall	Urban, Mixed Use		Multi-Use Path & Bike Lanes	S, BOUND, STAMPEDE	-	-	-	-	Stop Spacing	A
32nd	CU East Campus	Urban, Mixed Use		-	J, S, STAMPEDE	-	-	X	X	Stop Spacing	A
33rd	CU East Campus	Urban, Mixed Use		-	J, S	-	-	-	-	Stop Spacing	A
38th	CU East Campus	Urban, Mixed Use		Boulder Creek Multi-Use Path; Underpass; Future CU bus/bike bridge	J, S, STAMPEDE	-	-X	X	X	Major Generator, Ped/Bike Connections	A
Foothills	-	Highway Interchange	Dual or triple left-turn lanes	Underpass (east)	J, STAMPEDE	-	-	-	*	* Mid-block 48th station east of MacArthur in shorter stop spacing scenario	B
MacArthur	Boulder Comm. Hosp. (BCH)	Urban, Lower-Density Residential (S), Institutional (N)		Stated demand for crossing (none existing)	S	-	-	-	*	* Mid-block 48th station east of MacArthur in shorter stop spacing scenario	B
48th	BCH; Ball Aerospace	Urban, Lower-Density Residential (S), Institutional (N)		N: Boulder Creek Path (0.25 mi) S: Bike Route (0.2 mi)	206 (0.2 mi)	Proposed	X	X	X	Major Generator, Highest Ridership	B
Eisenhower/ Commerce	BCH; Ball Aerospace			S: Bike Route	206		-	-	X		B

Location	Station Assessment						Recommended BRT Station Scenario				
	Major Generators	Land Use Environment	Right-of-Way Constraints	Ped/Bike Connections	Transit Connections	Mobility Hub	Long	Moderate	Shorter	Primary Rationale	Notes
55th	Retail (various)	Medium Density Mixed Use/Light Industrial (N), Residential (S)	-	Bike Lanes	206, 208	-	X	X	X	Stop Spacing, Multimodal Connections, Land Use	C
Flatirons Golf Course	Flatirons Golf Course	Light Industrial (N) Golf Course (S)	-	Golf course limits access and connectivity to south	-		-	-	X	Low Ridership	D
Cherryvale	New Jewish Community Center	Institutional, Auto Dealerships, Low Density Residential	-	Pedestrian undercrossing at S. Boulder Creek Path (0.1 mi)	-	-	X	X	X	Future Major Generator	E
63rd	Naropa Planned Expansion; Sports Facility	Institutional, Light industrial	-	Bike lane and multimodal path connection to north	-	-	-	X	X	Stop Spacing, Major Generator	F
65th	BVSD; Resource Yard/Edge Parking	Institutional, Light industrial	-	-	-	-	X	X	X	Major Generator	F
Valtec	Tech Center	Institutional, Rural	-		-	-	-	-	X	Stop Spacing	G
75th		Rural	-	Good bike facility	-	Future	X	X	X	Park & Ride	

Notes:

A: 28th – 29th – 30th – 32nd/33rd – 38th: 28th Street would be an optimal location for transfers to/from US 36 BRT, however the project team felt that limited right-of-way would constrain the station footprint. The team therefore targeted a station at 29th for relatively close proximity to US 36 BRT stations on 28th Street. A station at 29th would provide relatively close access to the BOUND route along 30th Street. Although 30th Street has the highest ridership of this set of stops, stop spacing with 29th would be very short. 29th and 38th Streets are about a half-mile apart. In the shorter and moderate stop spacing scenarios, a station at 32nd Street (east of 30th and west of 33rd) is approximately equidistant between 29th and 38th and provides closer connections to the BOUND than 33rd. A station at 32nd or 33rd would provide improved connections to CU East Campus.

B: Foothills – MacArthur - 48th – Eisenhower: 48th Street has the higher existing ridership than either the MacArthur Drive and Eisenhower Drive stops, although all three stops have high ridership. The addition of an Eisenhower station in the shorter spacing scenario would serve employment east of 48th including Ball Aerospace, but would result in very short spacing between a 48th Street station located at the 48th intersection. However, a mid-block station located west of 48th and east of MacArthur Drive (see proposed design concept in Chapter 3) would balance the distance between stops with an Eisenhower station. A station was also considered at Foothills Drive in the shorter spacing scenario, but would be only a short distance from the proposed mid-block location between MacArthur Drive and 48th Street. Foothills Drive has lower ridership than the other three existing stops.

C: 55th: Conestoga Street has higher ridership than 55th Street, however these two streets are only 0.14 miles apart. Land use south of Arapahoe & Conestoga is primarily residential while there is more of a residential/employment mix south of Arapahoe & 55th. A proposed design concept for the 55th station could be located mid-block between these streets.

D: Flatirons Golf Course. Low existing ridership, but included in the shorter stop spacing scenario. This could be considered in conjunction with an alternative with no/infrequent local underlay service.

E: Cherryvale: A new Jewish Community Center is planned on the southeast corner of Arapahoe and Cherryvale.
F: 63rd/65th: 65th has higher existing ridership than 63rd, and is included in the longer stop spacing scenario. However, both station areas have major attractors and are included in the moderate and shorter stop spacing scenarios.
G: Valtec: Low existing ridership, but included in the shorter stop spacing scenario. This could be considered in conjunction with an alternative with no/infrequent local underlay service.

Figure B.1-4 East Arapahoe BRT Station Areas: Scenario 1 – Longer Stop Spacing

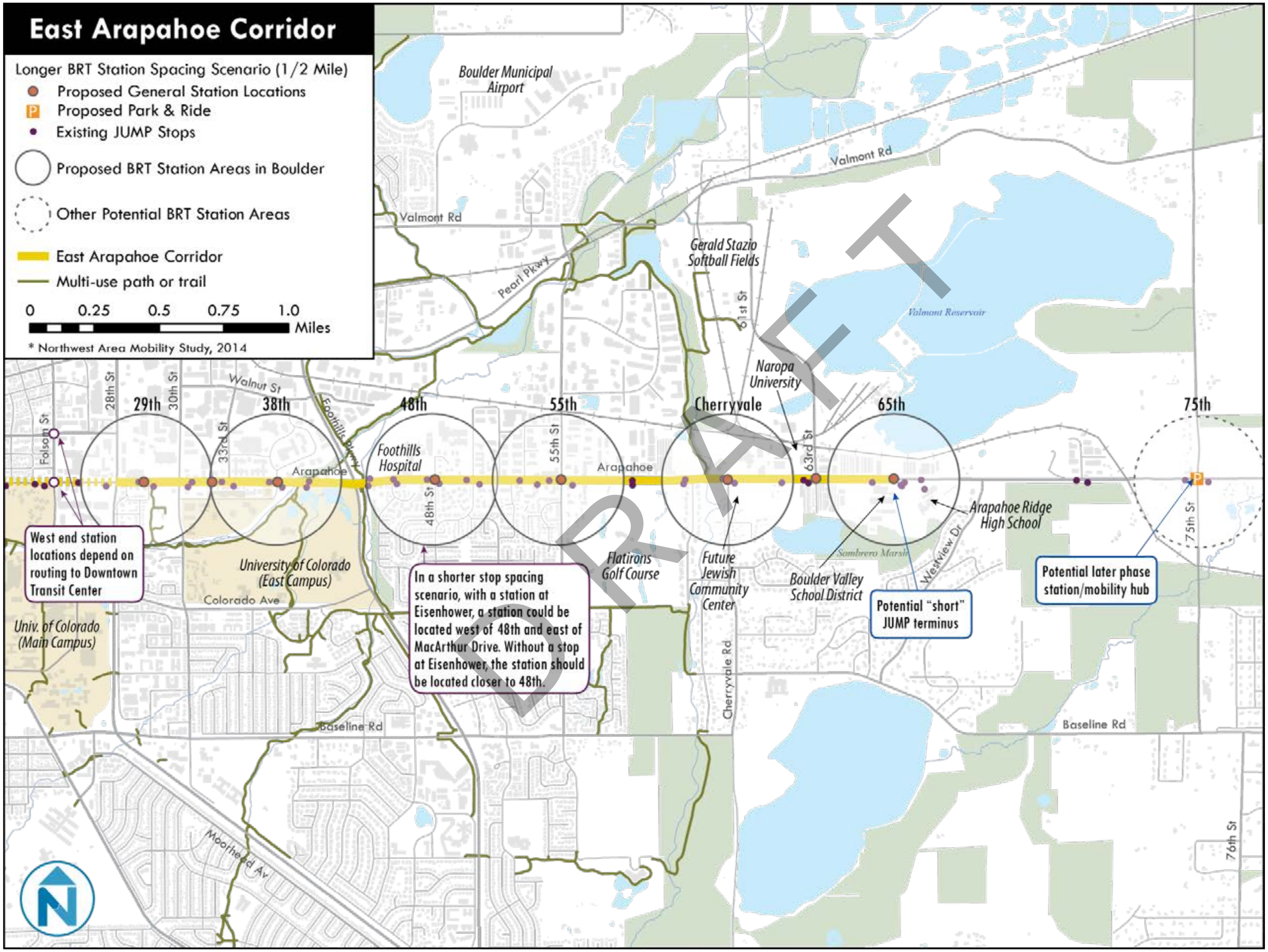


Figure B.1-5 East Arapahoe BRT Station Areas: Scenario 2 – Moderate Stop Spacing

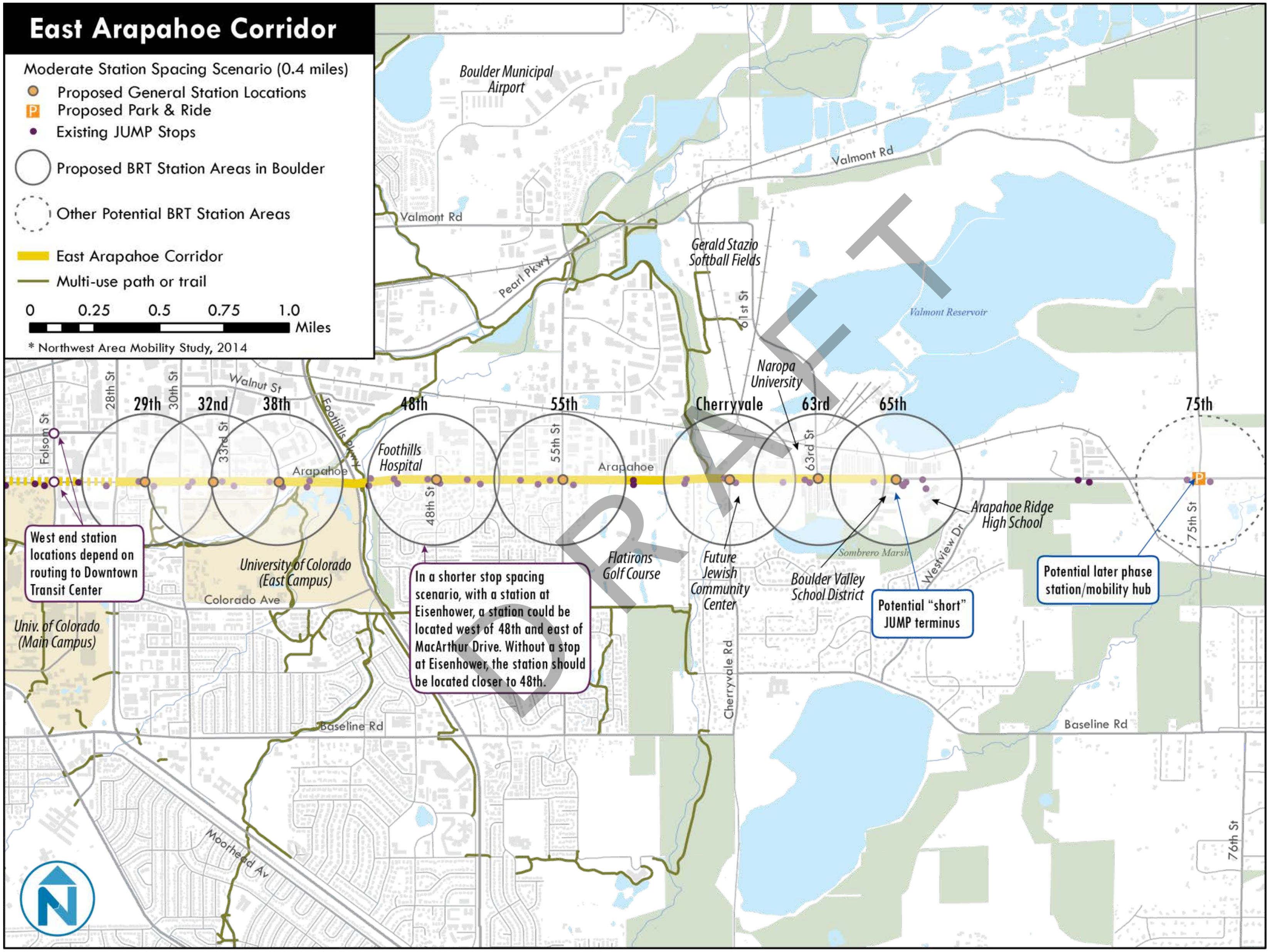


Figure B.1-6 East Arapahoe BRT Station Areas: Scenario 3 – Shorter Stop Spacing

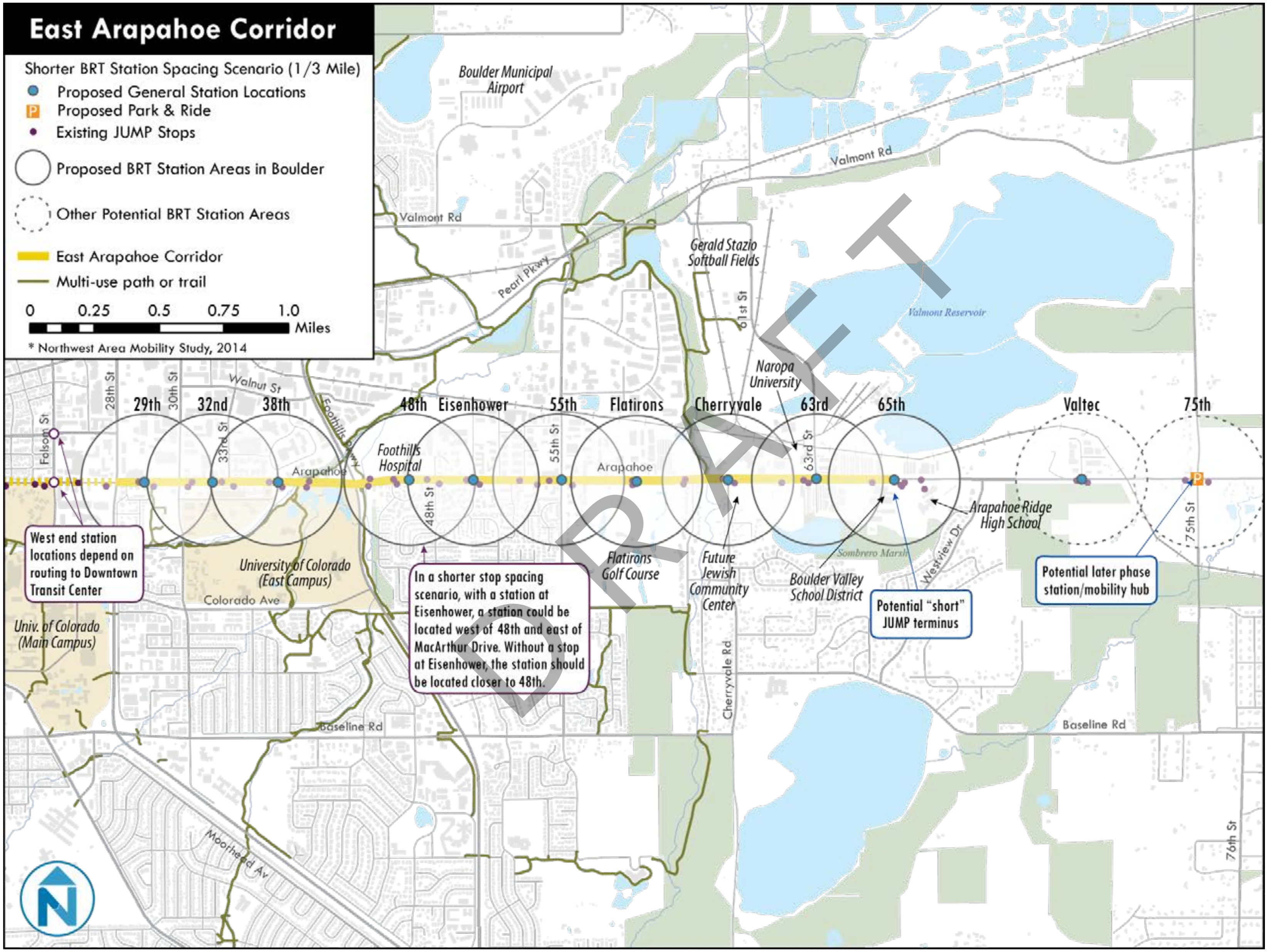


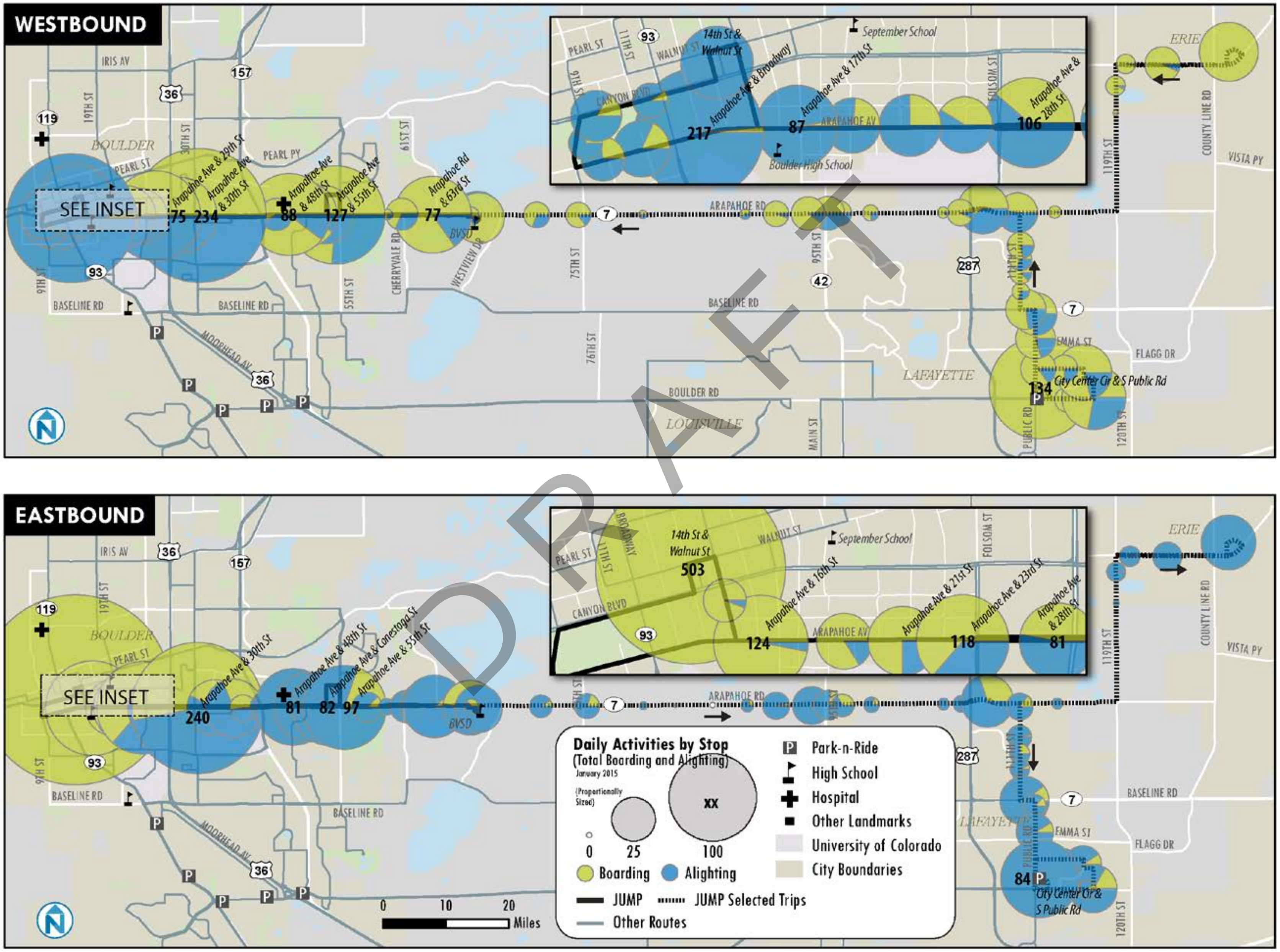
Figure B.1-7 Station Location Scenarios Detailed Characteristics

Stop/Station Location	Miles [1]	Existing JUMP Stop	Existing JUMP Ridership	Proposed NAMS			1: Longer Stop Spacing (Avg 1/2 mile)		2: Moderate Stop Spacing (Avg 0.4 mile)		3: Shorter Stop Spacing (Avg 1/3 mile)	
				Station	Park & Ride	Miles from Previous Station [1]	Stations Included	Miles from Previous Station [1]	Stations Included	Miles from Previous Station [1]	Stations Included	Miles from Previous Station [1]
Arapahoe/28th St	0.00	X	188	X								
Arapahoe/29th St	0.13	X	138	X		0.13	X	0.00	X	0.00	X	0.00
Arapahoe/30th St	0.25	X	475	X		0.12						
Arapahoe/32nd St	0.33								X	0.20	X	0.20
Arapahoe/33rd St	0.44	X	86									
Arapahoe/38th St	0.63	X	93	X		0.38	X	0.50	X	0.30	X	0.30
Arapahoe/Foothills Pkwy	0.94	X	51	X		0.31						
Arapahoe/MacArthur Dr	1.08	X	107									
Arapahoe/48th St	1.25	X	139				X	0.62	X	0.62	X	0.62
Arapahoe/Eisenhower Dr	1.40	X	112								X	0.15
Conestoga St	1.61	X	210									
Arapahoe/55th St	1.75	X	113	X		0.81	X	0.50	X	0.50	X	0.35
Arapahoe/Flatirons Golf Course	2.01	X	13								X	0.26
Arapahoe/Old Tale Rd	2.27	X	18									
Arapahoe/Cherryvale Rd	2.41	X	92	X		0.66	X	0.66	X	0.66	X	0.40
Arapahoe/62nd St	2.66	X	32									
Arapahoe/63rd St	2.75	X	60	X		0.34			X	0.34	X	0.34
Arapahoe/6400 Block	2.96	X	5									
Arapahoe/Vo Tech Dr (65th St)	3.06	X	109				X	0.65	X	0.31	X	0.31
Arapahoe/Valtec Ln	3.80	X	16				*Future*	--	*Future*	--	X	0.74
Arapahoe/75th St	4.27	X	17	X	X	1.52	X	1.21	X	1.21	X	0.47
Arapahoe/Willow Creek Dr	4.88	X	2									
Arapahoe/East Boulder Trail	5.23	X	0									
Arapahoe/Marshallville Ditch Rd	5.59	X	0									

Stop/Station Location	Miles [1]	Existing JUMP Stop	Existing JUMP Ridership	Proposed NAMS			1: Longer Stop Spacing (Avg 1/2 mile)		2: Moderate Stop Spacing (Avg 0.4 mile)		3: Shorter Stop Spacing (Avg 1/3 mile)	
				Station	Park & Ride	Miles from Previous Station [1]	Stations Included	Miles from Previous Station [1]	Stations Included	Miles from Previous Station [1]	Stations Included	Miles from Previous Station [1]
Arapahoe/Park Lane Dr	5.94	X	4									
Arapahoe/Wicklow St	6.29	X	19									
Arapahoe/Cross Creek Dr	6.60	X	35									
Arapahoe/95th St [3]	6.76	X	27				X	2.49	X	2.49	X	2.49
Arapahoe/Forest Park Dr	6.92	X	15									
Arapahoe/Yarrow St	7.25	X	7									
Arapahoe/101 St St	7.57	X	0									
Arapahoe/10300 Block	7.98	X	3									
Arapahoe/Stonehenge Dr	8.17	X	13									
Arapahoe/107th St (US 287)	8.26			X	X	3.99	X	1.50	X	1.50	X	1.50
Baseline/107th St (US 287)	9.28			X			X	1.02	X	2.52	X	2.52
Baseline/111th St	9.79			X			X	0.51	X	0.51	X	0.51
Baseline/119th St	10.79			X	X	2.53	X	1.00	X	1.00	X	1.00
Baseline/County Line Rd	11.53			X			X	0.74	X	0.74	X	0.74
Baseline/Lowell Blvd	12.78			X			X	1.25	X	1.25	X	1.25
Baseline/Sheridan Pkwy	14.32			X	X	3.53	X	1.54	X	1.54	X	1.54
Baseline/Huron St	14.89			X			X	0.57	X	0.57	X	0.57
Baseline/Washington (I-25)	16.15			X	X	1.83	X	1.26	X	1.26	X	1.26

Notes: [1] Distances based on cross-street centerline. [2] Assumes moderate stop spacing (approximately ½ mile). [3] Shorter stop spacing option (approximately 0.3 to 0.4 miles), for evaluation of alternatives without a local underlay service. [3] This station was not identified in NAMS reports/maps (January 2014), but was identified by RTD as a park & ride location along SH 7.

Figure B.1-8 Existing JUMP Ridership, Weekdays, January 2016



APPENDIX B.2 WEST END ALIGNMENT AND STATION LOCATION OPTIONS

This appendix provides a high level assessment of alignment and stop location options for the West End of the East Arapahoe corridor (defined as areas west of 28th Street).

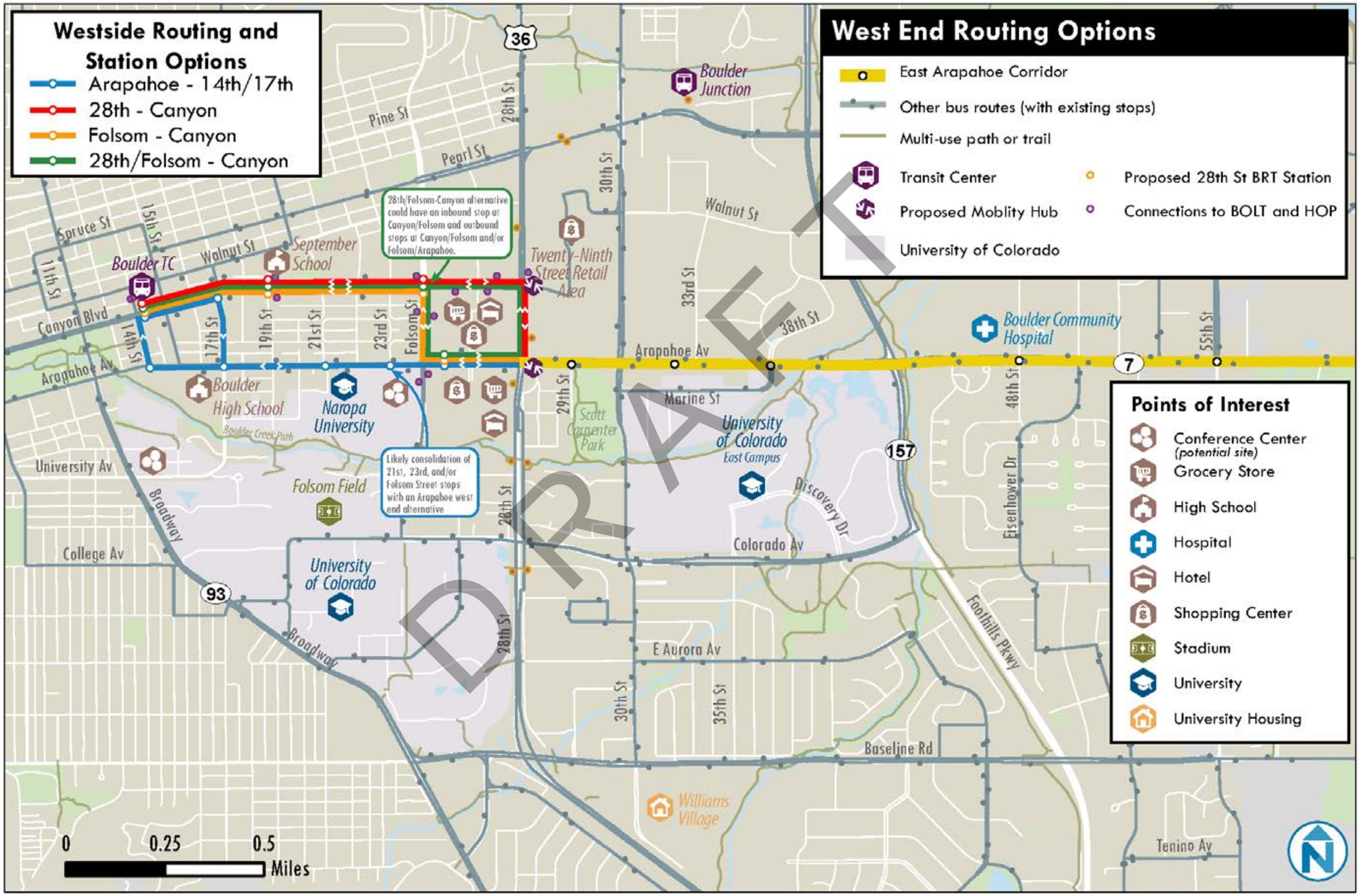
WEST END ALIGNMENTS

There are multiple alignments that can be selected for BRT or Enhanced Bus service west of 28th Street. Figure B.2-1 identifies four potential West End alignments that were identified for BRT or Enhanced Bus service on the Arapahoe corridor:

- **Arapahoe:** Arapahoe Avenue, 14th Street (inbound), and 17th Street (outbound)
- **Canyon via 28th**: 28th Street and Canyon Boulevard
- **Canyon via Folsom:** Folsom Street and Canyon Boulevard
- **Canyon via 28th/Folsom:** 28th Street (inbound), Canyon Boulevard, and Folsom Street (outbound)

Based on the high-level evaluation summarized in this section, the East Arapahoe Transportation Plan includes preliminary assumptions about the West End (e.g., transit travel time), but does not recommend a specific West End alignment or station locations. It also assumes that the Downtown Boulder Transit Center (TC) will be the western terminus of the Arapahoe Corridor BRT, recognizing that an alternate terminus may be desirable based on a future, detailed assessment of transit markets. Terminal options and detailed routing, facility capacity, and costs, etc., would need to be developed during a later study phase, and coordinated with other studies including the Canyon Boulevard Complete Street Study and future studies of BRT service between Longmont and Boulder.

Figure B.2-1 West End Alignment Options



ASSESSMENT OF POTENTIAL WEST END ALIGNMENTS

Figure B.2-2 identifies the key factors for each of the four alignments that will impact the quality of service, speed and cost, among other factors.

Figure B.2-2 Qualitative Assessment of Routing Options

<table>
<tr><th></th><th>Arapahoe</th><th>28th – Canyon</th><th>Folsom – Canyon</th><th>28th/Folsom - Canyon</th></tr>
<tr><td rowspan="3">Right-of-Way</td><td>• Narrow roadway with one lane in each direction, and generally a center left-turn lane (east of 11th Street)</td><td colspan="3">• Canyon Blvd has two general travel lanes in each direction with a center median/left turn lane
• 28th Street has three travel lanes in each direction with dual left-turn lanes at both Canyon Blvd and Arapahoe Avenue
• Folsom Street has two travel lanes in each direction, with dual left-turn lanes at both Canyon Blvd and Arapahoe Avenue</td></tr>
<tr><td rowspan="2">• Arapahoe west of 28th Street is not a state roadway</td><td colspan="3">• Canyon Blvd west of 28th Street is a State roadway</td></tr>
<tr><td>• 28th Street is a State roadway</td><td>N/A</td><td>• 28th Street is a State roadway</td></tr>
<tr><td rowspan="2">Multimodal Connectivity</td><td>• Connections to US 36 BRT service (FF4 and FF6) stops at 28th & Arapahoe (NB/SB), or to FF1 at the downtown Boulder TC
• Connections to HOP along 9th Street, at Folsom Street, or at the downtown Boulder Transit Center (TC)</td><td colspan="3">• Connects with other existing transit routes along Canyon Blvd, including the BOLT route (Longmont-Boulder)
• Canyon Blvd is a proposed alignment for BRT service from Longmont.
• Connections to US 36 BRT service (FF4 and FF6) stops at 28th & Arapahoe (NB/SB), Canyon (NB), and Walnut (NB), or to FF1 at the downtown Boulder TC
• Connections to HOP along Canyon (Folsom – 28th) or at the downtown Boulder TC
• Proposed Mobility Hubs at 28th & Canyon and 2th & Arapahoe</td></tr>
<tr><td>• Generally short spacing between pedestrian crossings, and a relatively short crossing distance
• Pedestrian crossing signal between 21st and 22nd St
• Long distance between 21st/22nd crossing and Folsom St</td><td>• Enhanced pedestrian crossings at Canyon Blvd and 19th St and 21st St
• Long distance between crossings of Canyon at 21st and Folsom St.</td><td>• Pedestrian crossing beacons on Folsom St
• Enhanced pedestrian crossings at Canyon Blvd and 19th and 21st Sts.</td><td>• Enhanced pedestrian crossings at Canyon Blvd and 19th St and 21st St
• Long distance between crossings of Canyon at 21st and Folsom St.</td></tr>
<tr><td>Transit Markets</td><td>• Serves University of Colorado's northern edge
• Serves Boulder High School
• Densification of CU student housing
• Fewer destinations than Canyon Blvd</td><td>• Serves new hotels
• The closest stations to University of Colorado would be along Canyon Blvd, 0.20 miles away</td><td>• Close proximity to shopping centers
• Close to University of Colorado and Folsom Field</td><td>• No bi-directional station at Folsom St and Arapahoe Ave. The closest inbound station would be along Canyon Blvd.</td></tr>
<tr><td rowspan="2">Urban Design Opportunities</td><td colspan="4">• Coordinate BRT alignment option on Canyon with Civic Center planning process (design between 9th and 17th Streets), and Canyon Boulevard Complete Street Study</td></tr>
<tr><td>• Limited space to install specialized stations or amenities, except for Civic Center area.</td><td colspan="3">• Greater opportunity along Canyon based on upcoming corridor planning</td></tr>
</table>

	Arapahoe	28th – Canyon	Folsom – Canyon	28th/Folsom - Canyon
Transit Operations	▪ BRT vehicle could get stuck behind JUMP ▪ Verify turning radius allows for both standard and articulated buses	▪ Challenging to get from Canyon to SB left onto Arapahoe	▪ Queue jump could be installed on EB Arapahoe at 28th St ▪ Easy through movement on Arapahoe at 28th St	▪ N/A
Traffic Operations	▪ Traffic congestion at Boulder High School ▪ Does not pass through any intersections with a LOS of E or F.	▪ Has three turn movements at locations with a LOS rating of E or F	▪ Has a single turn movement with a LOS rating of E or F	▪ Has three turn movements at locations with a LOS rating of E or F

Station Siting Options

BRT or Enhanced Bus stations would be strategically located to serve high ridership areas, important destinations, and to provide passengers with access to connecting routes. The station spacing for each option ranges from an average of 0.23 miles with the Arapahoe option, to 0.42 miles with the 28th-Canyon option. Figure B.2-3 identifies the average stop spacing and the list of potential station locations for each option.

Capital Costs Assessment

A high-level analysis was conducted of potential capital costs of the four options. Of the cost components included in Figure B.2-3, the options have approximately the same length and would pass through approximately the same number of traffic signals. The Arapahoe alignment has more potential station locations per direction than options along Canyon, but less potential for station development (limiting cost). Canyon has more potential for developing transit priority treatments (which could potentially be shared with other BRT projects, e.g., service on SH 119 between Boulder and Longmont).

Figure B.2-3 Characteristics by Option

Option	Average station spacing (miles)	Potential Station Locations	Number of One-Way Stations	Round Trip Length (miles)	Auto Travel Time (min)[2]		Number of Existing Traffic Signals	Potential for Transit Only Treatments
					Westbound	Eastbound		
Arapahoe	0.23	▪ Arapahoe/23rd (IB/OB) ▪ Arapahoe/21st (IB/OB) ▪ Arapahoe/17th (IB/OB) ▪ Arapahoe/14th (IB) ▪ Boulder TC ▪ Canyon/17th (OB)	9 [1]	2.27	5	4-5	12	▪ EB queue jump at Arapahoe & 28th
28th-Canyon	0.42	▪ Canyon/Folsom ▪ Canyon/19th ▪ Boulder TC	5	2.33	4	4-6	11	▪ EB queue jump at Arapahoe & 28th ▪ Potential transit-only lanes on Canyon
Folsom-Canyon	0.32	▪ Folsom/Arapahoe ▪ Canyon/Folsom ▪ Canyon/19th ▪ Boulder TC	7	2.32	4	5	12	▪ Potential transit-only lanes on Canyon
28th/Folsom-Canyon	0.36	▪ Canyon/Folsom (IB and/or OB) ▪ Canyon/19th ▪ Boulder TC ▪ Arapahoe/Folsom (OB)	6	2.33	4	5	12	▪ Potential transit-only lanes on Canyon

[1] Limited potential for station development based on right-of-way. Stations could be consolidated.
[2] Travel times from Google Maps, between 4 and 7 pm MDT (Thursday and Monday), 2015.

Transit Operations and Traffic Assessment (Speed and Reliability)

Google Maps was used to compare travel times for each alignment and provide a high-level assessment of congestion. The auto travel times and distances between the Downtown Boulder Transit Center and the east side alignment at 28th Street and Arapahoe Avenue have little variation between the four alternatives. The round trip distance ranges between 2.27 and 2.33 miles, and round trip auto travel time ranges between 8 and 10 minutes (see Figure B.2-3 above). An average of this estimate was assumed in developing the conceptual Enhanced Bus and BRT alternative operating plans and operating cost estimates.

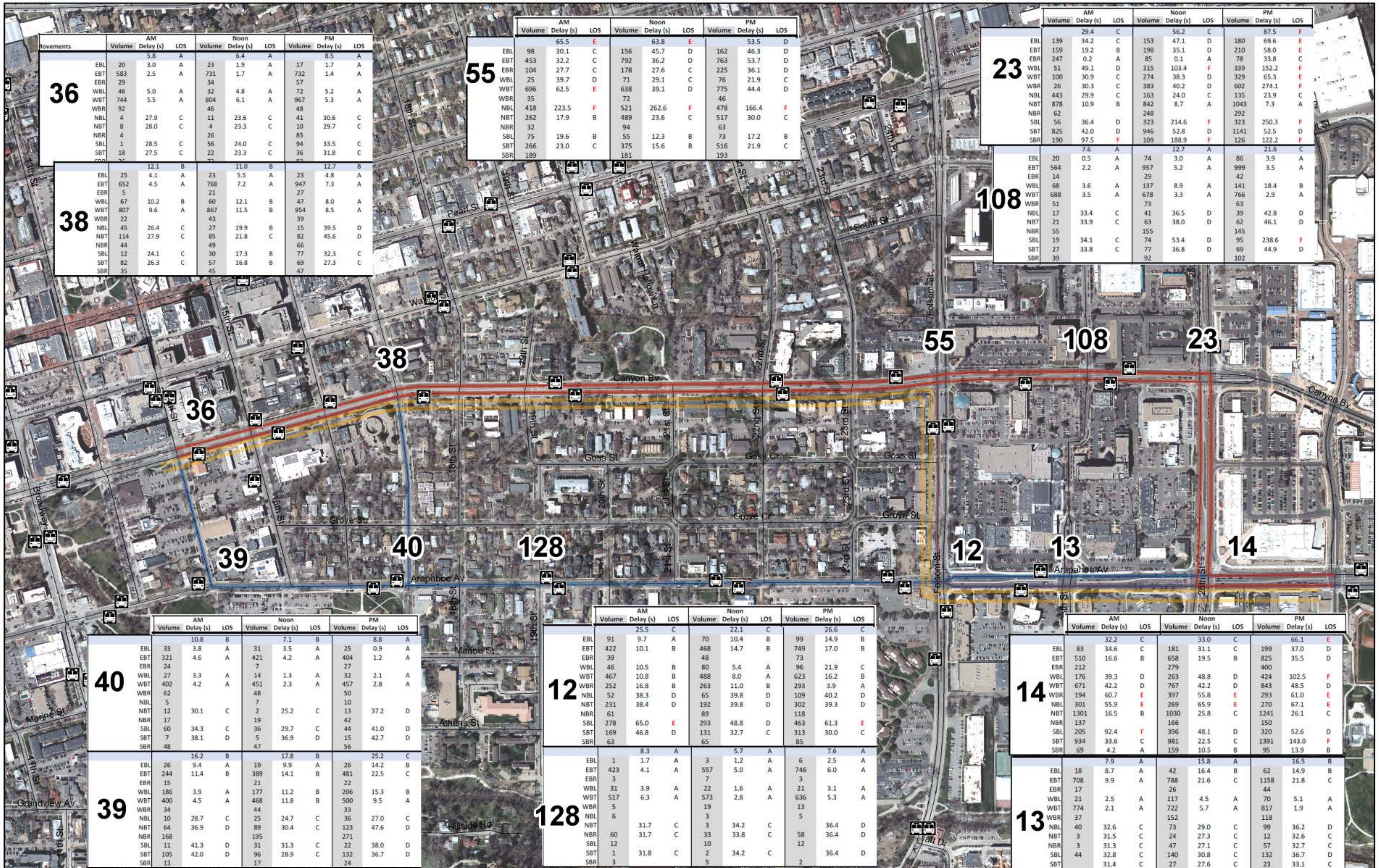
Traffic at Boulder High School in the morning and when classes are dismissed in the afternoon could be a potential issue for a BRT alignment due to congestion, delay, and increased travel times, particularly for the Arapahoe option given that Arapahoe Avenue has only one travel lane per direction west of Folsom Street. The use of 17th Street as the southbound connection between Canyon and Arapahoe in the Arapahoe alignment option is intended to minimize this impact.

Additionally, some of the alignment options would use intersections and turning movements that currently have an intersection level-of-service (LOS) of E or F. These are listed in Figure B.2-4 and Figure B.2-5. The first option, service along Arapahoe Avenue, does not have a turning movement with an LOS lower than D. The 28th-Canyon and 28th/Folsom-Canyon alternatives would each have three turning movements with an LOS of E or F. Another concern is the potential difficulty for BRT vehicles to make right turns onto 28th Street given queues from the upstream intersections. This applies in either option using 28th Street to make a left turn onto Arapahoe Avenue (eastbound) and/or turn left onto Canyon Boulevard (westbound). The Folsom-Canyon option has two movements with a LOS of E or F.

