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MEMORANDUM

Date:	April 12, 2016	Job No.:	4162-07
To:	Paul Starratt, P.E., Town Engineer		
Cc:	Jeremy Downs, P.E., Assistant Town Engineer		
From:	Kien Ho, P.E., PTOE Tyler de Ruiter, EIT		
Subject:	Westford School Area Traffic Review		

BETA Group, Inc. (BETA) has completed the Westford School Area Traffic Review. As part of this assignment, three previously completed traffic studies for the school area were provided for review/reference. These documents are:

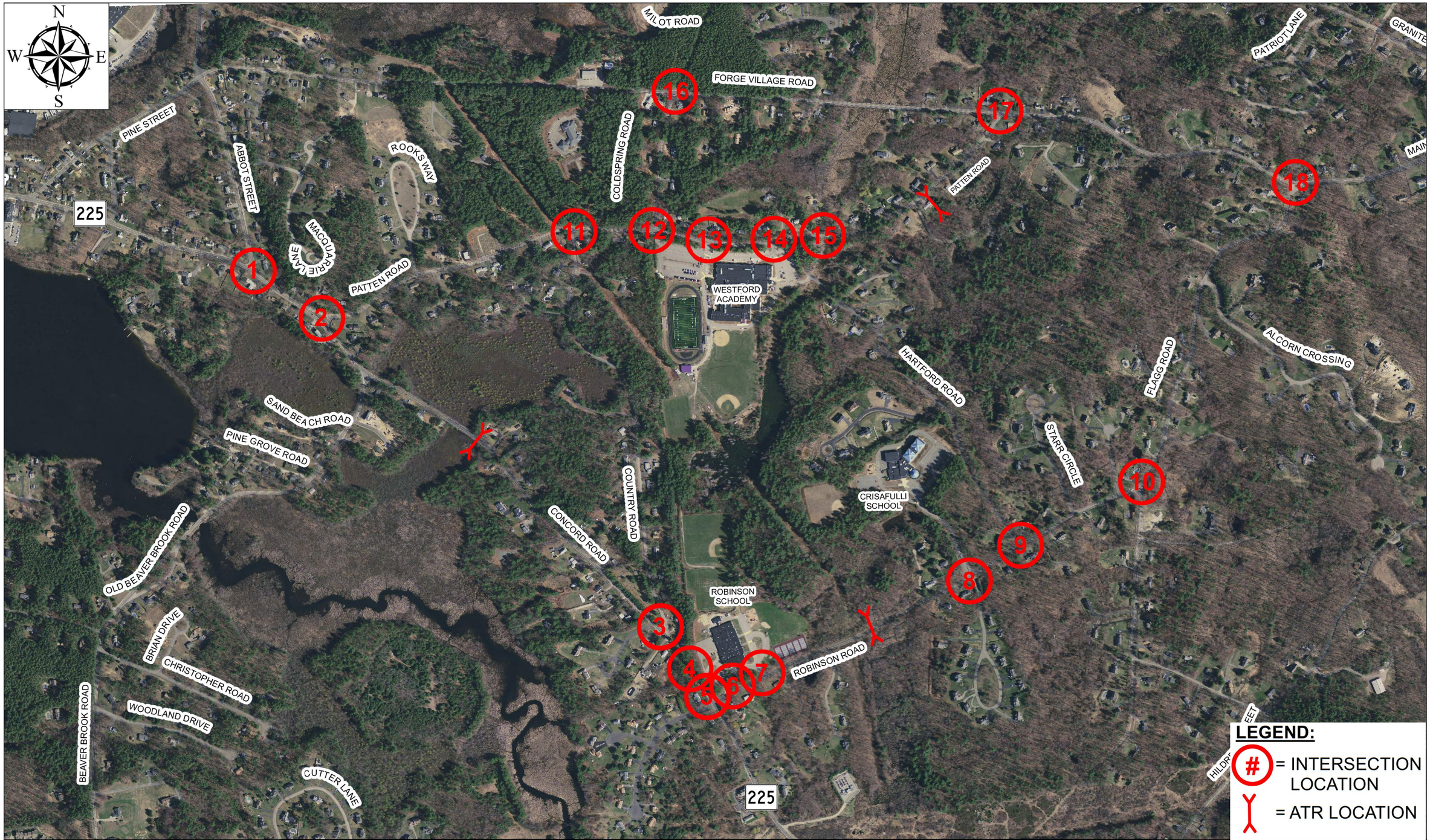
- *Road Safety Audit - Forge Village Road at Cold Spring Road*; dated October 8, 2014 by The Engineering Corp. (TEC)
- 2002 Traffic Study for Patten Road, Forge Village Road, and Route 225; by Northern Middlesex Council of Governments (NMCOG)
- *Westford Academy Expansion Traffic Study*, dated July 15, 1997 by Abend Associates

As part of the scope of services, BETA collected traffic data and field observations for 18 study area intersections and driveways surrounding the Westford Academy (WA), Robinson School, and Crisafulli School. Furthermore, BETA validated current roadway and intersection deficiencies throughout the study area. Based on these findings, possible short-term and long-term recommendations to improve safety and operational conditions were developed.

STUDY AREA

The study area for this review included approximately 18 intersections and driveways, seen in Figure 1, nearby the three schools. These intersections included:

1. Concord Road (Rte. 225) at Abbott Street
2. Concord Road (Rte. 225) at Patten Road
3. Concord Road (Rte. 225) at Country Road
4. Concord Road (Rte. 225) at Robinson School – North Driveway
5. Concord Road (Rte. 225) at Robinson Road / Buckingham Drive
6. Robinson Road at Robinson School – West Driveway
7. Robinson Road at Robinson School – East Driveway
8. Robinson Road at Crisafulli School Driveway / Hutchins Way
9. Robinson Road at Hartford Road
10. Robinson Road at Flagg Road
11. Patten Road at Country Road



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WESTFORD SCHOOL AREA TRAFFIC REVIEW
WESTFORD, MA

FIGURE 1
STUDY LOCATIONS

12. Patten Road at Cold Spring Road / Westford Academy – West Driveway
13. Patten Road at Westford Academy – Center Driveway
14. Patten Road at Westford Academy – East Driveway
15. Patten Road at Hartford Road
16. Forge Village Road at Cold Spring Road
17. Forge Village Road at Patten Road
18. Forge Village Road at Flagg Road

FIELD INVESTIGATIONS

BETA examined field conditions at the study area intersections and school driveways, on Tuesday, May 26, 2015. Field observations included:

- Observing pedestrian and vehicle circulation patterns
- Noting operational and safety deficiencies throughout the network
- Examining geometric conditions including existing sight distance at intersections
- Verifying the location of sidewalks, signs, and pavement markings

All study area intersections were found to operate with STOP signs. No traffic signals are present within the study area. The following sections discuss roadway conditions throughout the study area.

CONCORD ROAD (ROUTE 225)

Concord Road (Route 225) is an arterial roadway that generally runs from the northwest to southeast throughout the study area and connects the Towns of Littleton and Groton with Interstate 495 and the Town of Carlisle. The roadway is approximately 25' to 30' wide throughout the study area and provides one travel lane in each direction with varying shoulder widths and rolling terrain. The roadway is posted with 30 miles per hour speed limits with a 20 mile per hour school zone at the intersection of Robinson Road. School zone signage was found to be outdated and non-MUTCD compliant as the sign is rectangular with a painted doghouse shape; see Figure 2. Several handmade signs are also posted in the study area alerting motorists to slow down. One of these signs depicts a green figure and is located in the southbound direction between Country Road and Robinson Road; see Figure 2.

Figure 2: Concord Road (Route 225) - School Zone Signs

Edge of road is delineated by edge line striping only as cubing and/or sidewalks are not provided in this area. Sections of guardrail are provided on both sides of the roadway particularly in the area of wetlands south of Beaver Brook Road. Utility poles are located on the east side of the roadway north of Westlawn Cemetery (Country Road) where they cross over to the west side of the roadway.

ROBINSON ROAD

Robinson Road is a local/residential roadway that generally runs in the east/west direction and connects Concord Road (Route 225) to Flagg Road and provides access for two elementary schools. The roadway is approximately 20' to 25' wide with one travel lane in each direction and no shoulders. The roadway is posted with a 30 miles per hour speed limit. Two 20 mile per hour school zones are located along the roadway. Flashing school zone beacons are provided for Crisafulli School and are located approximately 500 feet to the west of the school driveway and 400 feet to the east of the intersection adjacent to Hartford Road. Each school zone is associated with "SCHOOL" pavement markings. Edge of road is generally not delineated for this roadway, though asphalt berm is provided nearby the Crisafulli School driveway; see Figure 3. Sidewalks are not provided on this roadway.

Figure 3: Robinson Road (Westbound)

PATTEN ROAD

Patten Road is a collector roadway that generally runs in the east/west direction and connects Concord Road (Route 225) with Forge Village Road and provides access to Westford Academy. The roadway is approximately 20' to 30' wide with one travel lane in each direction and variable shoulders. The roadway is posted with a 30 miles per hour speed limit. Westford Academy is located on the south side of the roadway between Cold Spring Road and Hartford Road. On-street parking is restricted on both sides of the roadway in the vicinity of Westford Academy. Roadway widths were found to be widest (approximately 30 feet) in the area of Westford Academy. An asphalt sidewalk of varying width is provided along Patten Road from Rooks Road to Westford Academy. The sidewalk meanders along the north side of the roadway beginning at Rooks Road and crosses to the south side of the roadway at a crosswalk located between Country Road and Cold Spring Road. Adequate ADA compliant handicap ramps for this crosswalk are not provided. The sidewalk follows the edge of the roadway, separated by sloped granite edging, from the crosswalk to Cold Spring Road where it begins to meander again; see Figure 4.

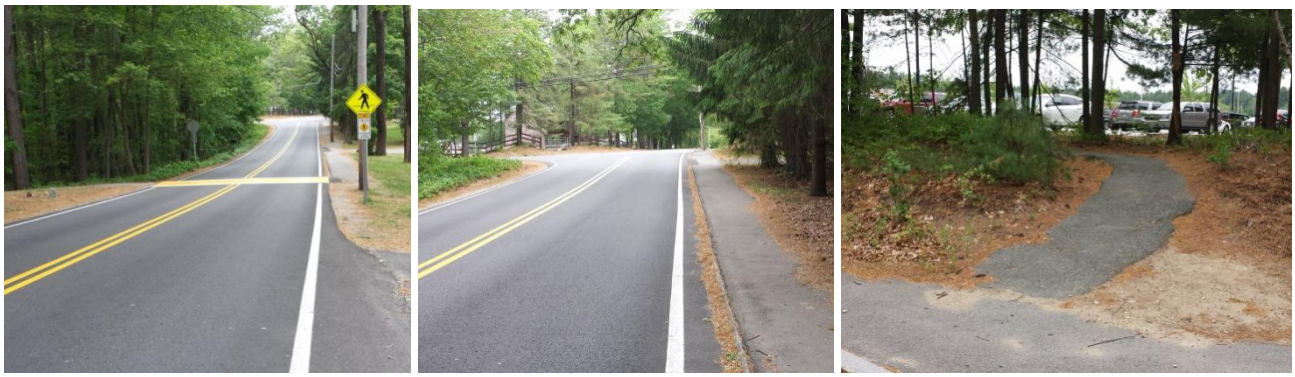

Figure 4: Patten Road (Eastbound)

Patten Road follows rolling terrain with large radius curves. Country Road intersects Patten Road on the inside of a curve resulting in inadequate sight lines for vehicles exiting Country Road. Warning signage is provided for eastbound vehicles on Patten Road, though vehicles exiting Country Road cannot see vehicles on Patten Road until they start to navigate the curve; see Figure 5.

Figure 5: Patten Road Approaching Country Road

Signs located at the intersection of Forge Village Road and Patten Road restrict turns into Patten Road from Forge Village Road during the school peak periods (7:00AM – 9:00AM and 1:30PM – 3:00PM); see Figure 6. These signs create a "one-way" condition on Patten Road in the eastbound direction. The signs do not restrict vehicles from traveling westbound (from driveways or other side streets) but instead only restrict vehicles from entering the roadway from Forge Village Road. This requires all vehicles to utilize the intersection Forge Village Road at Cold Spring Road to access Westford Academy.

Figure 6: Patten Road Restriction

FORGE VILLAGE ROAD

Forge Village Road is an arterial roadway that generally runs in the east/west direction and connects Forge Village via Route 225 to downtown Westford. The roadway is approximately 25' to 35' wide with one travel lane in each direction with variable shoulders. The roadway is posted with a 30 miles per hour speed limit. Consistent with the other roadways in the study area, this roadway is wooded with no roadway edging. Guardrail is provided in a wetland area between Patten Road and Pine Ridge Road. Utility poles are located on the south side of the roadway. Sidewalks are not provided along Forge Village Road. The intersection of Forge Village Road at Flagg Road was recently reconstructed to remove a large delta island in place of a flush cobblestone median island. The improvements narrowed the intersection and provided a large retaining wall on the north side of the roadway. The roadway is generally straight with rolling terrain but becomes very curvy and decreases in grade from Flagg Road to Patten Road (westbound); see Figure 7. Sidewalks are not provided along this roadway within the study area.

Figure 7: Forge Village Road (Westbound)

ABBOT STREET

Abbot Street is a residential roadway that generally runs north/south and connects Forge Village Road with Concord Road (Route 225). The roadway is approximately 23' to 28' and provides one travel lane in each direction with variable shoulders. Abbot Street intersects Concord Road at a skewed angle that widens out to provide large amounts of pavement; see Figure 8. The large turning radii are used heavily by trucks and buses traveling towards Town Farm Road (north of Forge Village Road). Two schools are located north of Forge Village Road as well as Dee Bus Services (who provide school buses for the Town). Sidewalks are not provided along this roadway within the study area.

Figure 8: Abbot Street at Concord Road (Route 225) (Northbound)

COUNTRY ROAD

Country Road is a wooded residential road that generally runs north/south and connects Patten Road with Concord Road (Route 225). The roadway is approximately 20' to 25' wide and is not striped; see Figure 9. Country Road has a curvy horizontal alignment and intersects Concord Road at a skewed angle bordered by an existing cemetery. Traffic was observed utilizing Country Road as a means of avoiding the intersection of Route 225 at Patten Road. Sidewalks are not provided along this roadway.

Figure 9: Country Road (Northbound)

HARTFORD ROAD

Hartford Road is a narrow wooded residential roadway that generally runs north/south and connects Patten Road with Robinson Road. The roadway is approximately 16' to 23' wide and is not striped; see Figure 10. Hartford Road was originally a dirt road but was recently paved. A residential development is located north of Crisafulli School that is accessed via Hartford Road. Sidewalks are not provided on this roadway, though pedestrians were observed walking along the roadside. Vehicles were observed utilizing this roadway to access Westford Academy.

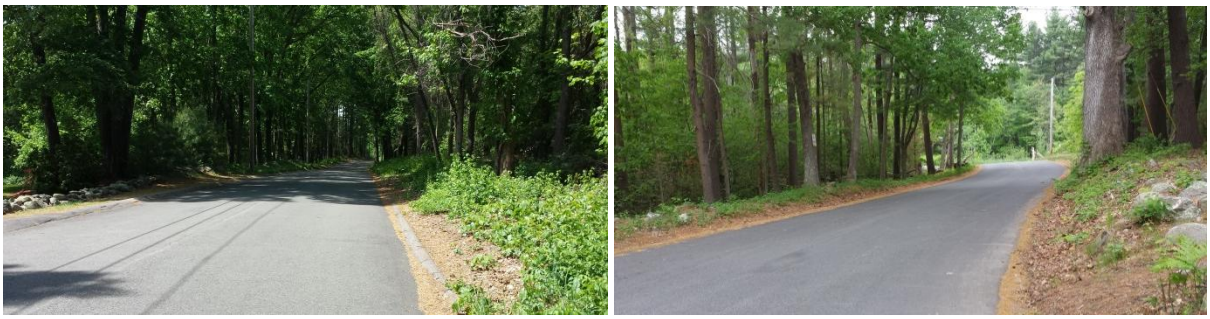

Figure 10: Hartford Road

FLAGG ROAD

Flagg Road is a residential roadway that generally runs north/south and connects Forge Village Road with residential areas to the south. The Roadway is approximately 20' to 25' wide in the study area with one travel lane in each direction and no shoulders; see Figure 11. Edge of roadway is delineated with asphalt berm in some locations, though the majority of the roadway does not provide edge striping or curbing. Sidewalks are not provided along Flagg Road. Utility poles are generally located along the east side of the roadway.

Figure 11: Flagg Road

COLD SPRING ROAD

Cold Spring Road is a collector roadway that generally runs north/south (in this study area) and connects Westford Academy with Graniteville Road. The roadway is approximately 20' to 25' wide with one travel lane in each direction and variable shoulders. Cold Spring Road is posted with 30 miles per hour speed limits in this area; see Figure 12. Curbing is not provided throughout the study area and utility poles are located on the west side. On-street parking is restricted on the east side of the street. The intersections of Cold Spring Road with Forge Village Road and Patten Road are slightly offset intersections with large turning radii. Both intersections were found to become congested during peak periods.

Figure 12: Cold Spring Road (Southbound)

SCHOOL PEAK HOUR OBSERVATIONS

Traffic conditions were observed for each of the school arrival and dismissal periods on Tuesday, May 26, 2015 and Thursday, November 5, 2015. As seen in Table 1, the three schools operate with slightly offset/staggered schedules. This helps to alleviate some of the congestion in the area. It should be noted that the elementary school districts for Robinson School and Crisafulli School are primarily located to the south of the study area, whereas Westford Academy draws students from the entire town.

Table 1: School Summary

School Name	School Type	Grades	Arrival - Dismissal
Westford Academy	High School	9-12	7:30AM - 1:55PM
Crisafulli School	Elementary	3-5	8:25AM - 2:30PM
Robinson School	Elementary	K-2	9:05AM – 3:10PM

WESTFORD ACADEMY (WA)

Observations on May 26th occurred when seniors at Westford Academy had previously been relieved of regular school activity. According to the school administration, many seniors continue to report to school for various extra-curricular activities after being relieved of regular school activity. Since extra-curricular activities don't normally last the entire school day, senior arrivals and dismissals are offset from typical drop-off/pick-up times. Since only seniors are allowed to drive to school, siblings of a student who drives often carpool together. School officials noted that without the option of students carpooling, the number of students being dropped off in the morning and picked up in the afternoon may have been higher than usual. Observations in November occurred while all students were in session. It was noted that operations on November 5th were smoother, with no significant queuing problems, than those observed in May when seniors were not in school. This suggests that students parking on-site reduce overall congestion along Patten Road.

High school observations were centralized around Patten Road, Hartford Road, and Cold Spring Road. As noted previously, vehicles are prohibited from entering Patten Road from the north at Forge Village Road during school hours. All traffic coming from the north (via Forge Village Road) is required to utilize Cold Spring Road or choose alternate routes. One alternate route noticed includes the utilization of Flagg Road, Robinson Road, and Hartford Road. During the school peak, Patten Road becomes very congested as vehicles queue to enter and exit the school for drop-off and pick-up activity. Many vehicles were observed using Hartford Road as a secondary means of entrance via an existing driveway on Hartford Road. This roadway was recently paved which may have made this roadway more appealing than in previous years. The existing roadway is very narrow in some places, which is further exacerbated with the presence of walking students.

As noted above, Patten Road becomes increasingly congested as vehicles enter and exit WA. To help alleviate this, traffic is regulated by a crossing guard and up to two other school officials. The crossing guard stands in the middle of the intersection of Patten Road at Cold Spring Road/WA West Driveway and directs traffic and pedestrians. All approaches to this intersection queue extensively. The other school officials help to meter traffic entering and exiting the school driveways. Queues on Cold Spring Road were observed extending from Patten Road to Forge Village Road, thereby blocking traffic from entering Cold Spring Road. This extended queues along Forge Village Road during the school peak hours. Congestion on Patten Road was found to worsen due to congestion on-site. Traffic is required to enter via the East Driveway, travel around the rear of the school and exit via the Center Driveway; see Figure 13.

Figure 13: Westford Academy (Morning)

Many parents were observed violating this travel pattern in exchange for entering/exiting other driveways. This increases delays and queues for parents actually adhering to the recommended traffic pattern. Notable conflicts occurred with vehicles entering/exiting via the Hartford Road driveway, as well as vehicles entering via the West Driveway (Student Parking) and exiting the Center Driveway. During the November observations when seniors were observed parking in the student lot, pedestrians constantly cross the Center Driveway at multiple locations and disregard the designated striped crosswalks. This slows traffic exiting via the Center Driveway as they must be on the lookout for unexpected vehicles and pedestrians.

ROBINSON SCHOOL / CRISAFULLI SCHOOL

Peak periods for these schools were observed in May and were found to operate with much smoother conditions than Westford Academy. Observations were centralized around Robinson Road which was found to have minimal congestion with respect to school related traffic. The intersection of Concord Road (Route 225) at Robinson Road was found to queue approximately 10 vehicles during school peaks, namely due to school buses; see Figure 14.

Figure 14: Concord Road at Robinson Road Queues

Pedestrian activity was minimal as most students arrived via bus or car. Most buses were observed turning left onto Concord Road, consistent with the elementary school districts. It was noted that these turns required more time than typical cars which required buses to accept larger gaps in traffic. One instance occurred where a vehicle attempted to turn right into the Robinson School parking lot. A vehicle exiting Robinson Road assumed the right directional was associated with a right turn onto Robinson Road and started to enter the intersection.

EXISTING TRAFFIC DATA COLLECTION

BETA retained Accurate Counts from North Reading, MA to collect traffic data at all study area intersections as well as Concord Road (Route 225), Robinson Road, and Patten Road in April 2015.

AUTOMATIC TRAFFIC RECORDER (ATR)

Continuous Automatic Traffic Recorder (ATR) counts were collected for 48 hours between Wednesday April 8, 2015 and Thursday, April 9, 2015 on three roadways within the study area including: Concord Road (Route 225) east of Beaver Brook Road; Robinson Road west of Crisafulli School; and Patten Road west of Patten Lane. These ATR units collected vehicular volumes (including bicycles), speeds, and vehicle classifications. The two days were averaged together to determine an average weekday condition. A summary traffic volume data collected by the ATR units is provided in Table 2. Explanation of specific peak hour times per collection unit is provided in Table 3.

Table 2: ATR Data Summary

Location	Daily Weekday	Morning Peak Hour[a] Volume	K Factor	Dir. Dist	Afternoon Peak Hour[b] Volume	K Factor	Dir. Dist	Evening Peak Hour[c] Volume	K Factor	Dir. Dist
Route 225 East of Beaver Brook Rd	**5,230**	600	11%	EB 82%	N/A	N/A	N/A	595	11%	WB 78%
Robinson Road West of Crisifulli School	**1,360**	245	18%	EB 58%	190	14%	WB 52%	100	7%	EB 58%
Patten Road West of Patten Lane	**1,435**	250	17%	EB 88%	185	13%	EB 92%	130	9%	WB 54%

Table 3: ATR Peak Hours

Location	ATR Peak Hour a	b	c
Route 225 East of Beaver Brook Rd	7:15 - 8:15AM	N/A	4:45 - 5:45PM
Robinson Road West of Crisifulli School	7:00 - 8:00AM	2:30 - 3:30PM	4:45 - 5:45PM
Patten Road West of Patten Lane	6:45 - 7:45AM	2:00 - 3:00PM	6:00 - 7:00PM

Based on the data provided in Table 2, Concord Road (Route 225) was found to have an Average Daily Traffic (ADT) of approximately 5,230 vehicles per day. The ADT is the average number of vehicles using a roadway in bother directions over an average day. For the purposes of this study, only weekdays were examined

given the locations of the nearby schools. Robinson Road and Patten Road were found to have an ADT of approximately 1,360 vehicles per day and 1,435 vehicles per day, respectively.