Figure B.2-4 Turning Movements with LOS of E or F, with Route Options Affected

	Arapahoe	28th – Canyon	Folsom – Canyon	28th/Folsom - Canyon
NB Folsom St, left onto Canyon Blvd	-	-	AM/Noon/PM	-
SB Folsom St, left onto Arapahoe Ave	-	-	AM/PM	AM/PM
WB Arapahoe Ave, right onto 28th St	-	AM/Noon/PM	-	AM/Noon/PM
SB 28th St, left onto Arapahoe Ave	-	AM	-	-
WB Canyon Blvd, through traffic at Folsom St	-	AM	-	AM
Total	0	3	2	3

Figure B.2-5 Delay and Level of Service Data, 2015



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Movements	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		5.8	A		6.4	A		8.5	A
EBL	20	3.0	A	23	1.9	A	17	1.7	A
EBT	583	2.5	A	731	1.7	A	732	1.4	A
EBR	29			34			57		
WBL	46	5.0	A	32	4.8	A	72	5.2	A
WBT	744	5.5	A	804	6.1	A	967	5.3	A
WBR	92			46			48		
NBL	4	27.9	C	11	23.6	C	41	30.6	C
NBT	8	28.0	C	4	23.3	C	10	29.7	C
NBR	4			26			85		
SBL	1	28.5	C	56	24.0	C	94	33.5	C
SBT	18	27.5	C	22	23.3	C	36	31.8	C
SBR	[illegible]			[illegible]			[illegible]		

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Movements	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		12.1	B		11.0	B		12.7	B
EBL	25	4.1	A	23	5.5	A	23	4.8	A
EBT	652	4.5	A	768	7.2	A	947	7.3	A
EBR	5			21			27		
WBL	67	10.2	B	60	12.1	B	47	8.0	A
WBT	807	9.6	A	867	11.5	B	954	8.5	A
WBR	22			43			39		
NBL	45	26.4	C	27	19.9	B	15	39.5	D
NBT	114	27.9	C	85	21.8	C	82	45.6	D
NBR	44			49			66		
SBL	12	24.1	C	30	17.3	B	77	32.3	C
SBT	82	26.3	C	57	16.8	B	69	27.3	C
SBR	35			45			47		

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		65.5	E		63.8	E		53.5	D
EBL	98	30.1	C	156	45.7	D	162	46.3	D
EBT	453	32.2	C	792	36.2	D	763	53.7	D
EBR	104	27.7	C	178	27.6	C	225	36.1	D
WBL	25	39.7	D	71	29.1	C	76	21.9	C
WBT	696	62.5	E	638	39.1	D	775	44.4	D
WBR	35			72			46		
NBL	418	223.5	F	521	262.6	F	478	166.4	F
NBT	262	17.9	B	489	23.6	C	517	30.0	C
NBR	32			94			63		
SBL	75	19.6	B	55	12.3	B	73	17.2	B
SBT	266	23.0	C	375	15.6	B	516	21.9	C
SBR	189			181			193		

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		29.4	C		56.2	C		87.5	F
EBL	139	34.2	C	153	47.1	D	180	69.6	E
EBT	159	19.2	B	198	35.1	D	210	58.0	E
EBR	247	0.2	A	85	0.1	A	78	33.8	C
WBL	51	49.1	D	315	103.4	F	339	152.2	F
WBT	100	30.9	C	274	38.3	D	329	65.3	E
WBR	26	30.3	C	383	40.2	D	602	274.1	F
NBL	443	29.9	C	163	24.0	C	135	23.9	C
NBT	878	10.9	B	842	8.7	A	1043	7.3	A
NBR	62			248			292		
SBL	56	36.4	D	323	214.6	F	323	250.3	F
SBT	825	42.0	D	946	52.8	D	1141	52.5	D
SBR	190	97.5	F	109	188.9	F	126	122.2	F

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		7.6	A		12.7	A		21.6	C
EBL	20	0.5	A	74	3.0	A	86	3.9	A
EBT	564	2.2	A	957	5.2	A	999	3.5	A
EBR	14			29			42		
WBL	68	3.6	A	137	8.9	A	141	18.4	B
WBT	688	3.5	A	678	3.3	A	766	2.9	A
WBR	51			73			63		
NBL	17	33.4	C	41	36.5	D	39	42.8	D
NBT	21	33.9	C	63	38.0	D	62	46.1	D
NBR	55			155			145		
SBL	19	34.1	C	74	53.4	D	95	238.6	F
SBT	27	33.8	C	77	36.8	D	69	44.9	D
SBR	39			92			102		

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		10.8	B		7.1	B		8.8	A
EBL	33	3.8	A	31	3.5	A	25	0.9	A
EBT	321	4.6	A	421	4.2	A	404	1.2	A
EBR	24			7			27		
WBL	27	3.3	A	14	1.3	A	32	2.1	A
WBT	402	4.2	A	451	2.3	A	457	2.8	A
WBR	62			48			50		
NBL	5			7			10		
NBT	12	30.1	C	2	25.2	C	13	37.2	D
NBR	17			19			42		
SBL	60	34.3	C	36	29.7	C	44	41.0	D
SBT	7	38.1	D	5	36.9	D	15	42.7	D
SBR	48			47			56		

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		16.2	B		17.8	B		25.2	C
EBL	26	9.4	A	19	9.9	A	26	14.2	B
EBT	244	11.4	B	389	14.1	B	481	22.5	C
EBR	15			21			22		
WBL	186	3.9	A	177	11.2	B	206	15.3	B
WBT	400	4.5	A	468	11.8	B	500	9.5	A
WBR	34			44			33		
NBL	10	28.7	C	25	24.7	C	36	27.0	C
NBT	64	36.9	D	89	30.4	C	123	47.6	D
NBR	168			195			271		
SBL	11	41.3	D	31	31.3	C	22	38.0	D
SBT	105	42.0	D	96	28.9	C	132	36.7	D
SBR	13			17			24		

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		25.5	C		22.1	C		26.6	C
EBL	91	9.7	A	70	10.4	B	99	14.9	B
EBT	422	10.1	B	468	14.7	B	749	17.0	B
EBR	39			48			73		
WBL	46	10.5	B	80	5.4	A	96	21.9	C
WBT	467	10.8	B	488	8.0	A	623	16.2	B
WBR	252	16.8	B	263	11.0	B	293	3.9	A
NBL	52	38.3	D	65	39.8	D	109	40.2	D
NBT	231	38.4	D	192	39.8	D	302	39.3	D
NBR	61			89			118		
SBL	278	65.0	E	293	48.8	D	463	61.3	E
SBT	169	46.8	D	131	32.7	C	313	30.0	C
SBR	63			65			85		

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		8.3	A		5.7	A		7.6	A
EBL	1	1.7	A	3	1.2	A	6	2.5	A
EBT	423	4.1	A	557	5.0	A	746	6.0	A
EBR	3			7			3		
WBL	31	3.9	A	22	1.6	A	21	3.1	A
WBT	517	6.3	A	573	2.8	A	636	5.3	A
WBR	5			19			13		
NBL	6			3			5		
NBT		31.7	C	3	34.2	C		36.4	D
NBR	60	31.7	C	33	33.8	C	58	36.4	D
SBL	12			10			12		
SBT	1	31.8	C	2	34.2	C		36.4	D
SBR	3			5			2		

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		32.2	C		33.0	C		66.1	E
EBL	83	34.6	C	181	31.1	C	199	37.0	D
EBT	510	16.6	B	658	19.5	B	825	35.5	D
EBR	212			279			400		
WBL	176	39.3	D	263	48.8	D	424	102.5	F
WBT	671	42.2	D	767	42.2	D	843	48.5	D
WBR	194	60.7	E	397	55.8	E	293	61.0	E
NBL	301	55.9	E	269	65.9	E	270	67.1	E
NBT	1301	16.5	B	1030	25.8	C	1241	26.1	C
NBR	137			166			150		
SBL	205	92.4	F	396	48.1	D	320	52.6	D
SBT	934	33.6	C	981	22.5	C	1391	143.0	F
SBR	69	4.2	A	159	10.5	B	95	13.9	B

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	AM Volume	AM Delay (s)	AM LOS	Noon Volume	Noon Delay (s)	Noon LOS	PM Volume	PM Delay (s)	PM LOS
		7.9	A		15.8	A		16.5	B
EBL	18	8.7	A	42	16.4	B	62	14.9	B
EBT	708	9.9	A	788	21.6	C	1158	21.8	C
EBR	17			26			44		
WBL	21	2.5	A	117	4.5	A	70	5.1	A
WBT	774	2.1	A	722	5.7	A	817	1.9	A
WBR	37			152			118		
NBL	40	32.6	C	73	29.0	C	99	36.2	D
NBT	3	31.5	C	24	27.3	C	12	32.6	C
NBR	3	31.3	C	47	27.1	C	57	32.7	C
SBL	44	32.8	C	140	30.8	C	132	36.7	D
SBT		31.4	C	27	27.6	C	23	33.1	C
SBR	11			40			56		

APPENDIX C PEDESTRIAN AND BICYCLE COMFORT AND ACCESS

This appendix provides detailed methodology for pedestrian and bicycle comfort and access analysis and supplements the evaluation results that are provided in the East Arapahoe Transportation Plan Evaluation of Alternatives Report.

OVERALL ASSUMPTIONS AND DATA SOURCES

Assumptions

Fehr & Peers analyzed four primary Active Transportation options for the East Arapahoe corridor:

- Option 1a: curbside raised protected bike lane with amenity zone and multiuse path

Note: Option 1b (curbside raised protected bike lane with amenity zone and sidewalk) was also originally considered in Character District E but was dismissed based on Community Working Group feedback.

- Option 2: curbside amenity zone with raised protected bike lane separated from sidewalk
- Option 3: street-level protected bike lane with amenity zone and multiuse path
- Option 4: street-level buffered bike lane with curbside amenity zone and sidewalk (south side) or existing multiuse path (north side)

Figure C-1 shows the Character Districts in which each option was analyzed.

Figure C-1 Options Analyzed by Character District

	District A	District B	District C	District D	District E
Options Analyzed	Option 1A Option 2	N/A	Option 1A Option 3	Option 1A Option 3	Option 4

Data Sources and Methods

Each group of options was analyzed at the street segment level according to the level of comfort provided to people walking and people biking using the Streetscore+ tool, which is the same tool previously used to analyze existing conditions. Streetscore+ provides a score of 1 to 4 that indicates the level of comfort provided to people walking or people biking as shown in Figure C-2 below. For a detailed explanation of the Streetscore+ tool and methodology, see Appendix C.1.

Beyond user comfort on street segments between intersections, achieving a high level of user comfort at intersections is critical. Fehr & Peers analyzed each intersection and provided recommendations to the City as to intersection enhancements for people walking and biking that will achieve at least a Streetscore 2 for all users. For a description of recommended intersection treatments see Appendix C.3.

Figure C-2 Streetscore+ Scoring

PEDESTRIAN COMFORT AND ACCESS

Analysis Overview

Figure C-3 Pedestrian Comfort and Access Analysis Summary Table

Perceived ease of access or comfort for walking along or across the corridor	
Metric	Walking access/comfort along corridor.
Purpose	Describe how the alternatives may affect the ease of access or perceived comfort of walking along Arapahoe
Analysis Methodology	Streetscore+ tool using the following factors: ▪ Sidewalk width, quality and accessibility ▪ Landscape buffer and street streets ▪ Number of roadway lanes ▪ Roadway prevailing speed ▪ Lighting ▪ Heavy vehicles For a detailed explanation of factors see Appendix C.2

Evaluation Results

Key Findings

The With Build scenario will significantly improve conditions for pedestrians over the existing condition. In the existing condition there are many locations where no pedestrian facility (sidewalk or multi-use path) is provided; additionally, where pedestrian facilities are provided many segments score at Streetscore 4 for pedestrians which suggests a relatively low comfort level. The With Build condition achieves Streetscore 2 from Folsom Street to Westview Drive and Streetscore 3 from Westview Drive to 75th Street.

Figure C-4 Pedestrian Comfort Evaluation Score

SCORE -3 -2 -1 0 1 2 3

Worse → Better

Year	2015	2040	2040	2040	2040
Alternative	Existing Existing Bus Existing Travel Lanes Existing Multi-use Path	Alt 1: No-Build Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	Alt 2 Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	Alt 3 Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	Alt 4 Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
Walking	0	1	3	3	3

BICYCLE COMFORT AND ACCESS

Analysis Overview

Figure C-5 Bicycle Comfort and Access Analysis Summary Table

Perceived ease of access or comfort for bicycling along or across the corridor	
Metric	Bicycling access/comfort along corridor.
Purpose	Describe how the alternatives may affect the ease of access or perceived comfort of bicycling along Arapahoe
Analysis Methodology	Streetscore+ tool using the following factors: ▪ Bikeway type (bike lane, protected bike lane, shared-use path, etc.) ▪ Bikeway width ▪ Vertical separation from roadway lanes ▪ Horizontal separation from roadway lanes ▪ Visibility at minor streets ▪ Roadway prevailing speed ▪ Conflicting turn treatments ▪ Bikeway blockage (by vehicles) For people walking: ▪ Sidewalk width, quality and accessibility ▪ Landscape buffer and street streets ▪ Number of roadway lanes ▪ Roadway prevailing speed ▪ Lighting ▪ Heavy vehicles For a detailed explanation of factors see Appendix C.2

Evaluation Results

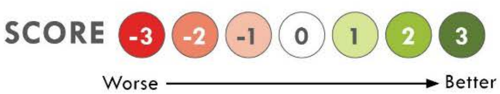
Key Findings

The With Build scenario will also significantly improve conditions for people biking.

For people biking in the on-street facility (in the existing condition either a shared lane or bike lane and in the With Build condition a protected bike lane or buffered bike lane), Streetscore in the With Build condition improves to Streetscore 2 from Folsom Street to 38th Street and Streetscore 3 from 38th Street to Westview Drive (compared to no facility provided or Streetscore 4 in the existing condition). Although the segment of East Arapahoe Avenue in the With Build scenario is Streetscore 4 this represents a significant improvement over the existing condition where no facility is provided.

For people biking in the off-street facility, Streetscore in the With Build condition improves to Streetscore 2 from Folsom Street to Westview Drive. East of Westview Drive the Streetscore is unchanged from the existing condition (Streetscore 3). Note that consistent with Community Working Group feedback no multi-use path is proposed on the south side of East Arapahoe Avenue east of Westview Drive. Additionally, a multi-use path may not be proposed west of 38th Street depending on Community Working Group and other public or decision maker input.

Figure C-6 Bicycle Comfort Evaluation Score



Year	2015	2040	2040	2040	2040
Alternative	**Existing** Existing Bus Existing Travel Lanes Existing Multi-use Path	**Alt 1: No-Build** Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	**Alt 2** Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	**Alt 3** Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	**Alt 4** Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
Biking	0	1	3	3	3

Appendix C.1

Streetscore+: Comfort and Level of Traffic Stress

Scoring Methodology for Bicyclists and Pedestrians

FEHR PEERS

Streetscore+: Comfort and Level of Traffic Stress Scoring Methodology for Bicyclists and Pedestrians

Prepared for City of Boulder

East Arapahoe Transportation Plan

April 2017

FEHR PEERS

Table of Contents

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INTRODUCTION

As jurisdictions are faced with increasingly complex transportation issues, the need for effective, low-data intensity, and customizable analysis tools to convey trade-offs and design alternatives to public and agency stakeholders is ever more apparent. Some existing tools, such as the Level of Traffic Stress methodology, better fit these needs and can be expanded to better meet the needs of bicycle and pedestrian planners. Other tools, such as the Highway Capacity Manual's Multi-Modal Level of Service methodology, are data intensive and onerous from a practitioner perspective and often feature complex calculations and outputs that are difficult to explain to non-transportation stakeholders. To address this need on active transportation and complete streets studies, Fehr & Peers prepared a quick-response tool – Streetscore+ – that allows jurisdictions to quickly and effectively compare design alternatives and convey project benefits to stakeholders.

Streetscore+ is an Excel-based tool that allows users to calculate comfort based indices for active transportation projects. For bicycle facilities, this builds off of the Level of Traffic Stress methodology developed by Mekuria, Furth, and Nixon (2012) with targeted enhancements to address shared use path, cycle track and bicycle boulevard comfort, making the methodologies consistent with the National Association of City Transportation Officials' (NACTO's) Urban Bikeway Design Guide, 2nd edition. For pedestrian facilities, Streetscore+ is calculated based on best practice guidance documentation, such as the NACTO Urban Streets Guide and safety research. Streetscore+ uses best practice guidance to measure bicycle and pedestrian comfort at links and intersections in urbanized environments. Streetscore+ easily and accurately assesses bicycle and pedestrian project benefits and trade-offs, assisting community and agency stakeholders in making informed decisions about complete streets projects, and assisting project development as a sketch-planning tool to ensure that key comfort considerations are included in bicycle and pedestrian designs.

BACKGROUND & DOCUMENTATION

BICYCLING COMFORT AND LEVEL OF TRAFFIC STRESS

Mekuria, Furth, and Nixon's 2012 *Low Stress Bicycling and Network Connectivity* report (also Transportation Research Board Annual Compendium of Paper, 2016) opened the door to the Level of Traffic Stress (LTS) methodology that has been the focus of practitioners for the last four years. The report takes a practical approach to defining and describing user tolerance along a given bikeway, balancing typically available data against a "weakest link" methodology informed by sound engineering judgment. Streetscore+ takes a the same approach but incorporates methodologies for bicycle boulevard and cycle tracks.

CYCLE TRACKS

With the current LTS methodology, off-street facilities and cycle tracks receive a LTS score of 1, indicating that they are ideal for bicyclists of all ages and abilities. Recent research and best practice guidance from the Federal Highway Administration (FHWA) Separated Bikeway Guide; NACTO Urban Bikeway Guide, 2nd edition; and similar publications, has demonstrated that cycle track design is complex and worthy of more rigorous LTS assessment.

To document a refined comfort methodology for separated bikeways, the *NACTO Urban Bikeway Guide, 2nd edition* was used to reference best practices in raised and in-roadway cycle track design, both with and without parking. NACTO differentiates between required and recommended features, which were either incorporated into Streetscore+ or were treated as assumptions. For example, the raised cycle track requirement of "bicycle lane word, symbol, and/or arrow markings (MUTCD Figure 9C-3) shall be placed at the beginning of a cycle track and at periodic intervals along the facility based on engineering judgment" is assumed to be present. By contrast, buffer space guidance is incorporated as a Streetscore+ variable. The three foot minimum buffer space between the cycle track and parking lane is assumed to represent a Streetscore+ of 3, as more than 3 feet will be more comfortable for pedestrians and enhanced accessibility for users for mobility impairments, which would instead return a Streetscore+ of 1. If the required elements are missing or deficient, then a Streetscore+ of 4 is typically received. Missing, deficient, or minimum dimension recommended features receive a slightly more lenient decrease in score, typically a Streetscore+2 or 3 depending on the importance of the design element for comfort and safety.

The NACTO Urban Bikeway Guide also includes two-way separated bikeways or side paths. The Streetscore+ methodology does not currently include those facility types, but these can be incorporated into future updates to the methodology.

BICYCLE BOULEVARDS

The *NACTO Urban Bikeway Guide, 2nd Edition* also proposes specific criteria for best practices in bicycle boulevard design, helping practitioners distinguish from potentially high-stress bicycle routes – with high auto volumes and speed – from true bicycle boulevards that are traffic calmed through low auto volumes and speeds and are truly appropriate for all ages and abilities. Academic research from Jennifer Dill and others have reinforced this distinction in terms of low-stress bikeways' ability to attract new ridership from the "Interested but Concerned" cohort.

The NACTO Guide states that bicycle boulevards "should be meet strict targets of fewer than 3,000 motor vehicles per day (1,500 preferred) and an 85th percentile speed of no more than 25 mph (20 mph preferred)."[1] Bicycle boulevard components such as connectivity and route identification/wayfinding, which are critical elements of successful implementations, are assumed in the bicycle boulevard Streetscore+ criteria. While these are key design elements, they are not considered to be major drivers of comfort. As a result, bicycle boulevards with 1,500 vehicles per day or less and speeds below 20 mph received a Streetscore+ of 1 while bicycle boulevards with over 3,000 vehicles per day and speeds above 25 mph received a Streetscore+ of 3 or 4.

The bicycle boulevard design elements at minor streets document bicycle travel time considerations with and without frequent stop signs at intersection with minor streets. While the NACTO Guide does not present a particular rule, it notes that giving right-of-way to the bicycle boulevard should be considered at all minor intersections.

PEDESTRIAN COMFORT

SIDEWALK ENVIRONMENT

The NACTO Urban Streets Design Guide (USDG) and engineering judgment provide the basis for pedestrian Streetscore+. The USDG provides critical, recommended, and optional parameters for the pedestrian environment consistent with best practices and documents supporting guidance and literature. Additional considerations of comfort are informed by practitioner and best practice experience.

The USDG specifically addresses the following topic areas:

[1] NACTO Urban Bikeway Guide, 2nd edition. "Bicycle Boulevard Route Planning" http://nacto.org/publication/urban-bikeway-design-guide/bicycle-boulevards/route-planning/

- **Usable Sidewalk Space**: A desired minimum through zone of six feet, with an absolute minimum of five feet, is listed as a critical strategy. Where sidewalk directly adjacent to moving traffic, the desired minimum is eight feet, providing a two-foot buffer for street furniture and utilities.
- **Driveways**: Maintaining sidewalk at-grade through driveways is describe as a critical strategy. As a result, frequent driveway curb cuts that impact the sidewalk zone, receive a Streetscore+ of 4.
- **Pedestrian-Scale Lighting**: This is a recommended strategy, resulting in sidewalks with only roadway lighting not receiving a Streetscore+ higher than 2.
- **Street Trees and Landscaping**: Street trees and tree wells that minimally impact sidewalk structure are a recommended strategy.
- **Speed**: Additional comfort measures, such as going beyond minimum dimensions for sidewalk and providing landscape buffer, are noted as important as speed increases. Design speed is also referenced as an overall safety consideration for urban streets, linking crash severity with increases in speed.

Other criteria that influence comfort that are not specifically addressed in the USDG include:

- **Sidewalk Quality**: Smooth, even surface is important from an accessibility perspective and creating great streetscape environments.
- **Number of Travel Lanes**: Increasing the number of travel lanes generally decreases the comfort and enjoyment of walking on that street.
- **Heavy Vehicle Volumes**: High volumes of heavy vehicles in the outside curb lane can create uncomfortable walking conditions for pedestrians even with buffer from the street.
- **Crosswalk Frequency**: In urban environment, having frequent marked crossing opportunities is important designate preferred crossing areas for pedestrians and to signal their presence to other roadway users.

UNCONTROLLED CROSSWALKS

Engineering considerations about when to install and enhance crosswalks based on pedestrian safety considerations have evolved significantly in the last ten years. Published in 2005, the Federal Highway Administration (FHWA) *Safety Effects of Marked Versus Unmarked Crosswalk at Uncontrolled Locations* (2005) report identified where marking crosswalks may lead to an increased safety risk based on average daily traffic volumes (ADT), speed, number of travel lanes, and presence of a median. Since then, case study research has focused on the efficacy of specific types of lighted enhancements that could be used to address crash risk, such as rectangular rapid flashing beacons (RRFBs) and pedestrian hybrid beacons (PHBs). Case studies have documented PHB efficacy in the 98th percentile[2] and RRFBs in the 80th

[2] Fitzpatrick, Turner, Brewer, et al. "Improving Pedestrian Safety at Unsignalized Crossings," NCHRP 562 (2006).

percentile.[3] RRFBs continue to have interim approval in the Manual of Uniform Traffic Control Devices (MUTCD), and PHBs, along with a warrant for their use, are included in the MUTCD.

SIGNALIZED CROSSWALKS

Signalized crosswalk criteria employ best practices and engineering judgment to determine comfort at crosswalks that already have a high level of traffic control given their location at signals. As a result, key variables may include:

- **Crossing Distance**: Lower crossing distance can reduce pedestrian exposure to vehicles and makes crossing easier for those with mobility impairments as well as seniors and students.
- **Accessibility**: While many signalized crosswalks have basic ADA requirements, additional consideration can be given to push buttons and curb ramps to better address the comfort of those with visual, auditory, and mobility impairments.
- **Right-Turn Slip Lanes**: In some environments, channelized right-turn lanes may be provided at intersections, which frequently allow for free or yield-controlled right-turn across crosswalks. Controlling speeds at these locations is important for pedestrian comfort.
- **LPI or Scramble**: Leading pedestrian interval (LPI) and pedestrian scramble should be considered as signalized pedestrian improvements in urbanized areas. To recognize the need for their consideration, these are included as a variable but not have no effect on the ultimate Streetscore+.

[3] FHWA, "Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks" (September 2010).

PEDESTRIAN STREETSCORE+ METHODOLOGY

The Pedestrian Streetscore+ has a parallel structure to the Level of Traffic Stress approach for bicyclists, using a 1-4 scale:

- **Streetscore+ 1**: Highly comfortable, pedestrian-friendly, and easily navigable for pedestrians of all ages and abilities, including seniors or school-aged children walking unaccompanied to school. These streets provide an ideal "pedestrian-friendly" environment.
- **Streetscore+ 2**: Generally comfortable for many pedestrians, but parents may not feel comfortable with children walking alone. Seniors may have concerns about the walking environment and take more caution. These streets may be part of a "pedestrian-friendly" environment where it intersects with a more auto-oriented roadway or other environmental constraints.
- **Streetscore+ 3**: Walking is uncomfortable but possible. Minimum sidewalk and crossing facilities may be present, but barriers are present that make the walking experience uninviting and uncomfortable.
- **Streetscore+ 4:** Walking is a barrier and is very uncomfortable or even impossible. Streets have limited or no accommodation for pedestrians and are inhospitable and possibly unsafe environment for pedestrians.

Like bicycle comfort, pedestrian comfort is based on a variety of factors, not just one variable, on both links and at intersections. Multiple variables ranging from the quality and presence of sidewalk to the conditions of the adjacent roadway (speed, number of travel lanes, and frequency of trucks) influence the pedestrian Streetscore+ methodology. Each variable is scored 1 through 4, with the highest stress (lowest comfort) condition resulting in the composite score. The weakest link approach accounts for the important role of intersections and gaps in the pedestrian environment, parallel to the Mekuria, Furth, and Nixon methodology for Level of Traffic Stress.

The Streetscore+ methodology is intended for use in urban and developed suburban areas. In highly urbanized areas or more rural areas, the tables should be contextualized to the local environment.

Example of the Weakest Link Methodology

A roadway with good quality sidewalk of ample width, landscaping, and buffer from the roadway (Streetscore+ 1) adjacent to a travel lane with high-speed traffic and no lighting (Streetscore+ 4) results in a composite Streetscore+ of 4.

PEDESTRIAN LINKS

Pedestrian Streetscore+ link criteria are presented in **Table 1** and discussed in the section below.

TABLE 1 STREETSCORE+ CRITERIA
SIDEWALKS IN URBANIZED AREAS

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Usable Sidewalk	>=8 feet	7 to 6 feet	<6 feet	No Sidewalk
Sidewalk Quality	Even, Smooth Surface	(no effect)	(no effect)	Cracks, Failing Pavement
Sidewalk Accessibility	Driveway Curb Cuts Out of the Sidewalk Zone	(no effect)	(no effect)	Frequent Driveway Curb Cuts into the Sidewalk Zone
Landscape Buffer and Street Trees	Yes, Continuous	Yes, Discontinuous[1]	No Landscaping	(no effect)
# of General Purpose Lanes	2-3	4-5	(no effect)	6+
Prevailing Speed	<=30 MPH	31-50 MPH	(no effect)	>50 MPH
Lighting	Pedestrian-Scale	Roadway Lighting	(no effect)	No Lighting[2]
Heavy Vehicle[3]	<=5%	5-8% with no buffer OR >8% with buffer	(no effect)	>8% with no buffer
Crosswalk Frequency[4]	Crosswalks Spaced 400 feet or Less	(no effect)	Crosswalks Spaced > 400 feet	(no effect)

1. Discontinuous is defined as not having a consistent effect on street life. Regularly spaced street trees may still feel like a "continuous" buffer and should receive a score of 1.
2. No lighting also includes ineffective roadway lighting.
3. Consider the percentage of heavy vehicles operating in the curbside travel lane as data is available.
4. In urbanized areas where pedestrians are expected, crosswalk frequency should be taken into consideration where there is demand based on land use and densities. As a general rule of thumb, consider marking a crosswalk if 20 pedestrians in a given hour may cross at that location.

Note: Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

SIDEWALK WIDTH, ACCESSIBILITY, AND QUALITY

Three variables are used to assess the sidewalk environment. First, sidewalk width is considered to ensure that pedestrians can comfortably walk side-by-side and pass each other. These dimensions are intended to be minimum standards for roadways in urbanized areas and may require modifications in highly dense areas or in lower-density contexts. Consistently deteriorated sidewalk quality scores an automatic

Streetscore+ 4, as a result of issues such as tripping hazards and accessibility. Similarly, sidewalk accessibility targets continuity of the walking experience through maintaining the sidewalk at grade through driveways, with minimal interference from driveways, curb cuts and slopes. Where driveways are frequent and do not maintain sidewalk grades through driveways, a Streetscore+ of 4 is received.

LANDSCAPE BUFFER AND STREET TREES

Street trees provide both buffered protection from through vehicles as well as shade for the pedestrian environment. Where this dual benefit is most pronounced is when street trees are spaced such that collectively they are perceived as a continuous buffer against vehicular traffic. As a result, a continuous buffer receives a Streetscore+ of 1. Where street trees are present but spacing is not as frequent or there are gaps in the landscaping, a Streetscore+ of 2 is received.

TRAVEL LANES, SPEED, AND HEAVY VEHICLES

The number of travel lanes, the prevailing automobile speeds, and the percentage of heavy vehicle traffic describe roadway conditions immediately adjacent to the pedestrian environment. The number of travel lanes is used as a way to describe the amount of automobile traffic on a roadway. Heavy vehicle percentage in the curbside travel lane should be input where data is available.

LIGHTING

Adequate visibility for pedestrians serves both security and safety functions. Lighting that is specifically designed for pedestrians receives a Streetscore+ of 1, with general roadway lighting receiving a Streetscore+ 2. No roadway lighting - or where roadway lighting is spaced so infrequently as to be rendered ineffectual for pedestrians - receives a Streetscore+ of 4.

CROSSWALK FREQUENCY

In urbanized areas with pedestrian traffic, crosswalks should be spaced every 400 feet or less to ensure adequate crossing opportunities. Where demand is present but crossing opportunities are limited, a Streetscore+ of 3 is assigned.

PEDESTRIAN STREETSCORE+ AT SIGNALIZED INTERSECTIONS

Table 2 presents the Pedestrian Streetscore+ criteria for signalized intersections. Given the large safety and comfort benefit offered by full traffic signals, the criteria focuses on crossing distance, accessibility, and intersection conflicts, as described below:

- **Crossing Distance**: Crossing distance is measured based on the number of travel lanes on the crosswalk approach. Narrower streets of 2-3 lanes received a Streetscore+ of 1, and roadways with 4-5 lanes received a Streetscore+ of 2. Wider roadway receives a score of 4. Medians do not receive additional consideration at signalized locations, as pedestrians are assumed to cross the street in one pedestrian phase.

- **Accessibility**: The presence of accessible elements, such as vibrotactile/audible push buttons at signals, are important to serving those with auditory and visual impairments. Signals that have auditory-only push buttons that meet ADA requirements, received a Streetscore+ of 2, and standard push buttons meeting ADA requirements received a Streetscore+ of 3. Accessibility is also assessed in terms of curb ramps. Directional curb ramps – two per corner – are desired to assist those with mobility and visual impairments, directing them into the crosswalk and receive a Streetscore+ of 1. One ramp per corner receives a Streetscore+ of 2, and if any of the curb ramps are missing, a Streetscore+ of 4 is received.

- **Channelized Right-Turns**: Right-turn slip lanes lengthen the distance that a pedestrian must cross to get from one side of the roadway to the other. As such, even when they are signal-controlled, they receive a Streetscore+ of 2. Pedestrian comfort decreases as right-turn lane slip lane control becomes yield (Streetscore+ 3) or becomes a free right-turn receiving a Streetscore+ of 4.

- **LPI or Scramble**: Leading pedestrian intervals (LPIs) and pedestrian scrambles give pedestrians priority at the intersection. Where these are present with no right-turn on red restrictions, Streetscore+ 1 is received. However, there is not a penalty for signals that do not incorporate LPIs or scrambles, so there is no overall effect on the total score from this variable.

TABLE 2 STREETSCORE+ CRITERIA
SIGNALIZED INTERSECTION CROSSWALKS IN URBANIZED AREAS

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Crossing Distance	2-3 general purpose lanes	4-5 general purpose lanes	(no effect)	6+ general purpose lanes
Pedestrian Signal Accessibility	Vibrotactile/ Audible Push Buttons[1]	Auditory Push Button Only	Standard Push Button Only	Missing Countdown Signals, Push Buttons Do Not Meet ADA Standards
Accessibility	Directional Curb Ramps	Diagonal Curb Ramps	(no effect)	Missing Curb Ramps
Right-Turn Slip Lanes	No RTOR	Signalized Slip Lane or Speed Table	Yield Control	No Control
LPI or Scramble	Yes with no RTOR	(no effect)	(no effect)	(no effect)

1. Signal may still operate on recall, but the push buttons allows for those with visual and/or auditory impairments to know when the signal phases change. Use of this at all signals is consistent with the Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG).

2. LPI or Scramble: Leading pedestrian intervals (LPIs) and pedestrian scrambles give pedestrians priority at the intersection. Where these are present with no right-turn on red restrictions, Streetscore+ 1 is received. However, there is not a penalty for signals that do not incorporate LPIs or scrambles, so there is no overall effect on the total score from this variable.

Note: Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

UNCONTROLLED CROSSWALKS

Table 3 presents uncontrolled pedestrian crossing Streetscore+ criteria. This method builds on *Safety Effects of Marked Versus Unmarked Crosswalk at Uncontrolled Locations* (FHWA, 2005) and adapts those findings to include specific recommended enhancements with the latest industry standards on flashing beacons. Based on available documentation of the efficacy of different types of beacons and practitioner perspective on maintenance, only rectangular rapid flashing beacons (RRFBs) and pedestrian hybrid beacons (PHBs) are considered as lighted crosswalk enhancements. Table 11 from the FHWA report is adapted to designate RRFBs specifically as an enhancement if a marked crosswalk is assumed to have a possible increase in pedestrian crash risk without enhancements, and to include PHBs and signals, if warranted, as the substantial crossing improvement required in order to mark a crosswalk if the location is designated as marked crosswalks alone are insufficient, as pedestrian crash risk may be increased by providing marked crosswalks alone. Geometric enhancements should always be considered.

The Streetscore+ is calculated by comparing **Table 3** against what the user has input regarding travel lanes, ADT, speed, median refuge, and crosswalk enhancements. If the input roadway characteristics and crosswalk enhancements, if any, match the recommended roadway characteristics and crosswalk enhancements, if any, then a Streetscore+ of 1 is received. If the recommended crosswalk enhancements do not match based on the roadway characteristics, then a Streetscore+ of 4 is received. The purpose of the binary scoring system is that the crosswalk either does or does not meet best practices in uncontrolled crosswalk safety. Therefore, if the existing or proposed crosswalk enhancements match the level of enhancements required based on speed, volumes, and number of travel lanes, then the Streetscore+ is considered to be "good" and received a Streetscore+ of 1. If not, then the Streetscore+ is considered to be "poor" or Streetscore+ 4.

TABLE 3 STREETSCORE+ CRITERIA
UNCONTROLLED PEDESTRIAN CROSSING

Roadway Type	Vehicle ADT <9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT > 12,000 to 15,000			Vehicle ADT > 15,000		
	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph
Two Lanes	A	A	B	A	A	B	A	A	C	A	B	C
Three Lanes	A	A	B	A	B	B	B	B	C	B	C	C
Multilane (4 lanes with raised median)	A	A	C	A	B	C	B	B	C	C[1]	C	C
Multilane (4 lanes without raised median)	A	B	C	B	B	C	C[1]	C	C	C[1]	C	C

Notes:

A=Level A, Signing and Striping Only;
B=Level B, Rapid Rectangular Flashing Beacons (RRFB);
C=Level C, Pedestrian Hybrid Beacon (PHB) or Signal.

Geometric treatments should also be considered prior to the implementation of recommended enhancement.

1. Depending on site observation, driver yielding rates, and other engineering considerations, RRFBs could be considered.

BICYCLE STREETSCORE+ METHODOLOGY

The Streetscore+ methodology for bicycle facilities builds on the Mekuria, Furth, and Nixon LTS methodology, with updates provided based on the NACTO Urban Bikeway Guide, 2nd edition documentation. As discussed in the literature review, two specific bicycle facility were identified in the existing LTS methodology when it comes to evaluating innovative bicycle facilities: cycle tracks and bicycle boulevards. Because both bikeway types hold a high potential to increase the number of bicycling trips, accurately assessing how their designs, which can vary greatly in level of protection and traffic calming, influence bicycle comfort is critical. The Streetscore+ methodology uses the LTS methodology as a base with the following modifications:

- **Bike Paths/Shared-Use Paths** – Bike paths and shared-use paths are automatically scored LTS 1 in the LTS methodology. The Streetscore+ methodology incorporates design criteria from the AASHTO Bike Design Guide, CROW Design Manual for Bicycle Traffic and California Highway Design Manual (HDM) to account for best practices in bike paths at the link and intersection level.
- **Cycle Tracks** (or "separated bikeways") – Off-street bikeways and cycle tracks are automatically scored LTS 1 in the LTS methodology. The Streetscore+ methodology incorporates design criteria from the NACTO Urban Bikeway Guide, 2nd edition to account for best practices in cycle track design at the link and intersection level.
- **Bicycle Boulevards** – Bicycle boulevards are treated as bicycle routes in the LTS methodology and do not include special consideration of traffic calming, volumes, or speeds. The Streetscore+ methodology incorporates design criteria from the NACTO Urban Bikeway Guide, 2nd edition to account for best practices in bicycle boulevards design on links and for major street crossings.

The Streetscore+ scoring methodology is intended to be fully parallel to the Mekuria, Furth, and Nixon's LTS methodology with a 1-4 scale. Four Types of Cyclists prepared by Roger Geller, Bicycle Coordinator for Portland Office of Transportation, describes these scales in detail and is attached for reference:

- Streetscore+ 1 - The lowest level of traffic stress and the design goal for a network that truly accommodates people of all ages and abilities. This level of traffic stress would allow children trained in traffic safety to bicycle to school by themselves as well as people "interested but concerned" about bicycling.[4]
- Streetscore+ 2 - The highest level of acceptable traffic stress for the "interested but concerned" segment of the population. This is the threshold for a "low traffic stress" bicycle network that truly accommodates people of all ages and abilities.

[4] Geller, "Four Types of Cyclists," Undated. https://www.portlandoregon.gov/transportation/article/237507

- Streetscore+ 3 - This level of traffic stress accommodates a much smaller segment of population - Geller's "enthused and confident" segment of the population - who are excited and more familiar with biking and will therefore accept a higher level of traffic stress.

- Streetscore+ 4 - This is a very high level of traffic stress that does not work for approximately 99% of the population according to Geller's classification scheme. Only the "strong and fearless" cohort will feel comfortable riding on these facilities.

SHARED-USE PATH – LINKS

The width of a bike path is specified in both the American Association of State Highway and Transportation Officials (AASHTO) Guide for Development of Bicycle Facilities and California Highway Design Manual (HDM). AASHTO specifies that a two-directional bike path should be at least 8 feet, with 8 feet being acceptable in rare circumstance. CA HDM suggests that bike paths be at least 8 feet, with 10 feet preferred. AASHTO and CA HDM also recommend a horizontal separation of at least 5 feet. Similar to cycle tracks with parking, NACTO acknowledges that driveways and minor street crossings create potential visibility issues between bicyclist and drivers. As a result, it recommends that parking be prohibited 30 feet from either side of an intersection to improve driver-bicyclist sight lines.

TABLE 4: STREETSCORE+ CRITERIA
BIKE PATHS/SHARED-USE PATHS IN ROADWAY RIGHT-OF-WAY (SIDEPATHS)

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Shared-use path width	≥12′	≥10-12′	≥8-10′	<8′
Horizontal separation	≥5′	(no effect)	<5′	(no effect)
Visibility at Minor Streets	Parking prohibited ≥30′ from intersections	(no effect)	Parking prohibited <30′ from intersections	(no effect)
Prevailing Speed	<=30 MPH or less	31 MPH – 50 MPH	(no effect)	>50 MPH

SHARED-USE PATHS AT SIGNALIZED INTERSECTIONS

CROW addresses conflicting right and left-turn treatments in stating that "sub-conflicts between motor vehicles and bicycles are not recommended if…a two-way cycle track is involved, as some of the cyclists will then appear from an unexpected direction." Right turn slip lanes are scored similarly to crosswalks at signalized intersections, with a Streetscore+ of 2 due to a lengthened crossing distance. Signalized intersections in particular require consideration of protected intersection treatments, protected signal phasing, and consideration of left- and right-turn auto movements across the cycle track.

TABLE 5: STREETSCORE+ CRITERIA
BIKE PATHS/SHARED-USE PATHS IN ROADWAY RIGHT-OF-WAY (SIDEPATHS) AND TWO-WAY CYCLETRACKS AT SIGNALIZED INTERSECTIONS

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Conflicting right-turn treatment	Protected-only conflicting right-turns[1]	Right-turn slip lane with speed table[2]	Permissive conflicting right-turns[1]	(no effect)
Conflicting left-turn treatment	Protected-only conflicting left-turns[1]	(no effect)	(no effect)	Permissive (or protected-permissive) conflicting left-turns[1]
Bicyclist turns[3]	Protected intersection	Painted treatments: two-stage turn queue box or bike box	Crosswalks/curb ramps with pedestrian push buttons	(no effect)

CYCLE TRACK – LINKS

NACTO guidance details separate methodologies for raised cycle tracks versus in-roadway cycle tracks as the designs differ. Parking is another critical variable that affects design elements, as a result with and without parking criteria are presented for each. For each set of criteria, it is assumed that the cycle track is a direct route with clear wayfinding signs and pavement legends to help guide bicyclists of all ages and abilities on the corridor.

RAISED CYCLE TRACKS WITH PARKING

NACTO states a preferred dimension of 6.5 feet for a raised cycle track riding surface to allow bicyclists to travel side-by-side or to pass other bicyclists with a minimum of 5 feet. Adjacent to parking a minimum 3 foot buffer is required to allow passenger loading and protect bicyclists from dooring incidents. NACTO acknowledges that driveways and minor street crossings create potential visibility issues between bicyclist and drivers. As a result, it recommends that parking be prohibited 30 feet from either side of an intersection to improve driver-bicyclist sight lines.

Blockages to the cycle track, such as with double-parked vehicles, may be enabled if mountable curb or a cycle track at half the curb height is used. If the cycle track design specifies designated loading zones that are attractive for commercial and/or passenger loading or if the design physically prevents the cycle track from being blocked by vehicles, a Streetscore+ of 1 is received. If the design does not address curb management or if the cycle track can be blocked by vehicles, a Streetscore+ of 3 is received. **Table 4** presents the methodology.

TABLE 6: STREETSCORE+ CRITERIA
RAISED CYCLE TRACK WITH PARKING

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Buffer Width	>3 feet	(no effect)	3 feet	<3 feet
Bicycle Lane Width	>=6.5 feet	5 to 6.5 feet	(no effect)	<5 feet
Visibility at Minor Streets	Parking prohibited >=30 feet from intersections	(no effect)	Parking prohibited <30 feet from intersections	(no effect)
Cycle Track Blockage	Vehicle loading is accommodated through design	(no effect)	Vehicle loading is not accommodated through design and blockages are expected	(no effect)

Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

TWO-WAY (RAISED AND IN-STREET) CYCLE TRACKS WITH PARKING

NACTO states a desired minimum buffer dimension of 3 feet for two way cycle tracks; greater than or equal to 4 feet is preferred. A solid or raised buffer is the most comfortable, receiving a Streetscore+ of 1 and a painted buffer with a vertical element reducing the Streetscore+ to at most a 2. The NACTO Urban Bikeway Design Guide recommends a desired minimum cycle track width of 12 feet, with a minimum of 8 feet in constrained conditions. The NACTO guide recommends that a no-parking area is 30 feet from each side of the crossing.

RAISED CYCLE TRACKS WITHOUT PARKING

Raised cycle tracks without parking generally use the same criteria as raised cycle tracks with parking

TABLE 7: STREETSCORE+ CRITERIA
TWO-WAY (RAISED AND IN-STREET) CYCLE TRACK WITH PARKING

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Buffer Width[1]	>=4 feet	>=3-4′	(no effect)	<3 feet
Buffer Type	Solid/raised (includes raised two-way cycle tracks)	Painted + some vertical elements	(no effect)	(no effect)
Two-way Cycle Track Width[2]	≥12′	≥10-12′	≥8-10′	<8′
Visibility at Minor Streets and Driveways[3]	Parking prohibited ≥30′ from intersections	(no effect)	Parking prohibited <30′ from intersections	(no effect)
Cycle Track Blockage	Vehicle loading is accommodated through design	(no effect)	Vehicle loading is not accommodated through design and blockages are expected	(no effect)

except that adjustments are made to the horizontal separation criterion and a speed criterion is introduced. Separation can be provided by either a mountable curb with a desired 4:1 slope or a furnishing zone buffer separating the cycle track from the travel lane per NACTO. The highest score that the cycle track with mountable curb can receive is Streetscore+ 2. Raised cycle tracks with mountable curbs less the NACTO-recommended minimum one (1) foot buffer receive Streetscore+ 3. Where a furnishing zone buffer of at least 3 feet is provided, raised cycle tracks receive Streetscore+ 1.

With no parked cars to buffer the cycle track from the travel lane, speed is introduced to account for traffic stress associated with riding adjacent to fast moving vehicles. The Streetscore+ is balanced against the network-planning desire to site cycle tracks on higher speed roads, such as arterials. As a result, Streetscore+ of 1 still allows for a prevailing speed of up to 30 MPH.

Operable cycle track surface width, cycle track blockages, and visibility at minor streets are still included. Because parking is not included, the visibility at minor streets is instead defined by the sight triangle between the driver and the bicyclist. **Table 5** presents the methodology.