As seen in Table 2 and Table 3, morning peak hours varied by location between 6:45AM and 8:15AM. Concord Road (Route 225) did not show any specific afternoon peak hour as traffic volumes experienced a morning rush, slight decline, and then progressively increased throughout the day until the evening peak hour. Data for the other two locations, Robinson Road and Patten Road, showed three distinct peaks in the morning, afternoon, and evening. This can be attributed to the adjacent schools along Patten Road and Robinson Road whereas Route 225 functions as an urban arterial throughout Westford. The afternoon peaks were found to lie between 2:00PM and 3:30PM consistent with school dismissal times in the area. Evening peak hours were found to be between 4:45PM and 7:00PM. The evening peak hour for Patten Road was unusually late, 6:00 – 7:00PM, compared to the other roadways. It is expected that this traffic may have been due to an event at the school during the evening hours.

Robinson Road and Patten Road were found to have peak hour volumes of approximately 100 to 200 vehicles. It should be noted that school peak hour traffic accounts for approximately 30% of all vehicles utilizing Robinson Road and Patten Road. School related traffic may actually account for a larger percentage of daily traffic on these roads; however, as school peak periods tend to overlap for a period greater than one hour; especially since the different schools stagger their arrival and dismissal times. Concord Road was found to have peak hour volumes of approximately 600 vehicles. Commuting patterns through the area show more eastbound vehicles on Route 225 in the morning and westbound vehicles in the evening. Patten Road shows overwhelmingly more eastbound vehicles during the school peak hours as a result of the turn restriction at the intersection of Forge Village Road and Patten Road. However, the Robinson Road ATR showed a relatively even split (eastbound/westbound) throughout the course of the day.

Travel speeds were also examined as part of the ATR data collection effort. For the purposes of this study, speeds were examined in relation to the 85th percentile speed. This represents the speed at which approximately 85% of all traffic is traveling at or below during the course of a day. It was found that Concord Road (Route 225) has an 85th percentile speed of greater than 45 miles per hour (between 44mph and 47mph). Speed limits are not posted along the stretch of Route 225 in the study area, with exception of a 20 mph school zone near Robinson Road. Since speed limits are not posted at the location of the ATR, higher speeds are generally expected giving the arterial nature of the roadway. Based on the Massachusetts Drivers Manual, prima facie speeds (should speed limit signs not be posted) consist of: 20 mph in a school zone; 30 mph in a thickly settled or business district; 40 mph outside a thickly settled or business district; and 50 mph on a highway outside a thickly settled or business district. According to those recommendations, drivers could consider this type of roadway to have reasonable speeds between 40 mph and 50 mph. Robinson Road was found to have an 85th percentile speed of approximately 42 miles per hour. Given the narrow, wooded characteristics and educational nature of this roadway, this speed is very high. Two school zones (20 mph) are located on Robinson Road near the Robinson School and the Crisafulli School. According to the data, only 0.2% of all cars were observed traveling at 20 mph or below throughout the day. It should be noted, however, that this data collection area was located between the two school zones allowing vehicles to pick up speed before arriving at the next school zone. Most vehicles were found traveling between 35 and 40 mph in this area. Patten Road was found to have an 85th percentile speed of approximately 35 miles per hour which is much lower than the other two roads but still fast for the narrowness of the road combined

with vertical and horizontal curvature of the road. Patten Road is posted at 20 mph approaching Westford Academy, but no posted speed limits are located near the ATR location.

The 85th percentile speeds for each of the three roadways are displayed with the Average Daily Traffic (ADT) for each roadway in Figure 15.

TURNING MOVEMENT COUNTS (TMC)

Turning Movement Counts (TMC) were collected on Thursday, April 9th, 2015 at all 18 study area intersections and driveways. All intersections were counted between 7:00 – 9:00AM and 4:00 – 6:00PM consistent with morning and evening commuting peak periods. In addition, 10 intersections were counted between 2:00 – 4:00PM to examine the afternoon school dismissal period. Location/intersection numbers include:

4. Concord Road (Rte. 225) at Robinson School – North Driveway
5. Concord Road (Rte. 225) at Robinson Road / Buckingham Drive
6. Robinson Road at Robinson School – West Driveway
7. Robinson Road at Robinson School – East Driveway
8. Robinson Road at Crisafulli School Driveway / Hutchins Way
12. Patten Road at Cold Spring Road / Westford Academy – West Driveway
13. Patten Road at Westford Academy – Center Driveway
14. Patten Road at Westford Academy – East Driveway
15. Patten Road at Hartford Road
16. Forge Village Road at Cold Spring Road

Finally, the intersection of Forge Village Road at Cold Spring Road was counted between 9:00AM – 2:00PM to provide a total of 11 hours of data collection at the intersection for signal warrant analysis purposes. A summary of TMC data is provided in Figure 15 and Figure 16. Pedestrian volumes, where observed, are also provided in these figures.

Count Date: Thursday, April 9th, 2015

Pine St

Rte. 225

Abbot St

Forge Village Rd

Cold Spring Rd

Patten Rd

Patten Rd

Patten Rd
One-Way ↑
(7:00-9:00AM,
1:30-3:00PM, M-F)

ADT: 1,435 vpd
SPD: 34mph EB,
37mph WB

Country Rd

ADT: 5,230 vpd
SPD: 47mph EB,
44mph WB

Flagg Rd

Hartford Rd

West Dwy

Center Dwy

East Dwy

Westford Academy

Rte. 225

Robinson School

Crisafulli School

North Dwy

West Dwy

East Dwy

Dwy

Buckingham Dr

Robinson Rd

ADT: 1,360 vpd
SPD: 42mph EB,
42mph WB

Hutchins Way

N

NAD 83

Legend:
- Automatic Traffic Recorder
- Vehicle Travel
- Pedestrian Travel (Crosswalk)
- Pedestrian Travel (No Crosswalk)

AM(PM) Peak Hour Traffic Volumes
AM Peak Hour = 7:00 - 8:00AM
PM Peak Hour = 4:45 - 5:45PM

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WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

FIGURE 2

2015 EXISTING WEEKDAY
COMMUTING PEAK HOUR TRAFFIC VOLUMES
N.T.S.

Count Date: Thursday, April 9th, 2015

Pine St

Abbot St

Forge Village Rd

Cold Spring Rd

Patten Rd

Patten Rd
One-Way ↑
(7:00-9:00AM,
1:30-3:00PM, M-F)

Patten Rd

Country Rd

Rte. 225

Flagg Rd

Hartford Rd

N

NAD 83

West Dwy

Center Dwy

East Dwy

Westford Academy

Robinson School

Crisafulli School

North Dwy

West Dwy

East Dwy

Dwy

Buckingham Dr

Robinson Rd

Hutchins Way

Legend:
→ Vehicle Travel
<-------> Pedestrian Travel (Crosswalk)
<- - - -> Pedestrian Travel (No Crosswalk)

Academy(Elementary) School PM Peak Hour
Traffic Volumes
Westford Academy Peak Hour = 2:00PM - 3:00PM
Elementary School Peak Hour = 2:30PM - 3:30PM

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WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

FIGURE 3

2015 EXISTING WEEKDAY SCHOOL
PM PEAK HOUR TRAFFIC VOLUMES
N.T.S.

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Similar to the discussion regarding the ATR data, each study area intersection experiences its own peak hour during each peak period. This represents one hour where the total volume entering an intersection from all approaches is the highest. For the purposes of this study, conditions were examined using a common network peak hour. This represents one hour where the total volume entering all intersections from all approaches is the highest. Examining individual intersection peak hours allows the ability to examine the worst case scenario at each individual intersection, whereas examining the network peak hour allows the ability to better examine travel patterns as a whole. That said, the peak hours examined in Figure 15, and Figure 16 were found to occur as follows:

- Morning Commuting Peak Hour= 7:00 – 8:00AM
- Evening Commuting Peak Hour = 4:45 – 5:45PM
- Westford Academy Afternoon Peak Hour = 2:00 – 3:00PM
- Elementary School Afternoon Peak Hour = 2:30 – 3:30PM

Note that two afternoon peak hours were examined. The overall afternoon peak hour (the highest amount of traffic in the study area) was found to be 2:00 – 3:00PM. The additional of an alternate peak hour was determined due to travel patterns in the area based on the districts of the different schools. Since the districts for both elementary schools, Robinson School and Crisafulli School, are located to the south of the study area, traffic generated to these schools generally does not utilize Patten Road. As a result, during the school release period for these schools traffic on Robinson Road is higher than during the Westford Academy afternoon release period. Congruently, traffic on Patten Road was found to be higher during the Westford Academy afternoon release period than the elementary school afternoon release period.

As seen in Figure 15, a minimal amount of pedestrians were observed in the morning and evening peak hours These pedestrian volumes were found to slightly increase (±18) during the afternoon school release peak hours, Figure 16. It is expected that these pedestrians may be larger than shown as these counts only examine pedestrians crossing the roadway within an intersection. They do not account for pedestrians crossing on-site or elsewhere. For instance, approximately 18 pedestrians were observed crossing the Westford Academy West Driveway (south of Cold Spring Road) during the afternoon peak hour. This does not account for pedestrians who may have exited the parking lot heading west on Patten Road. A negligible amount of bicyclists were observed during the counting period. Those few that were observed traveled east/west on Route 225 and north/south on Cold Spring Road. During field observations, a group of 10-20 bicyclists were observed traveling in a pack along Cold Spring Road, Forge Village Road, and Patten Road. It was assumed that these were students potentially taking a physical education class. They rode along the shoulder, though could ride in the grass/dirt alongside the roadway if needed due to the lack of curbing.

Based on the peak hour volumes, it was found that drivers generally adhere to the turn restrictions onto Patten Road at Forge Village Road during the school peak periods. The number of turns increases outside of the school peak periods. As a result, most vehicles destined to Westford Academy from the east turn left onto Cold Spring Road from Forge Village Road.

CRASH DATA ANALYSIS

Crash data for all study area intersections and roadways were collected from the MassDOT Crash Database. The crash database provides information for all crashes reported to the Registry of Motor Vehicles. Crash

information was obtained for the years of 2010 to 2013 (the most recent four years of available data). A summary of crash history at the study area intersections can be seen in Table 4. Only seven of the 18 study area intersections were found to have a crash history between 2010 and 2013. Even so, six of these seven intersections were found to have three or fewer crashes over four years with no crashes resulting in injury or fatality. This suggests that the majority of intersections in the study area do not have major issues regarding safety. A low number of crashes can also be reflected in the low amount of traffic volume traveling through the study area networks, with exception of during the school peak periods.

The most active intersection was found to be Forge Village Road at Cold Spring Road which had 18 crashes reported over the four years (approximately 3 to 4 crashes per year). The intersection crash rate for this location was calculated to be 1.55 crashes per million entering vehicles (MEV). The crash rate examines the number of crashes per year with the total volume of vehicles traveling through the intersection for a number of years. The Massachusetts statewide average for an unsignalized intersection is 0.58 crashes per MEV, and the MassDOT District 3 average crash rate is 0.65 crashes per MEV. Given these statewide averages, Westford's intersection is much higher (nearly double) the statewide and district average crash rates. As a result, the Town (and other stakeholders) conducted a Road Safety Audit (RSA) at this intersection in October 2014. The RSA noted concerns regarding intersection layout, intersection control, queuing due to school activity and lack of pedestrian infrastructure as reasons for the high crash rate. The MassDOT crash data shows that most crashes at this intersection were angle and single vehicle type crashes. Angle crashes are consistent with vehicles attempting to exit the side street (Cold Spring Road) without an adequate gap in vehicles traveling on Forge Village Road. Likewise, these can also be related to left turning vehicles from Forge Village Road onto Cold Spring Road. This is consistent with the large number of left turning vehicles onto Cold Spring Road destined to the Westford Academy site. Only four of the 18 crashes were recorded as resulting in injury. It was noted that the lack of injury crashes may be due to the low speeds as a result of excessive queuing during the peak hour.

A summary of crash history on study area roadways between the study area intersections can be seen in Table 5. It was found that Forge Village Road and Concord Road (Route 225) have the largest crash history over the four years examined. All other roads were found to have three or fewer crashes over four years. It should be noted that 71% of crashes occurring along the study area roads (not at study area intersections) were single vehicle crashes. This correlates to vehicles running off the roadway striking an object or a vehicle striking an animal. The crash data provides detail regarding the types of objects struck in each single vehicle crash incident. A summary of these roadside obstructions is listed in Table 6.

Table 4: Intersection Crash Summary

MassDOT Crash Data Summary*													
		Collision Type							Collision Severity				
	Total	Angle	Rear-End	Sideswipe	Head-On	Single Vehicle	Pedestrian	Other/ Unknown	Property Damage	Non-Fatal Injury	Fatality	Other/ Unknown	
1. Concord Road (Route 225) at Abbot Street													
2010	0	-	-	-	-	-	-	-	-	-	-	-	
2011	0	-	-	-	-	-	-	-	-	-	-	-	
2012	3	1	1	-	-	1	-	-	3	-	-	-	
2013	0	-	-	-	-	-	-	-	-	-	-	-	
Total	**3**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**3**	**0**	**0**	**0**	
3. Concord Road (Route 225) at Country Road													
2010	0	-	-	-	-	-	-	-	-	-	-	-	
2011	1	1	-	-	-	-	-	-	1	-	-	-	
2012	1	-	1	-	-	-	-	-	1	-	-	-	
2013	0	-	-	-	-	-	-	-	-	-	-	-	
Total	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	
5. Concord Road (Route 225) at Robinson Road													
2010	0	-	-	-	-	-	-	-	-	-	-	-	
2011	0	-	-	-	-	-	-	-	-	-	-	-	
2012	1	-	1	-	-	-	-	-	1	-	-	-	
2013	0	-	-	-	-	-	-	-	-	-	-	-	
Total	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	
15. Patten Road at Hartford Road													
2010	0	-	-	-	-	-	-	-	-	-	-	-	
2011	1	-	1	-	-	-	-	-	1	-	-	-	
2012	0	-	-	-	-	-	-	-	-	-	-	-	
2013	0	-	-	-	-	-	-	-	-	-	-	-	
Total	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	
16. Forge Village Road at Cold Spring Road													Crash Rate = 1.55 MEV
2010	7	4	-	1	-	2	-	-	5	2	-	-	
2011	2	-	-	-	-	2	-	-	2	-	-	-	
2012	5	4	1	-	-	-	-	-	5	-	-	-	
2013	4	4	-	-	-	-	-	-	2	2	-	-	
Total	**18**	**12**	**1**	**1**	**0**	**4**	**0**	**0**	**14**	**4**	**0**	**0**	
17. Forge Village Road at Patten Road													
2010	2	-	2	-	-	-	-	-	2	-	-	-	
2011	1	1	-	-	-	-	-	-	1	-	-	-	
2012	0	-	-	-	-	-	-	-	-	-	-	-	
2013	0	-	-	-	-	-	-	-	-	-	-	-	
Total	**3**	**1**	**2**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	
18. Forge Village Road at Flagg Road													
2010	0	-	-	-	-	-	-	-	-	-	-	-	
2011	1	-	1	-	-	-	-	-	1	-	-	-	
2012	0	-	-	-	-	-	-	-	-	-	-	-	
2013	1	-	-	1	-	-	-	-	1	-	-	-	
Total	**2**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	

Average crash rates for unsignalized intersections: Statewide (0.60 MEV), District 3 (0.66 MEV)
* 2010 - 2013 Source: Massachusetts Department of Transportation
MEV = Crashes per Million Entering Vehicles

Table 4: Intersection Crash Summary (Continued)

MassDOT Crash Data Summary* (Cont.)										
		Weather					Lighting			
	Total	Clear	Rain	Cloudy	Sleet/Hail	Unknown	Daylight	Dark - with Streetlights	Dark - w/o Streetlights	Other/ Unknown
1. Concord Road (Route 225) at Abbot Street										
2010	0	-	-	-	-	-	-	-	-	-
2011	0	-	-	-	-	-	-	-	-	-
2012	3	1	-	2	-	-	1	2	-	-
2013	0	-	-	-	-	-	-	-	-	-
Total	**3**	**1**	**0**	**2**	**0**	**0**	**1**	**2**	**0**	**0**
3. Concord Road (Route 225) at Country Road										
2010	0	-	-	-	-	-	-	-	-	-
2011	1	-	-	1	-	-	1	-	-	-
2012	1	1	-	-	-	-	1	-	-	-
2013	0	-	-	-	-	-	-	-	-	-
Total	**2**	**1**	**0**	**1**	**0**	**0**	**2**	**0**	**0**	**0**
5. Concord Road (Route 225) at Robinson Road										
2010	0	-	-	-	-	-	-	-	-	-
2011	0	-	-	-	-	-	-	-	-	-
2012	1	1	-	-	-	-	1	-	-	-
2013	0	-	-	-	-	-	-	-	-	-
Total	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
15. Patten Road at Hartford Road										
2010	0	-	-	-	-	-	-	-	-	-
2011	1	1	-	-	-	-	1	-	-	-
2012	0	-	-	-	-	-	-	-	-	-
2013	0	-	-	-	-	-	-	-	-	-
Total	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
16. Forge Village Road at Cold Spring Road										Crash Rate = 1.55 MEV
2010	7	4	-	2	1	-	5	-	2	-
2011	2	2	-	-	-	-	1	-	1	-
2012	5	3	1	1	-	-	5	-	-	-
2013	4	4	-	-	-	-	3	-	-	1
Total	**18**	**13**	**1**	**3**	**1**	**0**	**14**	**0**	**3**	**1**
17. Forge Village Road at Patten Road										
2010	2	-	1	1	-	-	2	-	-	-
2011	1	1	-	-	-	-	-	1	-	-
2012	0	-	-	-	-	-	-	-	-	-
2013	0	-	-	-	-	-	-	-	-	-
Total	**3**	**1**	**1**	**1**	**0**	**0**	**2**	**1**	**0**	**0**
18. Forge Village Road at Flagg Road										
2010	0	-	-	-	-	-	-	-	-	-
2011	1	-	-	-	1	-	1	-	-	-
2012	0	-	-	-	-	-	-	-	-	-
2013	1	1	-	-	-	-	1	-	-	-
Total	**2**	**1**	**0**	**0**	**1**	**0**	**2**	**0**	**0**	**0**

Average crash rates for unsignalized intersections: Statewide (0.60 MEV), District 3 (0.66 MEV)
* 2010 - 2013 Source: Massachusetts Department of Transportation
MEV = Crashes per Million Entering Vehicles

Table 5: Segment Crash Summary

MassDOT Crash Data Summary*†									
		Collision Type				Collision Severity			
	Total	Angle	Rear-End	Single Vehicle	Other/ Unknown	Property Damage	Non-Fatal Injury	Fatality	Other/ Unknown
Concord Road (Route 225)									
2010	3	2	1	-	-	2	1	-	-
2011	2	-	-	2	-	1	-	-	1
2012	2	-	1	1	-	1	1	-	-
2013	2	-	1	1	-	2	-	-	-
Total	**9**	**2**	**3**	**4**	**0**	**6**	**2**	**0**	**1**
Patten Road									
2010	1	-	-	1	-	1	-	-	-
2011	0	-	-	-	-	-	-	-	-
2012	0	-	-	-	-	-	-	-	-
2013	0	-	-	-	-	-	-	-	-
Total	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**
Flagg Road									
2010	0	-	-	-	-	-	-	-	-
2011	0	-	-	-	-	-	-	-	-
2012	1	-	-	1	-	1	-	-	-
2013	0	-	-	-	-	-	-	-	-
Total	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**
Forge Village Road									
2010	0	-	-	-	-	-	-	-	-
2011	2	1	-	1	-	1	1	-	-
2012	1	-	-	1	-	1	-	-	-
2013	9	-	1	8	-	6	3	-	-
Total	**12**	**1**	**1**	**10**	**0**	**8**	**4**	**0**	**0**
Hartford Road									
2010	0	-	-	-	-	-	-	-	-
2011	1	-	-	1	-	1	-	-	-
2012	0	-	-	-	-	-	-	-	-
2013	2	-	-	2	-	2	-	-	-
Total	**3**	**0**	**0**	**3**	**0**	**3**	**0**	**0**	**0**
Country Road									
2010	0	-	-	-	-	-	-	-	-
2011	1	1	-	-	-	1	-	-	-
2012	0	-	-	-	-	-	-	-	-
2013	1	-	-	1	-	1	-	-	-
Total	**2**	**1**	**0**	**1**	**0**	**2**	**0**	**0**	**0**

* 2010 - 2013 Source: Massachusetts Department of Transportation
† Crashes on roadways between study area intersections

Table 5: Segment Crash Summary (Continued)

MassDOT Crash Data Summary*† (Cont.)									
		Weather				Lighting			
	Total	Clear	Rain	Cloudy	Snow, Sleet, Hail	Daylight	Dark - with Streetlights	Dark - w/o Streetlights	Other/ Unknown
Concord Road (Route 225)									
2010	3	3	-	-	-	1	1	-	1
2011	2	2	-	-	-	1	1	-	-
2012	2	-	1	-	1	-	-	1	1
2013	2	1	-	-	1	2	-	-	-
Total	**9**	**6**	**1**	**0**	**2**	**4**	**2**	**1**	**2**
Patten Road									
2010	1	-	-	1	-	1	-	-	-
2011	0	-	-	-	-	-	-	-	-
2012	0	-	-	-	-	-	-	-	-
2013	0	-	-	-	-	-	-	-	-
Total	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**
Flagg Road									
2010	0	-	-	-	-	-	-	-	-
2011	0	-	-	-	-	-	-	-	-
2012	1	-	-	-	1	1	-	-	-
2013	0	-	-	-	-	-	-	-	-
Total	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**
Forge Village Road									
2010	0	-	-	-	-	-	-	-	-
2011	2	2	-	-	-	1	1	-	-
2012	1	1	-	-	-	-	-	1	-
2013	9	8	-	1	-	6	3	-	-
Total	**12**	**11**	**0**	**1**	**0**	**7**	**4**	**1**	**0**
Hartford Road									
2010	0	-	-	-	-	-	-	-	-
2011	1	-	-	-	1	-	1	-	-
2012	0	-	-	-	-	-	-	-	-
2013	2	2	-	-	-	2	-	-	-
Total	**3**	**2**	**0**	**0**	**1**	**2**	**1**	**0**	**0**
Country Road									
2010	0	-	-	-	-	-	-	-	-
2011	1	-	-	-	1	1	-	-	-
2012	0	-	-	-	-	-	-	-	-
2013	1	-	-	-	1	-	1	-	-
Total	**2**	**0**	**0**	**0**	**2**	**1**	**1**	**0**	**0**

* 2010 - 2013 Source: Massachusetts Department of Transportation
† Crashes on roadways between study area intersections

Table 6: Single Vehicle Crash Summary (Segment Crashes)

Single Vehicle Crash Summary									
		Object Struck in Crash							
	Total	Tree	Utility Pole	Curb	Ditch	Embank-ment	Guardrail	Animal	Unknown / Other
Concord Road (Route 225)									
Total SV Crashes	4	-	-	-	-	1	1	1	1
Patten Road									
Total SV Crashes	1	-	-	-	-	-	-	-	1
Flagg Road									
Total SV Crashes	1	-	-	-	-	-	1	-	-
Forge Village Road									
Total SV Crashes	10	-	6	1	-	-	-	1	2
Hartford Road									
Total SV Crashes	3	1	1	-	1	-	-	-	-
Country Road									
Total SV Crashes	1	-	1	-	-	-	-	-	-

As seen in the previous tables, most single vehicle collisions occurred on Forge Village Road where roadside utility poles were struck. Forge Village Road within the study area is a wooded roadway with no curbing. Some sections of the roadway are delineated by asphalt berm. The roadway crosses a wetland area (Boutwell Brook) between Patten Road and Pine Ridge Road. This section of Forge Village Road is protected by steel guardrail on either side such that vehicles don't drive into the wetland. Utility poles are located on the south side of Forge Village Road approximately two to three feet off the edge of road. Utility poles are also located on the inside of the guardrail separating the roadway from the wetland area. Approximately half of the single vehicle crashes on Forge Village Road occurred during dawn/dusk or overnight hours, suggesting that darkness isn't a primary cause for these types of crashes given that many occur during daylight hours.