TABLE 8: STREETSCORE+ CRITERIA
RAISED CYCLE TRACK WITHOUT PARKING

Criteria		Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Separation	***Mountable Curb with 4:1 Slope***	(no effect)	>= 1 foot	<1 foot	(no effect)
	Furnishing Zone Buffer	>=3 feet	(no effect)	<3 feet	(no effect)
Speed Limit or Prevailing Speed		<=30 MPH or less	31 MPH – 35 MPH	36 MPH – 45 MPH	>45 MPH
Bicycle Lane Width		>=6.5 feet	5 to 6.5 feet	(no effect)	<5 feet
Visibility at Minor Streets		Design accommodates 20 feet for sight triangle to the cycle track from minor street crossings and 10 feet from driveway crossings	(no effect)	Sight triangles <20 feet / 10 feet	(no effect)
Cycle Track Blockage		Vehicle loading is accommodated through design	(no effect)	Vehicle loading is not accommodated through design and blockages are expected	(no effect)

Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

TWO-WAY (RAISED AND IN-STREET) CYCLETRACK WITHOUT PARKING

NACTO states a desired minimum buffer dimension of 3 feet for two way cycle tracks; greater than or equal to 4 feet is preferred. A solid or raised buffer is the most comfortable, receiving a Streetscore+ of 1 and a painted buffer with a vertical element reducing the Streetscore+ to at most a 2. The NACTO Urban Bikeway Design Guide recommends a desired minimum cycle track width of 12 feet, with a minimum of 8 feet in constrained conditions. Given the lack of parking buffer, this facility is sensitive to the prevailing speed on the roadway.

TABLE 9: STREETSCORE+ CRITERIA
TWO-WAY (RAISED AND IN-STREET) CYCLE TRACK WITHOUT PARKING

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
***Buffer Width*[1]**	>=4 feet	>=3-4′	(no effect)	<3 feet
Buffer Type	Solid/raised (includes raised two-way cycle tracks)	Painted + some vertical elements	(no effect)	(no effect)
***Two-way Cycle Track Width*[2]**	≥12′	≥10-12′	≥8-10′	<8′
***Visibility at Minor Streets and Driveways*[3]**	Parking prohibited ≥30′ from intersections	(no effect)	Parking prohibited <30′ from intersections	(no effect)
Speed Limit of Prevailing Speed	≤30 MPH	>30 MPH – 35 MPH	>35 MPH – 40 MPH	>40 MPH
Cycle Track Blockage	Vehicle loading is accommodated through design	(no effect)	Vehicle loading is not accommodated through design and blockages are expected	(no effect)

IN-ROADWAY CYCLE TRACKS WITH PARKING

Parking-protected in-roadway cycle tracks have similar Streetscore+ criteria to raised cycle tracks, but include additional details on the operable cycle track lane width as well as the type and width of buffer.

Per NACTO, the desired width of the operable cycle track area is 7 feet in uphill portions or where bicycle volumes are higher and is otherwise 6 feet, allowing for a Streetscore+ of 1. A minimum width of 5 feet is required, resulting in a Streetscore+ of 2.

While parking is assumed in this scenario, buffer type offers an additional level of protection for the cycle track. If the buffer is solid or raised, the maximum Streetscore+ of 1 is received. If the buffer is painted and has some vertical elements, such as soft-hit posts or rubber curb, a Streetscore+ of 2 is calculated. While the highest score a paint-only cycle track can receive is 3. Likewise, the desired minimum dimension for parking and the parking-side buffer is 11 feet with a minimum 3 foot buffer. Parking widths of 7 feet that still provide the 3 foot buffer receive a score of 3 to account for added friction and more constrained cross-section. **Table 6** presents the methodology.

TABLE 10: STREETSCORE+ CRITERIA
IN-ROADWAY CYCLE TRACK WITH PARKING

Criteria		Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Bicycle Lane Width	***Uphill or High Volume***	>=7 feet	<=6 feet	(no effect)	(no effect)
	Otherwise	>=6 feet	<=5 feet	(no effect)	(no effect)
Buffer Type		Solid/Raised	Painted + Some Vertical Elements[1]	Painted Only	(no effect)
Parking + Buffer Width		>=11 feet, with >3 feet buffer	(no effect)	10 feet total, with minimum 3 feet buffer	<10 feet total or buffer <3 feet
Visibility at Minor Streets		Parking prohibited 30 feet from intersections	(no effect)	Sight triangles <30 feet	(no effect)
Cycle Track Blockage		Vehicle loading is accommodated through design	(no effect)	Vehicle loading is not accommodated through design and blockages are Expected	(no effect)

1. Such as soft-hit posts, landscape planters, and other vertical elements that provided additional protection but do not provide a continuous raised barrier.

Note: Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

IN-ROADWAY CYCLE TRACKS WITHOUT PARKING

In-roadway cycle tracks without parking includes the same criteria as in-roadway cycle tracks with parking, but also includes the speed criteria to account for the lack of parking buffer. Visibility at minor streets focuses on sight triangles since parking is prohibited in this condition. **Table 7** presents the methodology.

TABLE 11 STREETSCORE+ CRITERIA
IN-ROADWAY CYCLE TRACK WITHOUT PARKING

Criteria		Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Bicycle Lane Width	***Uphill or High Volume***	>=7 feet	<=6 feet	(no effect)	(no effect)
	Otherwise	>=6 feet	<=5 feet	(no effect)	(no effect)
Buffer Type		Solid/Raised	Painted + Some Vertical Elements[1]	(no effect)	(no effect)

Buffer Width	>=4 feet	3 feet	<3 feet	(no effect)
Visibility at Minor Streets	Design accommodates sight triangle of 20 feet to the cycle track from minor street crossings and 10 feet from driveway crossings	(no effect)	Sight triangles less than 20 feet and 10 feet	(no effect)
Speed Limit or Prevailing Speed	<=30 MPH or less	31 MPH – 35 MPH	36 MPH – 45 MPH	>45 MPH
Cycle Track Blockage	Vehicle loading is accommodated through design	(no effect)	Vehicle loading is not accommodated through design and blockages are Expected	(no effect)

1. Such as soft-hit posts, landscape planters, and other vertical elements that provided additional protection but do not provide a continuous raised barrier.

Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

CYCLE TRACKS AT SIGNALIZED INTERSECTIONS

Intersections are a very sensitive design area for cycle tracks and have a high potential to provide a weak link in an otherwise robust facility. Signalized intersections in particular require consideration of protected intersection treatments, protected signal phasing, and consideration of left- and right-turn auto movements across the cycle track. The Streetscore+ methodology for cycle tracks is calculated by intersection approach, similar to the LTS methodology. It is assumed that clear wayfinding and pavement legends provide guidance to bicyclists through these intersections. **Table 8** presents the Streetscore+ criteria for cycle tracks at signalized intersections.

TABLE 12 STREETSCORE+ CRITERIA
CYCLE TRACKS AT SIGNALIZED INTERSECTIONS

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Separation	Separate signal Phasing[1] for cycle track with barrier[2] at intersection approach	Barrier and good sightlines but permitted turns (RT <150 vph) during cycle track green phase	Barrier and good sightlines but permitted turns (RT >150 vph) during cycle track green phase OR No barrier separation i.e., mixing zone or striped bike lane with right-turn pocket (RT<150 vph)	No barrier separation i.e., mixing zone or striped lane with right-turn pocket (RT >150 vph)
Bicycle Left-Turns	Protected Intersection	Painted Treatments: Two-Stage Turn Box or Bike Box	Break in separation/barrier for bikes to merge out	(no effect)
Conflicting Left-Turn Treatments	Protected Left-Turns	(no effect)	Permissive Left-Turns	(no effect)

1. Either with protected right-turn phase or dedicated bicycle only phase that does not overlap with permitted turning autos or opposing auto movements.
2. Barrier would be a solid, raised elements (curb, landscape-buffer, etc) or a protected intersection that remain up until the intersection.

Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

SEPARATION

A variety of methods can be used to separate conflicts between turning vehicles and through bicyclists at signalized intersections. Separate signal phasing between through bicyclists and turning vehicles entirely remove the conflict, therefore receiving a Streetscore+ of 1. This treatment should include a solid barrier up to the intersection to reinforce the cycle track protection.

The protected intersection treatment alone substantially reduces the potential and impact of conflict, putting bicyclists ahead of turning vehicles and reducing the speeds of right-turning vehicles; however, they do not remove the conflict all together. Where these treatments are implemented with right-turn vehicle volumes per hour less than 150, a Streetscore+ of 2 is provided. Where right-turn volumes are higher than 150 vehicles per hour or where mixing zones or striped bike lanes with low right-turn volumes are striped, a score of 3 is received. This accounts for the real drop in protection of the cycle track.

BICYCLE LEFT-TURNS

Cycle track designs should accommodate left-turns out of the cycle track. Streetscore+ 1 is reserved for protected intersections, which facilitate two-stage turns with a raised barrier and full protection from the roadway. Painted facilities allowing bicyclists to cross in two stages – two stage turn boxes and bike boxes – received a Streetscore+ of 2. Breaks in cycle track barriers or similar treatments requiring bikes to confidently move out of the cycle track and merge across lanes receive a Streetscore+ of 3.

CONFLICT LEFT-TURN TREATMENTS

While right-hook conflicts are the commonly discussed conflict for bicyclists, auto left-turns across the cycletrack should also be considered. Protected vehicular left-turns which fully remove the bicyclist-auto conflicts receive a Streetscore+ of 1. Permissive left-turns receive a Streetscore+ of 3, as that phasing does not mitigate the conflict.

CYCLE TRACKS AT STOP-CONTROLLED AND UNCONTROLLED INTERSECTIONS

Cycle tracks at stop-controlled or uncontrolled intersections have different needs than signalized intersections which are likely to have higher traffic volumes and more turning conflicts. The focus of stop-controlled and uncontrolled is on conflicts with right-turn vehicles and maintaining good sightlines. **Table 9** presents the methodology.

TABLE 13 STREETSCORE+ CRITERIA
CYCLE TRACKS AT STOP-CONTROLLED AND UNCONTROLLED INTERSECTIONS

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
Approach Geometry	-	Separation or barrier with permitted right turns <150 vph	Through bike lane and right-turn lane OR mixing zone with <150 vph	Through bike lane and right-turn lane OR mixing zone with >150 vph

Visibility at Minor Streets	Design accommodates sight triangle of 20 feet to the cycle track from minor street crossings and 10 feet from driveway crossings. If parking, prohibited 30 feet from Intersection	(no effect)	Sight triangles less than 20 feet /10 feet	(no effect)

Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

BICYCLE BOULEVARD – LINKS

The Streetscore+ methodology incorporates design criteria from the NACTO Urban Bikeway Guide, 2nd edition to account for best practices in bicycle boulevard design at the link-level. The Mekuria, Furth, and Nixon LTS methodology evaluates a bicycle boulevard using the same criteria – speed and travel lanes – as any other bicycle route. Given the sensitivity of bicycle boulevards to average daily traffic (ADT) and speeds, Streetscore+ for bicycle boulevards requires ADT and posted speed limit (ideally prevailing speed) and incorporates a higher sensitivity to those two factors for designated bicycle boulevards. To account for bicyclist delay on bicycle boulevards, the frequency of controlled intersection was also introduced to account for less desirability associated with losing momentum when stopping/starting at controlled intersections. **Table 10** presents the methodology.

TABLE 14: STREETSCORE+ CRITERIA
BICYCLE BOULEVARD LINKS

Criteria	Streetscore+ 1	Streetscore+ 2	Streetscore+ 3	Streetscore+ 4
ADT on Link	<1,500	1,500-3,000	3,000-6,000	>6,000
Speed	<=20 MPH	Up to 25 MPH	(no effect)	>25 MPH
Number of Stop Signs per Mile	2	4	6	>6

Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

AVERAGE DAILY TRAFFIC (ADT)

Bicycle boulevards are typically located on two-lane residential streets. As such, the number of travel lanes does not provide substantial differentiation in the traffic stress on the facility. As a result, only ADT is used. NACTO states that 1,500 ADT is desirable, with up to 3,000 allowed on limited section of the corridor. As a result, these were assigned to Streetscore+ 1 and 2, respectively.

SPEED

The NACTO Urban Bikeway Guide recommends that bicycle boulevards should have a target speed of 20 MPH to maximize bicycle comfort and safety. Where speed is higher than 20 MPH, speed management strategies should be used to lower the 85th percentile speed. Given this target speed, bicycle boulevards with 20 MPH or slower speeds are given a Streetscore+ of 1, upt to 25 MPH a Streetscore+ of 2, and greater than 25 MPH is Streetscore+ 3.

NUMBER OF STOP-CONTROLLED INTERSECTIONS PER MILE

The NACTO Urban Bikeway Guide states that at intersections with local streets and minor collectors, bicycle boulevards should have right-of-way priority to reduce or minimize delay by limiting the number of stop signs along the route. Segments of at least one half mile with continuous travel i.e., no stop sign controls are desirable. A metric of the number of controlled intersections per mile was developed to account for bicycle boulevard priority and bicyclist delay. The metric considers stop-control on the bicycle boulevard and not signalized intersections.

BICYCLE BOULEVARDS – MAJOR STREET CROSSINGS

The bicycle boulevard major street crossing methodology proposes a parallel approach to uncontrolled crosswalk locations. While the efficacy of RRFBs and PHBs are better documented for pedestrians, many cities are beginning to utilize these enhancements on bicycle boulevards. Given the sensitive nature of these crossings for bicyclists of all ages and abilities, the needs are assumed to be similar to that of a pedestrians at uncontrolled crosswalks at major streets. As detailed in the Pedestrian Streetscore+ section, this method assumes a three-tiered level of crossing enhancements:

- A: Crosswalk Enhancements with Signing and Striping Only
- B: Crosswalk Enhancement with Signing, Striping, and Rectangular Rapid Flashing Beacons (RRFBs). Note that this assumes bicyclists would be able to actuate the RRFB through a separated push button located adjacent to the travelway.
- C: Crosswalk Enhancement with Signing, Striping, and Pedestrian Hybrid Beacon (PHB) or Traffic Signal. Note that this assumes bicyclists would be able to actuate the PHB or signal through bicycle detection.

The Streetscore+ for bicycle boulevard crossings therefore defines the minimum recommended design elements based on ADT, number of travel lanes, and speed, as presented in Table 11. Based on user input regarding the presence of signing and striping only or beacons, Streetscore+ delivers a score of 1 if the level of treatment matches the recommended treatment, and a score of 4 if the existing/proposed treatments input by the user do not match recommended treatments. In addition to the signing, striping, and beacon and/or signal enhancements, users should also examine the feasibility of geometric improvements at the crosswalk, such as curb extensions or median refuges.

TABLE 15 STREETSCORE+ CRITERIA
BICYCLE BOULEVARD MAJOR STREET CROSSING

Major Street Criteria	Vehicle ADT <9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT > 12,000 to 15,000			Vehicle ADT > 15,000		
	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph
Two Lanes	A	A	B	A	A	B	A	A	C	A	B	C
Three Lanes	A	A	B	A	B	B	B	B	C	B	C	C
Multilane (4 lanes with raised median)	A	A	C	A	B	C	B	B	C	C[1]	C	C
Multilane (4 lanes without raised median)	A	B	C	B	B	C	C[1]	C	C	C[1]	C	C

Notes:
1. Depending on site observations, driver yielding rates, and other engineering considerations, RRFBs could be considered. Geometric treatments should also be considered prior to the implementation of recommended enhancement.

A=Level A, Signing and Striping Only
B=Level B, Rapid Rectangular Flashing Beacons (RRFB)
C=Level C, Pedestrian Hybrid Beacon (PHB) or Signal
Same as the Mekuria, Furth, and Nixon (2012) methodology, "no effect" signifies that there is no further decrease in comfort for that variable.

Conclusion

The Streetscore+ methodology builds on Mekruia, Furth, and Nixon's LTS methodology to incorporate a finer grain understanding of bicyclist comfort on cycle tracks and bicycle boulevards and creates a parallel methodology to measure pedestrian comfort on streets and at intersections. This methodology is intended to be easy-to-use with the typical datasets that transportation practitioners utilize on corridor studies and active transportation projects. As a result, transportation practitioners can use this tool in a sketch planning capacity to further active transportation designs and more accurately understand the impacts of design decisions on comfort and stress tolerance for people who walk and bike. Where data may not be available or local conditions may warrant adjusted criteria, the tool is intended to be flexible and customizable.

Appendix C.2

Detailed Description of Factors Affecting StreetScore

BACKGROUND

This technical appendix summarizes the analysis of pedestrian and bicycle infrastructure improvements for two proposed alternatives—Option 1 and Option 2—for East Arapahoe Avenue from Folsom Street to 75th Street. For each option, the proposed multimodal improvements (pedestrian, on-street bicycle, and off-street bicycle) are analyzed for each segment and intersection. This analysis consists of a level of comfort rating and a list of infrastructure components included for each. Bicycle intersection improvements are divided into low traffic impact and high traffic impact improvements, with low traffic impact representing no major changes to the intersection geometry and signal operations and high traffic impact representing changes to intersection geometry and signal operations necessary to achieve the project's bicyclist comfort goals.

Level of comfort for both links and intersections of pedestrian, on-street bicycle, and off-street bicycle infrastructure was measured using Fehr & Peers StreetScore+ tool and methodology, described in the Scoring Methodology section and in **Appendix A**.

Typical elements included in each option include:

Pedestrian

- Sidewalk: six to twelve feet based on surrounding context; for pedestrians only.
- Multiuse path: ten to twelve feet, shared by people walking and people biking.

On-Street Bicycle

- Raised Protected Bike Lane: bicycle facility inside of the curb at the level of the sidewalk or multiuse path; separated from both the travel lane and the sidewalk/multiuse path by an amenity zone.
- In-Roadway Protected Bike Lane: bicycle facility outside of the curb at street level, separated from travel lanes by a vertical buffer such as a concrete curb.
- Buffered Bike Lane: bicycle facility outside of the curb at street level, separated from travel lanes by a painted buffer.

Off-Street Bicycle

- Multiuse path: a facility shared by people walking and people biking intended for two-way travel, ten to twelve feet wide, and seperated from travel lanes.

See **Figure 1a** for the existing pedestrian facilities, on-street bicycle facilities, and off-street bicycle facilities along the western portion of corridor (west of Flatirons Golf Course), as well as connections from the surrounding area. See **Figure 1b** for the same information in the eastern portion of the corridor (east of Flatirons Gold Course).

SCORING METHODOLOGY

Fehr & Peers' StreetScore+ methodology and tool quickly and effectively calculates the bicycle and pedestrian level of comfort for bicycle and pedestrian infrastructure. Calculations for the bicycle facilities were derived from the Level of Traffic Stress (LTS) methodology developed by Mekuria, Furth, and Nixon (2012), the National Association of City Transportation Officials (NACTO's) *Urban Bikeway Design Guide* (2^{nd} edition), and Roger Geller's (Bicycle Coordinator for Portland Office of Transportation) "Four Types of Cyclists". Pedestrian facilities were calculated using best practice guidance documentation from the NACTO *Urban Streets Guide* and other safety research.

The scoring methodology for StreetScore+ considers and builds upon these resources, as well as best practice data for bicycle and pedestrian infrastructure. Each input is scored one through four, with a score of four as the highest stress (lowest comfort). The various criteria used to determine a score applies the "weakest link" approach. That is, a segment or intersection receives the score of its lowest scoring criteria. For example, even if a good quality sidewalk has ample width, landscaping, and buffer, if the sidewalk is also adjacent to a travel lane with high-speed traffic and no lighting, it would be rated as a StreetScore 4 (also called "Pedestrian LOS 4" or "Bicyclist LTS 4"). Descriptions of the StreetScore+ methodology can be found below in **Table 3** for each of the improvement types. The white paper outlining this methodology is in **Appendix A**.

TABLE 3: STREETSCORE+ RATING DESCRIPTION PER INFRASTRUCTURE TYPE

	Pedestrian	On-Street Bicycle	Off-Street Bicycle
1	Highly comfortable, easily navigable for pedestrians of all ages and abilities, including unaccompanied children walking to school.	Presents little traffic stress and attractive enough for a relaxing bike ride that is suitable for cyclists of all ages and abilities, including children. Intersections are easy to approach and cross.	Lowest level of traffic stress, accommodates people of all ages and abilities, including children and those that are "interested but concerned" about bicycling.
2	Generally comfortable for many pedestrians, but parents may have concerns letting children walk alone or seniors needing to take caution.	Suitable to most adult cyclists but not ideal for children or those with other abilities. Crossings are not difficult for most adults.	The highest level of acceptable stress for the "interested but concerned" population, and represents the lowest threshold for accommodating all ages and abilities.
3	Walking is uncomfortable bus possible, barriers are present that make the walking experience uninviting or uncomfortable.	Presents more traffic stress, though still less than riding in mixed traffic, and is still suitable for most adults. Crossings are still acceptably safe to most adults.	Accommodates a much smaller segment of population and includes only the "enthused and confident" cyclist that is more familiar with biking.
4	Walking is a barrier and is very uncomfortable or even impossible. Streets are inhospitable and possibly unsafe environment for pedestrians.	Very high level of stress that does not accommodate a majority of the adult population except for the "strong and fearless".	Does not work for approximately 99% of the population and accommodates only the "strong and fearless" cohort.

Sources: Mekuria, Furth, and Nixon (2012); NACTO *Urban Bikeway Design Guide*, 2nd edition; and Roger Geller's "Four Types of Cyclists"

EXISTING CONDITIONS

PEDESTRIAN INFRASTRUCTURE

Existing pedestrian facilities along East Arapahoe Avenue include at minimum a sidewalk of five feet to a maximum of a 12-foot multiuse path. To the west of Foothills Parkway, most sidewalks or multiuse paths have a buffer; east of Foothills Parkway, most facilities do not have a buffer. There are gaps in the existing sidewalk and multiuse path network.

All signalized intersections along the corridor include push buttons and countdown signals. Most also include directional curb ramps and, where right-turn slip lanes exist, speed tables at the pedestrian crossings. Existing crossing distances include five general purpose through lanes from Folsom Street to 29th Street, six lanes from 29th Street to 55th Street, five lanes from 55th Street to 63rd Street, and two lanes from 63rd Street to 75th Street. Gaps that exist for crossing infrastructure along East Arapahoe include diagonal or missing curb ramps at four intersections and free-flowing right-turn slip lanes at 75th Street.

See **Figure 2** for a map illustrating the pedestrian level of service (LOS) rating of the existing conditions for each pedestrian facility segment and intersection.

BICYCLE INFRASTRUCTURE

On-Street

Existing on-street bicycle infrastructure includes a bike lane both eastbound and westbound from 55th Street to Westview Drive and a bike lane or wide shoulder both eastbound and westbound from Westview Drive to 75th Street. Intersection treatments along this segment consist of mixing-zones at right-turn pockets. No designated on-street bicycle facilities exist west of 55th Street.

Off-Street

Existing off-street infrastructure includes a 12-foot multiuse path along much of the north side of East Arapahoe Avenue and a noncontiguous multiuse path along portions of the south side which fluctuates between a sidewalk and a multiuse path. A 12-foot multiuse path exists from Folsom Street to 30th Street and continues between Foothills Parkway and 55th Street with large gaps. The eastern part of the corridor consists of either a sidewalk or a 10-foot multiuse path. The multiuse path west of Foothills Parkway has an amenity zone, while the majority of the multiuse paths to the east do not have an amenity zone. The crossing treatments at multiuse paths along the corridor are either right-turn slip lanes with a speed table or crosswalks/curb ramps with pedestrian push buttons. There are a number of intersections with protected permissive and permissive turning movements (right and left) creating conflicts for bicyclists traveling along the corridor.

See **Figure 3** for a map illustrating the bicyclist LTS rating of the existing conditions for each bicycle facility segment and intersection.

OPTION 1

PEDESTRIAN INFRASTRUCTURE

Segments

The proposed pedestrian improvements and associated pedestrian LOS along segments for Option 1 are:

- Folsom Street to Westview Drive: 12-foot multiuse path with a 17 to 18-foot buffer (in the form of an amenity zone and bicycle facility).
    - **Pedestrian LOS 2**: Key contributing factors are the amenity zone, four general purpose thru-lanes, and a posted speed limit of less than 45 mph.
- Westview Drive to 75th Street: 10-foot multiuse path with an 18-foot buffer (in the form of an amenity zone and bicycle facility).
    - **Pedestrian LOS 4**: The key contributing factor is the posted speed limit greater than 45 mph.

A pedestrian LOS 1 for pedestrian facilities is not achievable for East Arapahoe Avenue due to the number of general purpose through lanes and high posted speed limit. The high posted speed limit of 50 mph in the eastern section of the corridor is the determining factor that prevents this segment from a pedestrian LOS 2.

Intersections

Proposed pedestrian intersection improvements for Option 1 are:

- Directional curb ramps at all intersections.
- Where a right-turn slip lane exists, the lane will be signalized or feature a speed table.

The pedestrian LOS at intersections in this proposed scenario range from a pedestrian LOS 2 to pedestrian LOS 4. The only intersection with a pedestrian LOS 4 is 28th Street in the eastbound and westbound directions due to the six general purpose through lanes. All other intersections have a pedestrian LOS 2, given the presence of push buttons and countdown signals, a crossing distance of five or less general purpose through lanes, and a signal or speed table at all right-turn slip lanes.

No intersection obtained a pedestrian LOS 1 because there are not any no right-turn-on-red (RTOR) controls recommended at intersections in this scenario.

See **Figure 4** for a map illustrating the pedestrian LOS of all proposed pedestrian improvements under Option 1.

BICYCLE INFRASTRUCTURE

Segments

On-Street

Proposed on-street bicycle improvements and bicyclist LTS scores for segments in Option 1 are:

- Folsom Street to 38th Street: Seven-foot raised protected bike lane with a three-foot buffer.
  - **Bicyclist LTS 2**: Key contributing factors are the three-foot buffer, protected bike lane width greater than five feet, and 35 mph posted speed limit.
- 38th Street to Boulder Creek (immediately west of Foothills Parkway): Seven-foot raised protected bike lane with a three-foot buffer.
  - **Bicyclist LTS 3**: Though similar infrastructure is proposed as the westernmost segment, the bicyclist LTS is lowered because the posted speed limit is 45 mph.
- Foothills Parkway to Westview Drive: Six-foot raised protected bike lane with a three-foot buffer.
  - **Bicyclist LTS 3**: Though similar infrastructure is proposed as the westernmost segment, the bicyclist LTS is lowered because the posted speed limit is 45 mph.
- Westview Drive to 75th Street: Seven-foot in-roadway protected bike lane with a three-foot concrete curb.
  - **Bicyclist LTS 4**: Though similar infrastructure exists as the segments to the east, the bicyclist LTS is lowered because the posted speed limit is greater than 45 mph.

A bicyclist LTS 1 was not achieved for the easternmost segment because the posted speed limit is greater than 30 mph. The 38th Street to Westview Drive segment satisfied all of the criteria for bicyclist LTS 2, except for a posted speed limit of 45 mph, which caused the segment to be bicyclist LTS 3. The easternmost segment receives a bicyclist LTS 4 due to the posted speed limit of 50 mph.

Off-Street

Proposed off-street bicycle improvements and bicyclist LTS scores for the off-street bicycle facilities in Option 1 are:

- Folsom Street to Westview Drive: 12-foot multiuse path with a 17 to 18-foot buffer (in the form of an amenity zone and bicycle facility).
    - **Bicyclist LTS 2**: Key contributing factors are the 12-foot multiuse path, horizontal separation greater than five feet, and a posted speed limit between 35 and 45 mph.
- Westview Drive to 75th Street: 10-foot multiuse path with an 18-foot buffer (in the form of an amenity zone and bicycle facility).
    - **Bicyclist LTS 4**: Though similar infrastructure exists as the segments to the west, the bicyclist LTS is lowered because of a narrower facility and a posted speed limit greater than 45 mph.

A bicyclist LTS 1 was not achieved for the easternmost segment because the posted speed limit is greater than 30 mph. The easternmost segment receives a bicyclist LTS 4 due to the posted speed limit of 50 mph; aside from the posted speed limit, this segment met all of the criteria for a bicyclist LTS 2.

Intersections

Bicycle intersection improvements are divided into low traffic impact and high traffic impact improvements, with low traffic impact representing no major changes to the intersection geometry and signal operations and high traffic impact representing changes to intersection geometry and signal operations necessary to achieve the project's bicyclist comfort goals.

In order for the intersection of a protected bike lane to achieve a bicyclist LTS 1, it needs to have a protected intersection. Protected intersections are a relatively new bicycle treatment in the United States with only a few applications. They require substantial investment. Boulder should consider a protected intersection demonstration project on this corridor to determine if a permanent implementation of this treatment is appropriate.

See **Appendix C** for a comprehensive list of treatments proposed at each intersection.

Low Traffic Impact Improvement & Bicyclist LTS Rating

On-Street

Proposed on-street low traffic impact improvements to intersections for bicyclists all achieve a bicyclist LTS 3 or bicyclist LTS 4 (except for a bike box at Folsom street resulting in bicyclist LTS 1) due to the following factors:

- Bicyclist LTS 3 intersections:
  - Conflicting right turn volume less than 150 vehicles per hour.
  - No barrier separation – mixing zone or striped bike lane with right-turn pocket.
  - Break in separation/barrier for bikes to merge out during left-turns.
  - Maintain existing left-turn phasing (permissive, protected permissive).
- Bicyclist LTS 4 intersections:
  - Conflicting right turn volume greater than 150 vehicles per hour.
  - No barrier separation – mixing zone or striped bike lane with right-turn pocket.
  - Break in separation/barrier for bikes to merge out during left-turns.
  - Maintain existing left-turn phasing (permissive, protected permissive).

Off-Street

The proposed low traffic impact infrastructure improvements for bicyclists at intersections for off-street facilities will not change the existing infrastructure or signal timing, and thus maintains the same bicyclist LTS as in the existing conditions.

High Traffic Impact Improvement & Bicyclist LTS Rating

On-Street

Proposed on-street high traffic impact improvements for bicyclists at intersections all achieve a bicyclist LTS 2 due to the following factors:

- Bicyclist LTS 2 intersections with conflicting right-turn volume less than 150 vehicles per hour:

  - Barrier and good sightlines but permitted right-turns during protected bike lane green phase.
  - Painted treatments: two-stage turn box or bike box.
  - Protected left-turns where volumes require.
- Bicyclist LTS 2 intersections with conflicting right-turn volume greater than 150 vehicles per hour:
  - Separate signal phasing for protected bike lane with barrier at intersection approach.
  - Painted treatments: two-stage turn box or bike box.
  - Protected left-turns where volumes require.

To achieve a bicyclist LTS 1, an intersection needs a protected bicycle intersection.

Off-Street

Proposed off-street high impact improvements for bicyclists at intersections all achieve a bicyclist LTS 2 due to the following factors:

- Right-turn slip lane with speed table.
- Protected-only conflicting left turns.
- Painted treatments, in the form of either a two-stage turn queue box or bike box.

To achieve a bicyclist LTS 1, an intersection needs protected-only right-turns, protected-only left-turns, and a protected intersection.

See **Figure 5** for the bicyclist LTS of all on-street low traffic impact and high traffic impact improvements for bicyclists, and **Figure 6** for all off-street low traffic impact and high traffic impact improvements for bicyclists for Option 1.

OPTION 2

PEDESTRIAN INFRASTRUCTURE

Segments

Proposed pedestrian improvements include:

- Folsom Street to Boulder Creek (just west of Foothills Parkway): 12-foot sidewalk with a 20-foot buffer (in the form of an amenity zone and bicycle facility).
  - **Pedestrian LOS 2:** Key contributing factors are the amenity zone, four general purpose through lanes, and a posted speed limit of less than 45 mph.
- Foothills Parkway to Westview Drive: 10-foot multiuse path with an 18 foot buffer (in the form of an amenity zone and bicycle facility).
  - **Pedestrian LOS 2:** Key contributing factors are the amenity zone, four general purpose through lanes, and a posted speed limit of less than 45 mph.
- Westview Drive to 75th Street: Six-foot sidewalk on the south side and 10-foot multiuse path on the north side with a 13.5 foot buffer (in the form of an amenity zone and bicycle facility).
  - **Pedestrian LOS 4**: The key contributing factor is the posted speed limit greater than 45 mph.

A pedestrian LOS 1 is not achievable for East Arapahoe Avenue due to the number of general purpose through lanes and high posted speed limit. The high posted speed limit of 50 mph in the eastern section of the corridor is the determining factor that prevents this segment from a pedestrian LOS 2.

Intersections

Proposed improvements and pedestrian LOS scores for intersection infrastructure are the same as explained in Option 1 described previously. See **Figure 7** for a map illustrating the pedestrian LOS rating of all proposed improvements under Option 2.

BICYCLE

Segments

On-Street

Proposed on-street bicycle improvements and bicyclist LTS scores for segments in Option 2 are:

- Folsom Street to Boulder Creek (immediately west of Foothills Parkway): Six-foot raised protected bike lane with an eight-foot amenity zone.
  - **Bicyclist LTS 2**: Key contributing factors are the minimum three-foot buffer, protected bike lane greater than five feet, and 35 mph speed limit.
- Foothills Parkway to Westview Drive: seven-foot in-roadway protected bike lane with a three-foot concrete median.
  - **Bicyclist LTS 3**: Though similar infrastructure is proposed as the westernmost segment, the bicyclist LTS is lowered because the posted speed limit is 45 mph.
- Westview Drive to 75th Street: 6.5-foot, in-roadway protected bike lane with a two-foot striped buffer.
  - **Bicyclist LTS 4**: Key contributing factors are the lack of vertical or solid/raised buffer, less than three-foot buffer, and a postedspeed limit greater than 45 mph.

A bicyclist LTS 1 was not achieved for the westernmost segment because the protected bike lane is less than 6.5-feet in width and the posted speed limit is greater than 30 mph. The Foothills Parkway to Westview Drive segment satisfied all of the criteria for bicyclist LTS 2, except for a posted speed limit of 45 mph, which caused the segment to be bicyclist LTS 3. The easternmost segment receives a bicyclist LTS 4 due to the posted speed limit of 50 mph.

Off-Street

There are no proposed off-street bicycle infrastructure improvements from Folsom Street to Foothills Parkway under Option 2.

Proposed off-street bicycle infrastructure improvements for the remaining segments are:

- Foothills Parkway to Westview Drive: 10-foot multiuse path with an 18-foot buffer (in the form of an amenity zone and bicycle facility).

  - **Bicyclist LTS 2**: Key contributing factors are the 10-foot multiuse path, horizontal separation greater than five feet, and a posted speed limit greater than 30 mph.
- Westview Drive to 75th Street: 10-foot multiuse path with a 13.5-foot buffer on the north-side only.
  - **Bicyclist LTS 4**: They key contributing factor is the posted speed limit is greater than 45 mph.

The easternmost segment receives a bicyclist LTS 4 due to the posted speed limit of 50 mph; aside from the posted speed limit, this segment met all of the criteria for a bicyclist LTS 2.

Intersections

Bicycle intersection improvements are divided into low traffic impact and high traffic impact improvements, with low traffic impact representing no major changes to the intersection geometry and signal operations and high traffic impact representing changes to intersection geometry and signal operations necessary to achieve the project's bicyclist comfort goals.

As described in Option 1, in order for the intersection of a protected bike lane to achieve a bicyclist LTS 1, it needs to have a protected intersection. Protected intersections are a relatively new bicycle treatment in the United States with only a few applications. They require substantial investment. Boulder should consider a protected intersection demonstration project on this corridor to determine if a permanent implementation of this treatment is appropriate.

See **Appendix C** for a comprehensive list of treatments proposed at each intersection.

Low Traffic Impact Improvement & Bicyclist LTS Rating

On-Street

Proposed on-street low traffic impact improvements to bicycle intersections all achieve a bicyclist LTS 3 or bicyclist LTS 4 (except for a bike box at Folsom street resulting in bicyclist LTS 1) due to the following factors:

- Bicyclist LTS 3:
  - Conflicting right turn volume less than 150 vehicles per hour.
  - No barrier separation – mixing zone or striped bike lane with right-turn pocket.

  - Break in seperation/barrier for bikes to merge out during left-turns.
  - Maintain existing left-turn phasing (permissive, protected permissive).
- Bicyclist LTS 4:
  - Conflicting right turn volume greater than 150 vehicles per hour.
  - No barrier seperation – mixing zone or striped bike lane with right-turn pocket.
  - Break in seperation/barrier for bikes to merge out during left-turns.
  - Maintain existing left-turn phasing (permissive, protected permissive).

<u>Off-Street</u>

The proposed low traffic impact infrastructure improvements for bicyclists at intersections for off-street facilities will not change the existing infrastructure or signal timing, and thus maintains the same bicyclist LTS scores as in the existing conditions.

High Traffic Impact Improvement & Bicyclist LTS Rating

<u>On-Street</u>

Proposed on-street high traffic impact bicycle intersections all achieve a bicyclist LTS 2 due to the following factors:

- Bicyclist LTS 2 intersections with conflicting right-turn volume less than 150 vehicles per hour:
  - Barrier and good sightlines but permitted right-turns during protected bike lane green phase.
  - Painted treatments: two-stage turn box or bike box.
  - Protected left-turns where volumes require.
- Bicyclist LTS 2 intersections with conflicting right-turn volume greater than 150 vehicles per hour:
  - Separate signal phasing for protected bike lane with barrier at intersection approach.
  - Painted treatments: two-stage turn box or bike box.
  - Protected left-turns where volumes require.

To achieve a bicyclist LTS 1, an intersection needs a protected bicycle intersection.

Off-Street

Proposed off-street high traffic impact improvements to bicycle intersections all achieve a bicyclist LTS 2 due to the following factors:

- Right-turn slip lane with speed table.
- Protected-only conflicting left turns.
- Painted treatments, in the form of either a two-stage turn queue box or bike box.

To achieve a bicyclist LTS 1, an intersection needs protected-only right-turns, protected-only left-turns, and a protected intersection.

See **Figure 8** for the bicyclist LTS of all on-street low traffic impact and high traffic impact improvements, and **Figure 9** for all off-street low traffic impact and high traffic impact improvements for Option 2.

Appendix C.3

Bicycle and Pedestrian Intersection Treatments

FEHR PEERS

The following table identifies intersection treatments that will increase pedestrian and bicyclist comfort, and potentially safety, at East Arapahoe Avenue study area signalized intersections. These intersection treatments should be considered through the implementation of the East Arapahoe Avenue Transportation Plan.

NO RIGHT-TURN ON RED

This treatment is recommended for consideration at approaches where a neither a channelized right-turn lane with speed table nor a protected right-turn signal phase is recommended or feasible. Prohibiting right-turn on red increases pedestrian comfort by decreasing driver encroachment into crosswalks during the pedestrian "Walk" phase. There may be an associated reduction in intersection capacity when right-turn on red is prohibited.

DIRECTIONAL CURB RAMP

This treatment is recommended at all intersections consistent with standards and best-practices for accessible design.

CHANNELIZED RIGHT-TURN LANE WITH SPEED TABLE

This treatment is recommended at approaches to increase pedestrian and off-street bicyclist comfort. When appropriately designed, channelized right-turn lanes can reduce effective shorten crossing distances by reducing the number of lanes that must be crossed in any single crossing and can reduce turning speeds. Speed tables further reduce turning speeds and increase yield compliance of pedestrians or bicyclists crossing the right-turn lane. Channelized right-turn lanes with speed tables typically require more space than non-channelized right-turn lanes are may not fit within right-of-way where recommended.

The City of Boulder has already successfully implemented several channelized right-turn lanes with speed tables on the East Arapahoe Avenue corridor and elsewhere in the City.

ADD SPEED TABLE TO EXISTING CHANNELIZED RIGHT-TURN LANE

This treatment is recommended at existing locations with channelized right-turn lanes that do not feature speed tables. The only East Arapahoe Avenue location where this condition exists is at 75th Street.

TWO-STAGE TURN QUEUE BOX

Some East Arapahoe alternatives recommend protected bike lanes (either in-street and raised). With protected bike lanes, it is difficult (and in some cases impossible) for bicyclists to transition out of the protected bike lane and into a left-turn pocket. Additionally, weaving across multiple general purpose lanes is uncomfortable for many bicyclists. Two-stage turn queue boxes provide infrastructure so that bicyclists in the protected bike lane can turn left without exiting the protected bike lane or weaving across multiple general purpose lanes. There may be an associated reduction in intersection capacity where two-stage turn queue boxes require the prohibition of right-turn on red.

PROTECTED LEFT-TURNS

Where off-street bicyclists cross at intersections, they will typically cross at the same time as corresponding through vehicles. Where permissive left-turns exist, left-turning drivers will have to judge for gaps in oncoming traffic and for pedestrians and bicyclists in the crosswalk/multi-use path crossing. It is particularly difficult to judge for bicyclists in the multi-use path crossing due to their high approach speed relative to pedestrians. Protected left-turns eliminate these potential conflicts by providing a left-turning phase that is exclusive from the corresponding through phase (when pedestrians and off-street bicyclists will cross). There may be an associated reduction in intersection capacity where permissive left-turns are converted to protected left-turns.

SEPARATE RIGHT-TURN SIGNAL PHASING

Where protected bike lanes approach an intersection they typically enter a mixing zone where through bicyclists and right-turning vehicles mix. This mixing activity can reduce bicyclist comfort in these zones especially where right-turn volumes are high. Dutch bikeway design guidance (the CROW *Design Manual for Bicycle Traffic*), by which North American best-practices including the NACTO *Urban Bikeway Design* are influence, recommends separate right-turn signal phasing when the peak hour right-turning volume is greater than 150 vehicles per hour. Separate right-turn signal phases are recommended where existing peak hour right-turning volume is greater than 150 vehicles per hour. As the East Arapahoe Transportation Plan is implemented, the City should use this 150 vehicles per hour threshold in consideration of new traffic counts or future traffic forecasts to determine whether or not a separate right-turn signal phase is appropriate. There may be an associated reduction in intersection capacity where separate right-turn signal phasing is implemented.

At many locations on the corridor there are channelized right-turn lanes with speed tables at locations with high right-turning volumes. While these treatments provide increased comfort for pedestrians and off-street bicyclists, they would not serve bicyclists in protected bike lanes and would not be necessary if a separate right-turn signal phase is provided. The City will need to evaluate the applicable considerations associated with removing channelized right-turn lanes with speed tables and replacing them with separate right-turn signal phases.

Proposed Intersection Treatments

Character Zone	Intersection	Pedestrian	Bicycle
		Folsom Street/East Arapahoe	
A	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
		26th Street/East Arapahoe	
A	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
		28th Street/East Arapahoe	
A	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box
	Southbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box
	Eastbound	none	Two-stage turn queue box; Separate right-turn signal phasing
	Westbound	none	Two-stage turn queue box; Separate right-turn signal phasing
		29th Street/East Arapahoe	
A	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns

Character Zone	Intersection	Pedestrian	Bicycle
30th Street/East Arapahoe			
A	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box
	Southbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
	Eastbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
	Westbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
33rd Street/East Arapahoe			
A	Northbound	Directional curb ramps; No RTOR	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	Directional curb ramps; No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Eastbound	Directional curb ramps; No RTOR	Two-stage turn queue box; Protected left-turns
	Westbound	none	Two-stage turn queue box; Protected left-turns
38th Street/East Arapahoe			
A	Northbound	No RTOR OR channelized RT lane with speed table if feasible	none
	Southbound	none	none
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
Foothills Parkway/East Arapahoe			
C	Northbound	none	none
	Southbound	none	none
	Eastbound	none	Two-stage turn queue box; Separate right-turn signal phasing
	Westbound	none	Two-stage turn queue box; Separate right-turn signal phasing
48th Street/East Arapahoe			
C	Northbound	No RTOR OR channelized RT lane with speed table if feasible	none
	Southbound	none	none
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns

Character Zone	Intersection	Pedestrian	Bicycle
	Westbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Commerce Street/East Arapahoe		
C	Northbound	No RTOR OR channelized RT lane with speed table if feasible	none
	Southbound	No RTOR OR channelized RT lane with speed table if feasible	none
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Conestoga Street/East Arapahoe		
C	Northbound	Directional curb ramps; No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	Directional curb ramps; No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Eastbound	Directional curb ramps; No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	Directional curb ramps; No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	55th Street/East Arapahoe		
D	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
	Eastbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
	Westbound	none	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
	Cherryvale Road/East Arapahoe		
D	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	Directional curb ramps & crosswalk; No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns

Character Zone	Intersection	Pedestrian	Bicycle
	Eastbound	Directional curb ramps & crosswalk	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
	Westbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
63rd Street/East Arapahoe			
D	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	none	Two-stage turn queue box; Protected left-turns
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
65th Street/East Arapahoe			
D	Northbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Southbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Eastbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
	Westbound	No RTOR OR channelized RT lane with speed table if feasible	Channelized RT lane with speed table; Two-stage turn queue box; Protected left-turns
75th Street/East Arapahoe*			
E	Northbound	Add speed table to channelized RT	Two-stage turn queue box; Separate right-turn signal phasing
	Southbound	Add speed table to channelized RT	Two-stage turn queue box; Separate right-turn signal phasing
	Eastbound	Add speed table to channelized RT	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns
	Westbound	Add speed table to channelized RT	Two-stage turn queue box; Separate right-turn signal phasing; Protected left-turns

*Treatments based on volume assumption - turning movement counts currently not available.

APPENDIX D MODE SHARE

This appendix provides detailed mode share analysis methodology and results to supplement the evaluation results that are provided in the East Arapahoe Transportation Plan Evaluation of Alternatives Report.

Mode share is the percentage of people using a particular means of transportation to travel from one point to another. The City of Boulder Transportation Master Plan (TMP) includes goals to reduce the single-occupant vehicle mode share, to help meet the city's transportation, livability, and Climate Commitment targets for reducing GhG emissions.

OVERALL ASSUMPTIONS AND DATA SOURCES

Estimates of mode share for people driving, riding transit, biking, and walking provide a comparison of how the alternatives would influence use of these modes for trips that include travel along Arapahoe Avenue. Mode share was estimated separately for each mode, at the following four "screenlines" along the corridor:

- Arapahoe & 28th
- Arapahoe & 30th
- Arapahoe & Foothills
- Arapahoe & 55th

AUTO MODE SHARE

Analysis Overview

Figure D-1 Auto Mode Share Analysis Summary Table

Change in Auto Mode Share	
Metric	Trips by people in autos
Purpose	Describe how the alternatives may affect the percentage of all trips that are made by people in vehicles
Analysis Methodology	This metric compares outputs from the travel demand mode: total trips by people in vehicles and total trips. Vehicle trips are converted to trips by people using a vehicle occupancy rate of 1.15 (FTA standard assumption).
Data Source	DRCOG 2040 Travel Demand Model (adjusted with local model refinement)

Evaluation Results

Figure D-2 lists person trips in vehicles by screenline. Person trips were converted from vehicle trips using an average auto occupancy factor of 1.15 to account for vehicles with multiple occupants, i.e., on average each vehicle carries 1.15 people.

As described in Appendix B:

- The 2040 No-Build and Enhanced Bus scenarios assume 20% traffic growth (based on regional projections).
- The 2040 BRT scenarios (side-running or center-running) that assume 0% growth in traffic (based on historic trends), assumed that automobile traffic has already been reduced as a means of achieving a 0% increase in traffic by 2040.
- The 2040 BRT scenarios (side-running or center-running) that include 20% growth in traffic (based on regional projections) assumed that BRT service will result in reducing daily traffic along Arapahoe by between 3,400 and 3,700 vehicles per day along the corridor.

Figure D-2 Person Trips in Vehicles, Daily Weekday

Alternative	28th	30th	Foothills	55th
Existing (2015)	35,700	32,500	36,000	30,100
Alt 1 – No-Build with 20% Traffic Growth (2040)	43,100	39,100	44,300	40,300
Alt 2 – Enhanced Bus with 20% Traffic Growth (2040)	43,100	39,100	44,300	40,300
Alt 3/4 – BRT with 0% Traffic Growth (2040)	35,700	32,500	36,000	30,100
Alt 3/4 – BRT with 20% Traffic Growth (2040)	38,600	34,100	39,900	36,400

TRANSIT MODE SHARE

Analysis Overview

Figure D-3 Transit Mode Share Analysis Summary Table

Change in Transit Mode Share	
Metric	Trips by people riding transit
Purpose	Describe how the alternatives may affect the percentage of all trips that are made by transit riders
Analysis Methodology	This metric relates ridership at key locations along the corridor (an output from the transit ridership estimate) to total trips by people at these locations (an output from the travel demand model)
Data Source	Localized transit ridership model based on existing JUMP ridership and industry-standard adjustments for service quality improvements

Evaluation Results

Figure D-4 lists trips by people using transit by screenline. Transit person trips at the screenlines were estimated as part of the transit ridership estimates (described in Appendix B):

- Average weekday daily transit boardings were assigned to screenlines based on existing transit travel patterns along Arapahoe, from existing RTD ridership data for the JUMP.
- Trips on BRT are projected to be within +/- 10% for either Side-Running or Center-Running BRT with either 0% or 20% traffic growth assumptions.

Figure D-4 Trips by People on Transit, Daily Weekday

Alternative	28th	30th	Foothills	55th
Existing (2015)	1,500	1,600	1,500	1,300
Alt 1 – No-Build with 20% Traffic Growth (2040)	1,600	1,800	1,500	1,100
Alt 2 – Enhanced Bus with 20% Traffic Growth (2040)	2,500	2,800	2,500	2,300
Alt 3/4 – BRT with 0% or 20% Traffic Growth (2040)	3,800 - 4,300	4,200 - 4,700	3,700 - 4,200	3,400 - 3,700

WALK AND BICYCLE MODE SHARE

Analysis Overview

Figure D-5 Bicycle and Pedestrian Mode Share Analysis Summary Table

Change in Bicycle and Pedestrian Mode Share	
Metric	Trips by people bicycling and walking
Purpose	Describe how the alternatives may affect the percentage of all trips that are made by people bicycling and walking
Analysis Methodology	Bicycle: A multivariable regression analysis was used to produce AM and PM peak bicyclist forecasts for East Arapahoe based on count locations on other roadways with on-street bike lanes in Boulder; existing bicyclist volumes on Arapahoe are low given the lack of comfortable facilities along the corridor, therefore it was not possible to “factor up” existing counts on Arapahoe: ▪ Broadway from US 36 to Iris Avenue ▪ Iris Avenue from Folsom Street to Broadway ▪ Folsom Street from Iris Avenue to Pine Street ▪ Valmont Road from Airport Road to Folsom Street Since none of these corridors had high-comfort, protected bike lanes as envisioned on East Arapahoe, before-and-after effects observed in other communities upgrading to protected bike lanes were used to factor up existing counts (by 61%). Pedestrian: A regression model could not be developed to predict future pedestrian volumes based on the data available, therefore pedestrian forecasts were developed by applying an overall ratio of pedestrians to bicyclists from the observed (count) data. Both Bicyclist and Pedestrian: Demographic forecasts from DRCOG were used to adjust for future population and employment growth. AM and PM peak estimates were then adjusted to daily levels (comparable to auto and transit estimates) based on multiple sources for the time distribution of trips. In the absence of local daily counts for bicyclists and pedestrians along Arapahoe,[1] PM peak trips were assumed to represent 9% of daily trips, which was relatively consistent among the various data sources: ▪ The City of Boulder Arterial Count Program provides 24-hour vehicular counts, which indicate that the PM peak hour represents approximately 8.7% of daily traffic. ▪ Ridership data for the JUMP aggregates the PM peak to a 3-hour period that represents a total of 28.5% of daily ridership. Assuming a straight average, the PM peak hour represents about 9.5% of daily ridership. ▪ Based on data from automatic counters in Denver, peak hour bicycle and pedestrian trips represented about 9% of daily trips. Mode share was calculated by comparing existing counts and future forecasts to the number of total trips by people from the travel demand model. See Appendix D.1 for additional details.
Data Source	▪ Bicycle counts at intersections or facilities in study area and on other comparable facilities, City of Boulder and national studies and research. ▪ DRCOG, TAZ-level population and employment projections for 2040.

Notes: [1] The City of Boulder is planning to conduct more detailed bicyclist and pedestrian counts along Arapahoe and this data could be used to confirm and refine the methodology in the future.

Evaluation Results

All future alternatives including No-Build support increased bicycle and pedestrian trips in the corridor, however the proposed facilities in any of the Build alternatives would enhance bicycle and pedestrian comfort the most (see Appendix C). Figure D-6 and Figure D-7 list bicycle and pedestrian trips by screenline, respectively.

- For **bicyclists**, population/employment growth along with improvements in the 2040 No-Build alternative (completion of gaps in the existing multi-use path network) account for increased bicycle trips in the corridor relative to the existing condition. Improvements in the Build alternative account for increase bicycle trips relative to the 2040 No-Build alternative.
- For **pedestrians**, population/employment growth along with improvements in the 2040 No-Build alternative (completion of gaps in the existing multi-use path network) account for increased pedestrian trips in the corridor relative to the existing condition. There is assumed to be no *quantifiable* difference in the number of pedestrian trips between any of the future-year alternatives (No-Build or Build) on the west end of the corridor (28th and 30th Streets). Further east (Foothills Pkwy and 55th Street) the improvements proposed in the Build alternative are assumed to increase bicycle trips relative to the 2040 No-Build alternative.

Figure D-6 Trips by People On Bicycles

Alternative	28th	30th	Foothills	55th
Existing (2015) *	10 *	630	20	50
Alt 1 – No-Build (2040)	1,200	1,000	730	730
Alt 2 – Enhanced Bus (2040) Alt 3/4 – Side or Center-Running BRT (2040)	1,940	1,610	1,180	1,180

Notes: Counts were conducted in April 2013 and April 2014. Intersections were counted on a separate days. *Although existing counts at 28th Street are significantly lower than 30th Street, counts at Folsom Street are higher than at 30th Street, suggesting that the low bicycle count a 28th Street may have been related to adverse conditions (e.g., weather) on the day that sample was taken.

Figure D-7 Trips by People Walking

Alternative	28th	30th	Foothills	55th
Existing (2015) *	170	900	20	220
Alt 1 – No-Build (2040)	750	1,090	270	270
Alt 2 – Enhanced Bus (2040) Alt 3/4 – Side or Center-Running BRT (2040)	750	1,090	430	430

Notes: Counts were conducted in April 2013 and April 2014. Intersections were counted on a separate days.

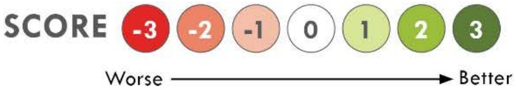
OVERALL MODE SHARE

Figure D-8 lists mode share estimates for all modes and alternatives, calculated based on the tables above.

Figure D-8 Mode Share Results

Alternative	28th	30th	Foothills	55th
Auto				
Existing (2015)	96%	91%	96%	95%
Alt 1 – No-Build with 20% Traffic Growth (2040)	92%	91%	95%	95%
Alt 2 – Enhanced Bus with 20% Traffic Growth (2040)	89%	88%	92%	91%
Alt 3/4 – BRT with 0% Traffic Growth (2040)	84%	81%	86%	85%
Alt 3/4 – BRT with 20% Traffic Growth (2040)	86%	83%	88%	86%
Transit				
Existing (2015)	4%	4%	4%	4%
Alt 1 – No-Build with 20% Traffic Growth (2040)	3%	4%	3%	3%
Alt 2 – Enhanced Bus with 20% Traffic Growth (2040)	5%	6%	5%	5%
Alt 3/4 – BRT with 0% Traffic Growth (2040)	10%	12%	10%	10%
Alt 3/4 – BRT with 20% Traffic Growth (2040)	8%	10%	8%	10%
Bicycle				
Existing (2015)	0.0%	1.8%	0.1%	0.2%
Alt 1 – No-Build with 20% Traffic Growth (2040)	2.6%	2.3%	1.6%	1.7%
Alt 2 – Enhanced Bus with 20% Traffic Growth (2040)	4.0%	3.6%	2.4%	2.7%
Alt 3/4 – BRT with 0% Traffic Growth (2040)	4.5%	4.0%	2.8%	3.3%
Alt 3/4 – BRT with 20% Traffic Growth (2040)	4.3%	3.9%	2.6%	2.8%
Pedestrian				
Existing (2015)	0.5%	2.5%	0.1%	0.7%
Alt 1 – No-Build with 20% Traffic Growth (2040)	1.6%	2.5%	0.6%	0.6%
Alt 2 – Enhanced Bus with 20% Traffic Growth (2040)	1.6%	2.4%	0.9%	1.0%
Alt 3/4 – BRT with 0% Traffic Growth (2040)	1.8%	2.7%	1.0%	1.2%
Alt 3/4 – BRT with 20% Traffic Growth (2040)	1.7%	2.7%	1.0%	1.0%

Figure D-9 Travel Mode Share Evaluation Score



Year	2015	2040	2040	2040	2040
Alternative	**Existing** Existing Bus Existing Travel Lanes Existing Multi-use Path	**Alt 1: No-Build** Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	**Alt 2** Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	**Alt 3** Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	**Alt 4** Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
Transit, Bike, Ped Trips	0	1	2	3	3

CARRYING CAPACITY ANALYSIS

Analysis Overview

The estimates for auto, transit, bicycle, and pedestrian travel were also used to analyze the impact on the corridor's carrying capacity—in terms of the number of people that can be accommodated—at two screenlines (30th and 55th Street). Carrying capacity can be used to assess the benefits of repurposing auto lanes to increase capacity for other modes.

The analysis is based on the following assumptions:

- **Vehicles:** Modeled traffic volumes (both through and right-turn movements) during the peak commute hour and direction (where demand for travel is highest) under the 20% traffic growth scenario (regional 2040 projection) are assumed to represent a practical limit for efficient vehicle travel along the corridor. At 30th Street, projected volumes are highest in the westbound direction in the PM peak.; at 55th Street, projected volumes are highest in the eastbound direction in the PM peak.
- **Transit:** Transit capacity is based on the number of people that could be accommodated on transit in the peak commute hour and direction (same direction as for vehicles). This was calculated as the number of buses per hour (6 existing and No-Build, every 10 minutes; up to 12 with BRT, every 5 minutes) multiplied by the number of people that could be carried on each bus (40 seated, not including people standing).
- **Biking and Walking:** Biking capacity assumes the projected number of trips by people on bikes (in one direction); see Figure D-6. Walking capacity assumes the projected number of trips by people walking (in both directions); see Figure D-7. Actual capacity to accommodate bicycle and pedestrian trips does not have a practical limit but is not easily quantified.

Evaluation Results

Total capacity of the corridor to carry people increases under all scenarios, as shown in Figure D-10.

- Compared to existing conditions, carrying capacity increases even in the No-Build alternative, based on increased auto volumes and completion of the multi-use path and sidewalks that is assumed in that alternative. The Build alternatives further increase capacity compared to existing conditions, by enhancing transit service and bicycle and pedestrian facilities.
- Comparing the future Build and No-Build alternatives, carrying capacity stills increases, but by a smaller amount.

Figure D-10 East Arapahoe Carrying Capacity (Number of People), 30th and 55th Streets, Peak Hour and Direction

Mode	Existing (2015)	No-Build (Alt 1 w/20% Traffic Growth, 2040)	Build (Alt 2/3/4 w/20% Traffic Growth, 2040)	% Change		
				No-Build vs. Existing	Build vs. Existing	Build vs. No-Build
30th Street – Westbound PM Peak						
Auto	1,507	1,747	1,647	16%	9%	-6%
Transit	240	240	480	0%	100%	100%
Bike	14	23	36	59%	156%	61%
Walk (both directions)	41	49	49	21%	21%	0%
Total	1,802	2,059	2,213	14%	23%	7%
55th Street – Eastbound PM Peak						
Auto	1,825	2,191	1,885	20%	3%	-14%
Transit	240	240	480	0%	100%	100%
Bike	8	19	31	154%	310%	61%
Walk (both directions)	25	31	34	21%	36%	12%
Total	1,939	2,259	2,312	17%	19%	2%

Notes: Projected auto, bike, and walk trips compiled from above tables; transit capacity calculated based on planned frequency and capacity (Appendix B).

Appendix D.1

Bicyclist and Pedestrian Count Methodology

FEHR PEERS

MEMORANDUM

Date: July 17, 2017

To: Jean Sanson, City of Boulder

From: Charlie Alexander & Carly Sieff, Fehr & Peers

Subject: Bicyclist & Pedestrian Forecasts for East Arapahoe Avenue

DN16-0519

INTRODUCTION

Fehr & Peers used a multivariable regression to produce bicyclist and pedestrian forecasts for East Arapahoe Avenue. This technical memorandum summarizes the data used to develop that multivariable regression and the resulting 2040 forecasts for East Arapahoe Avenue.

METHODOLOGY

Broadly speaking, any bicyclist and pedestrian forecasting methodology for East Arapahoe Avenue should be sensitive to the future infrastructure and land use changes on the corridor.

Currently, the East Arapahoe Avenue corridor provides such a low comfort level for people biking and people walking that the existing number of people biking and walking on the corridor is very low. This prohibits the application of methods that would "factor up" existing counts. Other more robust methods, such as activity-based model applications, have yet to prove successful based on the models available in the Denver region.

Given the inability of "factoring up" existing counts on the corridor, Fehr & Peers applied a multivariable regression to develop forecasts for the corridor.

How Does a Multivariable Regression Work?

A multivariable regression establishes a mathematical relationship between a dependent variable (in this case counts of bicyclists and pedestrians on other Boulder-area corridors) and a variety of independent variables.

Multivariable Regression for East Arapahoe Avenue

For Bicyclist Forecasts

Fehr & Peers developed a multivariable regression for East Arapahoe Avenue using available bicyclist count information (AM and PM peak hour) for four corridors in Boulder:

- Broadway from US 36 to Iris Avenue
- Iris Avenue from Folsom Street to Broadway
- Folsom Street from Iris Avenue to Pine Street
- Valmont Road from Airport Road to Folsom Street

A key challenge to this analysis was that, in the count years available (2013-2015), none of these corridors had high-comfort protected bike lanes as envisioned on East Arapahoe Avenue. Instead, these corridors had on-street bike lanes. Fehr & Peers researched before-and-after effects observed in other communities (Austin, TX; Chicago, IL; Portland, OR; and San Francisco, CA) when upgrading bike lanes to protected bike lanes and found, on average, a 61 percent increase in bicyclist counts (Monsere et al., *Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the U.S.*). Therefore, Fehr & Peers factored bicyclist counts on these corridors up by 61 percent to account for the expected infrastructure on East Arapahoe Avenue.

Fehr & Peers tested different independent variables to develop a multivariable regression that had a reasonably high explanatory power but also had variables that would seem reasonable according to engineers and planners. The multivariable regression uses four independent variables:

- **HH+EMP/mi** – Total number of households and employees within ½ mile of the corridor, divided by the corridor's length in miles. This was derived from 2015 DRCOG TAZ data for TAZs within ½ mile of the corridor and that are likely to load trips onto the corridor. Dividing the total households and employees by the corridor's length adjusts for corridors that are longer than one another.
- **Int HH + EMP** – Total number of households and employees within ½ mile of the intersection. This was derived from 2015 DRCOG TAZ data for TAZs within ½ mile of the intersection and that are likely to load trips onto the corridor near the intersection.
- **Mi from Downtown** – Distance in miles from the intersection to Downtown Boulder (assumed to be the Broadway/Canyon Boulevard intersection) when travelling the shortest path along the network.

- **Direct Connect?** – A binary variable describing whether the route offered a direct connection to the Downtown Boulder area or not (1 if the corridor does, 0 if it does not).

The resulting regression equation achieved an R^2 value of 0.76 which suggests that these variables explain 76 percent of the variation in the observed data. While not especially high by statistical standards, this was the highest R^2 value that could be achieved with the available data. The resulting regression equation is:

AM+PM PkHr 2-Way Bikes =
-13.4 + (0.0039 x **HH+EMP/mi**) + (0.019 x **Int. HH + EMP**) + (-19.7 x **Mi from Downtown**) + (129.6 x **Direct Connect?**)

For Pedestrian Forecasts

Fehr & Peers tested several independent variables for pedestrians including all of the variables used for the bicyclist regression and also including buses stopping each day within ½ mile of the intersection and pre-Kindergarten through 12th grade school enrollment. No combination of these independent variables resulted in a reasonably high R^2 value; therefore, we developed pedestrian forecasts by applying an overall ratio of pedestrians to bicyclists from the observed data. Where existing pedestrian counts exceeded these forecasts, we increased existing pedestrian counts by the ratios of 2040 population/employment to 2015 population/employment.

Converting Peak Hour to Daily and With Build to No Build

Analysis of Boulder traffic counts showed that PM peak hour traffic accounts for 9.3% of daily traffic; therefore, this same ratio was applied to convert PM peak hour bicyclist/pedestrian forecasts to daily forecasts.

With Build forecasts were converted to No Build forecasts by inverting the 61 percent increase in bicyclist counts when upgrading bike lanes to protected bike lanes previously assumed to account for the less comfortable infrastructure in the No Build scenario.

In some cases where the model did not perform as expected relative to existing counts or between scenarios, manual adjustments were applied accounting for growth in population and employment or the difference in comfort levels between the existing, with build and no build scenarios.

2040 EAST ARAPAHOE AVENUE FORECASTS

Table 1 shows 2040 bicyclist and pedestrian forecasts for East Arapahoe Avenue. There forecasts represent the expected daily number of bicyclist and pedestrians *travelling along* East Arapahoe Avenue near each study intersection. Fehr & Peers applied 2040 DRCOG TAZ data so that the forecasts would account for expected population and employment growth on the corridor. The observed count data had already been factored up to account for the high-comfort infrastructure expected on East Arapahoe Avenue.

Fehr & Peers produced two separate regressions: one for East Arapahoe Avenue west of 55th Street and another for East Arapahoe Avenue east of 55th Street. Applying two separate regressions affects the **HH+EMP/mi** variable (total number of households and employees within ½ mile of the corridor, divided by the corridor's length in miles) and recognizes that the character of the corridor is very different west and east of 55th Street.

TABLE 1 BICYCLIST AND PEDESTRIAN FORECASTS

Location	Existing		2040 With Build		2040 No Build	
	Daily Bikes	Daily Peds	Daily Bikes	Daily Peds	Daily Bikes	Daily Peds
East Arapahoe Ave. at Folsom St.	450	1,130	1,940	1,370	1,200	1,370
East Arapahoe Ave. at 28th St.	10	170	1,940	750	1,200	750
East Arapahoe Ave. at 30th St.	630	900	1,610	1,090	1,000	1,090
East Arapahoe Ave. at Foothills Pkwy.	20	20	1,180	430	730	270
East Arapahoe Ave. at 55th St.	50	220	1,180	430	730	270
East Arapahoe Ave. at Cherryvale Rd.	30	40	650	320	400	200
East Arapahoe Ave. at 63rd St.	0	30	650	320	400	200

Source: Fehr & Peers, 2017

LIMITATIONS

A multivariable regression is only as good as the data available for both the dependent variables (observed data) and the independent variables. Potential criticisms of this methodology include:

- Bicyclist and pedestrian count data only included one day of data, the days were not the same across all intersections and the weather conditions on the day of the counts is unknown.
- The multivariable regression could have been improved if count data for additional corridors were available; as developed, the multivariable regression is only based on 16 observations and is not statistically significant.
- Additional independent variables that were not tested may have increased the multivariable regression's explanatory power.

APPENDIX E SAFETY

This appendix provides more detailed discussion of the safety implications of vehicle, transit, and non-motorized transportation alternatives considered in the East Arapahoe Transportation Plan Evaluation of Alternatives Report.

ASSUMPTIONS

The implementation of any of the alternatives under consideration would be accompanied by some level of infrastructure change. The main infrastructure elements with potential safety impacts are summarized below. A discussion of the anticipated safety impacts for each element follows in the Evaluation section.

Enhanced Bus

- Queue jumps
- Transit signal priority (TBD)
- Potential BAT lane sections

Side-running BRT

- Transit signal priority (TBD)
- Lane repurposing
- BAT lanes

Center-running BRT

- Transit signal priority (TBD)
- Lane repurposing
- Center-lane busway
- Left-turns would not be prohibited in the center-running BRT alternative. Vehicles would be allowed to cross over the center bus lane in advance of an intersection to enter the left-turn lane.

Bicycle and Pedestrian Facilities

- Sidewalks
- Multi-use paths
- On-street bicycle facilities
- Protected/raised bicycle facilities

Amenity Zones

- Street trees

EVALUATION RESULTS

Improving transportation safety for all modes of travel along the East Arapahoe corridor is a priority for all alternatives under consideration. The primary mechanism for providing safe travel for all modes and supporting the "Toward Vision Zero" effort to eliminate fatalities and serious injuries includes a comprehensive review of crash history and identification of countermeasures to address crash trends. Care will be taken when advancing any alternatives to ensure their implementation will not compromise the safety of the corridor. Industry research and case studies also provide some insight into how the various elements of the alternatives may impact safety.

Research on the safety impacts of implementing bus rapid transit (BRT) in the developing world is somewhat limited or offers mixed findings. The implementation of center-running BRT has generally proven to reduce traffic crashes in many Latin American cities. Likewise, the use of bus priority systems, such as signal priority and dedicated lanes, has also demonstrated positive safety impacts in countries like Australia. Less research is available on the safety impacts of BRT in the United States. The magnitude of these crash reductions varies widely by location and is heavily dependent on the characteristics of the individual corridors. Comprehensive research on the traffic safety impacts of bus priority systems (including bus rapid transit) in the developing world suggests that the safety impacts are more a result of the street infrastructure changes made to implement the bus priority systems than the type of bus system being implemented.

Similarly, the safety impacts of providing specific types of bicycle facilities is not well understood. Research on the benefits of dedicated bicycle facilities has yielded mixed conclusions. However, as the National Cooperative Highway Research Program's *Guidelines for Analysis of Investments in Bicycle Facilities* points out, the "prevailing argument is that enhanced facilities—bike lanes, bikeways, and special intersection modifications—improve cyclist safety." Crash analysis within the City of Boulder shows that most crashes involving bicyclists or pedestrians occur at intersections. Thus, the safety of a facility depends heavily on the way it interacts with intersections and driveways.

Queue Jumps and Signal Priority

The use of bus priority measures, such as queue jumps and transit signal priority, has been shown to have positive safety impacts in Australia. A study that evaluated the effects of bus priority on road safety in Melbourne's SmartBus network found that bus priority treatments resulted in a statistically significant reduction of crashes. Bus priority lanes were found to yield higher safety benefits compared to signal priority at intersections.

References:

Goh, K., et al., "Road Safety Benefits from Bus Priority – An Empirical Study." Transportation Research Record - Journal of the Transportation Research Board, 2013.

Business-access-and-transit (BAT) Lanes

The safety impacts of curbside bus lanes (that are also used by right-turning vehicles) have been explored using real world data and experimental microscopic traffic simulation modeling and are generally positive. A study tested two configurations of a curbside bus priority lanes on a three-lane divided arterial in Melbourne: reallocation of an existing lane for buses and the addition of a new lane for buses. The results showed that in either configuration, BAT lanes reduced conflicts at intersection approaches and bus stop locations. These reductions came from fewer rear-end and sideswipe crashes, as BAT lanes remove buses from mixed traffic and provide space for right-turning vehicles. At the corridor level, conflicts increased in the lane reallocation scenario. However, this finding was not consistent with real world before and after data.

References:

Goh, K. C. K., G. Currie, M. Sarvi, and D. Logan. "Investigating the Road Safety Impacts of Bus Priority Using Experimental Micro-Simulation Modelling." Paper presented at the Transportation Research Board 93rd Annual Meeting, Washington DC., 2013.

Lane Repurposing

Understanding the safety impacts of repurposing a travel lane for transit is a complex issue, as different aspects may have different effects depending on the conditions of the corridor. For example, reducing the number of lanes for motor vehicles could lead to more congestion and an increase in rear-end crashes. On the other hand, reducing the number of lanes reduces the number of conflict points and can also result in slower speeds, both of which have positive safety impacts. An analysis if the safety impact of common infrastructure changes made when implementing bus priority systems in Latin America found that removing a traffic lane resulted in fewer total and severe crashes. The range of traffic volumes present in the cases analyzed is unknown.

References:

Duduta, N., C. Adriazola, D. Hidalgo, T. Lindhau, V. John, and C. Wass. Traffic Safety on Bus Priority Systems. EMBARQ, Washington, D.C., 2014.

Center-lane Busway

Research on bus priority corridors in Latin America suggests that center-lane bus systems provide greater safety improvements than curbside systems. However, the implementation of center-lane systems in these cases often involves infrastructure and operational changes such as prohibiting left-turns, adding a central median, and shortening crosswalks. While the detailed operational changes for East Arapahoe have not yet been determined, prohibiting left-turns along Arapahoe Avenue or restricting access from side streets would likely not be recommended. Therefore, the safety impacts of a center-running BRT are not expected to be as significant as in Latin American case studies. Instead, vehicles may be allowed to cross over the center transit lane in advance of an intersection to enter the left-turn lane. This could result in conflicts between buses and vehicles, but due to the lower occupancy rate of the transit lane, these crashes would likely be infrequent.

References:

Duduta, N., C. Adriazola, D. Hidalgo, T. Lindhau, V. John, and C. Wass. Traffic Safety on Bus Priority Systems. EMBARQ, Washington, D.C., 2014.

Sidewalks

Changes to the pedestrian facilities in the alternatives under consideration include completing missing sidewalk links or providing wider sidewalks. Providing sidewalks along urban arterials reduces the risk of "walking along roadway" pedestrian crashes, though these types of crashes are not common along Arapahoe Avenue. Nevertheless, sidewalks are not expected to have a negative effect on safety. Per the Boulder Revised Code, bicycling would be allowed on sidewalks in residential and park zones, and a lack of a dedicated bicycle facility could encourage more riding on sidewalks.

References:

American Association of State Highway Transportation Officials (AASHTO). Highway Safety Manual (1st Edition). Washington, D.C., 2010.

Multi-use Paths

Multi-use paths are already present along much of Arapahoe Avenue and are included in many of the alternatives under consideration. Multi-use paths can improve perceived safety for bicyclists, but may decrease perceived safety for pedestrians, as conflicts between bicyclists and pedestrians are more likely to occur. Few crashes of this type have historically been reported along Arapahoe Avenue's existing multi-use paths. Local crash data does show, however, that bicyclists riding on multi-use paths (or sidewalks) in the opposite direction of traffic are more likely to be involved in crashes with vehicles. Providing multi-use paths on both sides of a street may reduce these occurrences, but travel patterns are also influenced by land use. Care should be taken to increase the visibility of bicyclists riding against traffic on paths at intersections and driveways. Limited published research is available on the safety impacts of multi-use paths.

References:

City of Boulder 2016 Safe Streets Boulder Report, May 2016.

On-street Bicycle Facilities

A 2009 literature review of the impact of transportation infrastructure on bicycling injuries and crashes found limited studies on the effects of bicycle facility type on safety, but concluded based on existing research that dedicated bicycle-only facilities, such as bike lanes, bike paths, or cycle tracks, provided greater safety benefits compared to no facilities or facilities shared with pedestrians. Furthermore, the *Highway Safety Manual* suggests that providing dedicated bicycle lanes or separate bicycle facilities reduces conflicts between vehicles and bicycles along roadway segments, but the magnitude of the crash effect is not certain.

References:

Reynolds, C., M. Harris, K. Teschke, P. Cripton, M. Winters. "The impact of transportation infrastructure on bicycling injuries and crashes: A review of the literature". Environmental Health, 2009.

American Association of State Highway Transportation Officials (AASHTO). Highway Safety Manual (1st Edition). Washington, D.C., 2010.

Protected/Raised Bicycle Facilities

As mentioned above, bicycle-only facilities in general, whether on-street or separated, are expected to improve safety compared to no facilities or multi-use paths. A study of six separated bicycle facilities (cycle tracks) in Montreal found that cycle tracks have either lower or similar injury rates compared to comparable streets without bicycle facilities. Even though separated facilities may improve perceived safety for bicyclists, the crash effects appear to be similar to bicycle lanes. The crossing of separated facilities at intersections can result in more conflicts between vehicles and bicycles, according to one study. Therefore, the design of separated bicycle facility crossings at intersections and driveways will be an important aspect of the final design to ensure positive safety impacts.

References:

Reynolds, C., M. Harris, K. Teschke, P. Cripton, M. Winters. "The impact of transportation infrastructure on bicycling injuries and crashes: A review of the literature". Environmental Health, 2009.

Lusk, A. C., P. Furth, P. Morency, L. Miranda-Moreno, W. Willett, J. Dennerlein, "Risk of injury for bicycling on cycle tracks versus in the street". Injury Prevention, 2010.

American Association of State Highway Transportation Officials (AASHTO). Highway Safety Manual (1st Edition). Washington, D.C., 2010.

Street Trees

The alternatives with amenity zones of at least eight feet can accommodate street trees, which may positive safety benefits. A pilot study using a simulated environment to evaluate both urban and suburban landscapes with and without curbside street trees yielded a proof of concept for the safety benefits of street trees. The results indicated that curbside street trees improve drivers' perception of safety, especially in urban landscapes, and reduce driving speeds in suburban landscapes. Other research has concluded that streetscape improvements, including street trees, can reduce the frequency and severity of crash rates.

References:

Naderi, J.R., B. S. Kweon, P. Maghelal. "The Street Tree Effect and Driver Safety". ITE Journal on the Web, February 2008, pages 69-73.

Rosenblatt, J. and G. Bronfman-Bahar. "Impact of Environmental Mitigation on Transportation Safety: Five Toronto Case Studies." International Road Federation, World Conference Proceedings, 1999.

Access Management

Literature Review

Access management or the consolidation of driveways may be utilized in conjunction with any of the alternatives. Decreasing access point density on urban and suburban arterials is expected to reduce crash frequency, as documented in multiple studies. While an access management plan can be developed regardless of the alternative, implementation of a center-running BRT alternative is expected to have the greatest impact on access, since left-turns would likely not be permitted across the median BRT lanes. This would impact existing full-access movements which are most frequent in District D.

References:

American Association of State Highway Transportation Officials (AASHTO). Highway Safety Manual (1st Edition). Washington, D.C., 2010.

Analysis Overview

The project team developed an inventory of existing driveways in the study area. Driveway locations were mapped and driveway cuts were classified into four types:

- A = Right-in, Right-out; private driveway
- B = All turns allowed; private driveway
- C = Fully signalized; private driveway
- D = Right-in, Right-out; minor public street.

Assumptions

- Any intersection that has both a traffic signal, and public right-of-way extending away from Arapahoe was not counted as a driveway.
- Minor public right-of-ways that restrict turning access were counted as driveway type D.

- Signalized intersections that serve as access to a private property or parking lot were counted as driveway type C

Evaluation Results

Figure E-1 summarizes the inventory of existing driveways.

Maps that illustrate the access management analysis can be found in Appendix E.1 Access Management. The maps also identify locations along interior lot lines where parcels that have access onto or off of Arapahoe have interior vehicular circulation already established with a neighboring property.

Figure E-1 Existing Driveway Inventory

Driveway Type (Existing)	Overall	District A	District B	District C	District D	District E
A = Right-in, Right-out; private driveway	57	24	N/A	17	15	1
B = All turns allowed; private driveway	26	3	N/A	1	19	3
C = Fully signalized; private driveway	8	4	N/A	1	3	0
D = Right-in, Right-out; minor public street	4	1	N/A	2	1	0

Figure E-2 provides qualitative ratings for the impact of the alternatives on driveways by district.

Figure E-2 Driveway Impact Rating

	Overall	District A	District B	District C	District D	District E
Existing	0	0	0	0	0	0
Alt 1 (No-Build)	0	0	0	0	0	0
Alt 2 (Enhanced Bus)	0	0	0	0	0	0
Alt 3 (Side-Running BRT)	0	0	0	0	0	0
Alt 4 (Center-running BRT)	0 to -2	-1	0	-1	-2	-1

Key: -3 = greatest impact, 0 = neutral, +3 = greatest benefit

Key Findings

- The management alternatives for the East Arapahoe corridor may include access management, or the consolidation of driveways. Minimizing the number of access points is expected to reduce the frequency of crashes, as noted above.
- District A has 32 driveway cuts, District C has 21, District D has 37, and District E has 4.
- The "all-turns allowed" access category is most likely to be impacted in Alternative 4 (Center-running BRT), since left-turns would likely not be permitted across the median BRT lanes. There are relatively few of these types of driveways in Districts A, C, and E, but there are 19 in District D.

OVERALL KEY FINDINGS

- The City of Boulder works to provide a safe transportation system for people using all modes of travel. "Toward Vision Zero" is the city's effort to eliminate fatalities and serious injuries from future traffic collisions.
- Arapahoe Ave is one of the higher speed (posted speed limits between 35 and 45 mph) and higher volume roadways with the city.
- An analysis of crash data from 2012-2014 shows that crashes affect all modes of travel along Arapahoe Avenue. Several intersections (28th St, 30th st, and Foothills Pkwy) have particularly high crash rates. The data indicates a need to minimize conflict points, including intersections and driveways, and identify and mitigate safety issues for people walking, biking, and driving.
- In general, the vehicular, bicycle, and pedestrian infrastructure changes required to implement the build alternatives would be expected to provide safety benefits or have a neutral impact on safety.
- Dedicated bicycle facilities are expected to improve safety compared to no facilities or multi-use paths.
- The design of bicycle facility crossings at intersections and driveways will be an important aspect of the final design to ensure positive safety impacts.

Tables summarizing the safety evaluation for vehicles, transit, and people walking and biking can be found in the East Arapahoe Transportation Plan Evaluation of Alternatives Summary Report, page 51-52.

Figure E-3 Safety Evaluation Score

SCORE -3 -2 -1 0 1 2 3

Worse → Better

Year	2015	2040	2040	2040	2040
Alternative	Existing Existing Bus Existing Travel Lanes Existing Multi-use Path	Alt 1: No-Build Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	Alt 2 Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	Alt 3 Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	Alt 4 Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
Bicycle/Pedestrian	0	1	2	2	2
Transit	0	0	0	1	1
Auto	0	0	0	1	1