Country Road and Hartford Road (two other instances of Utility Pole crashes) are also windy wooded roadways with no curbing. Locations of utility poles vary on each of these roadways as power lines cross the roadways in multiple locations. It should be noted that two deer were struck within the study area, one on Concord Road (Route 225) and one on Forge Village Road.

EXISTING TRAFFIC CAPACITY ANALYSIS

Intersection operations were evaluated using the SYNCHRO software package (Version 8.0, Build 806.61). This software package is based on methodologies contained in the *Highway Capacity Manual* (HCM) published by the Transportation Research Board. Traffic operations are defined by Level of Service (LOS), which is a qualitative measure that associates LOS with vehicle delays. Delay is a measure of driver discomfort, frustration, fuel consumption, and lost travel time. As such, delay is categorized into six into six levels of service from LOS A (very good operations) to LOS F (very poor operations). The criteria for unsignalized intersections are different than for signalized intersections because drivers expect different performance levels from each type of intersection. For instance, drivers may become more easily frustrated at unsignalized intersections because they do not have the peace of mind that a traffic signal will provide a right-of-way at some point. Vehicles at a stop sign must accept their own gaps which can increase stress particularly if a long queue is behind the vehicle attempting navigate the stop sign. The relationship between

LOS and delay is summarized in Table 7. This study area includes 18 unsignalized intersections and no signalized intersections.

Table 7: Level of Service Criteria

LOS	Unsignalized Intersections Average Total Delay (seconds per vehicle)	Signalized Intersections Average Total Delay (seconds per vehicle)
A	< 10.0	< 10.0
B	10.1 to 15.0	10.1 to 20.0
C	15.1 to 25.0	20.1 to 35.0
D	25.1 to 35.0	35.1 to 55.0
E	35.1 to 50.0	55.1 to 80.0
F	> 50.0	> 80.0

Source: Highway Capacity Manual, Transportation Research Board; Washington, DC; 2000

Traffic analysis only examines queues and delays for approaches that may be delayed. In the case of a signalized intersection this represents all approaches as each approach must be required to stop while cross traffic receives a green signal. At an unsignalized intersection, the only approaches that can be analyzed are those with stop signs or yield signs (side streets) and left turns from the major street to a side street. This is because left turning vehicles may be required to stop and wait for a gap in oncoming traffic to make the left turning maneuver. During this time, vehicles may start to queue up behind the waiting left turning vehicle. This generates delay and thereby degrades level of service. A summary of the existing traffic capacity analysis is provided in Table 8. Note that the intersections in close proximity to the schools were analyzed during afternoon school release periods.

It should be noted that the intersections along Patten Road at Westford Academy are controlled by a crossing guard and/or school officials during the school arrival and dismissal peak periods. It was observed that these individuals stop oncoming traffic to allow vehicles to exit the school driveways unopposed for a period of time similar to that of a traffic detail officer. Driveways on Patten Road were modeled as STOP sign approaches without consideration for crossing guard activity.

Table 8 : Existing Level of Service Table

INTERSECTIONS	Morning Peak Hour			W.A. Afternoon Peak Hour			Elementary Afternoon Peak Hour			Evening Peak Hour		
	LOS	Delay (s/veh)	95%ile Queue	LOS	Delay (s/veh)	95%ile Queue	LOS	Delay (s/veh)	95%ile Queue	LOS	Delay (s/veh)	95%ile Queue
1. Concord Road (Rte. 225) at Abbot Street												
Abbot - WB	D	31	149							B	14	14
Concord - SB	A	0	0							A	1	0
2. Concord Road (Rte. 225) at Patten Road												
Patten - WBL	C	18	18							C	17	10
Patten - WBR	A	10	8							B	13	3
Concord - SB	A	2	6							A	1	2
3. Concord Road (Rte. 225) at Country Road												
Country - WB	C	20	36							C	16	17
Concord - SB	A	0	0							A	0	0
4. Concord Road (Rte. 225) at Robinson School Driveway												
Driveway - WB	B	14	1	A	9	0	B	11	6	A	0	0
Concord - SB	A	0	0	A	0	0	A	0	0	A	0	0
5. Concord Road (Rte. 225) at Robinson Road/Buckingham Drive												
Buckingham - EB	C	16	5	A	10	1	A	9	1	C	16	3
Robinson - WB	F	51	105	C	16	29	B	14	25	C	19	19
Concord - NB	A	0	0	A	0	0	A	0	0	A	0	0
Concord - SB	A	1	3	A	2	3	A	1	1	A	1	1
6/7. Robinson Road at Robinson School Driveways												
Robinson - EB	A	1	2	A	1	1	A	2	2	A	2	1
W. Driveway - SB	A	10	3	A	10	1	B	10	6	A	9	3
E. Driveway - SB	A	0	0	A	10	1	B	11	15	A	9	1
8. Robinson Road at Crisafulli School Driveway/Hutchins Way												
Robinson - EB	A	3	5	A	4	2	A	2	1	A	2	1
Robinson - WB	A	1	0	A	0	0	A	0	0	A	1	0
Hutchins - NB	B	10	3	A	10	1	B	11	1	A	9	0
Crisafulli - SB	B	12	13	B	13	41	B	11	33	A	9	3
9. Robinson Road at Hartford Road												
Robinson - EB	A	6	10							A	2	0
Hartford - SB	B	11	13							A	9	2
10. Robinson Road at Flagg Road												
Robinson - EBL	A	10	6							A	9	4
Robinson - EBR	A	9	1							A	8	1
Flagg - NB	A	6	3							A	2	1
11. Patten Road at Country Road												
Patten - WB	A	4	5							A	4	3
Country - NB	B	11	22							A	9	8
12. Patten Road at Cold Spring Road/Westford Academy (W. Driveway)												
Patten - EB	A	1	1	A	2	2	A	3	2	A	5	5
Patten - WB	A	0	0	A	0	0	A	0	0	A	0	0
Driveway - NB	C	16	2	D	32	161	B	11	2	B	11	1
Cold Spring - SB	F	*	1,449	C	23	60	B	11	12	A	10	5
13. Patten Road at Westford Academy (C. Driveway)												
Driveway - NBL	E	40	156	B	14	33	B	10	13	A	9	3
Driveway - NBR	C	24	98	B	11	22	A	9	8	A	9	2
14. Patten Road at Westford Academy (E. Driveway)												
Patten - WB	A	3	2	A	4	2	A	5	2	A	3	0
Driveway - NB	C	16	15	B	12	13	A	10	4	A	9	1
15. Patten Road at Hartford Road												
Patten - WB	A	1	0	A	1	0	A	0	0	A	0	0
Hartford - NB	B	12	17	B	11	12	A	9	2	A	9	1
16. Forge Village Road at Cold Spring Road												
Forge Village - EB	A	0	0	A	2	2	A	1	1	A	1	1
Forge Village - WB	A	8	34	A	2	2	A	1	1	A	0	0
Cold Spring - NB	F	**	**	D	29	159	B	13	17	B	12	18
Cold Spring - SB	F	**	**	B	13	21	B	12	12	B	11	8
17. Forge Village Road at Patten Road												
Forge Village - WB	A	0	1							A	1	1
Patten - NB	C	15	82							A	9	3
18. Forge Village Road at Flagg Road												
Forge Village - WB	A	6	21							A	1	2
Flagg - NB	C	16	17							A	9	8

Note: Dark Grey cells denote intersections not applicaple or not counted during a peak hour.
95th percentile volume exceeds capacity, queue may be longer. Queue shown is maximum after 2 cycles.
* Delay exceeds 300 seconds
** Exceeds Capacity, cannot be analyzed.

Given the relatively low traffic volumes throughout the study area, most of the study area intersections operate with acceptable level of service (LOS D or better) during the examined peak hours. Overall, it was found that the study area intersections operate under poorer conditions in the morning peak hour. This is likely due to the combination of both commuting traffic and school related traffic, whereas in the afternoon school release and evening commuting peak hours this traffic is more dispersed. In the evening commuting peak hour, all intersections and movements were found to operate with LOS C or better with queues of less than 20 feet. This suggests that none of the study area intersections experience any issues during the evening peak hour. Similarly, all intersections were found to operate with LOS C or better during the elementary school afternoon peak hour with minimal queues. Both intersections of Cold Spring Road (Patten Road and Forge Village Road) were found to have approaches operating with LOS D during the Westford Academy afternoon peak hour. This is due to the mass exodus of vehicles leaving the student parking lot conflicting with other parent's picking up students from the center driveway and east driveway. Given that this release period typically lasts only 30 minutes, it is not expected that these delays and queues are significant enough to warrant large changes.

Morning Peak Hour

Similar to other peak periods, most intersections and driveways operate with acceptable Level of Service (LOS C or better) during the morning peak hour. A summary of intersections and driveways with less than desirable LOS is provided as follows. It should be noted that these periods of unacceptable level of service occur during the school morning peak for less than one hour at which point traffic operations significantly improve.

Concord Road (Route 225) at Abbot Street

Abbot Street was found to operate with LOS D in the morning peak hour with a queue of approximately 150 feet (6 cars). This is due to a very large number of left turning vehicles destined to Route 225 eastbound from Abbot Street conflicting with 325 vehicles already traveling eastbound on Route 225. It was found that most westbound vehicles turn right onto Abbot Street. These right turning cars would not greatly impact level of service, but may cause confusion under existing conditions. It should be noted that this intersection flares out to form a very large lane exiting Abbot Street such that right turning cars can form their own lane for a short distance. To provide a conservative analysis, this type of field observed operations was not modeled which suggests that LOS at this intersection may be better than LOS D in the field.

Concord Road (Route 225) at Robinson Road / Buckingham Drive

Robinson Road was found to operate at LOS F with 51 seconds of delay during the morning peak hour. The threshold for LOS F at unsignalized intersections is 50 seconds per vehicles, which indicates that this approach operates under slight failing conditions. The long delays are due to heavy volumes on Route 225 coupled with the large number of left turns leaving Robinson Road (from the schools). Field observations confirmed that school buses tend to increase the queue length at this approach as they require more time and space to make a turning maneuver than a car. As a result, they must wait for a longer gap in traffic on Route 225.

Patten Road at Cold Spring Road / Westford Academy (West) Driveway

The southbound Cold Spring Road approach operates over capacity during the morning peak hour. So much so that the traffic analysis program cannot accurately determine delay for this approach. The program was able to determine a queue length of approximately 1,450 feet (58 cars). The distance from Patten Road to

Forge Village Road is approximately 1,000 feet. The poor conditions for this approach are caused by approximately 355 vehicles traveling through the intersection to the student parking lot or turning left towards the student drop off area.

PATTEN ROAD AT WESTFORD ACADEMY (CENTER) DRIVEWAY

This driveway provides a left turn lane and a right turn lane for vehicles exiting the school. Vehicles are prohibited from entering this driveway, but instead must enter at the East Driveway and loop around the school to exit the Center driveway. It was noted in the field that some vehicles enter the West driveway (Student Lot) and loop around to exit through the Center driveway. This causes conflicts on-site which may degrade level of service at this intersection. These interactions are not depicted in the model. The analysis showed vehicles exiting the driveway in the left turn lane operate with LOS E (40 seconds of delay) and queue approximately 156 feet.

FORGE VILLAGE ROAD AT COLD SPRING ROAD

The northbound and southbound Cold Spring Road approaches operate well over capacity in the morning peak hour. So much so that the traffic analysis program cannot accurately determine conditions for these approaches. This intersection operates poorly due to the large volumes from each of the four approaches. Queues from the intersection of Cold Spring Road at Patten Road often extend to the intersection of Forge Village Road. These queues prohibit vehicles from entering Cold Spring Road towards Westford Academy and can block the intersection.