APPENDIX E.1 DRIVEWAY ACCESS MAPS

Figure E.1-1 Location Map

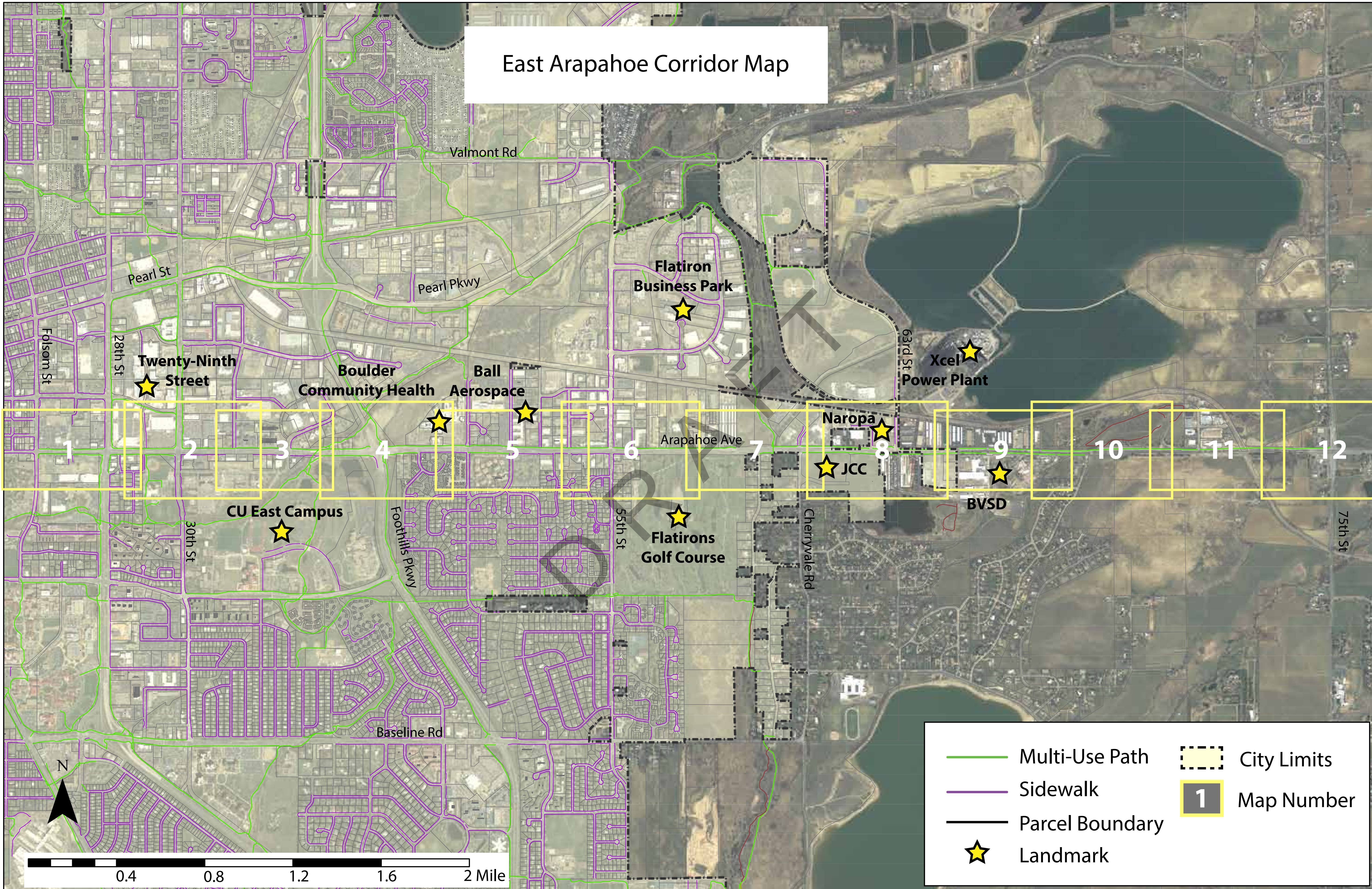


Figure E.1-2 Map 1 - Character District A

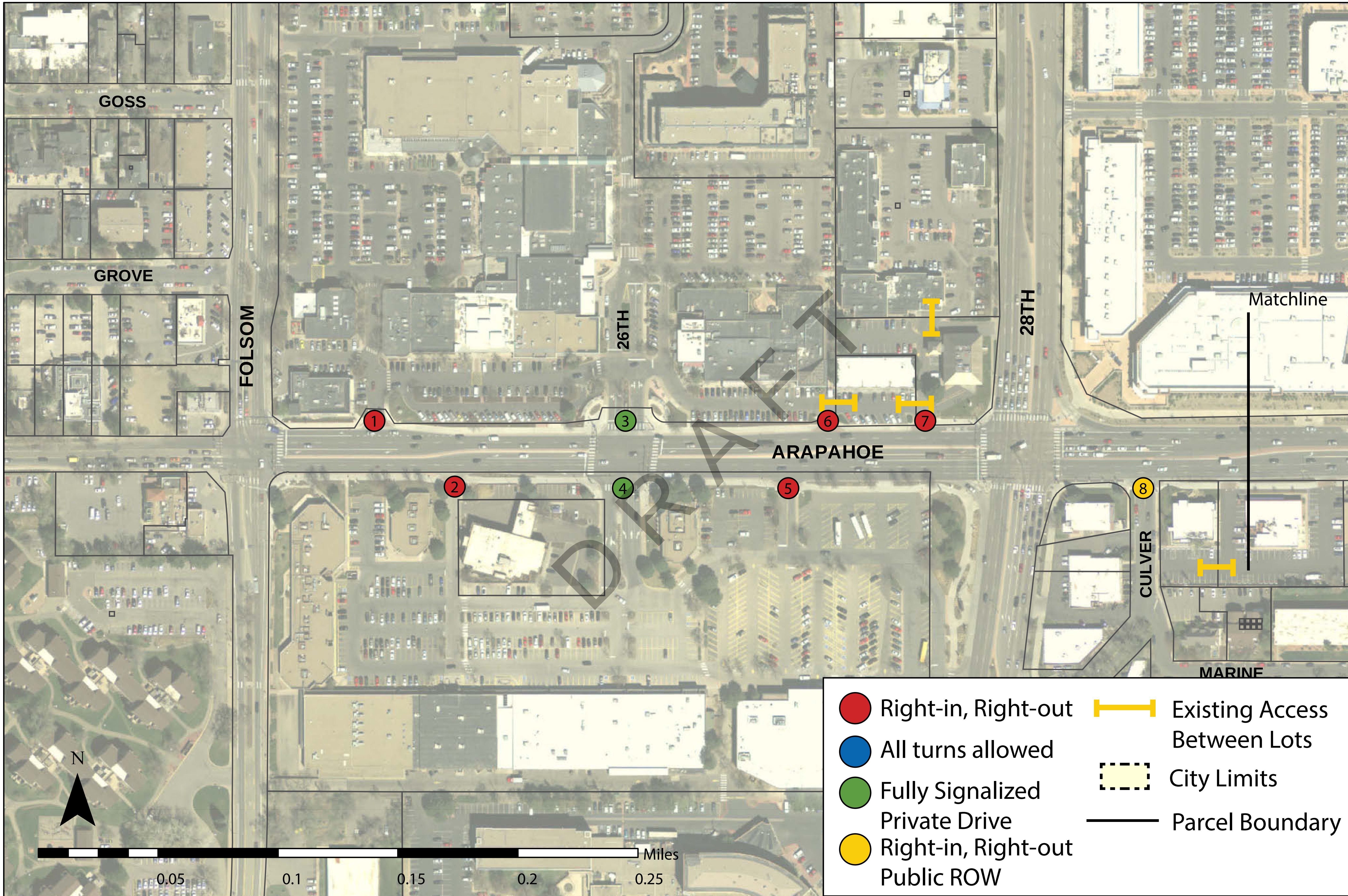


Figure E.1-3 Map 2 - Character District A

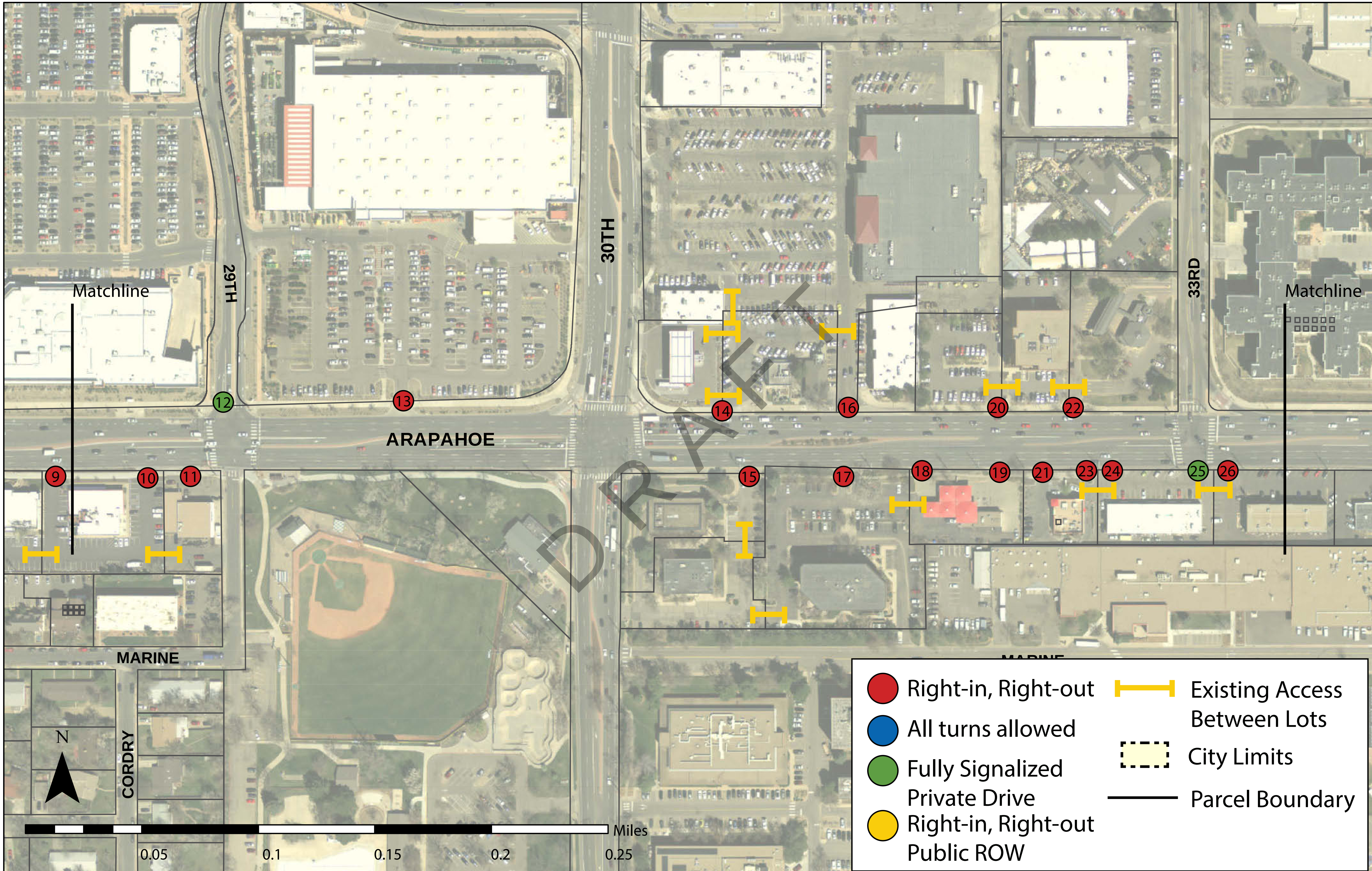


Figure E.1-4 Map 3 - Character District A

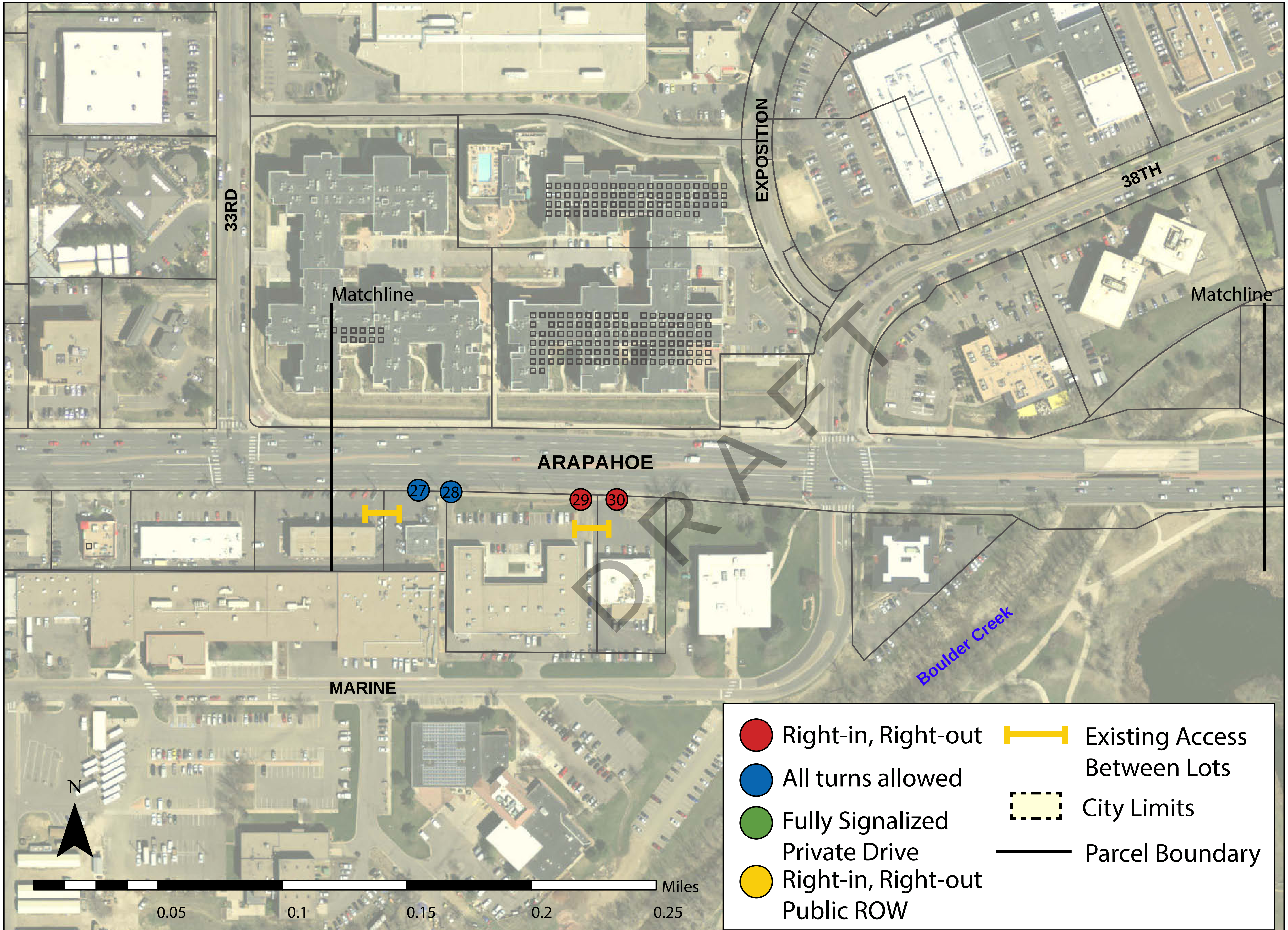


Figure E.1-5 Map 4 - Character District B

Figure E.1-6 Map 5 - Character District C

Figure E.1-7 Map 6 - Character District C

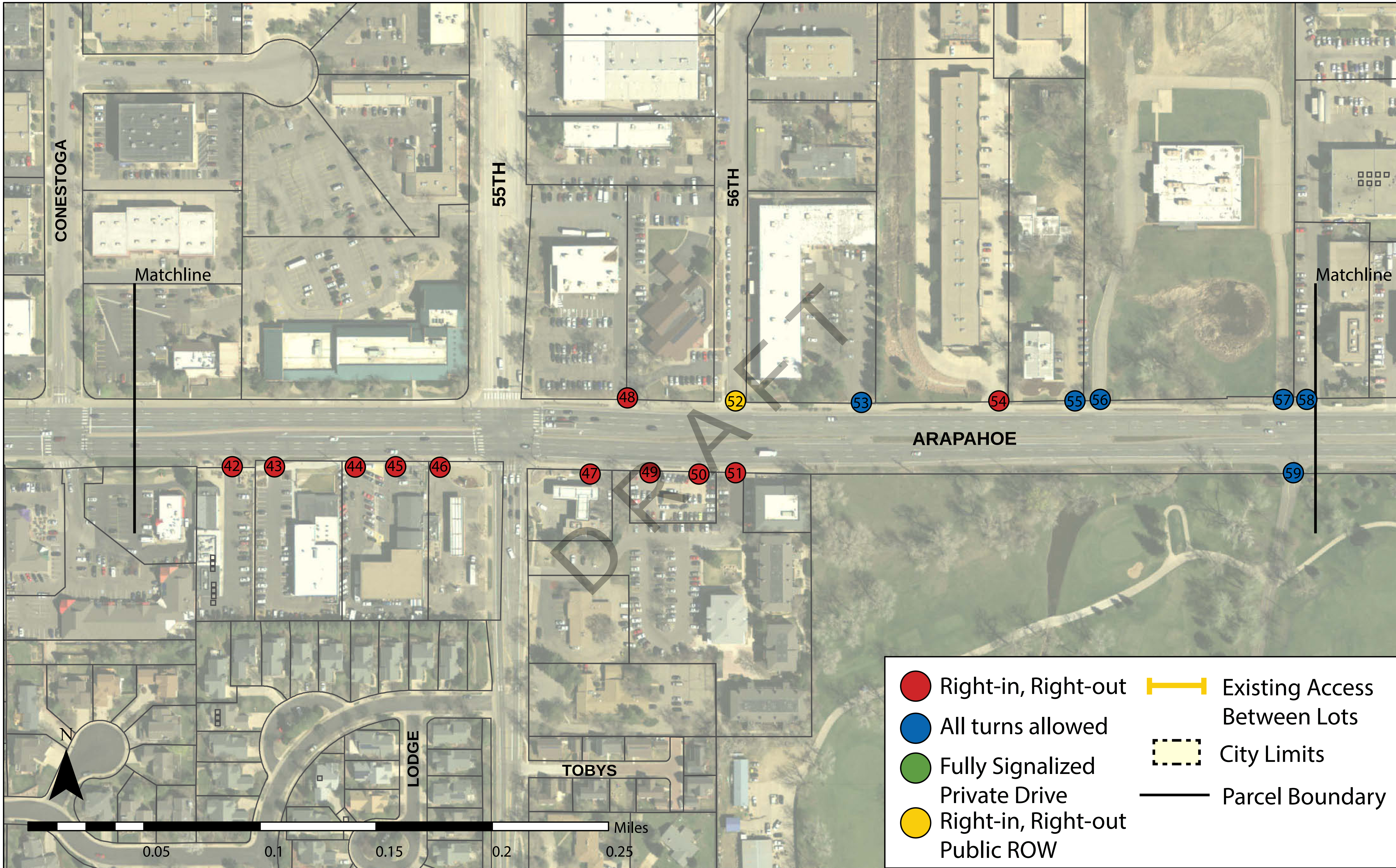


Figure E.1-8 Map 7 - Character District D

Figure E.1-9 Map 8 - Character District D

Figure E.1-10 Map 9 - Character District D

Figure E.1-11 Map 10 - Character District D - E

Figure E.1-12 Map 11 - Character District E

Figure E.1-13 Map 12 - Character District E

Figure E.1-14 Driveway Inventory Summary Tables

Character District A: Total = 32		
1	A	
2	A	
3	C	26th Street, private shopping center main entrance
4	C	26th Street, private shopping center main entrance
5	A	
6	A	
7	A	
8	D	Culver Court
9	A	
10	A	
11	A	
12	C	29th Street, shopping center entrance
13	A	
14	A	
15	A	
16	A	
17	A	
18	A	
19	A	
20	A	
21	A	
22	A	
23	A	
24	A	
25	C	33rd Street intersection
26	A	
27	B	
28	B	
29	A	
30	A	
31	B	
32	A	

Character District C: Total = 21		
33	A	
34	A	
35	A	
36	A	Riverbend Road
37	A	
38	A	
39	D	Patton Drive
40	A	
41	C	Conestoga; entrance to shopping center
42	A	
43	A	
44	A	
45	A	
46	A	
47	A	
48	A	
49	A	
50	A	
51	A	
52	D	56th Street
53	B	

Character District D: Total = 37		
54	A	
55	B	
56	B	
57	B	
58	B	
59	B	Flatirons Golf Course main entrance
60	A	
61	A	
62	A	
63	B	
64	B	
65	A	
66	C	Cherryvale - north side; entrance to car dealerships
67	A	
68	A	
69	A	Boulder JCC Entrance
70	B	Ben Place
71	A	
72	A	
73	A	
74	A	
75	A	
76	B	
77	B	
78	B	
79	B	
80	B	
81	B	BVSD West Entrance
82	C	65th Street; BVSD main entrance
83	C	65th Street north
84	B	
85	B	

Character District D: Total = 37		
86	B	
87	D	
88	B	BVSD East Entrance
89	B	
90	B	

Character District E: Total = 4		
91	B	Legion Park Entrance
92	B	
93	B	
94	A	

Legend
A = Right-in, Right-out; private driveway
B = All turns allowed; private driveway
C = Fully signalized; private driveway
D = Right-in, Right-out; minor public street

APPENDIX F COMMUNITY SUSTAINABILITY

This appendix provides additional details on analysis methodology and results to supplement the community sustainability measures that are provided in the East Arapahoe Transportation Plan Evaluation of Alternatives Report.

STREETSCAPE QUALITY

This section describes the evaluation methodology, assumptions, and additional results for the streetscape quality results provided on pages 55-59 of the Evaluation of Alternatives Summary Report.

Analysis Overview

Figure F-1 Streetscape Analysis Summary Table

Opportunity to Improve Streetscape	
Metric	Opportunity to increase public space and landscaping
Purpose	Describe how alternatives could affect the amount of public space and landscaping available along the corridor. Increasing public space and landscaping could make Arapahoe a more pleasant place to walk and bike; street trees can improve safety by visually narrowing the street and encouraging lower traffic speeds.
Analysis Methodology	Qualitative assessment of design alternatives
Data Source	Concept plans for design alternatives and industry research/case studies, City of Boulder, County of Boulder

Methodology

This analysis was conducted using ESRI ArcMap. Polygons were constructed representing the existing medians and sidewalk/multi-use path infrastructure. The lines were drawn from the roadway curb to the back of the sidewalk or multi-use path. Next, polygons were constructed representing the cross-sections of each of the proposed build alternatives. These were broken up by Character District, and the cross-section differences between Character Districts were included. Rough boundaries for intersections were sketched in to account for cross-streets.

Next, the square footage of each polygon was totaled to produce rough totals of the amount of land that would be allocated to the Roadway, the Bike/Pedestrian/Landscaping on the side, and to Medians. Medians and Bike/Pedestrian/Landscaping were added to produce the total amount of "Streetscape Features," and a final percentage breakdown generated. This number is rounded to account for margin of error, and should be used as a qualitative measure and not to plan-level of accuracy. Changes in the design of intersections and/or the median may still influence the final streetscape.

Assumptions

- Figure F-2 lists the streetscape width by alternative. This is based on the conceptual alternatives for each district (see pages 5 to 16 of the Evaluation Alternatives Summary Report for a description, along with a detailed listing of right-of-way assumptions in Appendix G.
- Analysis for this measure is intended to provide a high level, order-of-magnitude comparison of the alternatives. Elements of the conceptual designs for each alternative were drawn in GIS to estimate the proportions of each element present. These elements are the roadway (asphalt or concrete, lanes for automobiles and transit), medians, and the space at the street edge which contains pedestrian and bicycle infrastructure, and amenity zones.
- Medians and roadway cross-sections may change near intersections based on the preferred alternative and subsequent more detailed design for the corridor. This analysis assumes that 14' landscaped medians would be reduced to 4' concrete medians approaching major intersections to accommodate left turn lanes. Further reductions to landscaped medians may be required pending final design. Center-Running BRT may also reduce the size of the landscaped median based on more detail design, and so it can be assumed that space reserved for streetscaping in Alternative 4 may be smaller than these numbers reflect.
- The analysis assumes that many driveways, except for the very largest, would be consolidated, and breaks in the median would be removed. It includes driveways in the "bicycle/pedestrian/landscape" category for existing conditions, and the No-Build and Build alternatives.
- The analysis assumes reconstruction of the roadway from Cherryvale Avenue east to 75th Street. If the recently built multi-use paths are maintained in their current configuration (adjacent the roadway curb with no amenity zone), this segment will not allocate as much land to streetscaping as illustrated in the Build alternatives.
- For purposes of this analysis, Character District A runs between 28th Street and Foothills Parkway. Character District C begins at Foothills Parkway. Because of this, Character District B is summarized as part of Character Districts A and C.

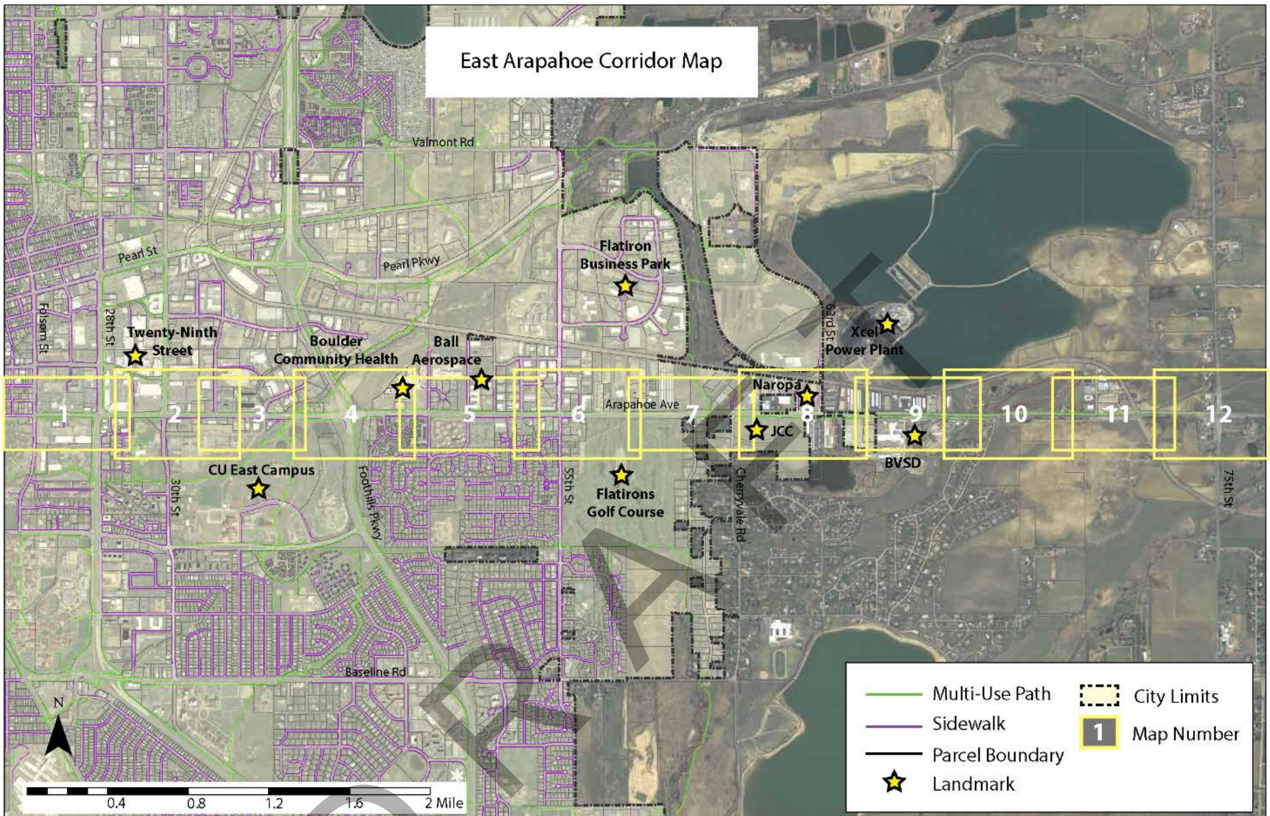
Figure F-2 Streetscape Width by Alternative

Alternative	District A	District B	District C	District D	District E
Existing	43'	N/A	39'	23'	10.5'
Alt 1	N/A	N/A	N/A	N/A	N/A
Alt 2	67'	N/A	61'	61'	27'
Alt 3	67'	N/A	61'	61'	27'
Alt 4	61'	N/A	61'	61'	47'

Evaluation Results

For detailed maps of evaluation results for the streetscape measure, see Appendix F.1. One set of maps is provided for Alternatives 2 and 3, since the right-of-way assumptions and streetscape calculations are nearly identical, and another for Alternative 4. Figure F-3 provides a key map illustrating the 12 sheets comprising the full corridor.

Figure F-3 Streetscape Analysis Key Map



Key Findings

Figure F-4 summarizes results of the analysis.

- All "build" alternatives will designate a larger percentage of land to streetscaping features.
- Alternatives 2 and 3 tend to create more streetscaping space that Alternative 4. In Character Districts C and D, this difference is very small, but is still present.
- The bike/pedestrian option has the largest effect on the numbers. This space can still be mixed and matched with the various BRT alternatives to create different results. See the below table for the width of the bike/pedestrian option for Alternatives in each Character District.
- Alternatives 2 and 3 create less streetscaping space than Alternative 4 in Character District E. This can be viewed as a positive however, because this reflects Community Working Group feedback to avoid excessive landscaping in this rural character district.
- In every alternative, except District E Alternatives 2 and 3, the curb-to-curb pedestrian crossing distance is shorter than existing conditions.

Figure F-4 Roadway vs. Streetscape Space by District and Alternative

GREENHOUSE GAS EMISSIONS

This section describes the evaluation methodology, assumptions, and additional results for the Greenhouse Gas Emission results provided on page 54 of the Evaluation of Alternatives Summary Report.

Analysis Overview

Figure F-5 Greenhouse Gas Emission Analysis Summary Table

Change in Greenhouse Gas Emissions	
Metric	Change in GhG emissions and progress towards City of Boulder goals
Purpose	Describe how alternatives affect transportation GhG emissions, e.g., due to shift from vehicle travel to other modes, and evaluate progress towards the city's Transportation Master Plan and Climate Commitment goals for reducing emissions
Analysis Methodology	Calculate emissions from vehicle miles traveled (VMT), which is an output from the travel demand model
Data Source	Based on VMT data output from travel model and Transportation Master Plan GhG methodology

Assumptions

- VMT converted to GhG emissions based on 0.000367 Metric Tons CO2e per mile.
- Assumes 2013 vehicle inventory and average fuel efficiency/emissions.
- Transit vehicle emissions are not included in the analysis.

Evaluation Results

Figure F-6 provides a table with detailed results from the GhG analysis.

Key Findings

- Based on regional projections for 20% traffic growth, the No-Build and Enhanced Bus alternatives are likely to increase emissions relative to existing conditions.
- The BRT alternatives would reduce emissions to near existing levels if they can help maintain the historic trend of 0% traffic growth.
- BRT with the 20% traffic growth scenario would still increase emissions moderately relative to existing.

Figure F-6 GhG Analysis Results

Alternative	Traffic Scenario	Vehicle Miles of Travel (VMT)	Average Auto Occupancy**	Person Miles of Travel in Automobiles (APMT)	Automobile Person Miles of Travel Comparison to Existing (% increase)	2013 Vehicle inventory GHG in LBS/Mile	LBS to Metric Ton	GhG Auto Emissions in Metric Tons	GhG Avoided in Metric Tons (vs Existing)
Existing	Existing	110,500	1.15	127,075	n/a	0.809	2204.623	40.548663	n/a
1	2040 + 20% Traffic (Regional Projection) Without BRT	130,100	1.15	149,615	17.70%	0.809	2204.623	47.741005	7.1923421
2	2040 + 20% Enhanced Transit	130,100	1.15	149,615	17.70%	0.809	2204.623	47.741005	7.1923421
3&4 Low	2040 + 0% Traffic (Historic Trend) With BRT	111,300	1.15	127,995	0.70%	0.809	2204.623	40.842228	0.293565
3&4 High	High 2040 + 20% Traffic (Regional Projection) With BRT	116,000	1.15	133,400	5.00%	0.809	2204.623	42.566922	2.0182593

Source: City of Boulder, TMP GhG Emissions Model

Figure F-7 GhG Emissions Evaluation Score

SCORE -3 -2 -1 0 1 2 3

Worse → Better

[1] 0% Traffic Growth (Historic Trends) X / X [2] 20% Traffic Growth (Regional model projection)

Year	2015	2040	2040	2040	2040
Alternative	**Existing** Existing Bus Existing Travel Lanes Existing Multi-use Path	**Alt 1: No-Build** Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	**Alt 2** Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	**Alt 3** Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	**Alt 4** Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
GhG Emissions	0	+20% Traffic Growth[2] -2	+20% Traffic Growth[2] -2	0%/20% Traffic Growth[1,2] 0 / -1	0%/20% Traffic Growth[1,2]* 0 / -1