TRAFFIC SIGNAL WARRANT

As noted previously, a Road Safety Audit (RSA) was conducted at the intersection of Forge Village Road at Cold Spring Road. The RSA recommended several potential safety improvements at the intersection. Three recommendations were provided in regards to traffic control at the intersection. These included:

- Installation of a traffic signal, if warranted.
- Installation of All-Way STOP control, if warranted.
- Installation of an overhead flashing beacon or advanced intersection warning beacons.

In order to justify the installation or continued operation of traffic signals at an intersection, one or more of the signal warrants in the *Manual on Uniform Traffic Control Devices* (MUTCD) must be met. If one or more of the warrants is met and it is felt the installation of a signal will improve the overall safety and operation of the intersection, then installation or continued operation of a signal operation is justified.

The nine warrants outlined in the MUTCD are as follows:

- *Warrant 1, Eight Hour Vehicular Volume*
- *Warrant 2, Four Hour Vehicular Volume*
- *Warrant 3, Peak Hour*
- *Warrant 4, Pedestrian Volume*
- *Warrant 5, School Crossing*
- *Warrant 6, Coordinated Signal System*
- *Warrant 7 Crash Experience*

- *Warrant 8, Roadway Network*
- *Warrant 9, Intersection Near a Grade Crossing*

Warrants 1, 2, 3, and 7 were considered as part of this signal warrant analysis. Generally, Warrants 4 and 5 would be applicable at an intersection nearby a school, though traffic counts revealed a total of eleven (11) pedestrians crossing this intersection during the 11 hour count period. The small number of pedestrians crossing this intersection (likely due to lack of pedestrian infrastructure or immediate destinations) does not satisfy these pedestrian related warrants.

A signal warrant analysis was performed for the intersection in accordance with the procedures and criteria described in MUTCD. Based on the traffic volumes collected as part of this study, the intersection does not satisfy any of the traffic volume related warrants (Warrant 1, 2, and 3). This is largely in part because traffic volumes at this location peak during the 30 to 45 minutes of school arrival and dismissal and then flatten out over the remaining hours of the day. Since the school peak period is so short, the influx of traffic experienced during these times does not sustain for one full hour thereby failing to satisfy Warrant 3. As seen in the Crash Data Review, above, the 18 crashes were reported at this intersection over four years, approximately 4.5 crashes per year. Warrant 5 examines whether or not the intersection has experienced more than five (5) crashes per year and whether any alternative measures have been used to mitigate or reduce the number of crashes. Since this intersection has experienced less than five crashes per year, Warrant 5 was not satisfied.

ALL-WAY STOP WARRANT

The second item noted in the RSA was an All-Way Stop. This condition applies STOP sign control on all four approaches to the intersection thereby requiring all vehicles to provide right-of-way. These types of conditions work on lower volume roads where all approaches have approximately the same volume. This is such that one or two approaches don't dominate or experience large queues. During these conditions, drivers become impatient and may not comply with STOP sign regulations which could result in an increase in crashes.

An all-way stop warrant examines whether the intersection has experienced five or more crashes in one year that may be corrected by an all-way stop (particularly angle crashes). This intersection, at most, experienced four angle crashes per year. The warrant also examines traffic volumes over the course of eight hours on a given day. Similar to the traffic signal warrant, it was found that traffic volumes at this location are not consistently high for a long period of time. As a result, an all-way stop condition is not warranted at this intersection.

FLASHING BEACON

The MUTCD does not provide any warrant scenario for a flashing beacon configuration. This is because flashing beacons do not physically control traffic, but rather they alert or inform traffic of an unexpected condition. An overhead or advanced flashing beacon alerting drivers of vehicles exiting Cold Spring Road could be installed at this intersection. This configuration would not mitigate the traffic congestion experienced during the school peak periods, but will provide some safety benefits given the added warning information.

CONCEPTUAL DESIGN IMPROVEMENTS

Based on field observations and existing traffic analysis results, BETA was tasked with developing conceptual design improvements to improve safety and intersection operations. Conceptual improvements were developed for each of the study area intersections with exception of Intersection 18: Forge Village Road at Flagg Road as this intersection was recently re-designed. The following section describes each of these conceptual improvements while conceptual sketches of each intersection are appended to this technical memorandum. Many of the recommended intersection improvement concepts include safety improvements that will not change intersection capacity and traffic operations (level of service). This is due to the low amount of delays and queues that the intersections experience under existing conditions.

1. CONCORD ROAD (ROUTE 225) AT ABBOT STREET

This skewed intersection provides a large amount of pavement such that vehicles exiting Abbot Street can form multiple lanes though only one lane is striped. This can cause confusion for drivers turning left and right. Vehicles were also observed making right turn maneuvers from Route 225 onto Abbot Street at higher than desirable speeds. This is due to the large turning radius needed for truck traffic. To increase safety and slow speeds (calm traffic), a flush stamped concrete median island (with a similar pattern to the existing cobblestone at Flagg Road) is proposed to delineate northbound and southbound traffic on Abbot Street as they approach Concord Road. A potential mountable truck apron may be constructed on the northeast corner of the intersection to further slow right turning cars while allowing trucks, school buses, and fire trucks to make the maneuver. The proposed safety improvement will not impact traffic capacity.

2. CONCORD ROAD (ROUTE 225) AT PATTEN ROAD

The conceptual design for this intersection includes re-configuring the large island that splits Patten Road into two legs and re-aligns Patten Street to form a conventional T intersection. This design would increase the greenspace provided in the area while improving safety by reducing the number of vehicular conflict points and improve sight lines. A raised stamped truck apron is recommended on the northeast corner of the proposed intersection to provide an adequate radius for trucks, buses, and fire truck turns while narrowing the radius allowed for car travel. This will slow car speeds as they make turning maneuvers. A sidewalk is proposed from 73 Pleasant Street along the right-of-way line to delineate a greenspace area similar to the existing median island. The sidewalk would follow along the north side of Patten Street to the existing sidewalk at Rooks Way. It is recommended that Patten Road be widened (where needed) to provide a minimum 24' width.

Funneling traffic from two intersections to one intersection was found to have minimal impacts to traffic operations during the peak hours with in an increase in delay of approximately 2 seconds and an increase in queues of approximately 30 feet.

3. CONCORD ROAD (ROUTE 225) AT COUNTRY ROAD

Country Road intersects Route 225 at a skewed angle with a wide area of pavement. Conceptual improvements include providing a flush stamped concrete median (with a similar cobblestone pattern) to delineate northbound and southbound travel. Sight distance for vehicles exiting Country Road would be improved by requiring vehicles to approach Route 225 perpendicularly. This configuration will not impact existing traffic capacity but would improve safety related to traffic calming.

4, 5, & 6. Concord Road (Route 225) at Robinson Road / Buckingham Drive

Delays and queues at this intersection were attributed to school related traffic exiting Robinson Road. Since this peak period is short, capacity increases (adding lanes, etc.) are not considered cost-effective improvement measures. Conceptual improvements in this area include updating school zone signage to be MUTCD compliant, providing flush stamped concrete median islands to separate northbound and southbound traffic on Concord Road. These islands will create a road narrowing effect thereby providing traffic calming by requiring vehicles to slow down in order to maneuver by the island. The stamped islands are expected to accentuate the crosswalks. Updated sidewalks are recommended along Concord Road, Robinson Road, and Buckingham Drive. It was noted that the Town plans for a sidewalk extending from Robinson Road to an existing sidewalk on Concord Road south of the study area. Crosswalks are recommended along the southbound Concord Road approach and the Robinson Road approach. Updated pedestrian signage is recommended as well. Finally, a delta island is proposed to narrow pavement exiting the Robinson School West Driveway and better denote the "one-way" configuration. Conceptual improvements to these intersections will have no impact to intersection capacity.

7. Robinson Road at Robinson School East Driveway

Conceptual design for this driveway includes re-striping the roadway to provide a minimum 24' width on Robinson Road, as well as striping the driveway to better alert drivers that the driveway is two-way. A STOP sign is also recommended. These improvements increase safety and will not impact intersection capacity.

8 & 9. Robinson road at Crisafulli School Driveway and Hartford Road

Improvements to the Crisafulli School Driveway intersection include updating sidewalks along the Crisafulli School Driveway and Hutchins Way and providing wheelchair ramps for the crosswalk. Two flush stamped concrete median islands are recommended for Robinson Road on either side of the Crisafulli Driveway. Similar to the islands noted for the intersection of Concord Road at Robinson Road, these islands will provide traffic calming by slowing vehicles as they approach the intersection. Updated pavement markings and widening Robinson Road to a minimum of 24' is recommended. Updated center line striping and a stop line is recommended for Hartford Road. An advanced intersection warning sign should be installed east of Hartford Road. The intention of these improvements is to increase safety by making Hartford Road more visible and appear less like a driveway and more like a roadway approach.

10. Robinson Road at Flagg Road

Conceptual improvements at this intersection include re-aligning Robinson Road to remove the existing delta island and create a conventional T intersection. This design would reduce the number of vehicle conflict points at the intersection and will slow turning traffic as they must maneuver a tighter turn. As a result of the re-aligning, additional greenspace will be provided on the northwest corner of the intersection. Two options are recommended for this intersection. Option 1 recommends re-aligning the driveway of 1 Robinson Road such that the driveway intersects Flagg Road perpendicularly further to the north of the intersection with Robinson Road. This is the preferred option, but will require easements and may require changing the address of 1 Robinson Road. Cooperation between property owner and Town will be required. Option 2 recommends changing the radius to allow the driveway of 1 Robinson Road to intersect in a similar location as existing conditions. In both options the northwest corner may be widened to provide a raised truck apron similar to other conceptual intersections if desired. The recommended re-alignment was not

found to impact traffic operations during the peak hour despite reducing the number of approaches to the intersection.

11. Patten Road at Country Road

This intersection was found to have considerable sight distance restrictions for vehicles exiting Country Road looking to the left (westbound). Country Road intersects Patten Road on the inside of a curve with significant vegetation along the south side of the roadway. Conceptual improvements include moving the Country Road stop bar closer to the intersection, clearing and grubbing vegetation to improve and increase sight distance, and providing updated advanced intersection warning signage. It is recommended that vegetation should be cleared at least 7.5 feet from the edge of roadway. Based on the Town's GIS basemap, the vegetation clearing is within the Town right-of-way. The street name sign is also recommended to be moved such as to increase visibility of the intersection.

12. Patten Road at Cold Spring Road / Westford Academy West Driveway

Conceptual improvements at this intersection include narrowing the northwest and northeast turning radii and providing raised stamped truck aprons. The mountable truck aprons will reduce vehicle speeds at the intersection while also allowing buses and trucks to utilize the truck apron. Cold Spring Road is recommended to be slightly re-aligned to provide a straighter travel path to the Westford Academy West Driveway. Updated sidewalks and wheelchair ramps along Patten Road are recommended with the addition of a crosswalk across the WA West Driveway. Patten Road is recommended to be widened to provide a minimum of 24 feet width as sections of Patten Road have substandard roadway widths. The recommended improvements will increase vehicular and pedestrian safety.

It was noted in field observations that non-student vehicles enter this driveway to drop-off students. A discussion recommended restricting vehicles from entering this driveway unless they have a parking permit. All other vehicles would be required to enter via the East Driveway. Enforcement will be required to restrict drop-off activity at this driveway.

13. Patten Road at Westford Academy Center Driveway

Conceptual improvements at this intersection include updating sidewalks and wheelchair ramps along Patten Road to provide a crosswalk across the WA Center Driveway. Updated pavement markings are recommended on the WA Center Driveway. Stop signs and "Do-Not-Enter" signs are recommended to prohibit vehicles from entering this driveway. As noted previously, Patten Road is recommended to be widened to a minimum of 24 feet wide as sections of Patten Road have substandard roadway widths.

It was noted in field observations that pedestrians consistently cross this driveway from many places rather than using the designated crosswalks. A decorated fence or railing was discussed to funnel pedestrians to a designated crossing location such that pedestrian platoons may be metered so vehicles can exit the driveway with minimum delays. This effort will require a crossing guard or a school official to help meter pedestrian platoons but would increase pedestrian safety by reducing vehicle/pedestrian conflicts.