APPENDIX F.1 STREETSCAPE MAPS

Figure F.1-1 Location Map

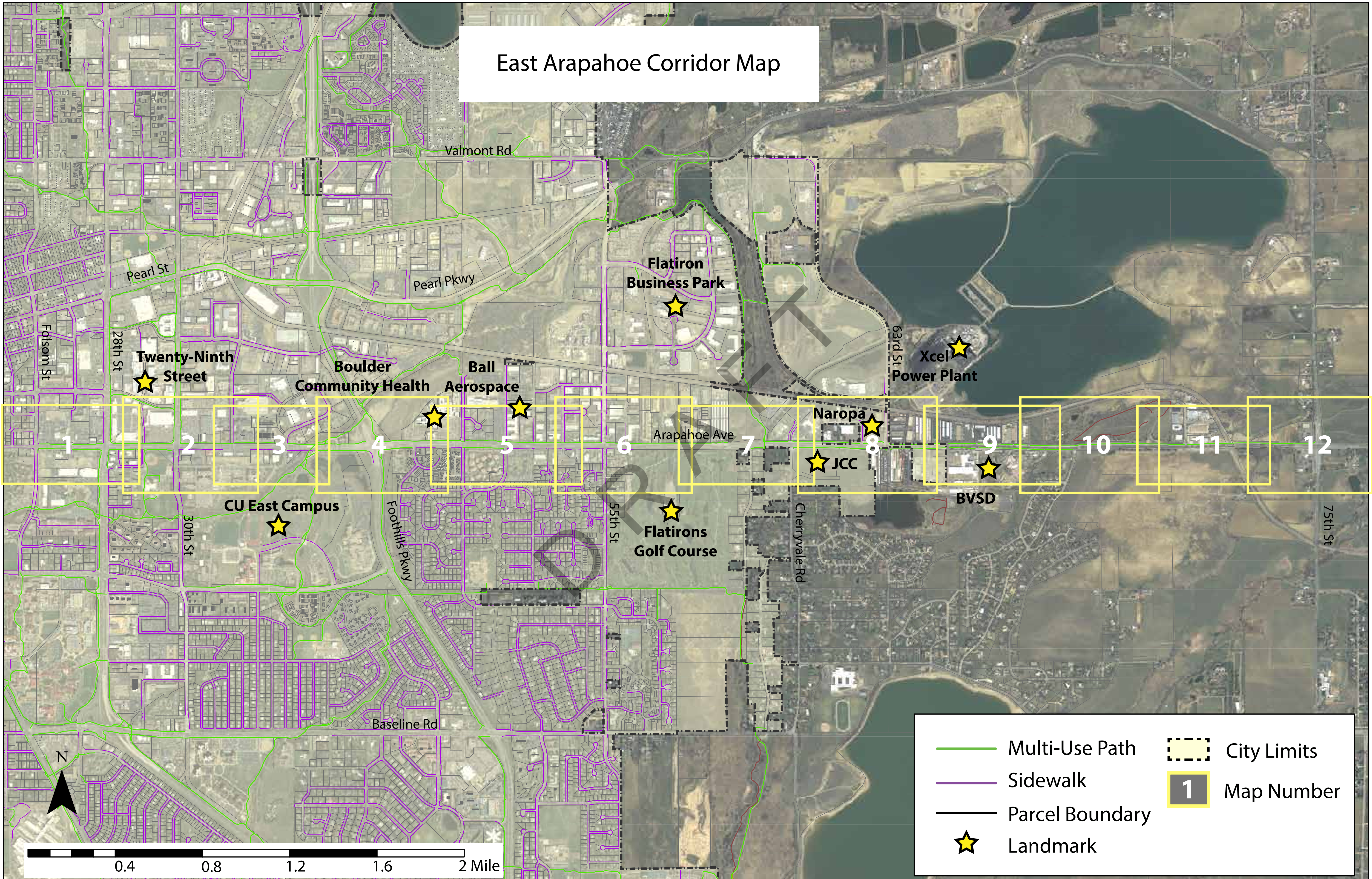


Figure F.1-2 Alternatives 2 and 3 - Map 2A Character District A

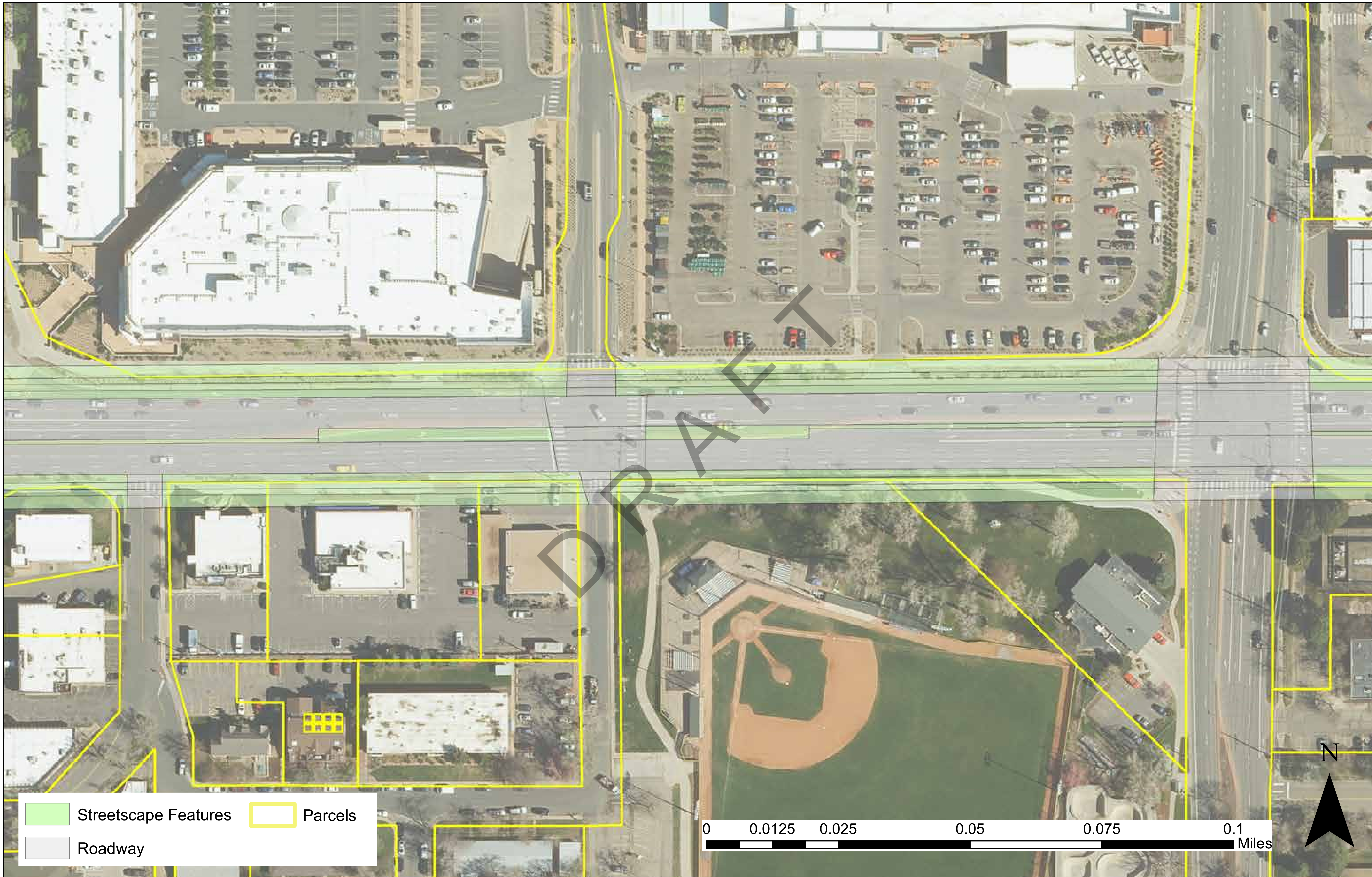


Figure F.1-3 Alternatives 2 and 3 - Map 2B Character District A

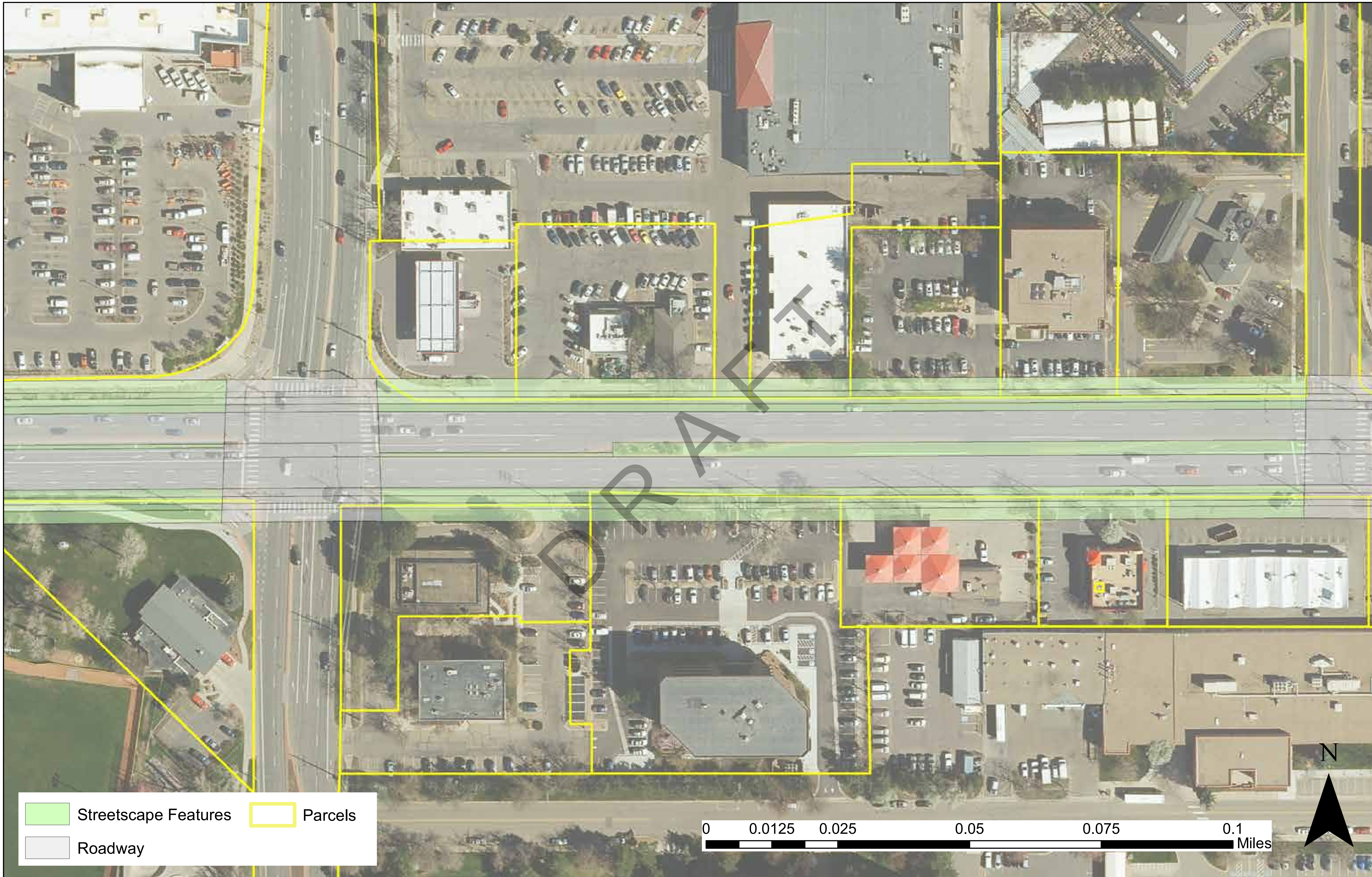


Figure F.1-4 Alternatives 2 and 3 - Map 3A Character District A

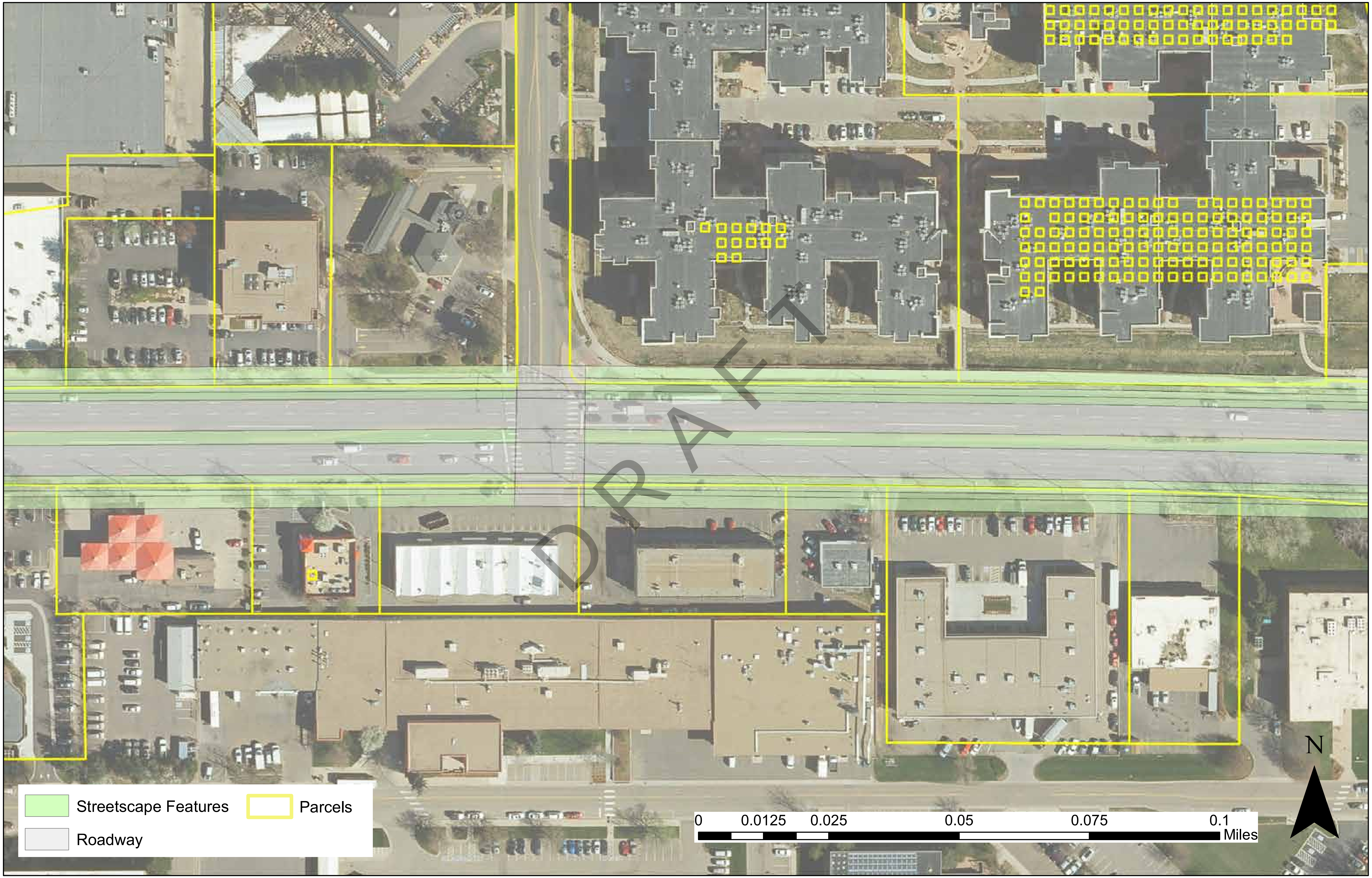


Figure F.1-5 Alternatives 2 and 3 - Map 3B Character District A

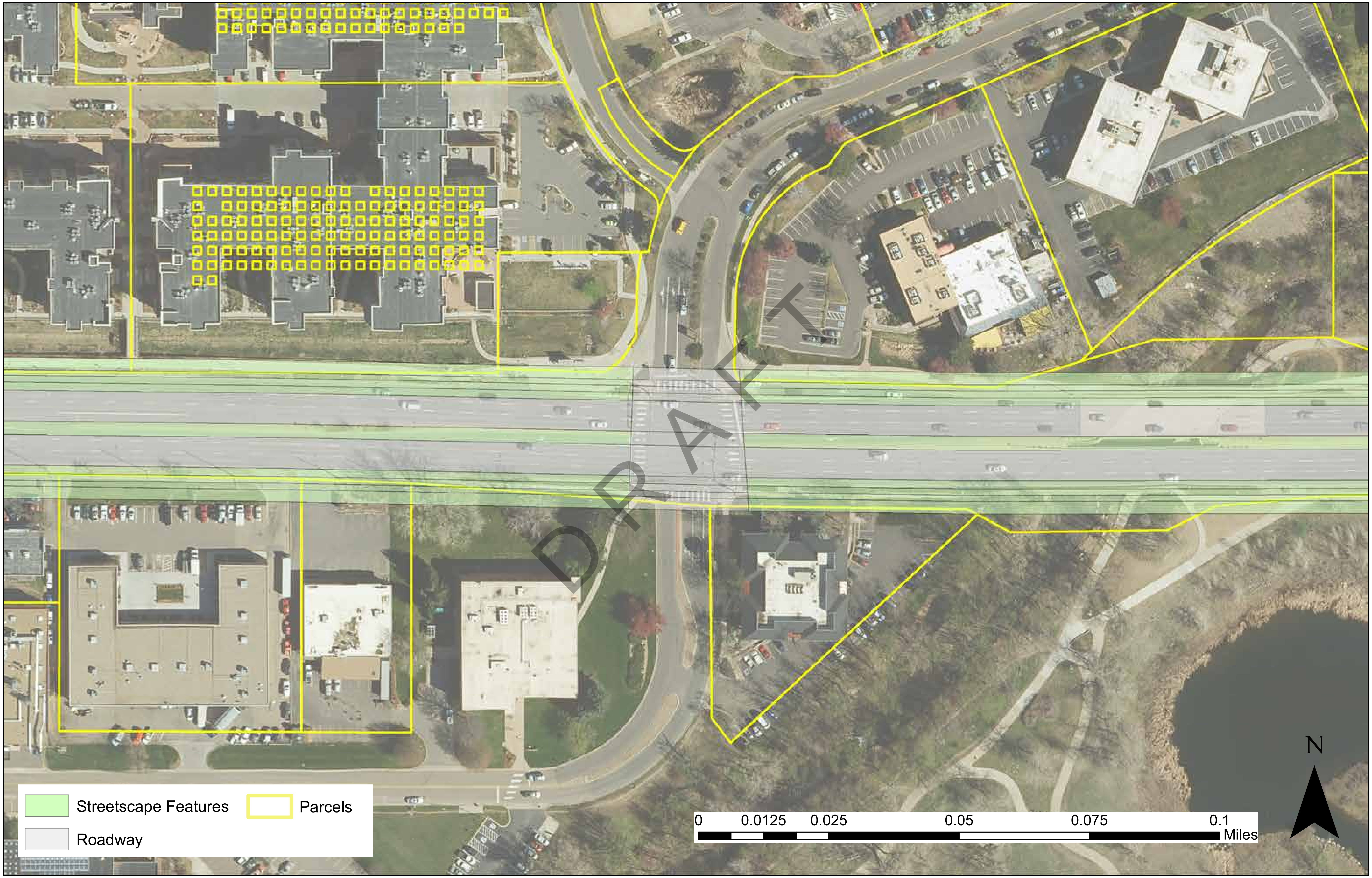


Figure F.1-6 Alternatives 2 and 3 - Map 4A Character District C

Figure F.1-7 Alternatives 2 and 3 - Map 4B Character District C

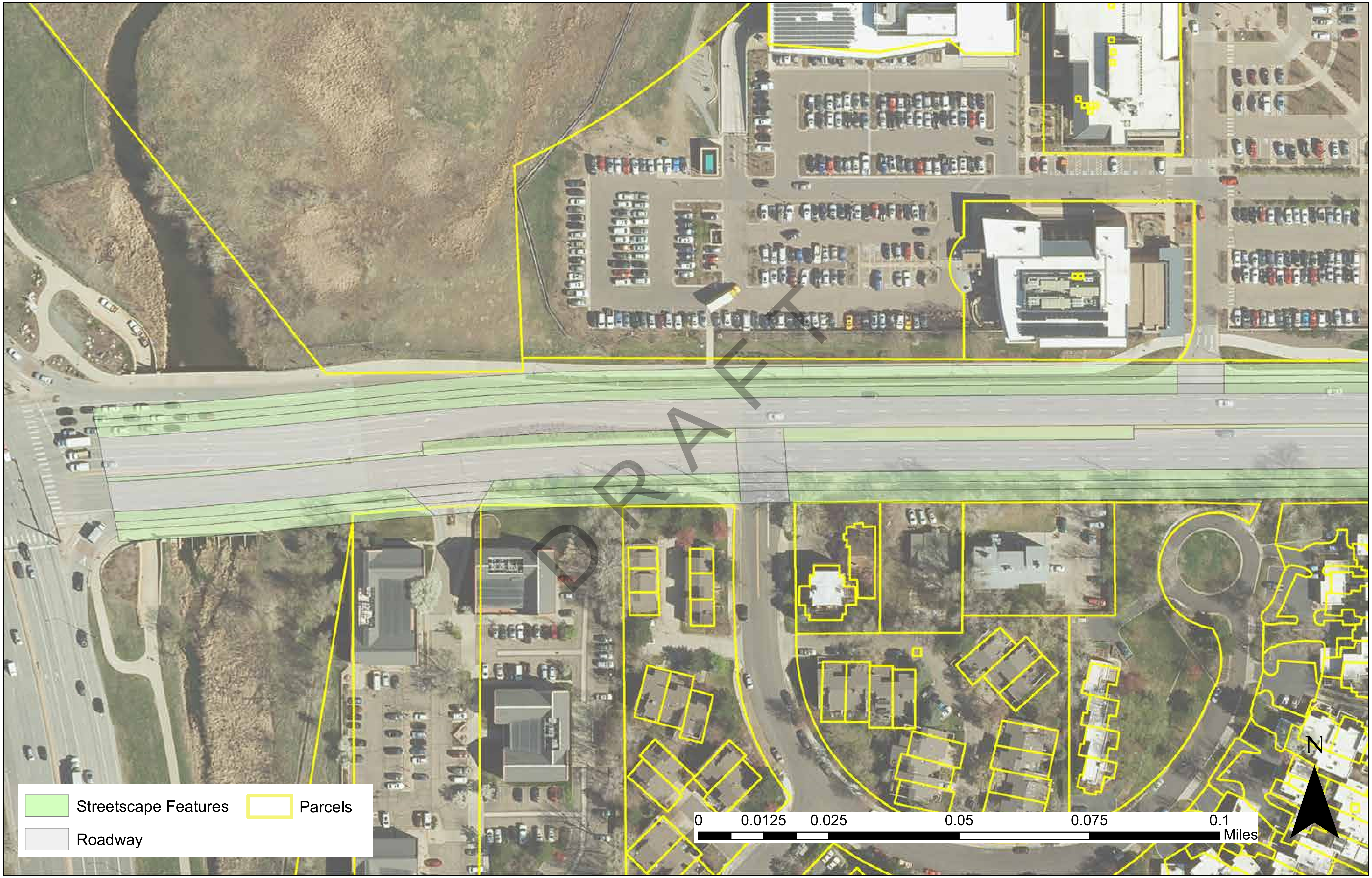


Figure F.1-8 Alternatives 2 and 3 - Map 5A Character District C

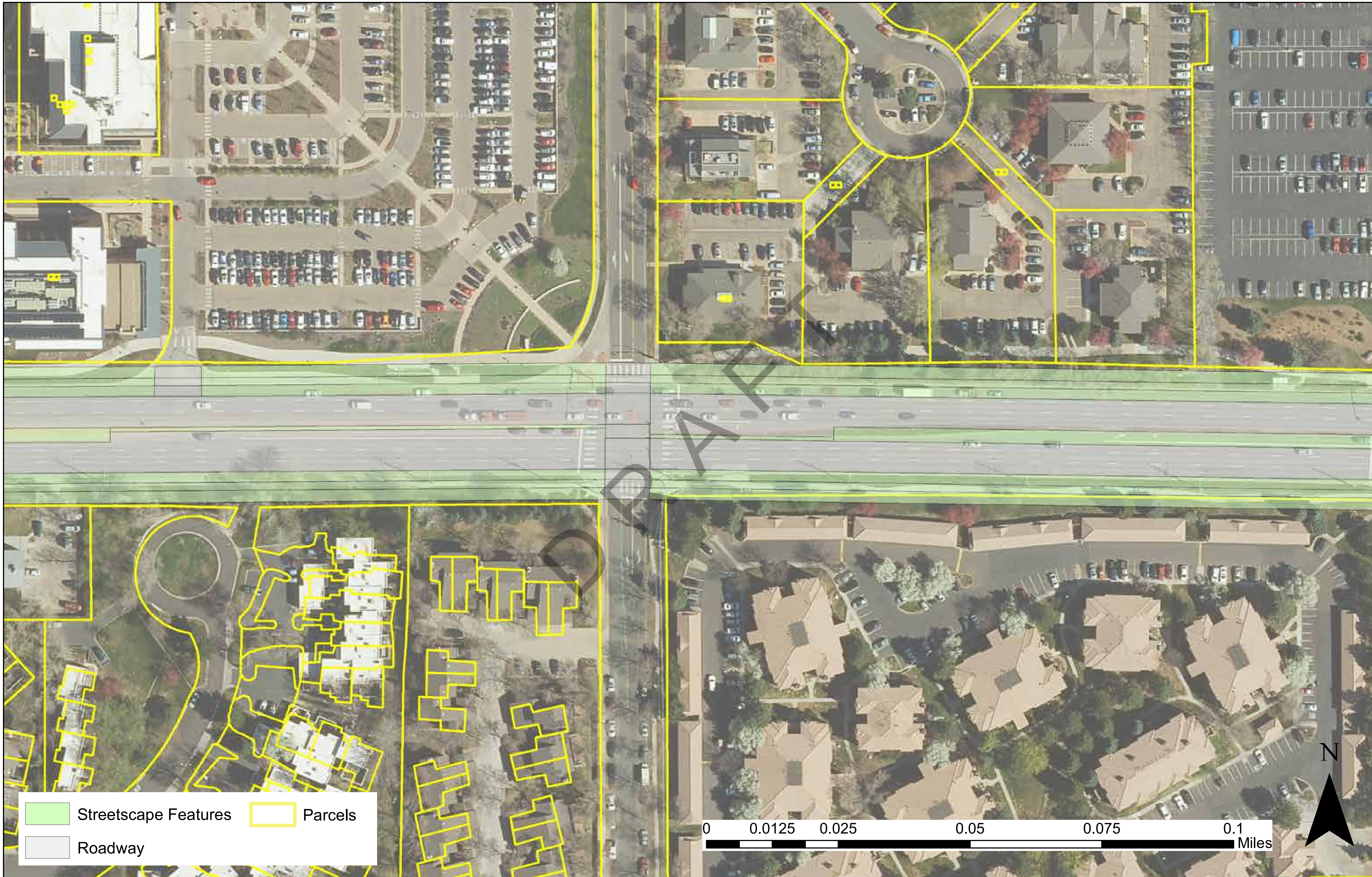


Figure F.1-9 Alternatives 2 and 3 - Map 5B Character District C

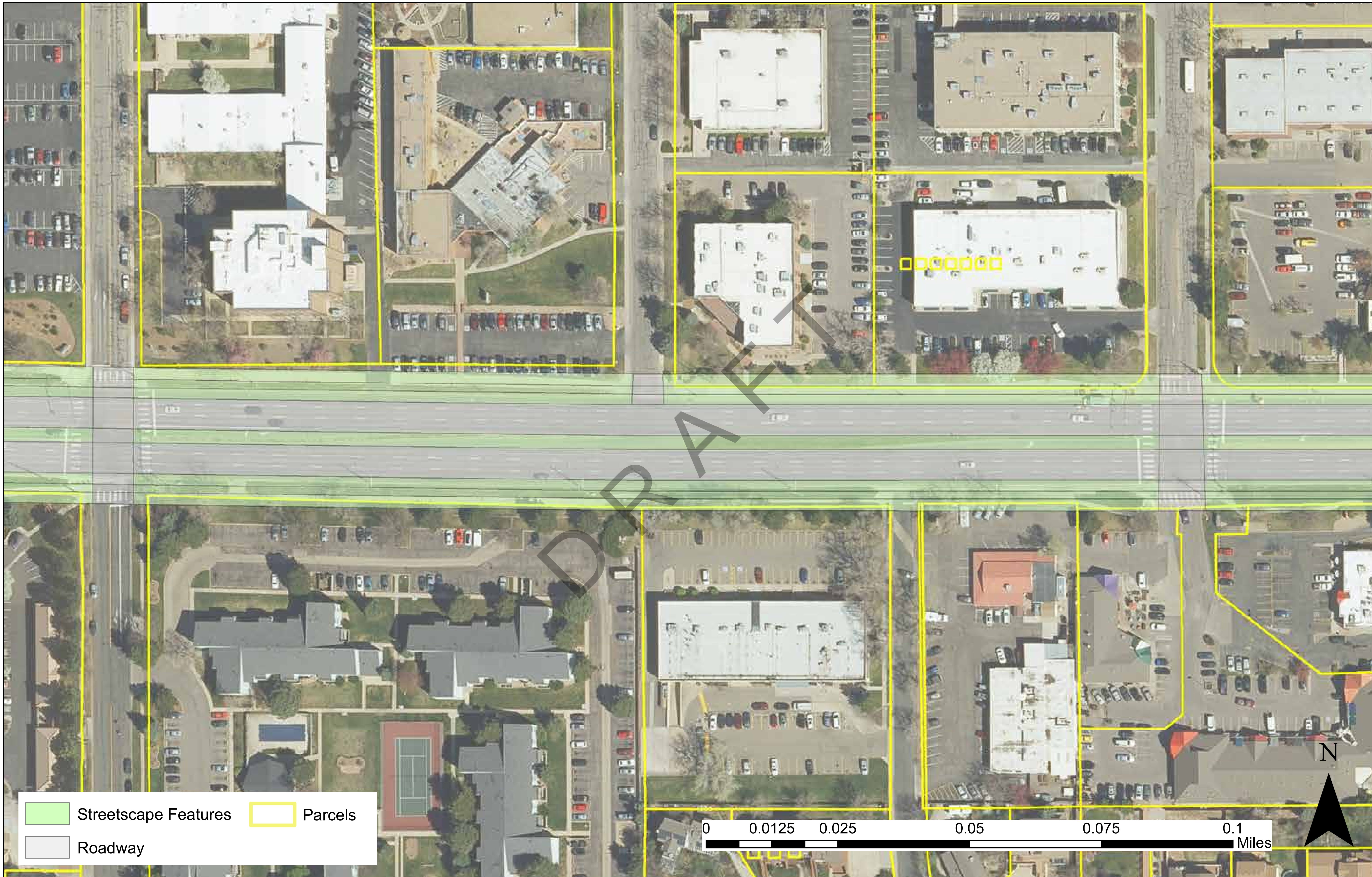


Figure F.1-10 Alternatives 2 and 3 - Map 6A Character District C

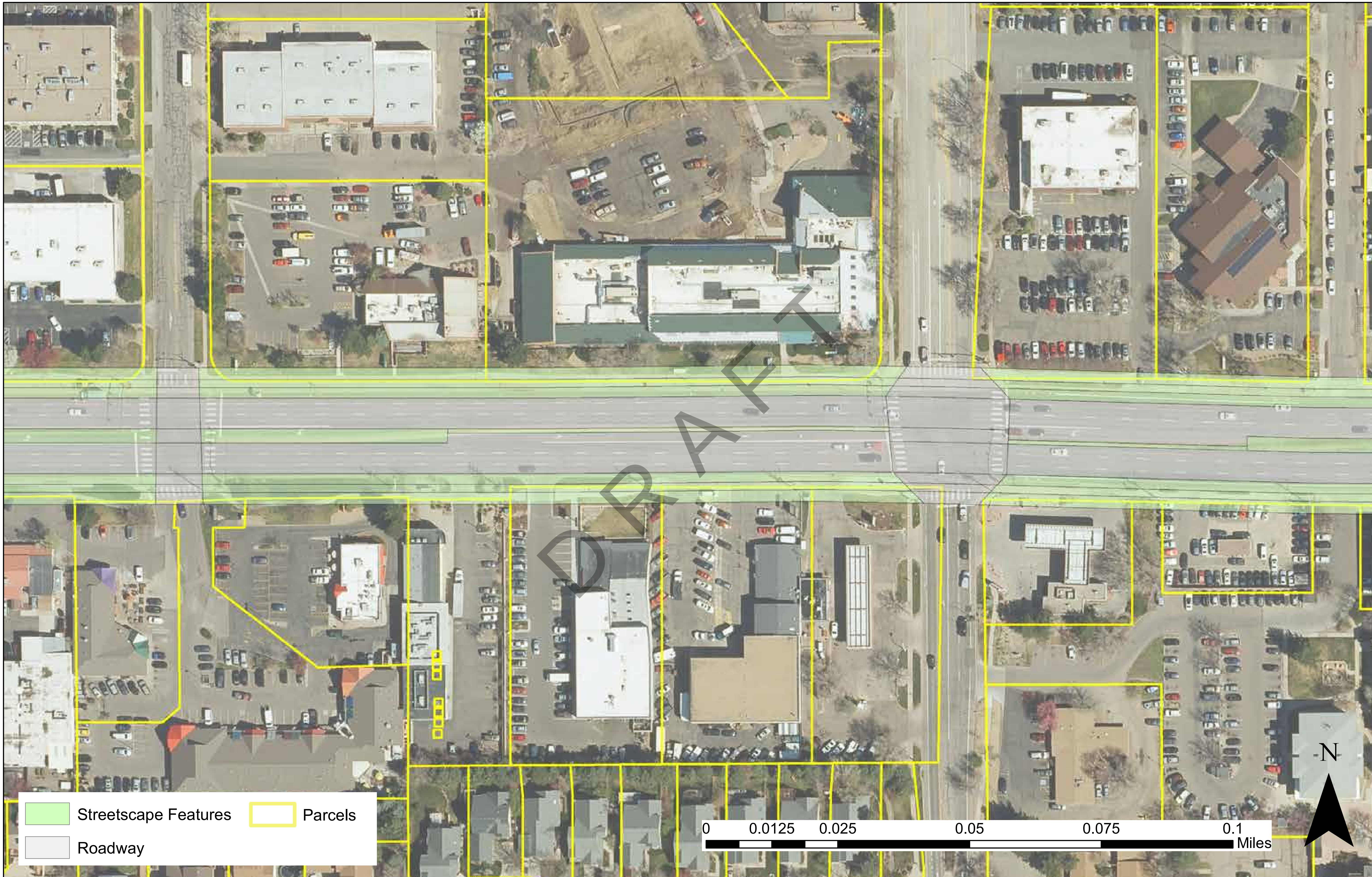


Figure F.1-11 Alternatives 2 and 3 - Map 6B Character District C and D

Figure F.1-12 Alternatives 2 and 3 - Map 7A Character District D

Figure F.1-13 Alternatives 2 and 3 - Map 7B Character District D

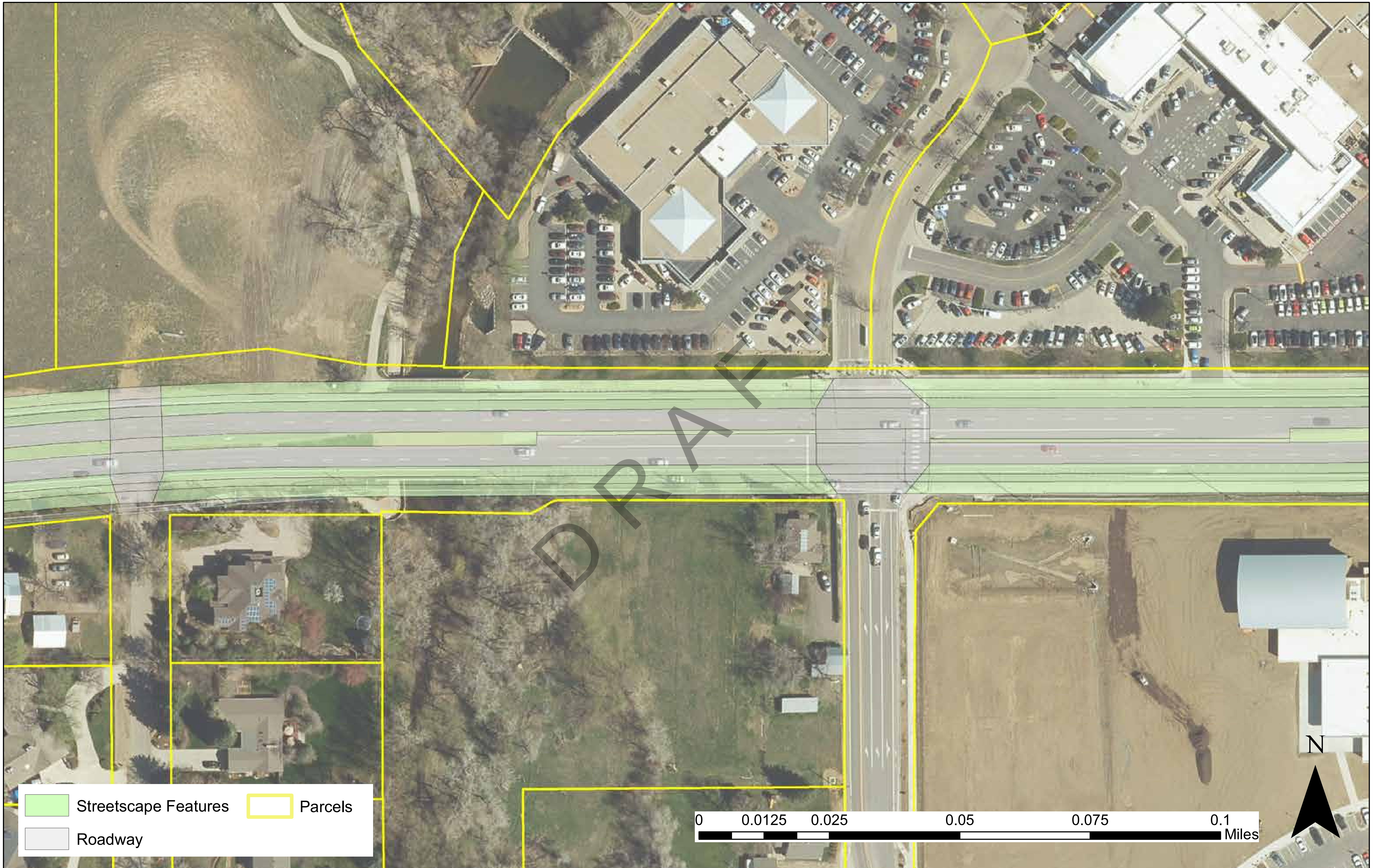


Figure F.1-14 Alternatives 2 and 3 - Map 8A Character District D

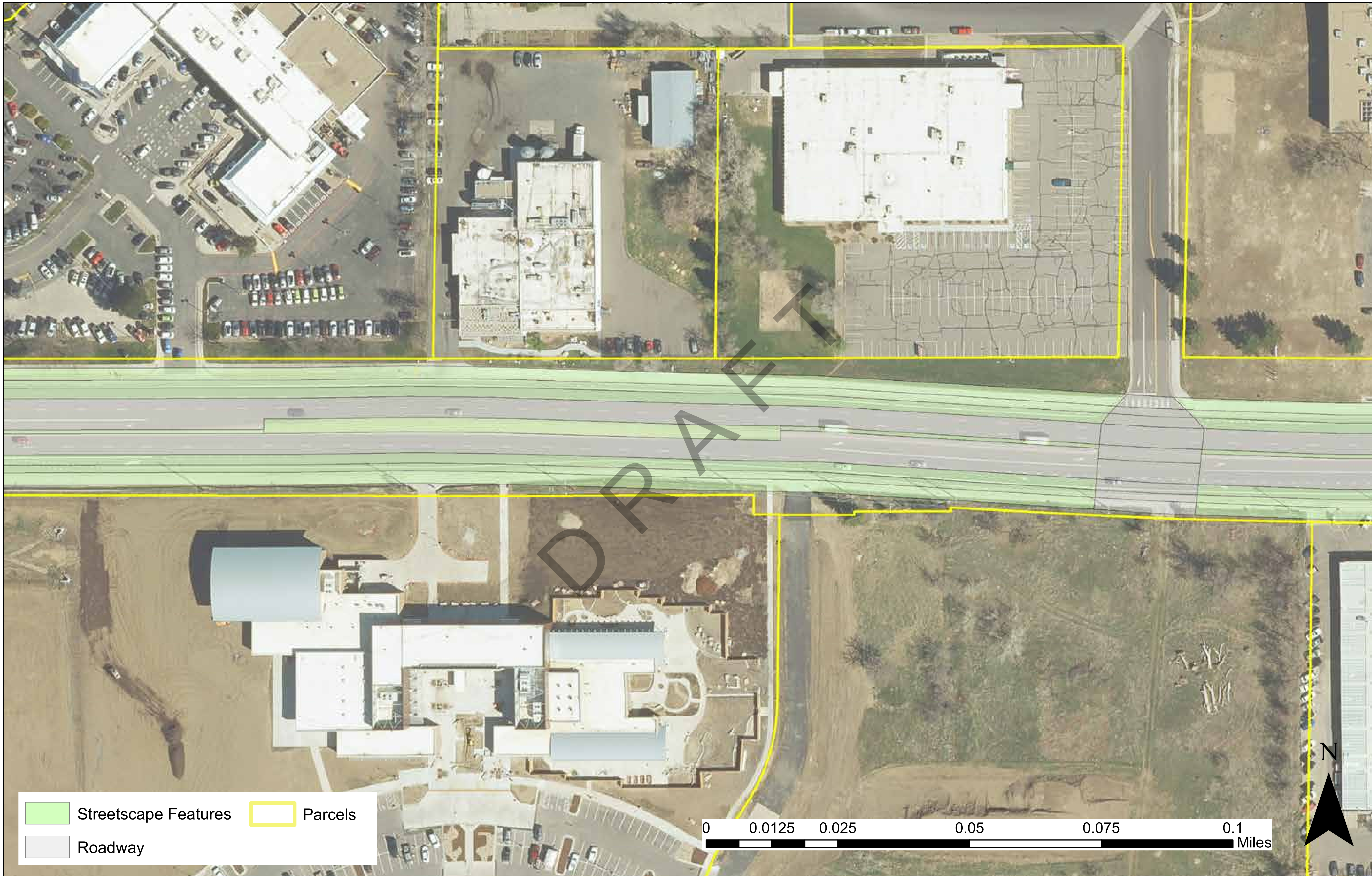


Figure F.1-15 Alternatives 2 and 3 - Map 8B Character District D

Figure F.1-16 Alternatives 2 and 3 - Map 9A Character District D

Figure F.1-17 Alternatives 2 and 3 - Map 10A Character District D

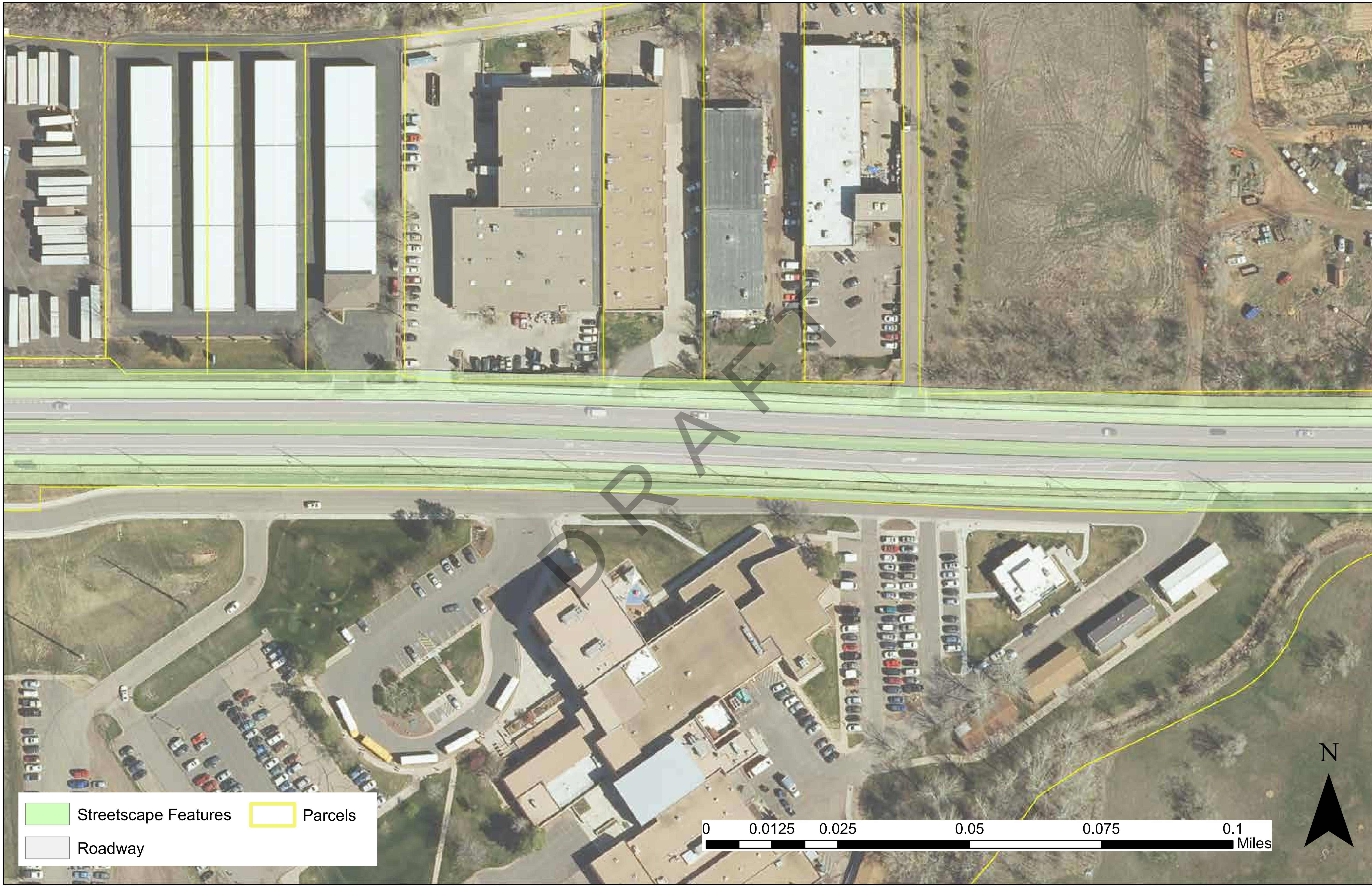


Figure F.1-18 Alternatives 2 and 3 - Map 10B Character District D to E

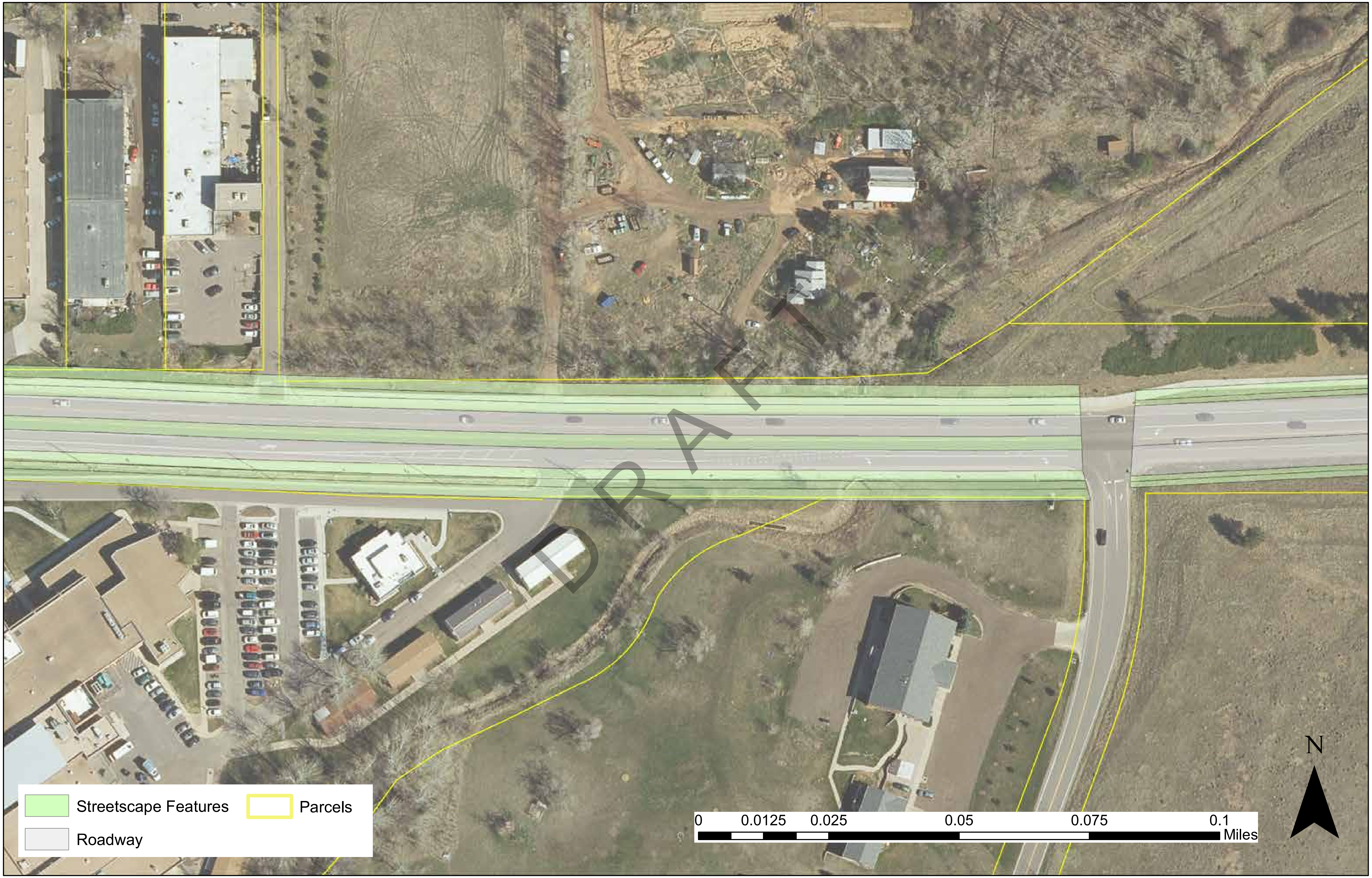


Figure F.1-19 Alternatives 2 and 3 - Map 11A Character District E

Figure F.1-20 Alternatives 2 and 3 - Map 11B Character District E

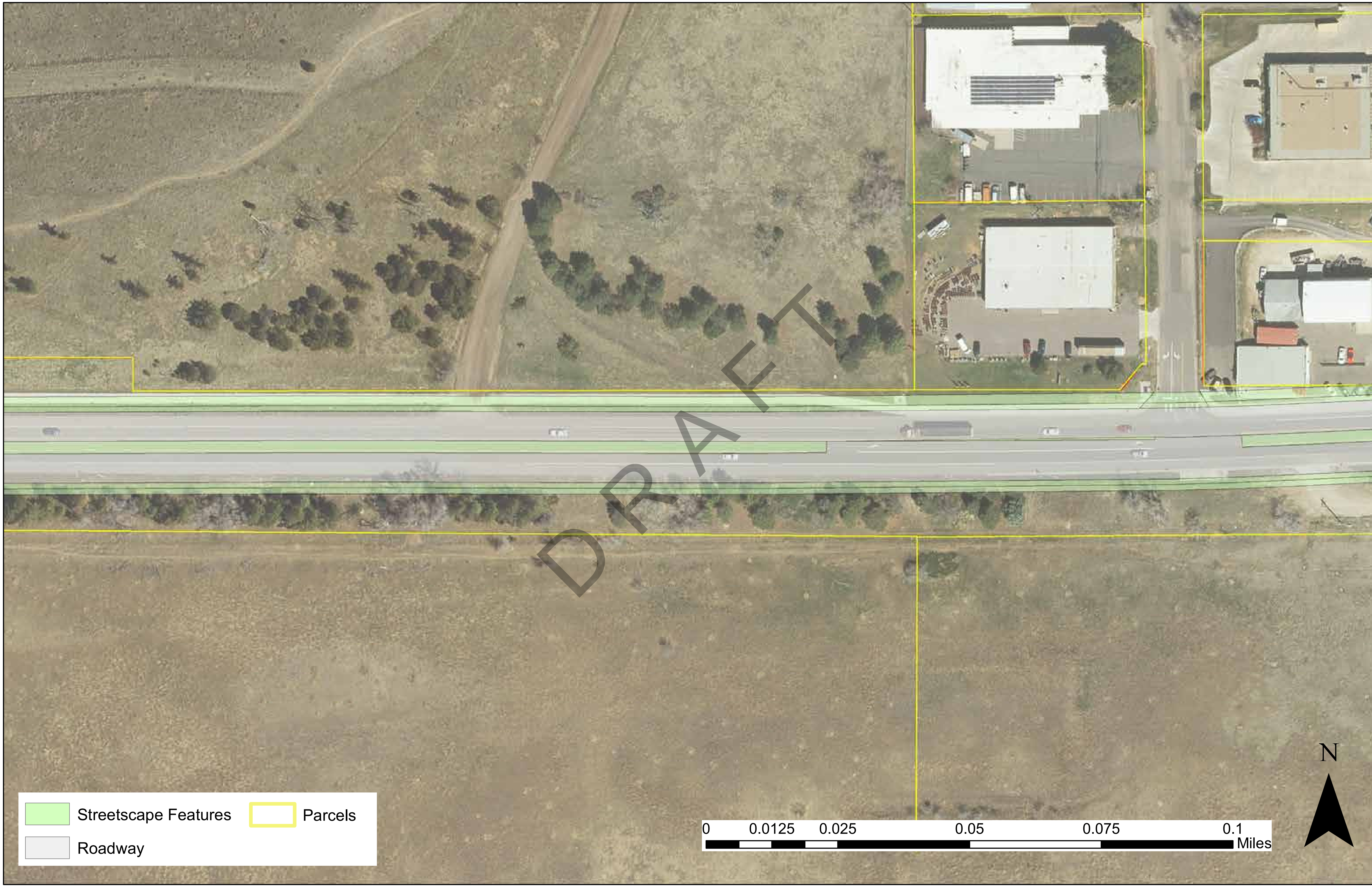


Figure F.1-21 Alternatives 2 and 3 - Map 12A Character District E

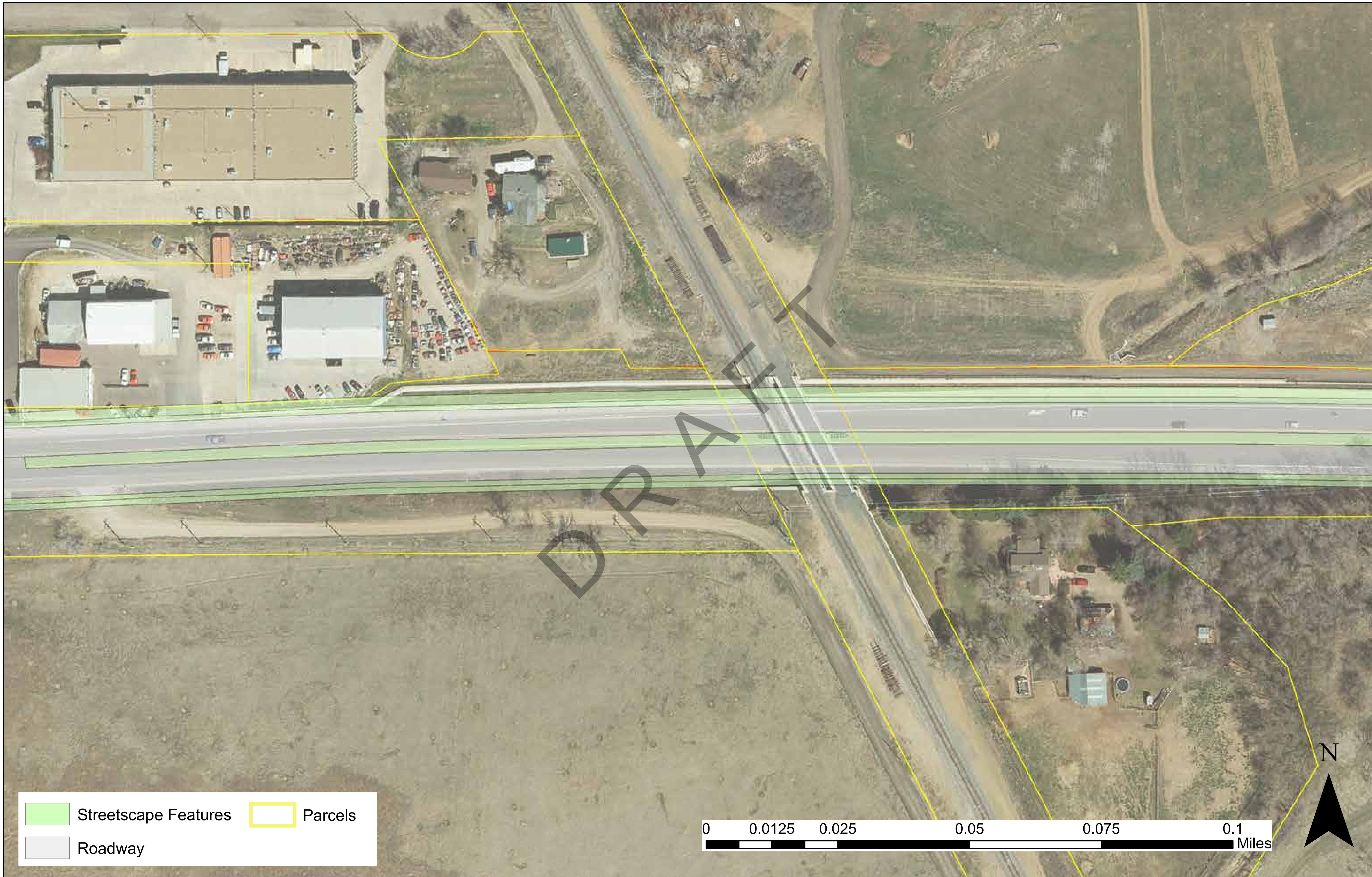


Figure F.1-22 Alternatives 2 and 3 - Map 12B Character District E

Figure F.1-23 Alternative 4 - Map 2A Character District A

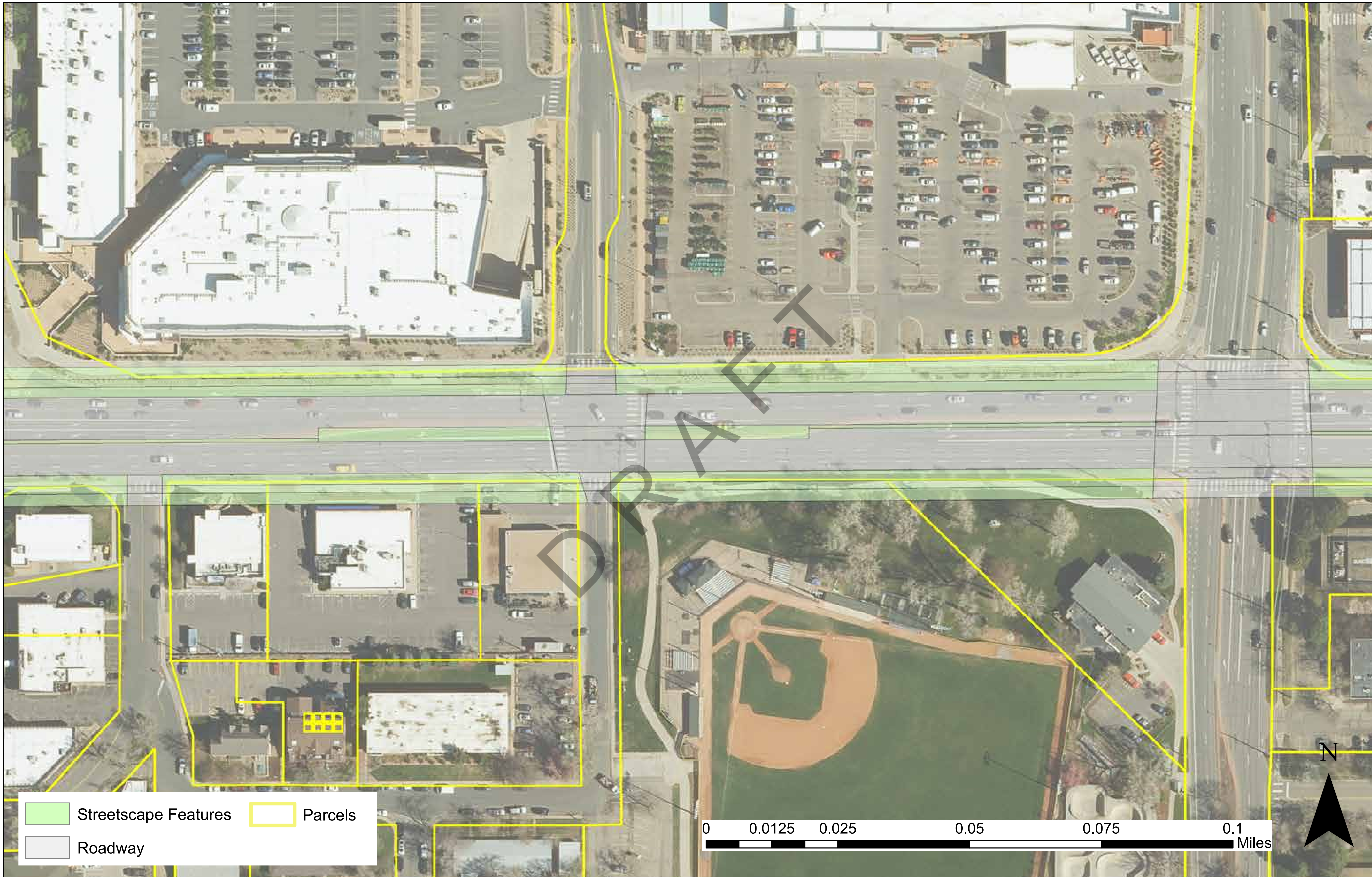


Figure F.1-24 Alternative 4 - Map 2B Character District A

Figure F.1-25 Alternative 4 - Map 3A Character District A

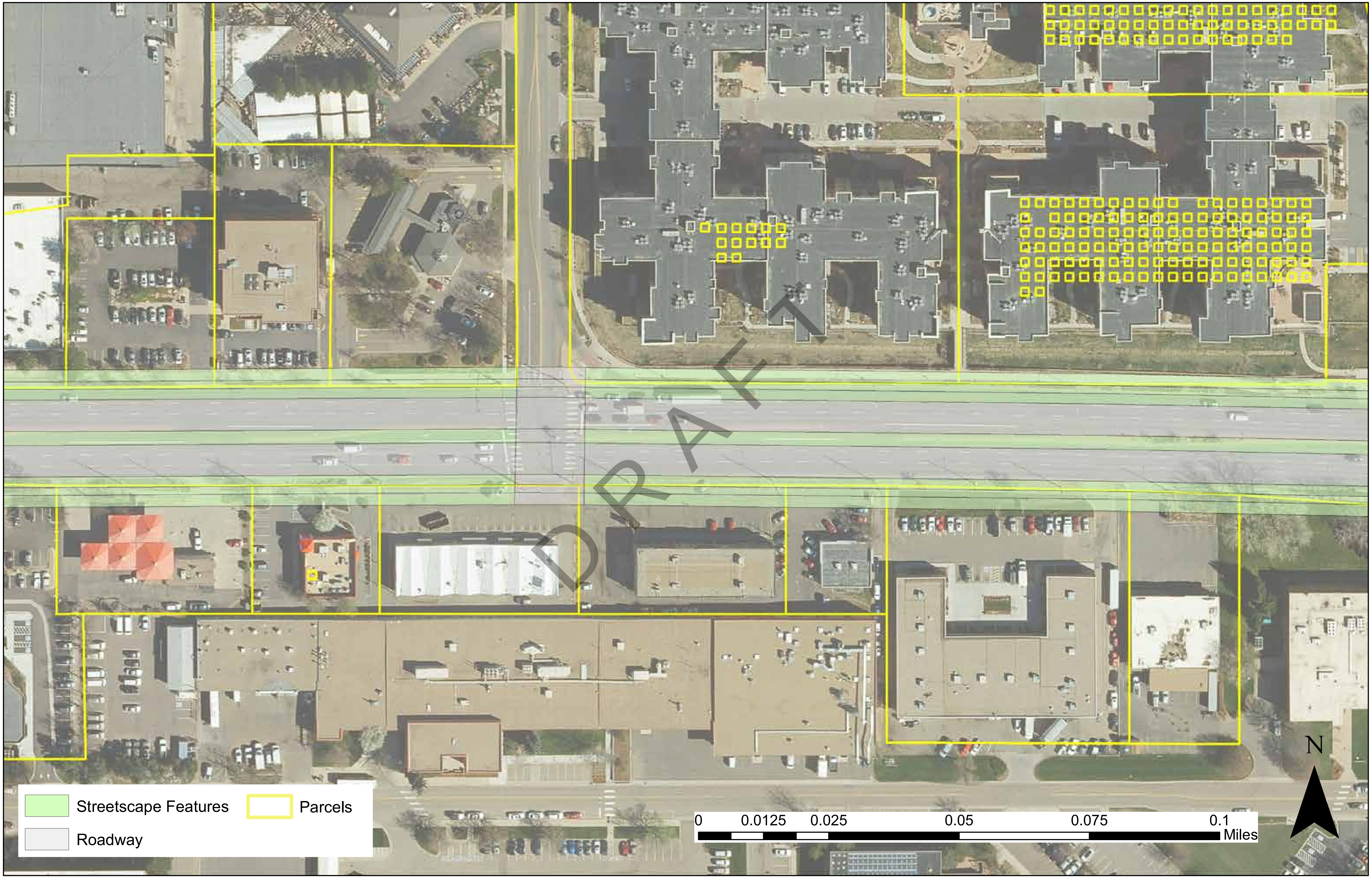


Figure F.1-26 Alternative 4 - Map 3B Character District A

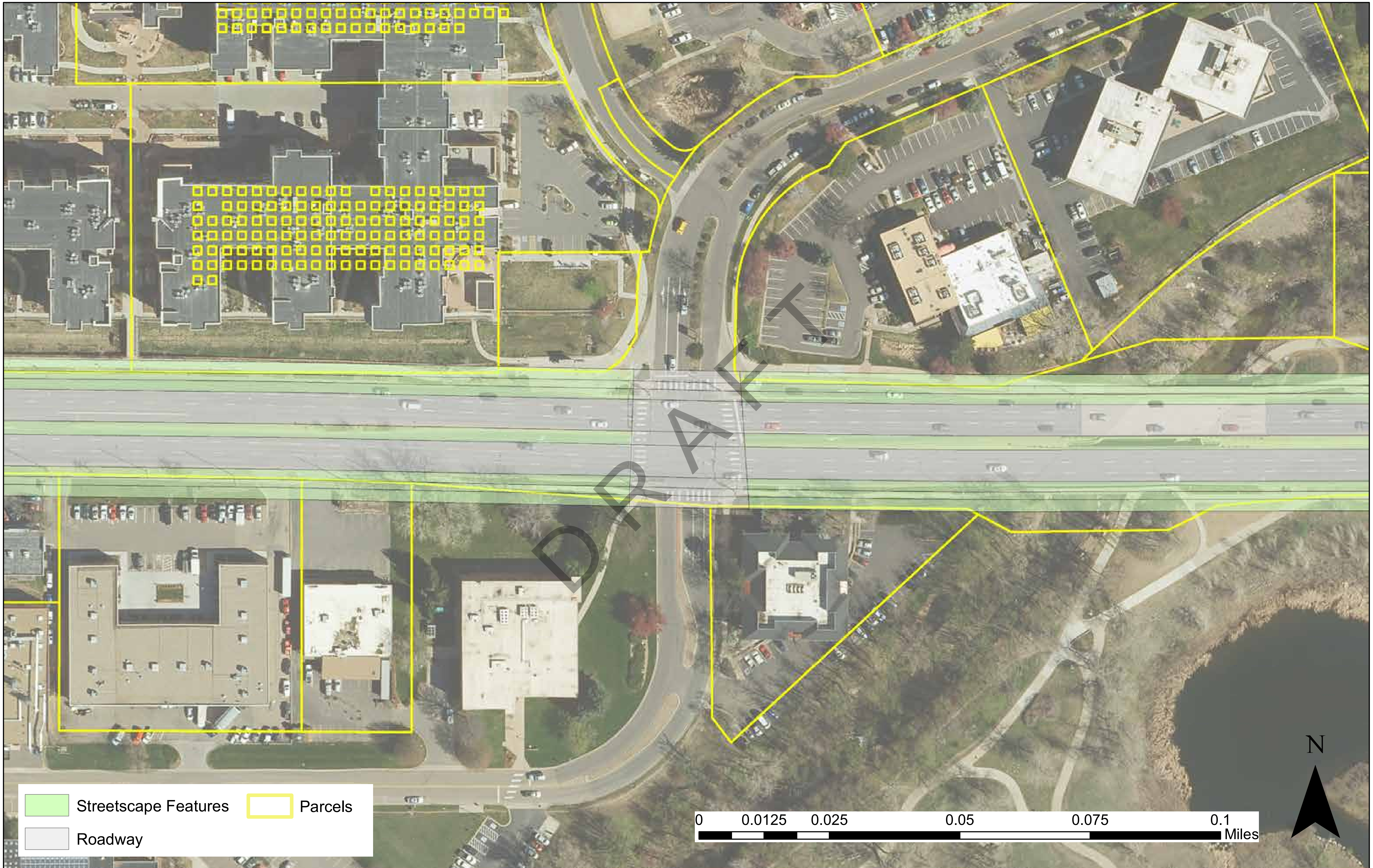


Figure F.1-27 Alternative 4 - Map 4A Character District C

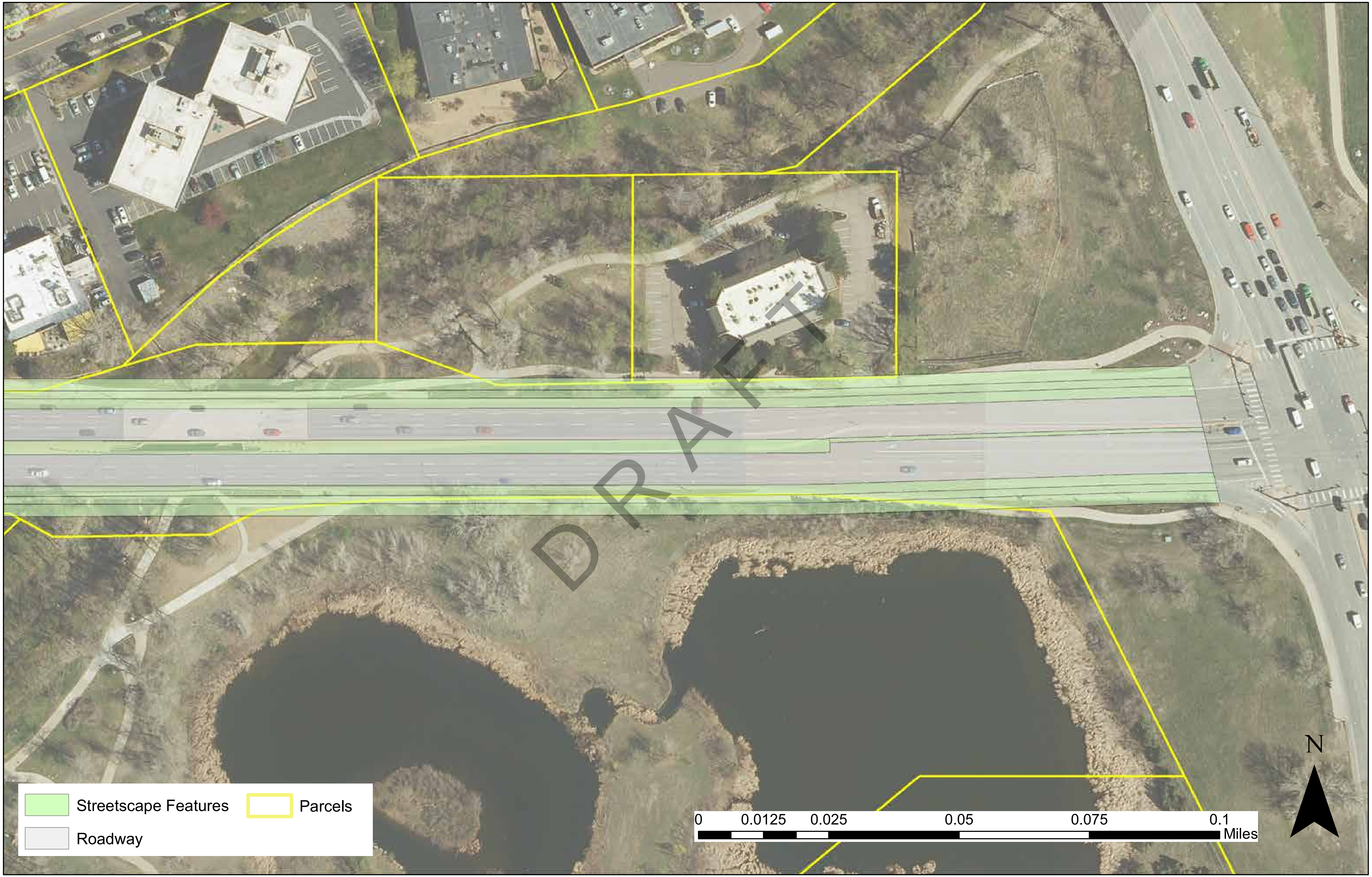


Figure F.1-28 Alternative 4 - Map 4B Character District C

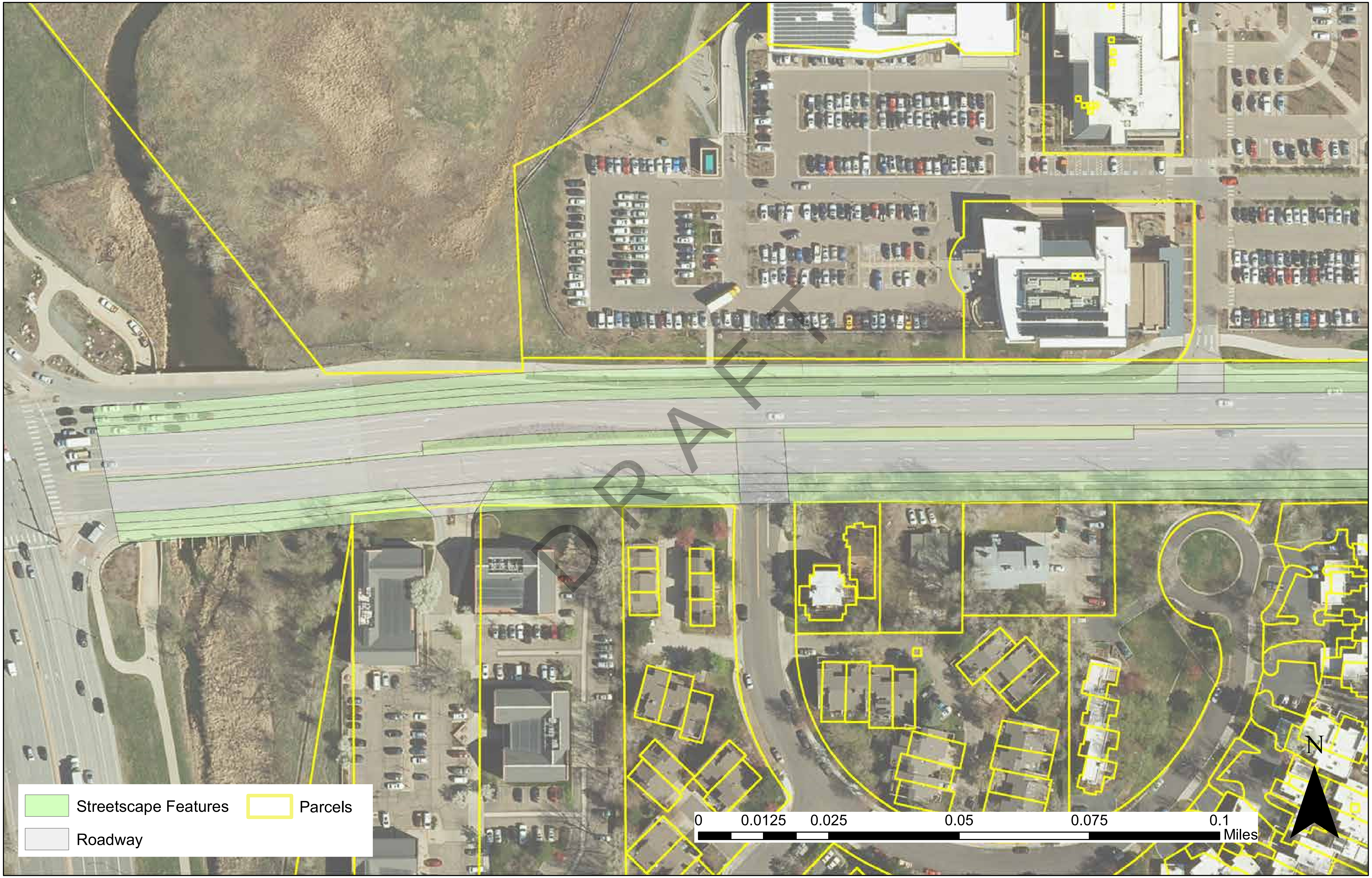


Figure F.1-29 Alternative 4 - Map 5A Character District C

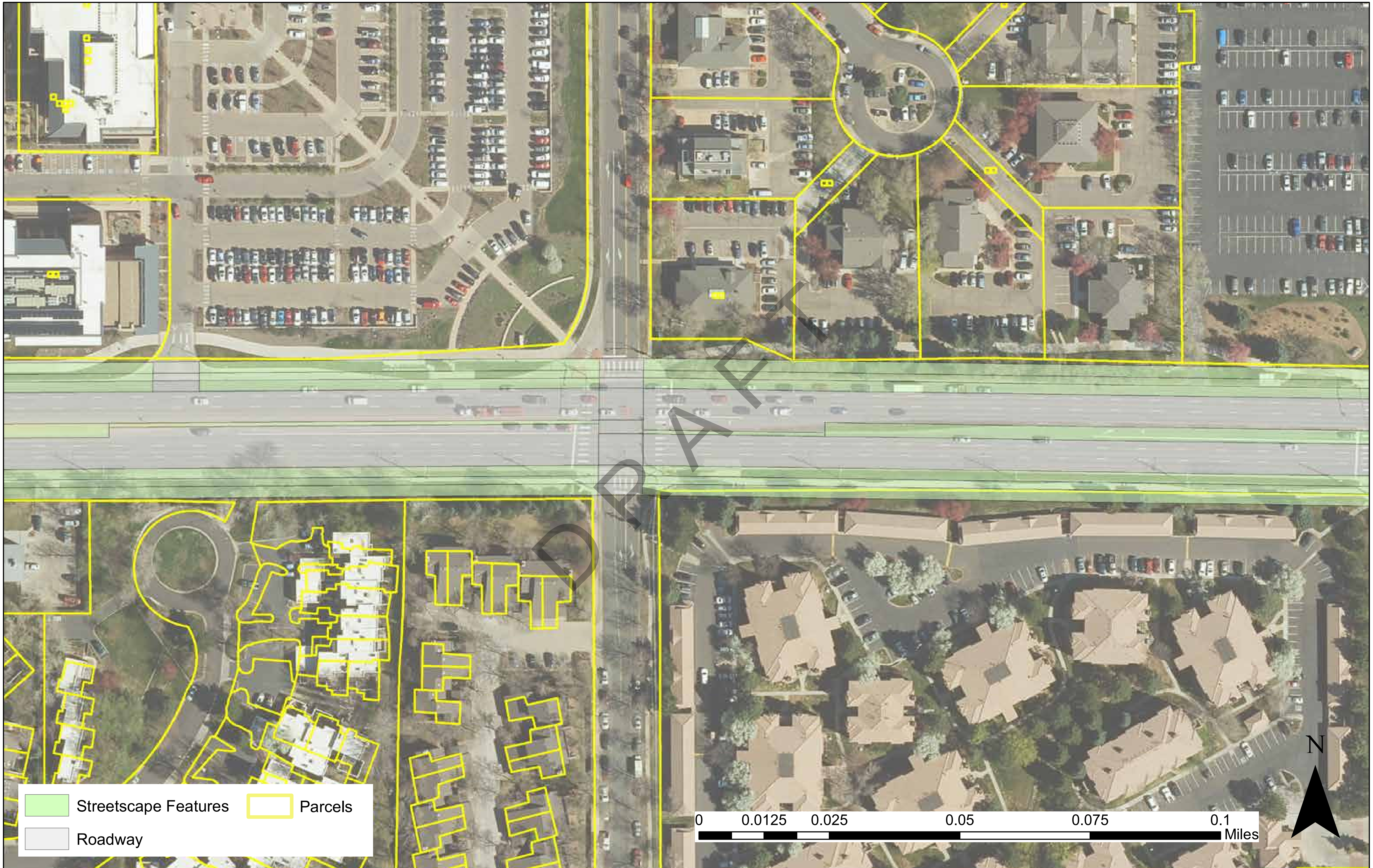


Figure F.1-30 Alternative 4 - Map 5B Character District C

Figure F.1-31 Alternative 4 - Map 6A Character District C

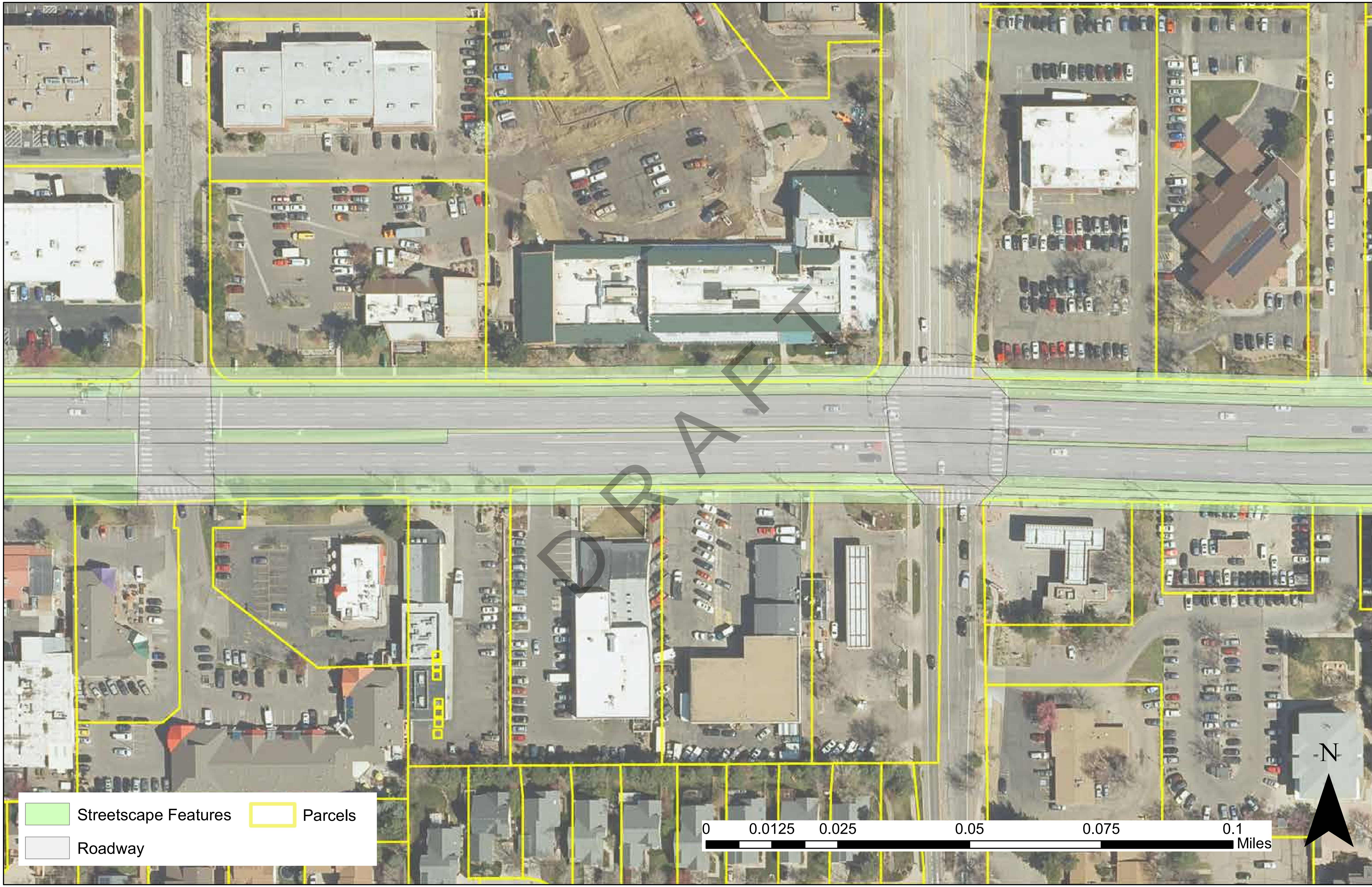


Figure F.1-32 Alternative 4 - Map 6B Character District C and D

Figure F.1-33 Alternative 4 - Map 7A Character District D

Figure F.1-34 Alternative 4 - Map 7B Character District D

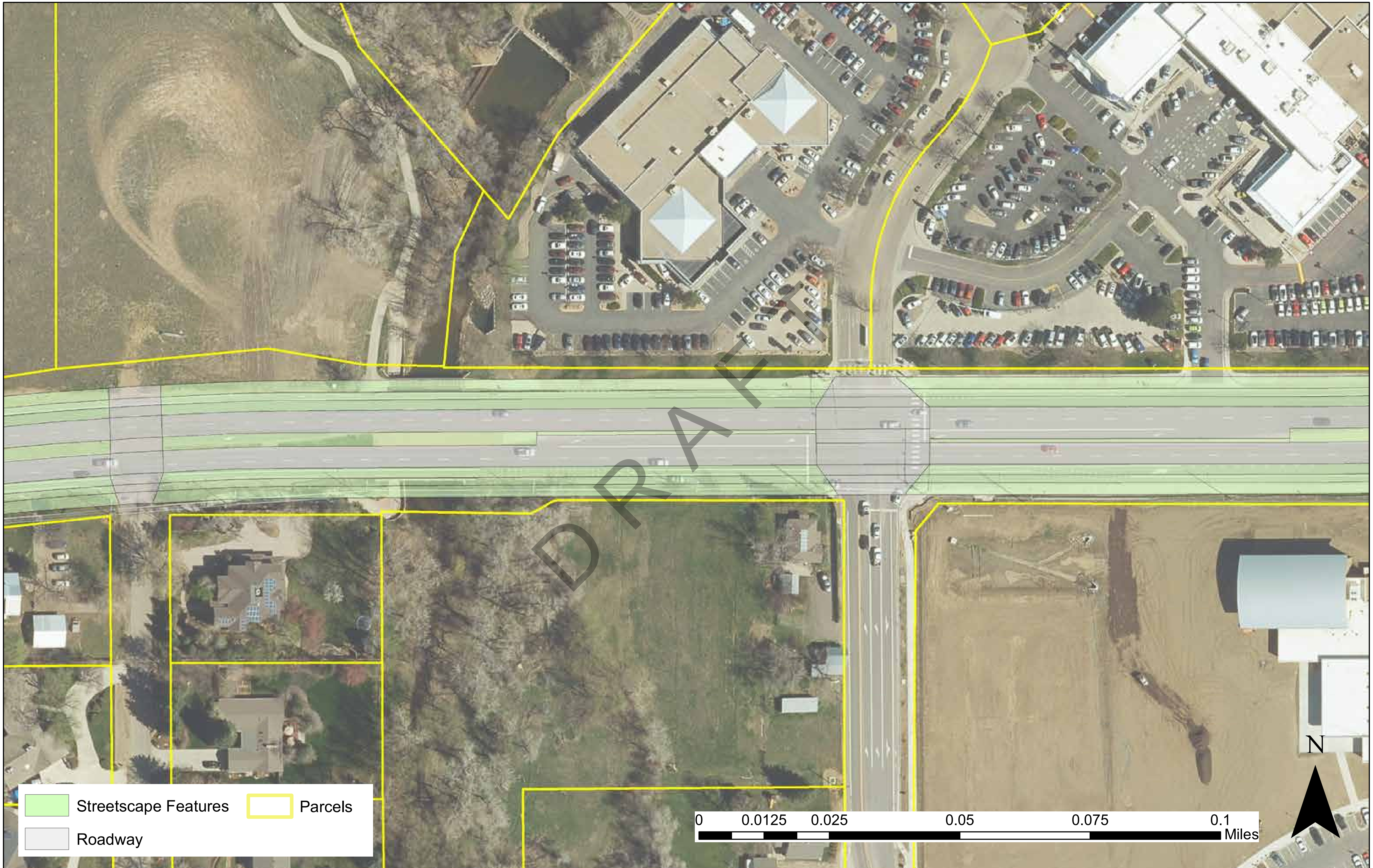


Figure F.1-35 Alternative 4 - Map 8A Character District D

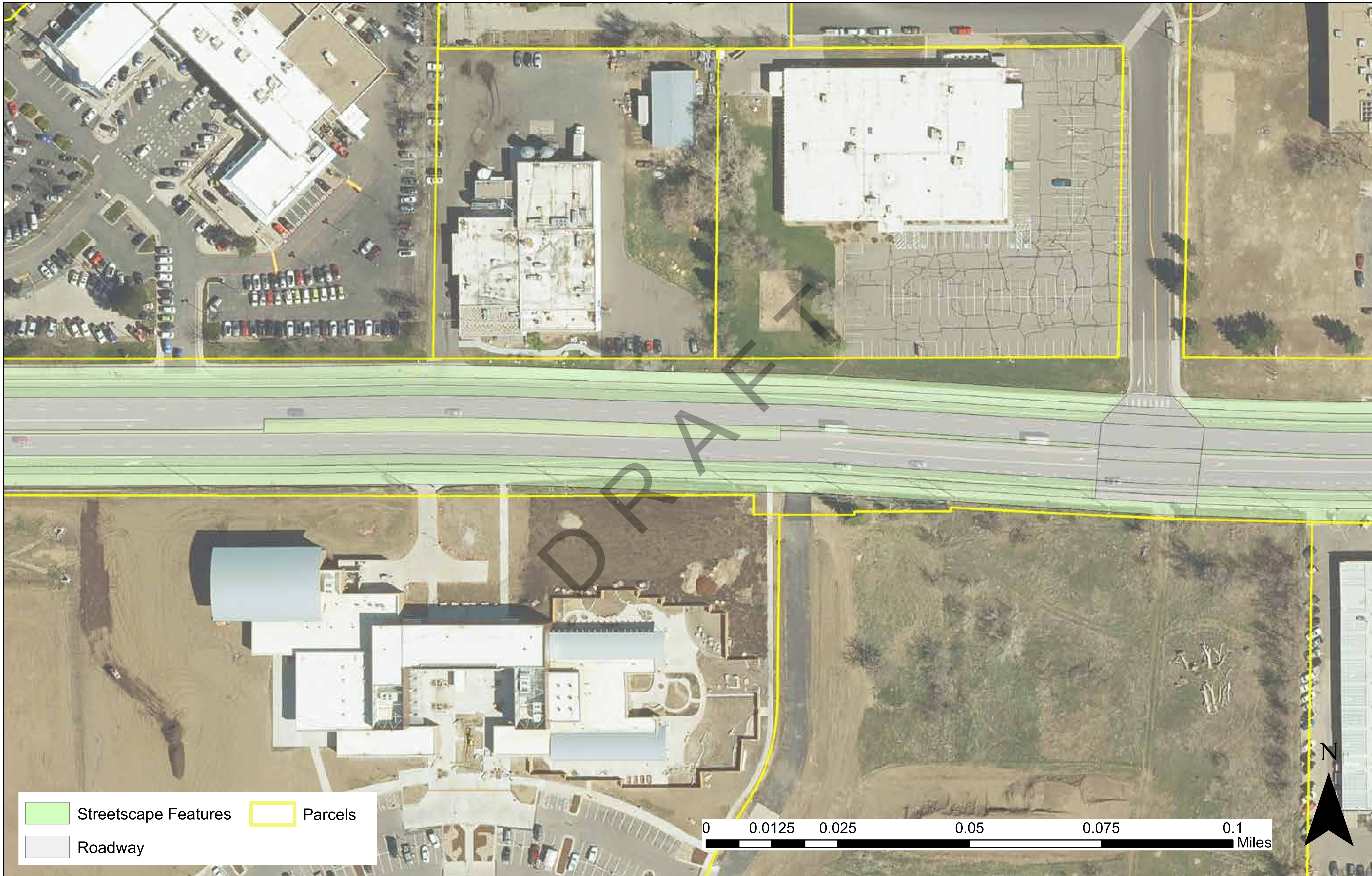


Figure F.1-36 Alternative 4 - Map 8B Character District D

Figure F.1-37 Alternative 4 - Map 9A Character District D

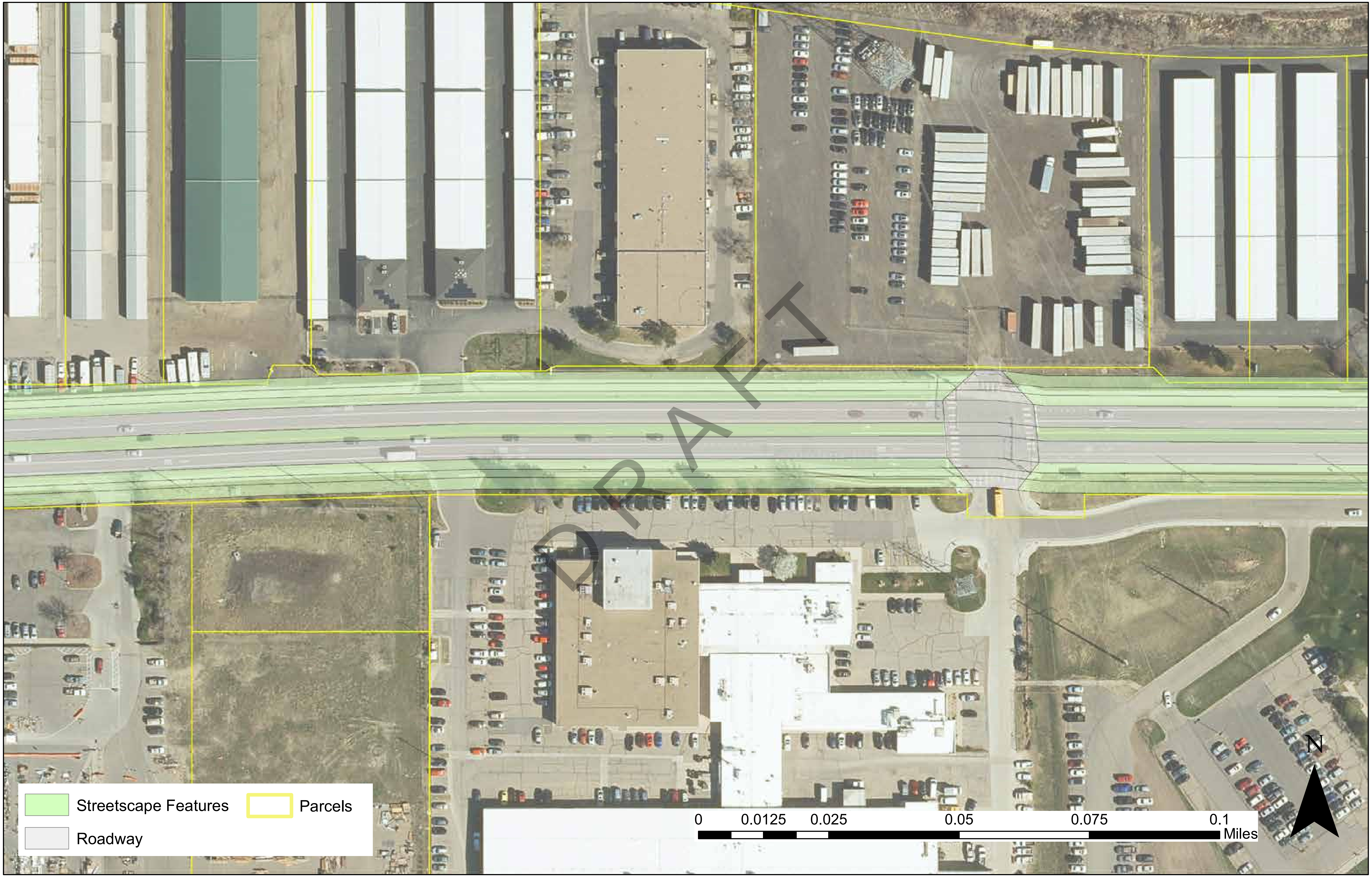


Figure F.1-38 Alternative 4 - Map 10A Character District D

Figure F.1-39 Alternative 4 - Map 10B Character District D to E

Figure F.1-40 Alternative 4 - Map 11A Character District E

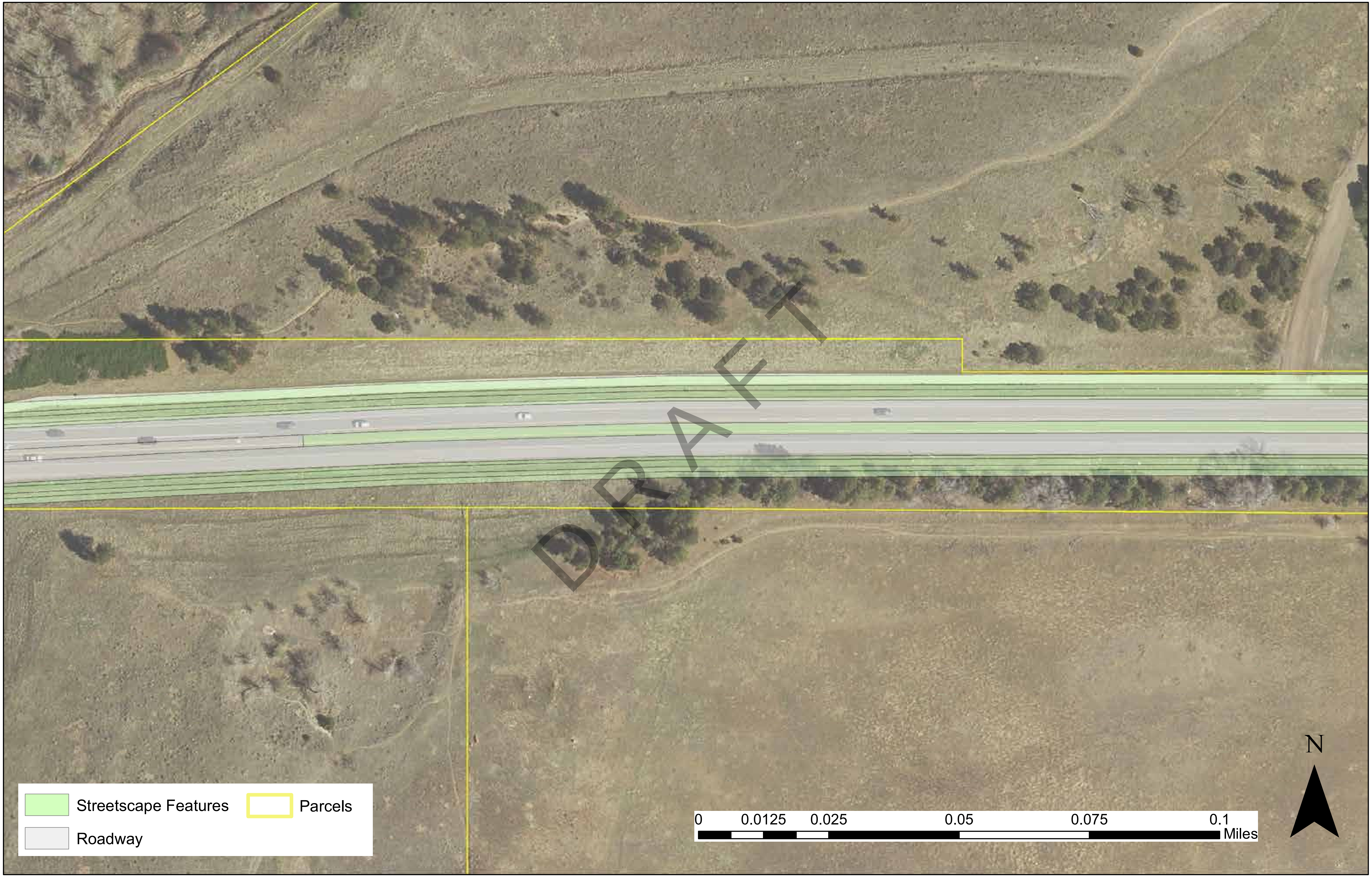


Figure F.1-41 Alternative 4 - Map 11B Character District E

Figure F.1-42 Alternative 4 - Map 12A Character District E

Figure F.1-43 Alternative 4 - Map 12B Character District E

APPENDIX G CAPITAL COSTS AND IMPLEMENTATION

This appendix provides detailed capital costs and implementation analysis methodology and results to supplement the evaluation results that are provided in the East Arapahoe Transportation Plan Evaluation of Alternatives Report. This analysis area considers capital and annualized transit capital and operating costs of the alternatives, and evaluates the potential to implement the improvements in phases.

CAPITAL COST

This section describes the evaluation methodology, assumptions, and additional results for the capital cost results provided on pages 60-62 of the Evaluation of Alternatives Summary Report. Capital cost estimates are high-level, order-of-magnitude costs for the purpose of comparing alternatives and would be refined in future design phases.

Analysis Overview

Figure G-1 Capital Cost Analysis Summary Table

Capital Cost	
Metric	Total capital cost
Purpose	Describe the one-time capital costs of constructing the improvements and facilities included in each alternative, including right-of-way acquisition, if any
Analysis Methodology	Apply FTA-standard cost category methodology to estimate costs for alternatives, by category. Cost will be *high-level order-of-magnitude cost* based on unit costs from comparable projects. Major cost items, e.g., bridges, will be identified.
Data Source	Unit costs from comparable projects; GIS analysis based on concept plans

Overall Assumptions

The Arapahoe Avenue Reconstruction Report, 28th-Cherryvale Road (2014), developed engineering concepts to evaluate and scope the required improvements and the associated project costs of roadway reconstruction for Arapahoe Avenue between 28th Street and Cherryvale Road—a significant portion of the study area for the East Arapahoe Transportation Plan. The purpose of this study was to “replace the aging infrastructure of Arapahoe Avenue within the project limits; improve mobility and corridor operations for pedestrians, cyclist, transit, and automobile users; and minimize impacts to adjacent properties and existing landscape features based on the following needs:

- Integration of other corridor studies and master planning projects
- Poor pavement conditions

- Deteriorated curb and gutter with insufficient hydraulic capacity
- Segments of narrow sidewalks, missing multi-use path segments,and lack of ADA compliant curb ramps and access driveways
- Lack of storm drainage catchments and conveyance system

For consistency with this highly relevant study, the cost methodology for various construction items (clearing, excavation, landscaping, traffic control, utility contingencies, etc.), and project development and administration were assumed on a percentage basis consistent with the Arapahoe Avenue Reconstruction Report, which based these elements on the Boulder TMP cost model.

Secondary Construction Items

The total cost of secondary construction items is assumed to be 140% of the primary construction costs. Assumptions for individual items can be found in Figure G-2.

Figure G-2 Secondary Construction Items

Item	Percent of Total Costs
Clearing and grubbing	2.5%
Removals and resets	20.0%
Excavation and embankment	8.0%
Erosion Control/Stormwater management	5.0%
Landscaping and topsoil	12.0%
Environmental health and safety	0.5%
Drainage	20.0%
Permanent water quality	5.0%
Lighting	5.0%
Construction surveying	4.0%
Mobilization	15.0%
Permanent signing and striping	5.0%
Flagging	8.0%
Traffic control management	5.0%
Traffic control inspection	1.0%
Construction zone traffic control	5.0%
City utility contingencies	10.0%
Forestry charges	1.0%
Wetland mitigation	1.0%
Flood mitigation	2.0%
Urban design features	1.0%
Miscellaneous	5.0%
Total Secondary Construction Items	141.0%

Administration and Services

45% of construction costs are assumed for administration and services.

Contingency

40% contingency on construction costs is assumed at this highly conceptual level of design.

Transit

Data Sources

Transit costs draw from two sources: the 2014 Northwest Area Mobility Study (NAMS) conducted by RTD, and previous work assessing BRT costs in other regions. Unit costs were inflation-adjusted to the current year, 2017.

Assumptions

Build Alternatives

Several capital cost assumptions are consistent across all three of the alternatives that involve transit enhancements (Alternative 2, 3 and 4).

- Construction of transit stations a half-mile or more apart within Boulder. Stations include branding, enhanced shelters, real-time information, off-board fare payments, and other amenities. Six stations are assumed within the City of Boulder study area, between Foslom – 75th Streets.
- East of 75th Ave, 11 stations are assumed at the locations identified by the NAMS Study. This includes two major and four minor station, one major Park and Ride (PnR), and four minor PnRs. Minor stations include the same amenities as major stations except for an information kiosk.
- Enhanced BRT-type vehicles.

Alternative 2 (Enhanced Bus) costs include only stations (similar to Alternative 3) and vehicles (no running way or TSP improvements).

Alternative 3 (Side-running BRT) includes the construction of two curb side station platforms at all BRT station locations. These stations would be shared with local buses, which would continue to serve existing local bus stops for which no improvements are assumed. Side-running BRT will also require roadway shoulder improvements and striping.

Alternative 4 (Center-running BRT) includes the construction of two center station platforms per station, with additional pedestrian access improvements. The center running busway includes median reconstruction.

Alternatives 3 and 4 assume transit signal priority will be implemented at all 14 signalized intersections along the portion of the corridor within Boulder. This is a conceptual design assumption, which will be refined later in the planning process.

For unit costs used in the analysis, see the tables below.

Unit Costs

Figure G-3 Busway Cost Assumptions, 2017 Dollars

Item	Unit	Cost
Queue Jump Lanes with mixed flow traffic	Mile	$1,050,625
Queue Jump Controller	Each	$11,557
Transit signal priority	Each	$98,574
Fiber installation for TSP	Mile	$429,087
TSP Intersection Improvements	Each	$14,971
TSP System Software	Each	$125,024
Traffic Signal Modification	Each	$91,404
Dedicated Curb Lane	Mile, both directions	$233,239
Center Running Busway	Mile, both directions	$1,050,625

Figure G-4 Station Cost Assumptions, 2017 Dollars

Item	Unit	Cost
Major Shelter	Each	$32,307
Shelter concrete footing	Each	$10,769
Shelter Installation (Mfg.)	Each	$2,692
Shelter installation (Site Contractor)	Each	$2,154
Information Kiosk	Each	$26,922
Information Kiosk installation (Site contractor)	Each	$2,154
Bicycle parking at station	Each	$10,241
Ticket Vending Machine	Each	$36,772
Real Time Arrival Sign	Each	$6,094
Side Station Construction (Bus Bulb/Boarding Platform)	Each	$136,581
Center Station Construction	Each	$265,808
Major Park and Ride	Each	$1,050,625
Minor Park and Ride	Each	$262,656

Figure G-5 Vehicle Cost Assumptions, 2017 Dollars

Item	Unit	Cost
40 Foot BRT Bus	Each	$990,000

Bike, Pedestrian, and Streetscape

Data Sources

Bike, Pedestrian and Streetscape costs are based on estimates from recent projects in the city of Boulder. The Diagonal Highway Transportation Improvements Project included construction of an off-street protected bike lane and multi-use path along the SH-119 corridor. The design of those facilities closely matches the vision for the East Arapahoe corridor: raised protected bike lanes with sidewalks and raised protected bike lanes with multi-use path options, which were evaluated for some or all of the character districts in Alternatives 2, 3 and 4. A per mile cost was estimated based on the total cost of the off-street bike and pedestrian facilities for the Diagonal Highway project. Demolition costs were also taken from the estimates for this project.