Restricting vehicles from exiting the student parking lot during the morning peak was also discussed. This would prohibit vehicles from entering via the West Driveway and exiting via the Center Driveway, an occurrence that was observed particularly for student drop-offs. This recommendation would increase safety by reducing vehicle conflicts on the Center Driveway.

14 & 15. Patten Road at Westford Academy East Driveway and Hartford Road

This intersection was found to have large queues for vehicles entering and exiting the WA East Driveway. Improvements include providing updated sidewalks, wheelchair ramps, and a crosswalk across the WA East Driveway as well as updated pavement markings including centerline striping on the WA East Driveway and Hartford Road. A minimum 24 foot roadway width is recommended for Patten Road and Hartford Road. This requires widening Hartford Road. To encourage vehicles to use the WA East Driveway, two custom Westford Academy signs are proposed for the WA East Driveway directing traffic to this entrance. Relocating the Hartford Road street name sign is also recommended to make Hartford Road more visible to drivers on Patten Road, thereby increasing safety.

16. Forge Village Road at Cold Spring Road

This intersection was examined as part of a Road Safety Audit to examine safety concerns related to a high number of crashes. The RSA recommended three different improvement methods for this intersection including: Full Signal (not warranted), All-Way Stop (not warranted), and Flashing Warning Beacons. BETA developed three design options for this intersection to address safety concerns.

Option 1 – Flashing Warning Beacons

This conceptual design recommends re-aligning Cold Spring Road southbound approach to provide a straighter travel path across Forge Village Road with smaller curve radii on all four corners of the intersection. Striping is provided to delineate each corner and lane. Dotted center line is recommended channelizing the two Cold Spring Road approaches due to the offset nature of the approaches. For this conceptual design, flashing beacons are recommended over the center of the intersection on a mast arm pole. The mast arm pole is located on the northwest corner of the intersection. Red beacons are recommended for Cold Spring Road, and yellow beacons are recommended for Forge Village Road. Stop Ahead warning signs are proposed for Cold Spring Road, and "intersection ahead" warning signs are recommended for Forge Village Road. These improvements will not improve or degrade the level of service or operations conditions at the intersection but will provide added warning for vehicles approaching the intersection. It was found that crashes at this intersection were generally Property Damage Only, likely due to excessive queues and low speeds. It is not expected that these improvements will help improve crashes or operations during the school peaks.

Option 2 – Re-Aligned Intersection

This design option recommends utilizing right-of-way on Cold Spring Road to shift the roadway in order to better align Cold Spring Road as it crosses Forge Village Road. The conceptual design option shows the relocation of Cold Spring Road north of Forge Village Road to the west and Cold Spring Road south of Forge Village Road to the east. Similar "Intersection Ahead" warning signs are recommended. These improvements will eliminate the offset Cold Spring Road alignment and make crossing Forge Village Road less confusing and safer. These improvements will not greatly improve the traffic queueing conditions during the school peak hours. Similarly, significant cost would be associated with shifting the roadways.

Option 3 – Roundabout

This conceptual improvement design recommends a modern roundabout. In order to accommodate a WB-50 truck and typical school bus traffic, a 100 foot diameter roundabout would be required. This conceptual design requires right-of-way impacts to abutting properties and may include moving stone walls, utility poles, and closing or relocating residential driveways. The roundabout concept would provide flush splitter

islands with advanced warning signage to delineate traffic. Since sidewalks are currently not provided near the intersection, and minimizing right-of-way impacts was of key concern, crosswalks were not provided in the design concept. The northeast and southwest corners provide a wider travel lane allowing for right turning vehicles to slightly by-pass the roundabout.

The improvement in traffic operations is shown in Table 9. As seen in the table, the LOS improves from failing conditions (LOS F) to LOS B in the morning peak hour. Queues were found to increase approximately 50 feet in the morning peak hour for Forge Village Road as a result of the roundabout. This is due to increasing the accessibility for vehicles to exit Cold Spring Road. The current configuration penalizes Cold Spring Road (stop signs) in favor of Forge Village Road. The roundabout configuration would provide equal traffic control for movements on all four approaches. It should be noted that this occurs during ideal conditions where vehicles on Forge Village Road will be required to slow down, allowing gaps for Cold Spring Road. These design operations may be impacted by operations at Intersection 12 – Patten Road at Cold Spring Road / WA West Driveway should Cold Spring Road queue back into the roundabout.

Table 9: Roundabout Level of Service Comparison

INTERSECTIONS	Morning Peak Hour						Evening Peak Hour					
	2015 Existing			Option 3 - Roundabout			2015 Existing			Option 3 - Roundabout		
	LOS	Delay (s/veh)	95%ile Queue	LOS	Delay (s/veh)	95%ile Queue	LOS	Delay (s/veh)	95%ile Queue	LOS	Delay (s/veh)	95%ile Queue
16. Forge Village Road at Cold Spring Road												
Forge Village - EB	A	0	0	B	13	47	A	1	1	A	5	12
Forge Village - WB	A	8	34	B	11	83	A	0	0	A	5	11
Cold Spring - NB	F	**	**	A	6	17	B	12	18	A	5	12
Cold Spring - SB	F	**	**	B	13	59	B	11	8	A	4	6
# 95th percentile volume exceeds capacity, queue may be longer. Queue shown is maximum after 2 cycles. * Delay exceeds 300 seconds ** Exceeds Capacity, cannot be analyzed.												

The roundabout would increase safety by decreasing the number of conflict points from 32 to 8 and would calm traffic by serving as a gateway for both the school and the neighborhood, requiring cars to slow down to navigate the circle.

17. Forge Village Road at Patten Road

Conceptual improvements to this intersection include narrowing the radius on the east side of the intersection to create a conventional T intersection rather than the skewed intersection. This configuration would require vehicles to come to a STOP before turning onto Forge Village Road, where the existing intersection functions as a YIELD condition. Patten Road is recommended to be widened to provide a 24 foot minimum width to allow for two-way travel. Intersection ahead warning signs are recommended on Forge Village Road, along with the removal of the turn restriction signs during the school peak hours. These conceptual improvements would improve safety but not traffic capacity at this intersection. Similar to previous concepts, flush stamped concrete median islands could be provided on Forge Village Road at this intersection to slow travel speeds as they approach the intersection.

TRAFFIC CIRCULATION PATTERNS

As part of the conceptual improvement evaluation, BETA examined four traffic circulation options in relation to the existing turning restriction during school peak periods from Forge Village Road to Patten Road. Currently traffic may not enter Patten Road from Cold Spring Road during school peak periods. These circulation options assumed all traffic on Forge Village Road will be two-way, while traffic on Cold Spring Road and Patten Road may vary from two-way to one-way. The purpose of this exercise was to determine if a circular traffic pattern may improve or degrade operations in comparison with allowing two-way traffic on all roads. The four options included:

- Existing Conditions – No turns onto Patten Road (One-way eastbound from Hartford Road to Forge Village Road)
- Option 1 – Counter-clockwise one-way travel on Cold Spring Road and Patten Road
- Option 2 – Clockwise one-way travel on Patten Road and Cold Spring Road
- Option 3 – Two-way travel on all streets (Preferred)

Based on the traffic analysis, Option 3 (two-way travel on all roadways) provides the most improved overall traffic operations. It was determined that restricting traffic to follow a circular pattern resulted in excessive delays and queues at the intersections of Forge Village Road at Cold Spring Road and Patten Road at Cold Spring Road. Similarly, the one-way patterns increased queues on Patten Road at each of the school driveways. It was found that Option 3, two-way travel, allows vehicles on Forge Village Road to turn onto Patten Road OR Cold Spring Road which evens out the traffic volume improving operational conditions at the overburdened intersections of Forge Village Road at Cold Spring Road and Patten Road at Cold Spring Road. Table 10 provides a summary of existing traffic operations and operations with two-way travel on Patten Road.

Table 10: Two-Way Circulation Level of Service Summary

INTERSECTIONS	Morning Peak Hour					
	2015 Existing			Two-Way Travel - Patten Rd		
	LOS	Delay (s/veh)	95%ile Queue	LOS	Delay (s/veh)	95%ile Queue
12. Patten Road at Cold Spring Road/Westford Academy (W. Driveway)						
Patten - EB	A	1	1	A	1	1
Patten - WB	A	0	0	A	0	0
Driveway - NB	C	16	2	C	16	2
Cold Spring - SB	F	*	1,449	F	133	428
13. Patten Road at Westford Academy (C. Driveway)						
Driveway - NBL	E	40	156	C	16	61
Driveway - NBR	C	24	98	B	13	43
14. Patten Road at Westford Academy (E. Driveway)						
Patten - WB	A	3	2	A	9	32
Driveway - NB	C	16	15	D	29	54
15. Patten Road at Hartford Road						
Patten - WB	A	1	0	A	0	0
Hartford - NB	B	12	17	C	16	26
16. Forge Village Road at Cold Spring Road						
Forge Village - EB	A	0	0	A	0	0
Forge Village - WB	A	8	34	-	-	-
Cold Spring - NB	F	**	**	B	14	28
Cold Spring - SB	F	**	**	C	17	70
17. Forge Village Road at Patten Road						
Forge Village - WB	A	0	1	A	6	23
Patten - NB	C	15	82	C	21	118

95th percentile volume exceeds capacity, queue may be longer. Queue shown is maximum after 2 cycles.
* Delay exceeds 300 seconds
** Exceeds Capacity, cannot be analyzed.

Level of service improves from LOS F to LOS C at the intersection of Forge Village Road at Cold Spring Road but continues to fail at the intersection of Patten Road at Cold Spring Road, albeit less so than during existing conditions.

To allow two-way traffic on Patten Road, the roadway requires widening to provide a minimum of 24 feet in width (two 12 foot wide lanes) as well as traffic calming measures on Forge Village Road to slow vehicles such that making the left turn is less drastic.

SCHOOL CIRCULATION

Westford Academy site circulation was also discussed as part of this review. Existing traffic is required to enter via the East Driveway, circulate around the back of the school where parents may drop off students, and then exist via the Center Driveway. Many parents were found utilizing other driveways and dropping off students in the front of the school or on the sides of the school in order to avoid waiting in the queue around the back of the school. To limit the number of driveways and thereby reduce the amount of conflicts on-site, as a long-term plan the school should examine relocating the student parking lot to the rear of the

school where the existing recreational fields currently reside. The recreational fields would then be relocated to the existing location of the student parking lot. This would require all vehicles to enter via the East Driveway, circulate around the rear of the building, and exit out the Center Driveway. It would also reduce the amount of pedestrians crossing the Center Driveway as these pedestrians would do so at the rear of the building where much of the pedestrian activity occurs during drop-offs. For short-term improvements, as discussed earlier, a decorative fence should be installed along the Center Driveway adjacent to the student parking lot to safely manage pedestrian and vehicle conflicts.

CONCLUSIONS

The traffic study examined operating conditions at 18 intersections near three public schools in Westford, MA. It was found that traffic operations are acceptable for the majority of the intersections studied during the commuting and school peak periods. It was found that Patten Road at Cold Spring Road and Forge Village Road at Cold Spring Road operate with the poorest conditions during the morning school peak hour. Since this period of poor operations is relatively short, 30 to 45 minutes, traffic capacity improvements at these intersections are generally not cost-effective measures.

Conceptual improvements were recommended for 17 of the 18 intersections. These include pavement striping, roadway widening, signage upgrades, flush median islands, raised truck aprons, and the potential for flashing beacons or a modern roundabout. It should be noted that the existing roadways do not provide curbing, and the addition of curbing will require additional drainage design. This is particularly important in consideration of raised truck aprons as well as the roundabout alternative. The most desirable conceptual improvements include widening Patten Road to provide a minimum 24 foot roadway width to provide two-way travel during the school peak periods, and the installation of a roundabout at the intersection of Forge Village Road at Cold Spring Road. These two improvements will improve operations during the school peak periods as well as improve safety at the intersections.