Assumptions

No Build Alternative

The majority of the East Arapahoe corridor study area has an existing multi-use path. The No-Build alternative includes only the cost of constructing a new multi-use path in the areas where gaps exist:

- Character District A: 30th Street – Foothills Parkway (south side)
- Character District C: East of Foothills Parkway – 55th Street (south side)
- Character District D: 55th Street – Cherryvale Road (north and south side)

The No-Build alternative does not include construction of pedestrian facilities on the south side of Arapahoe Avenue east of Westview Drive in Character District E.

The City of Boulder Capital Improvement Program estimated the following costs for multi-use path completion in May 2017.

Figure G-6 Multi-Use Path Completion Cost Estimates

Location	Character District	Project Type	Cost
South side of Arapahoe, Boulder Creek crossing	A	Multi-use path upgrade	$120,225
South side of Arapahoe, Eisenhower to Patton	C	Multi-use path upgrade	$253,539
South side of Arapahoe, McArthur to 48th St	C	Multi-use path upgrade	$282,716
South side of Arapahoe, adjacent to Flatiron Golf course	D	New multi-use path	$300,712
South side of Arapahoe, South Boulder Creek to Cherryvale	D	New multi-use path	$100,000
North side of Arapahoe, west of South Boulder Creek	D	New multi-use path	$54,800

City of Boulder Capital Improvement Program Cost Estimates, May 2017

Build Alternatives

Alternatives 2, 3 and 4 assume that additional right-of-way will be required to accommodate all of the street elements, and/or that existing right-of-way space will be re-allocated (between Folsom and Westview). The cost of all of the bike and pedestrian options includes curb and sidewalk demolition and the installation of new curbs, gutters, and facilities for the length of Character Districts A through D. For all alternatives, it is assumed that the existing multi-use path on the north side of Arapahoe in Character District E will remain in place. A more detailed analysis of design options will be required to refine these costs.

Elements of the street-level protected bikeway include striping, signage, a 1 foot wide concrete buffer and pavement markings.

The raised protected bike lane options are based on a 7 foot bikeway width and a 12 foot sidewalk or multi-use path.

An allowance for amenity zone elements such as benches, bicycle parking, and trash bins is included in the cost for each alternative.

For unit costs used in the analysis, see Figure G-5.

Figure G-7 Bike and Pedestrian Facility Unit Costs, 2017 Dollars

Item	Unit	Cost
Buffered Bike Lane with concrete buffer	Mile, per direction	$207,371
Multi-use path	Mile, both directions	$1,050,625
Raised PBL and Sidewalk/MUP	Mile, both directions	$1,575,938
Demolition (sidewalk, curb, gutter)	Mile, per direction	$64,719
Curb and Gutter Construction	Mile, per direction	$137,280
Amenity Zone Items (12 each benches, bicycle parking, and trash bins per side per mile)	Mile, both directions	$127,336

Right-of-Way

Data Sources

Land values were provided by the City of Boulder for parcels west of 55th Avenue (Districts A, B and C). Parcel boundary data was provided by both the City and County of Boulder. The assumed right-of-way needed for each alternative was overlaid with the existing right-of-way to calculate a high-level estimate of the area and cost of private land that would be acquired to implement each alternative.

Assumptions

No Build Alternative

No right-of-way acquisition will be necessary to complete the gaps in the existing multi-use path and sidewalk network along Arapahoe.

Build Alternatives

In cases where the Boulder County and City of Boulder parcel boundary data do not align, the more conservative boundary was used.

The land value was calculated for every portion of a privately owned parcel that falls within the right-of-way (ROW) needed for one of the alternatives. In practice, much of the pedestrian infrastructure along the corridor lies on private easements. For parcels east of 55th Avenue, where unit land cost assumptions were not provided by the assessor, a cost of $15 per square foot was assumed.

Alternatives 2 and 3 are assumed to require the same amount of ROW. Alternative 4 is assumed to require more ROW than 2 or 3, e.g., due to the center-running busway design, which requires additional space in the median for stations. For detailed cross section assumptions, see Figure G-8 to Figure G-11below.

Figure G-8 District A and B Cross-Section Assumptions (Widths in Feet)

Alt 1	SW	AZ	CURB			GP	GP	GP	Median	GP	GP	GP			CURB	AZ	MUP
	10	6	0.5			12	11	12	18	12	11	12			0.5	14	12
Alt 2	SW	AZ	BIKE	AZ	CURB	GP	GP	GP	Median	GP	GP	GP	CURB	AZ	BIKE	AZ	SW
	12	6	7	8	0.5	11	10	10	14	10	10	11	0.5	8	7	6	12
Alt 3	SW	AZ	BIKE	AZ	CURB	BAT	GP	GP	Median	GP	GP	BAT	CURB	AZ	BIKE	AZ	SW
	12	6	7	8	0.5	11	10	10	14	10	10	11	0.5	8	7	6	12
Alt 4	MUP	AZ	BIKE	BUFFER	CURB	GP	GP	BRT	Median	BRT	GP	GP	CURB	BUFFER	BIKE	AZ	MUP
	12	8	7	3	0.5	11	10	11	14	11	10	11	0.5	3	7	8	12

Figure G-9 District C Cross-Section Assumptions (Widths in Feet)

Alt 1	AZ	SW	AZ	CURB		GP	GP	GP	Median	GP	GP	GP				CURB	MUP
	7	12	4.5	0.5		12	11	12	16	12	11	12				0.5	14.5
Alt 2	MUP	AZ	CURB	BIKE	CURB	GP	GP	GP	Median	GP	GP	GP	CURB	BIKE	CURB	AZ	MUP
	12	8	0.5	7	3	11	10	10	14	10	10	11	3	7	0.5	8	12
Alt 3	MUP	AZ	BIKE	BUFFER	CURB	BAT	GP	GP	Median	GP	GP	BAT	CURB	BUFFER	BIKE	AZ	MUP
	12	8	7	3	0.5	11	10	10	14	10	10	11	0.5	3	7	8	12
Alt 4	MUP	AZ	BIKE	BUFFER	CURB	GP	GP	BRT	Median	BRT	GP	GP	CURB	BUFFER	BIKE	AZ	MUP
	12	8	7	3	0.5	11	10	11	14	11	10	11	0.5	3	7	8	12

Figure G-10 District D Cross-Section Assumptions (Widths in Feet)

Alt 1	AZ	SW	AZ	CURB		GP	GP	GP	Median	GP	GP	GP				CURB	MUP
	7	12	4.5	0.5		12	11	12	16	12	11	12				0.5	14.5
Alt 2	MUP	AZ	CURB	BIKE	CURB	GP	GP	GP	Median	GP	GP	GP	CURB	BIKE	CURB	AZ	MUP
	12	8	0.5	7	3	11	10	10	14	10	10	11	3	7	0.5	8	12
Alt 3	MUP	AZ	BIKE	BUFFER	CURB	BAT	GP	GP	Median	GP	GP	BAT	CURB	BUFFER	BIKE	AZ	MUP
	12	8	7	3	0.5	11	10	10	14	10	10	11	0.5	3	7	8	12
Alt 4	MUP	AZ	BIKE	BUFFER	CURB	GP	GP	BRT	Median	BRT	GP	GP	CURB	BUFFER	BIKE	AZ	MUP
	12	8	7	3	0.5	11	10	11	14	11	10	11	0.5	3	7	8	12

Figure G-11 District E Cross-Section Assumptions (Widths in Feet)

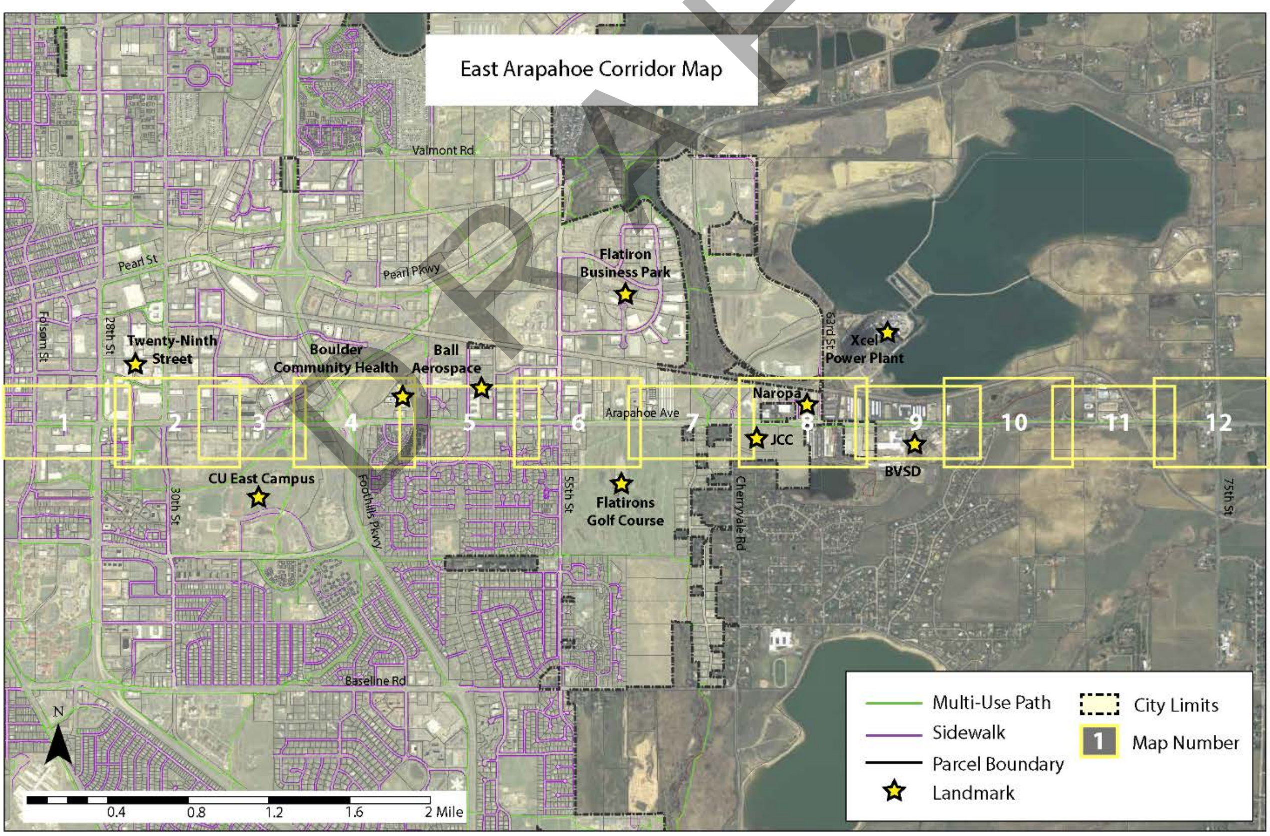
Alt 1						SHOULDER		GP	Median	GP	BIKE					CURB	MUP
							12	12	13	17	6.5					0.5	10
Alt 2	SW	AZ	CURB	BIKE	BUFFER	BAT	GP		Median		GP	BAT	BUFFER	BIKE	CURB	AZ	MUP
	6	5	0.5	6.5	2	11	10		12		10	11	2	6.5	0.5	5	10
Alt 3	SW	AZ	CURB	BIKE	BUFFER	BAT	GP		Median		GP	BAT	BUFFER	BIKE	CURB	AZ	MUP
	6	5	0.5	6.5	2	11	10		12		10	11	2	6.5	0.5	5	10
Alt 4	SW	AZ	BIKE	BUFFER	CURB		GP	BRT	Median	BRT	GP		CURB	BUFFER	BIKE	AZ	MUP
	6	5	7	3	0.5		11	11	12	11	11		0.5	3	7	5	10

Figure G-12 Right-of-Way Acquisition Estimated Area and Costs (Conceptual)

Measure	District A	District B	District C	District D	District E
Alt 1	No Cost	No Cost	No Cost	No Cost	No Cost
Alt 2	148,800 SqFt $6,980,000.00	N/A	59,700 SqFt $1,080,800.00	12,300 SqFt $184,400.00	1,100 SqFt $17,600.00
Alt 3	148,800 SqFt $6,980,000.00	N/A	59,700 SqF $1,080,800.00	12,300 SqFt $184,400.00	1,100 SqFt $17,600.00
Alt 4	133,300 SqFt $6,317,100.00	N/A	65,600 SqFt $1,190,000.00	14,600 SqFt $218,800.00	2,600 SqFt $38,300.00

For maps of approximate right-of-way needs see Appendix F.1 Streetscape Maps. The analysis is based on a conceptual overlay of the alternatives within the street right-of-way and does not reflect refinement of a preferred alternative during actual design. Figure G-13 provides a key map illustrating the 12 sheets comprising the full corridor.

Figure G-13 Streetscape Analysis Key Map



Evaluation Results

Figure G-14 summarizes costs by district and Figure G-15 summarizes costs by cost category.

Key Findings

- Transit Costs:
  - Enhanced bus (only station construction) would be the least expensive transit alternative to construct. Side-running BRT would also require construction of a business-access-and transit (BAT) lane and traffic signal changes.
  - Center-Running BRT (Alt 3) is likely to be the most expensive transit alternative due to median reconstruction.
  - Transit vehicle costs are lowest for side-running and center-running BRT (Alts 3 and 4), due to shorter travel times that make transit more efficient to operate. Vehicle costs are the highest for Enhanced Bus because additional vehicles will be needed to operate the service at the assumed frequencies.
- Bicycle-Pedestrian and Streetscape:
  - All protected bike lane options are generally comparable in cost
  - Right-of-way costs are most significant in District A.
- Right-of-way costs are most significant in District A.

Figure G-14 Total Non-Vehicle Capital Costs, City of Boulder Districts A-E Only (2017 Dollars)

Alternative	District A	District B	District C	District D	District E	Overall Per-Mile (District A-E)
Alt 1 (No-Build)	$0.2 M	$0.0 M	$0.8 M	$0.6 M	$0.0 M	$2 M
Alt 2 (Enhanced Bus)	$19 M	$6 M	$11 M	$39 M	$4 M	$81 M
Alt 3 (Side-Running BRT)	$21 M	$6 M	$11 M	$39 M	$4 M	$82 M
Alt 4 (Center-running BRT)	$24 M	$8 M	$14 M	$45 M	$10 M	$101 M

Figure G-15 Capital Cost by Cost Category, Including Vehicles for End-End Operation (2017 Dollars)

Alternative	Site Work	Bridge Replacement / Widening	Bike/Ped / Streetscape	Traffic Signals / Communications	Transit Facility	Transit Facility - Station	Vehicles	Right-of-Way	Administration / Services	Contingency	TOTAL
Alt 1 (No-Build)	0	0	$1M	0	0	0	0	0	0	$0.56 M	$1.67 M
Alt 2 (Enhanced Bus)	$15 M	$3 M	$11 M	$5 M	$0 M	$3 M	$5 M	$8 M	$17 M	$24 M	$90 M
Alt 3 (Side-Running BRT)	$16 M	$3 M	$10 M	$5 M	$1 M	$3 M	$4 M	$8 M	$17 M	$24 M	$91 M
Alt 4 (Center-running BRT)	$21 M	$3 M	$10 M	$5 M	$5 M	$4 M	$4 M	$8 M	$22 M	$29 M	$111 M

Figure G-16 Capital Costs Evaluation Score

Year	2015	2040	2040	2040	2040
Alternative	**Existing** Existing Bus Existing Travel Lanes Existing Multi-use Path	**Alt 1: No-Build** Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	**Alt 2** Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	**Alt 3** Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	**Alt 4** Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
Capital Costs	0	$	$$	$$$	$$$$

PHASING/COMPLEXITY OF IMPLEMENTATION

This section describes the evaluation methodology, assumptions, and additional results for the qualitative assessment of complexity of implementing and phasing the improvements associated with each alternative, provided on pages 63 of the Evaluation of Alternatives Summary Report.

Analysis Overview

Figure G-17 Phasing and Implementation Analysis Summary Table

Ability to Phase and Complexity of Implementation	
Metric	Potential to implement improvements in phases
Purpose	Describe the ability to implement each alternative in a phased, incremental approach
Analysis Methodology	Qualitative assessment of phasing potential and complexity of each alternative.
Data Source	Conceptual plans for each alternative

Assumptions

Considerations include:

- Availability of right-of-way relative to what is required to implement each alternative
- Major constraints:
  - District B: Bridge over Boulder Creek
  - District D: Bridge over South Boulder Creek
  - District E: Railroad bridge (likely affecting Alt 4 only)
- Ability to implement improvements in a phased approach

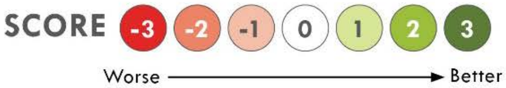
Additional Methodology Details

- See Capital Cost Assumptions and Methodology Details (above) for a right-of-way assumptions matrix.

Key Findings

- The overall right-of-way requirement compared to available right-of-way drives need for phased implementation. In developing a phasing plan for the eventual preferred alternative, some improvements (such as signal timing or transit signal priority) could be implemented shorter-term without need for expanding the public right-of-way (i.e., through dedication or easements).
- Side-running transit alternatives (Alts 2 and 3) will likely be easier to implement in phases than center-running BRT (Alt 4). Center-running BRT could more easily be implemented on the far eastern portion of the corridor, which generally does not have a separated median
- The phasing plan can consider where spot improvements are most feasible and beneficial based on traffic impacts, such as peak-direction transit lanes in Alt 3 (side-running BRT).
- There is likely to be little variance between bicycle/pedestrian alternatives, and they offer the greatest opportunity to work towards implementation as redevelopment occurs.
- District A has the most limited right-of-way compared to what would be required.

Figure G-18 Ability to Phase Evaluation Score



Year	2015	2040	2040	2040	2040
Alternative	Existing Existing Bus Existing Travel Lanes Existing Multi-use Path	Alt 1: No-Build Local Bus (Mixed Traffic) Existing Travel Lanes Completed Multi-use Path	Alt 2 Enhanced Bus (Mixed Traffic) Existing Travel Lanes Typically Street-Level PBL (2,3,4)	Alt 3 Side-Running BRT Curbside lanes repurposed as BAT lanes (right-turns allowed) Typically Raised PBL (1a,2,4)	Alt 4 Center-Running BRT Center lanes repurposed as dedicated transit lanes Typically Raised PBL (1a/1b
Ability to Phase	0	0	-1	-2	-3

APPENDIX H RENDERINGS OF EVALUATION ALTERNATIVES

This appendix includes renderings of the alternatives that were evaluated for the East Arapahoe Corridor.

Figure H-1 summarizes the alternatives. This table is organized into sub-sections for each character district.

- Each **column** of Figure H-1 identifies the four transit options considered end-end for the corridor. Each transit option is associated with vehicular assumptions (e.g., number of lanes available for general purpose travel).
- Each **row** of Figure H-1 identifies the proposed pedestrian/bike options for the district.
- In the cells of the table, each alternative is identified by its character district letter, transit option number, and pedestrian/bike and transition zone option number. For example, A.2.2 is includes character district A, transit option 2 (enhanced bus), and ped/bike option 2 (raised protected bike lane).

Figure H-1 Alternatives Evaluated, by Ped-Bike-Transition Zone and Transit Options

Pedestrian/Bike/Transition Zone Option	Alt 1 (No-Build)	Alt 2	Alt 3	Alt 4
	Transit/Vehicular Alternative			
	Existing Bus (Mixed Traffic)	Enhanced Bus (Mixed Traffic)	Side-Running BRT (BAT Lane)	Center-Running BRT (Dedicated Lane)
	Existing Travel Lanes	Existing Travel Lanes	Repurposed Lane	Repurposed Lane
District A: 29th Street District (3 vehicle lanes/direction)				
Option 0: Completed multi-use path (No-Build)	[A.1.0]			
Option 1a: Curbside raised protected bike lane with amenity zone and multi-use path				[A.4.1a]
Option 2: Curbside amenity zone with raised protected bike lane separated from sidewalk		[A.2.2]	[A.3.2]	
District B: Transition Zone (3 vehicle lanes/direction)				
Design options to be determined based on preferred facilities in Districts A and C	TBD	TBD	TBD	TBD
District C: Innovation & Health District (3 vehicle lanes/direction)				
Option 0: Completed multi-use path (No-Build)	[C.1.0]			
Option 1a: Curbside raised protected bike lane with amenity zone and multi-use path			[C.3.1a]	[C.4.1a]
Option 3: Street-level protected bike lane with amenity zone and multi-use path		[C.2.3]		
District D: Industry & Education District (2-3 lanes/direction)				
Option 0: Existing bike lanes and multi-use path (No-Build)	[D.1.0]			
Option 1a: Curbside raised protected bike lane with amenity zone and multi-use path			[D.3.1a]	[D.4.1a]
Option 3: Street-level protected bike lane with amenity zone and multi-use path		[D.2.3]		
District E: Gateway District (1-2 vehicle lanes/direction)				
Option 0: Existing bike lanes and/or multi-use path (No-Build)	[E.1.0]			
Option 1b: Curbside raised protected bike lane with amenity zone and sidewalk				[E.4.1b]
Option 4: Street-level buffered bike lane with curbside amenity zone and sidewalk (south) or existing multi-use path (north)		[E.2.4]	[E.3.4]	

[character district letter].[transit option number].[pedestrian/bike option number]

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Figure H-2 District A - Alt 1 No Build with Multi-Use Path (A.1.0)

Figure H-3 District A - Alt 4 Center-Running BRT with Raised Protected Bike Lane and Multi-Use Path (A.4.1a)

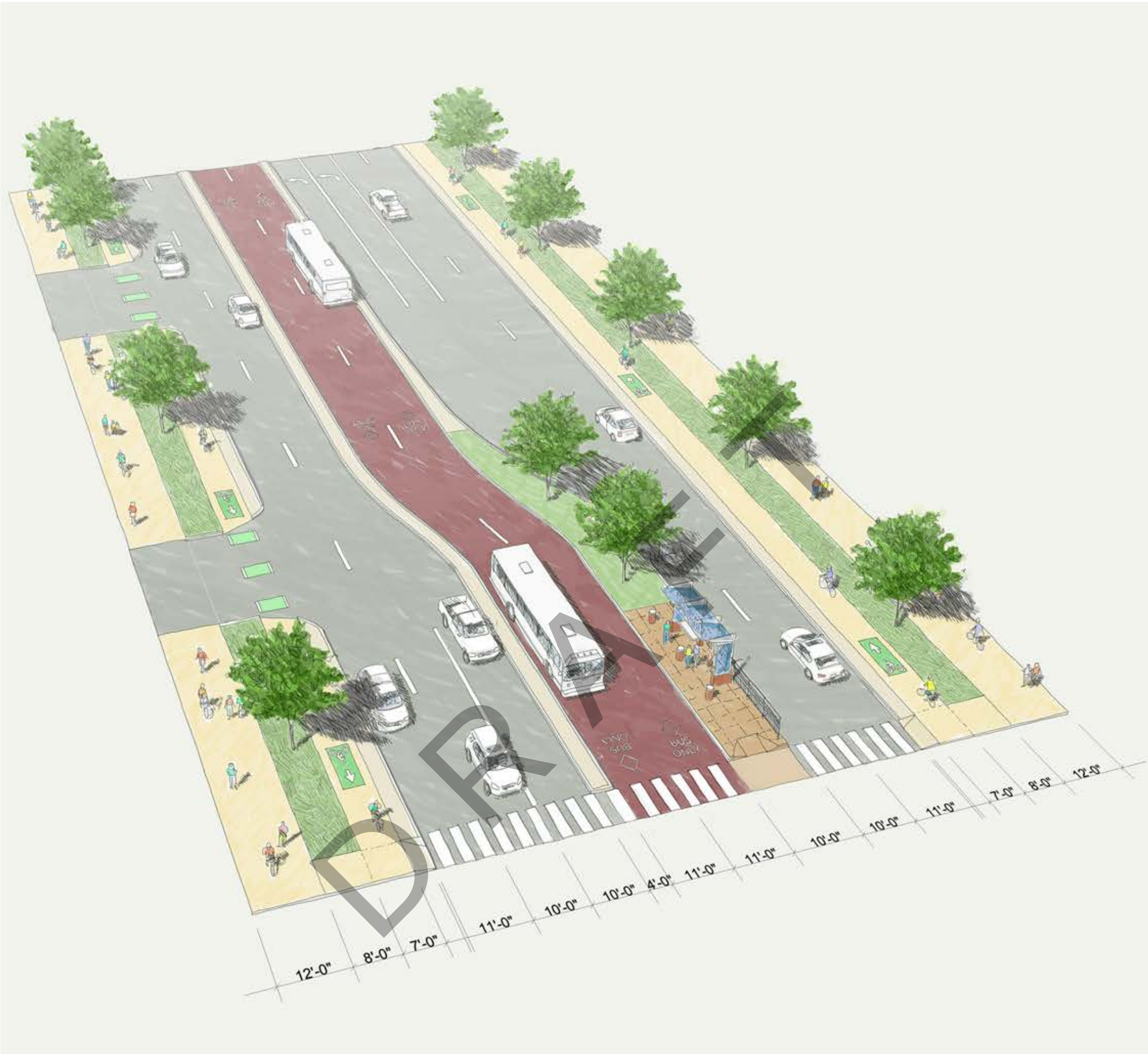

Figure H-4 District C - Alt 1 No Build with Multi-Use Path (C.4.0)

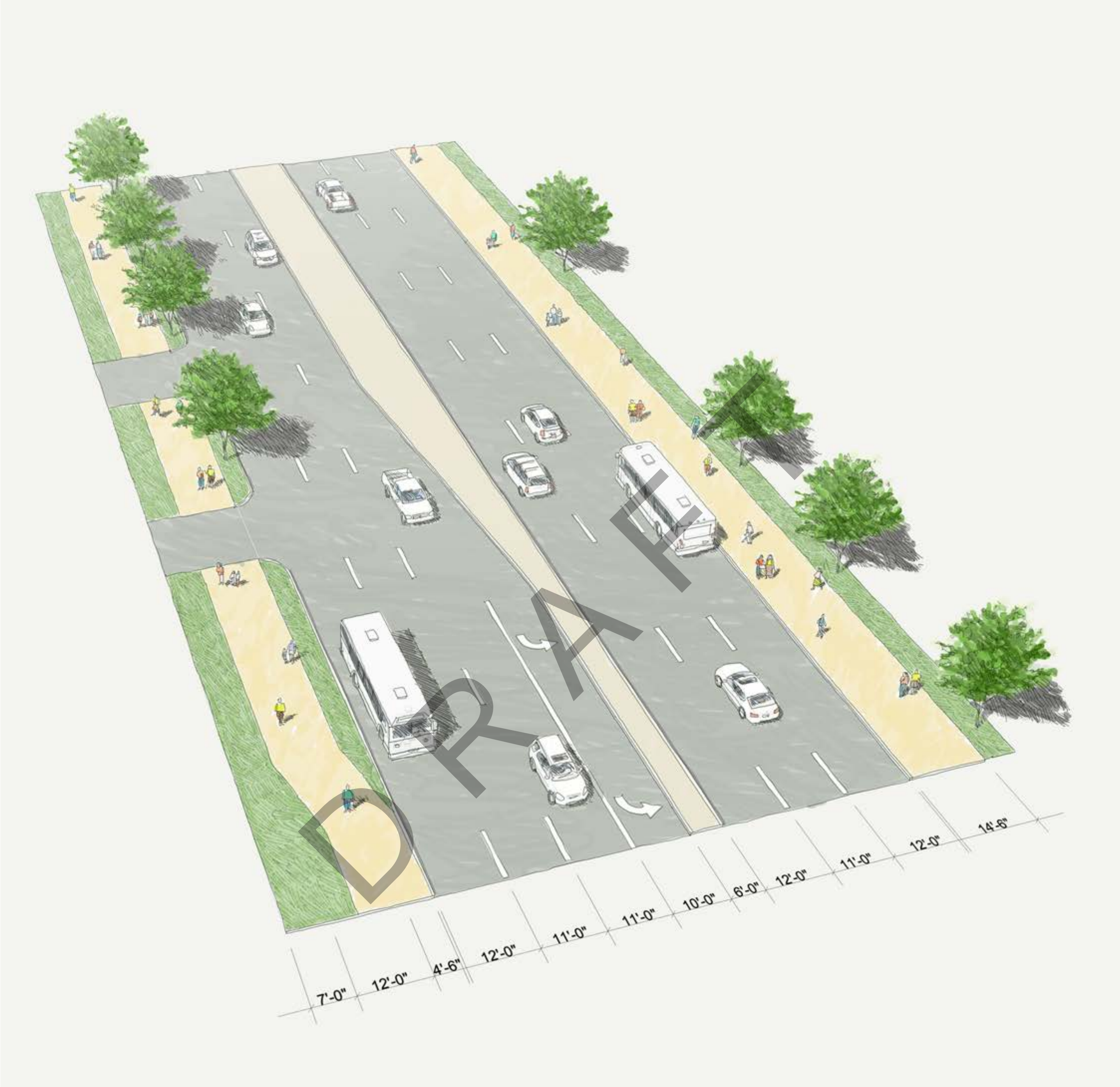

Figure H-5 District C - Alt 2 Enhanced Bus with Street-level Protected Bike Lane and Multi-Use Path (C.2.3)

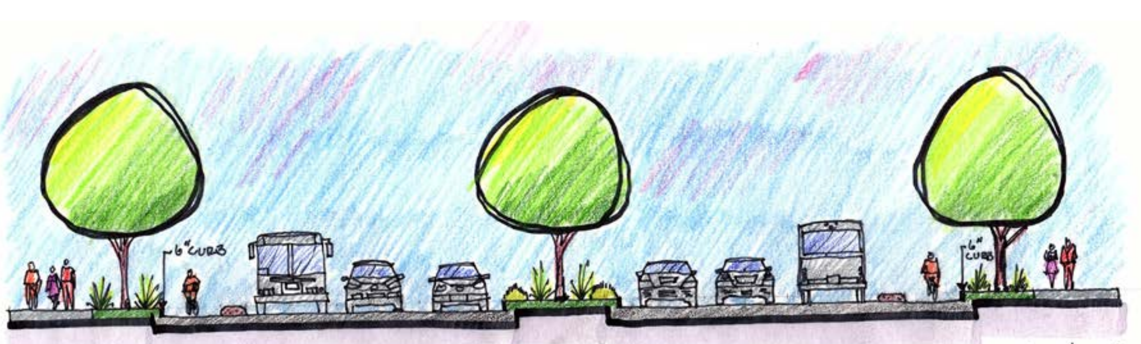

Figure H-6 District C - Alt 3 Side-Running BRT with Raised Protected Bike Lane and Multi-Use Path (C.3.1a)

Figure H-7 District D - Alt 1 No Build with Multi-Use Path (D.1.0)

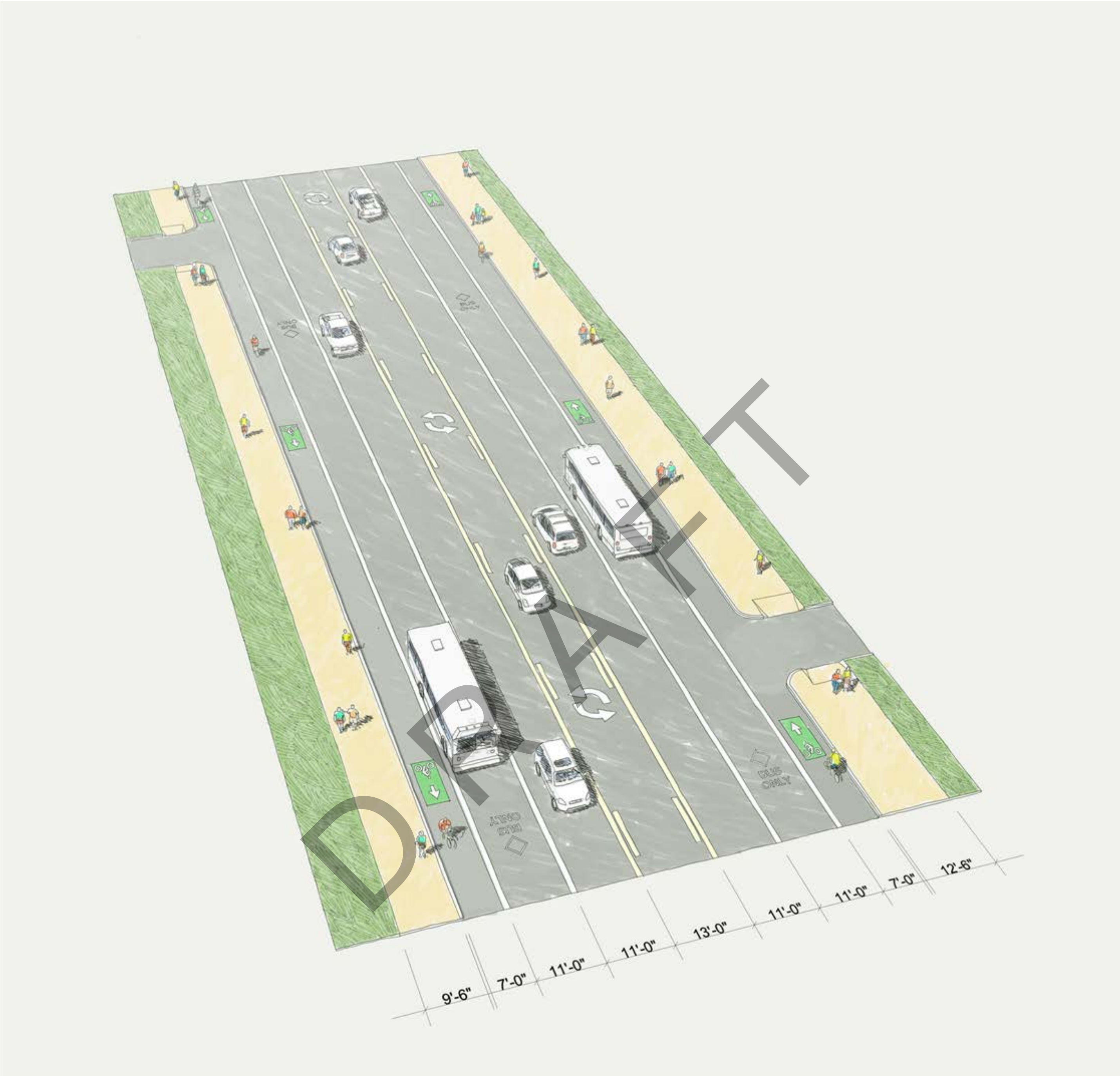

Figure H-8 District D - Alt 3 Side-Running BRT with Raised Protected Bike Lane and Multi-Use Path (D.3.1a)

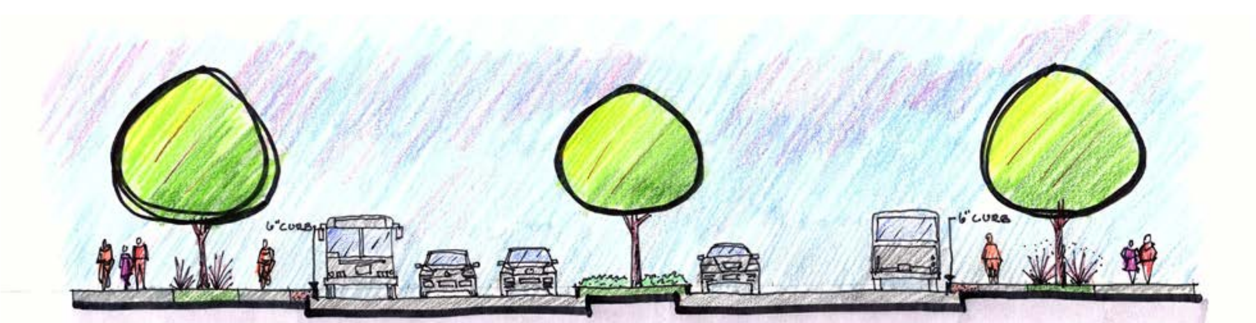

Figure H-9 District E - Alt 1 No Build with Existing Bike Lane and/or Multi-Use Path (E.1.0)

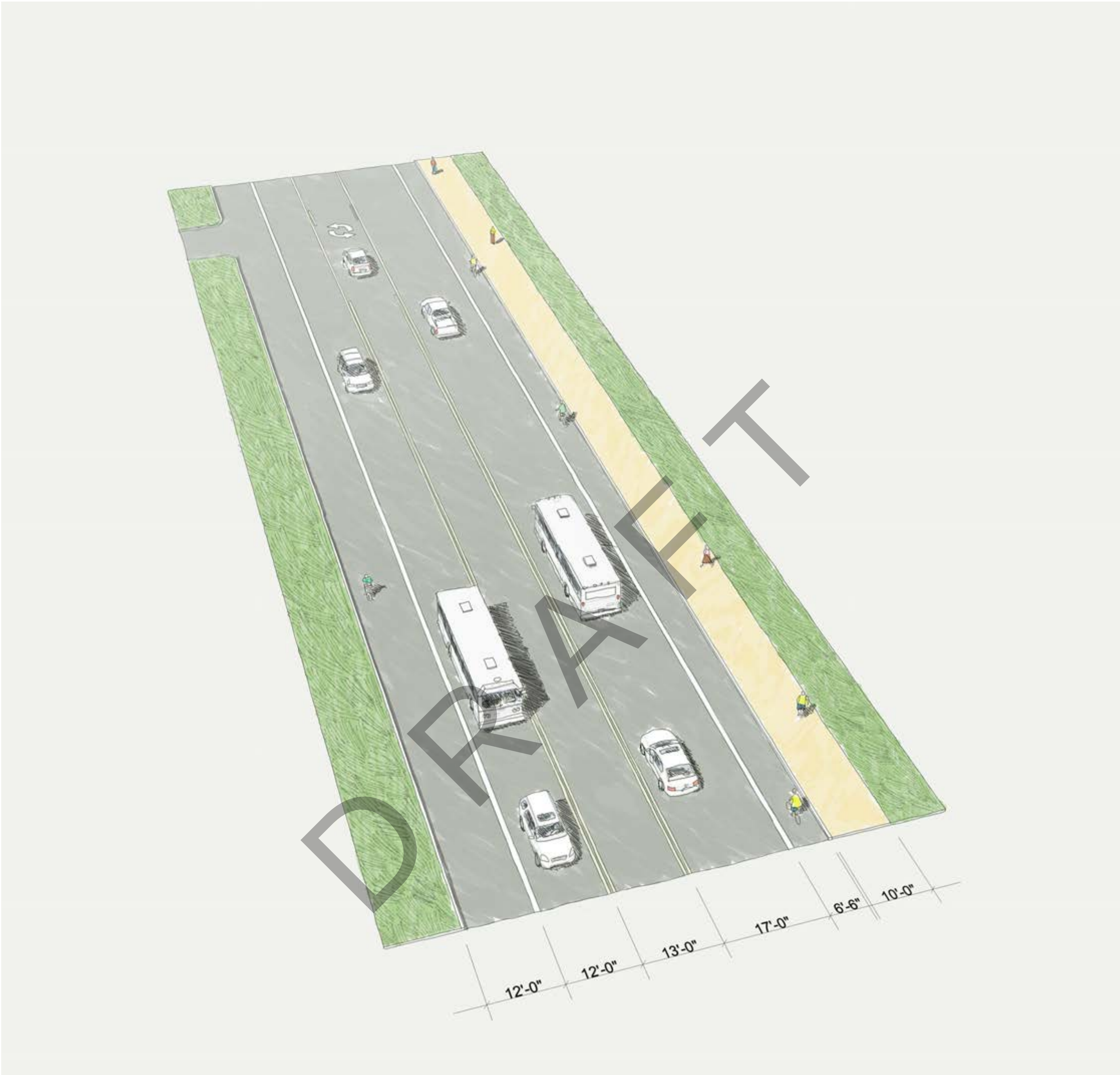

Figure H-10 District E - Alt 2 Enhanced Bus with Street-level Bike Lane and Sidewalk or Multi-Use Path (E.2.4)

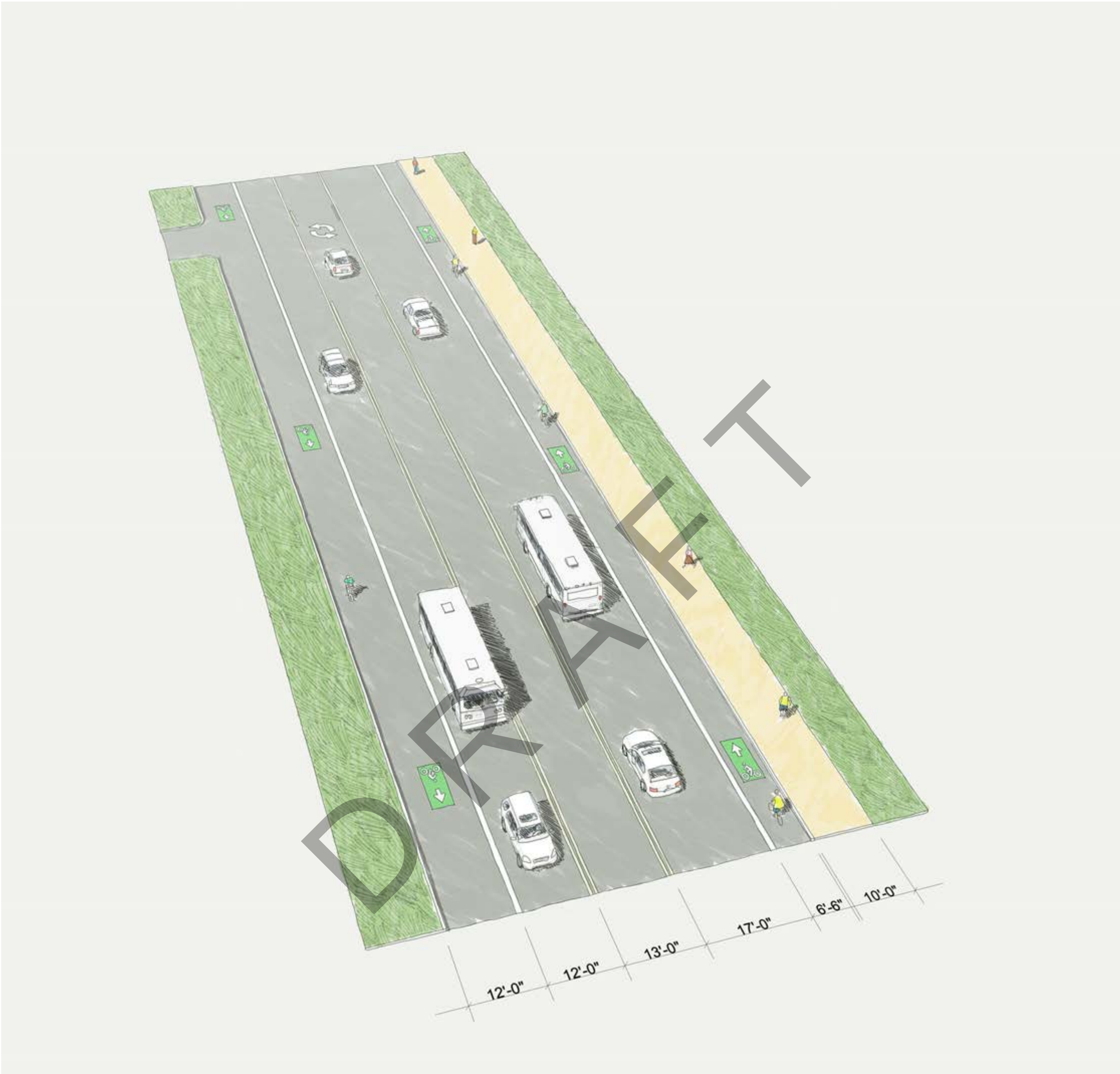

Figure H-11 District E - Alt 3 Side-Running BRT with Street-level Protected Bike Lane and Multi-Use Path (E.3.4)