In addition, in order to manage drop-off and pick-up activity, the development and use of standard school related signage and pavement markings is recommended. These standard traffic signage and pavement markings will be used for all schools within the district to provide uniformity. This allows parents and students to become accustomed to the standard signs and markings such that transitions to new schools and circulation patterns will be seamless.

APPENDIX

1. Conceptual Intersection Improvement Sketches – Intersection 1 through Intersection 17
2. Conceptual Traffic Circulation Diagram
3. Traffic Volume Data
    a. ATR Data
    b. Turning Movement Counts
4. Signal Warrant Analysis
5. Crash Rate Sheets
6. Traffic Analysis Sheets

INTERSECTION CRASH RATE WORKSHEET

CITY/TOWN : Westford | COUNT DATE : Apr-15

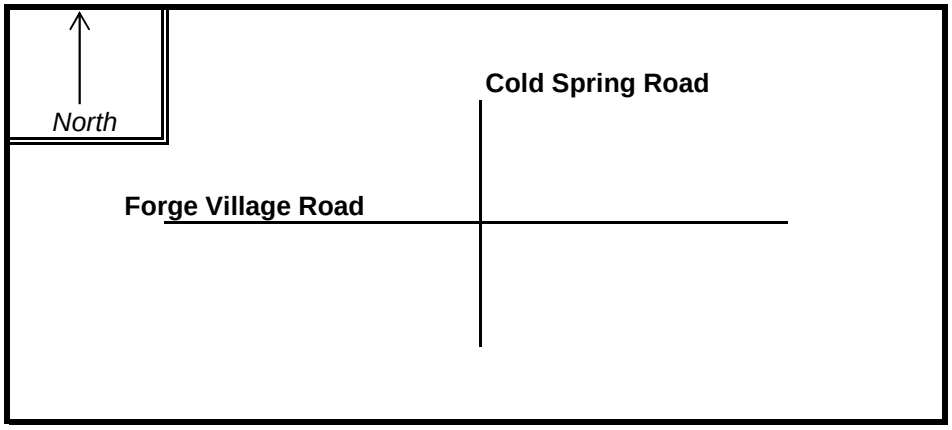
DISTRICT : 3 | UNSIGNALIZED : X | SIGNALIZED :

~ INTERSECTION DATA ~

MAJOR STREET : Forge Village Road

MINOR STREET(S) : Cold Spring Road

INTERSECTION DIAGRAM (Label Approaches)



PEAK HOUR VOLUMES

APPROACH :	1	2	3	4	5	Total Peak Hourly Approach Volume
DIRECTION :	EB	WB	NB	SB		
PEAK HOURLY VOLUMES (AM)/PM) :	187	222	101	207		**717**

" K " FACTOR : **0.090** | INTERSECTION ADT (**V**) = TOTAL DAILY APPROACH VOLUME : **7,967**

TOTAL # OF CRASHES : 18 | # OF YEARS : 4 | AVERAGE # OF CRASHES PER YEAR (**A**) : **4.50**

CRASH RATE CALCULATION : **1.55**

RATE = $\frac{(A * 1{,}000{,}000)}{(V * 365)}$

Comments : Uses default 0.09 K factor per Crash Rate Standard Procedures

Project Title & Date: 4162-07 Westford - School Study 24-Feb-16

Average Crash Rates, per Million Entering Vehicles, by Intersection Type

(Based upon crash information queried on February 9, 2016)

Location	Signalized Intersections	Unsignalized Intersections
Statewide	0.77	0.58
District 1*	0.92*	0.43*
District 2	0.82	0.70
District 3	0.90	0.65
District 4	0.73	0.56
District 5	0.76	0.58
District 6	0.70	0.53

* - District 1 should use Statewide Rates due to low sample total

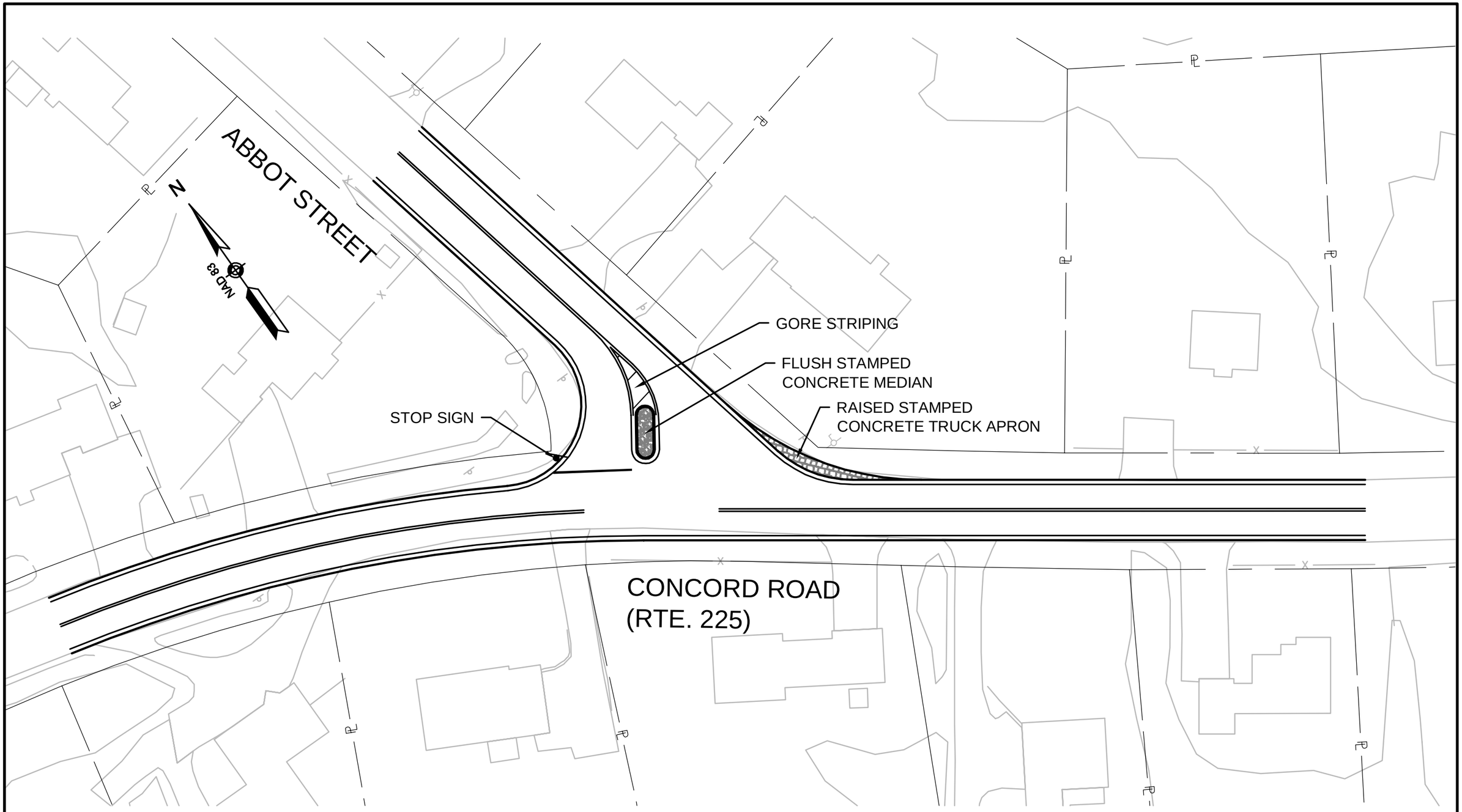
2013 Average Crash Rates, per Million Vehicle Miles Traveled, by Federal Functional Classification

(Based upon crash information queried on January 8, 2016)

Roadway Federal Functional Classification	Rural	Urban
Statewide	1.70	2.14
Interstate	0.66	0.60
Principal arterial - other freeways and expressways	1.39	0.70
Principal arterial - other	1.28	3.49
Minor arterial	1.81	3.65
Major collector	2.83	3.63*
Minor collector	3.55	-
Local	2.08	2.01

Notes on Functional Classification Data:

- * This rate is for all Urban Collector roads, including both Urban Major Collector and Urban Minor Collector roadways.
- If a crash occurred at an intersection or along two different functional classifications, the crash was assigned to the higher order roadway.



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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 1

PLEASANT STREET (RTE. 225)
AT ABBOTT STREET

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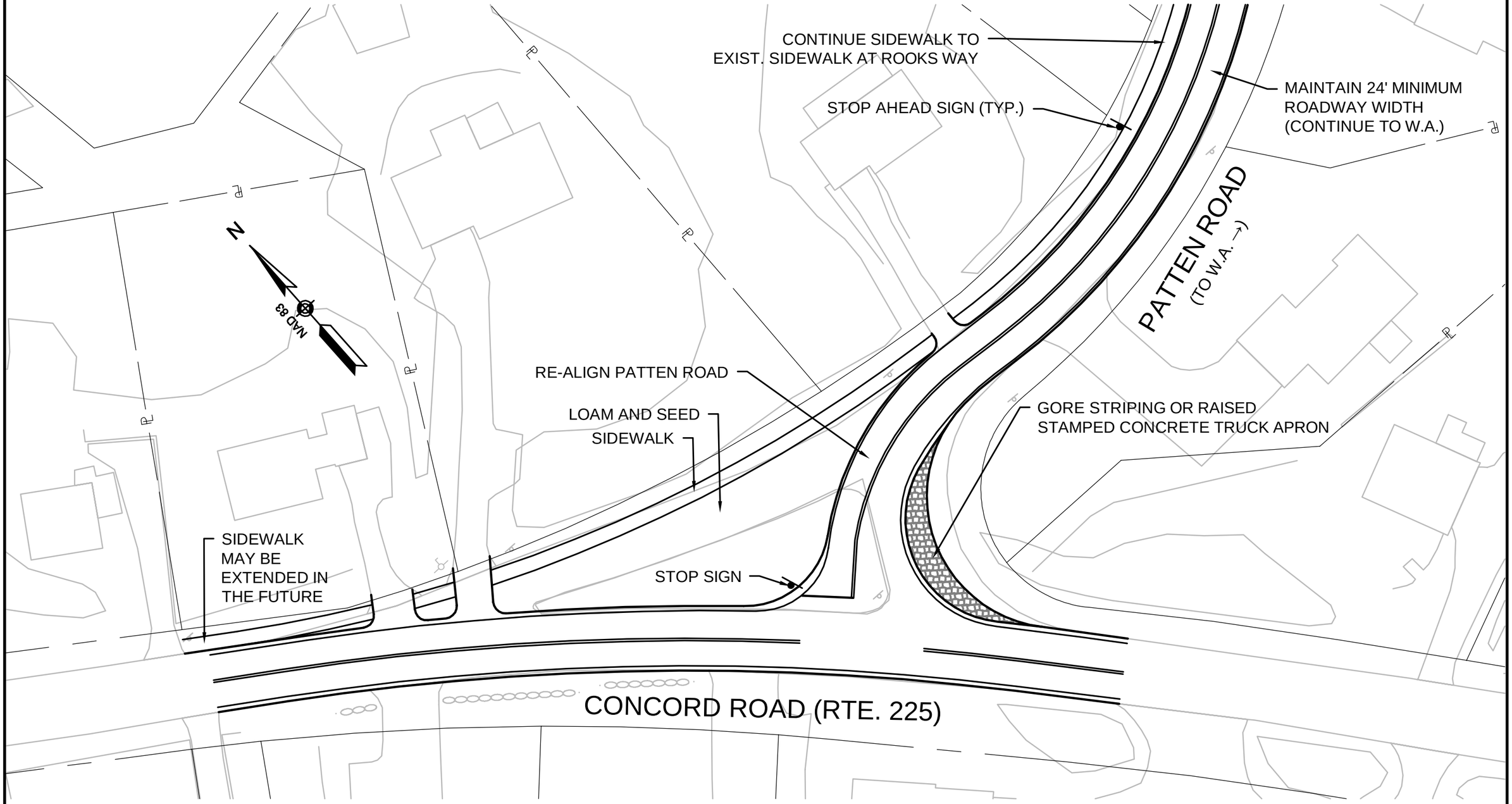

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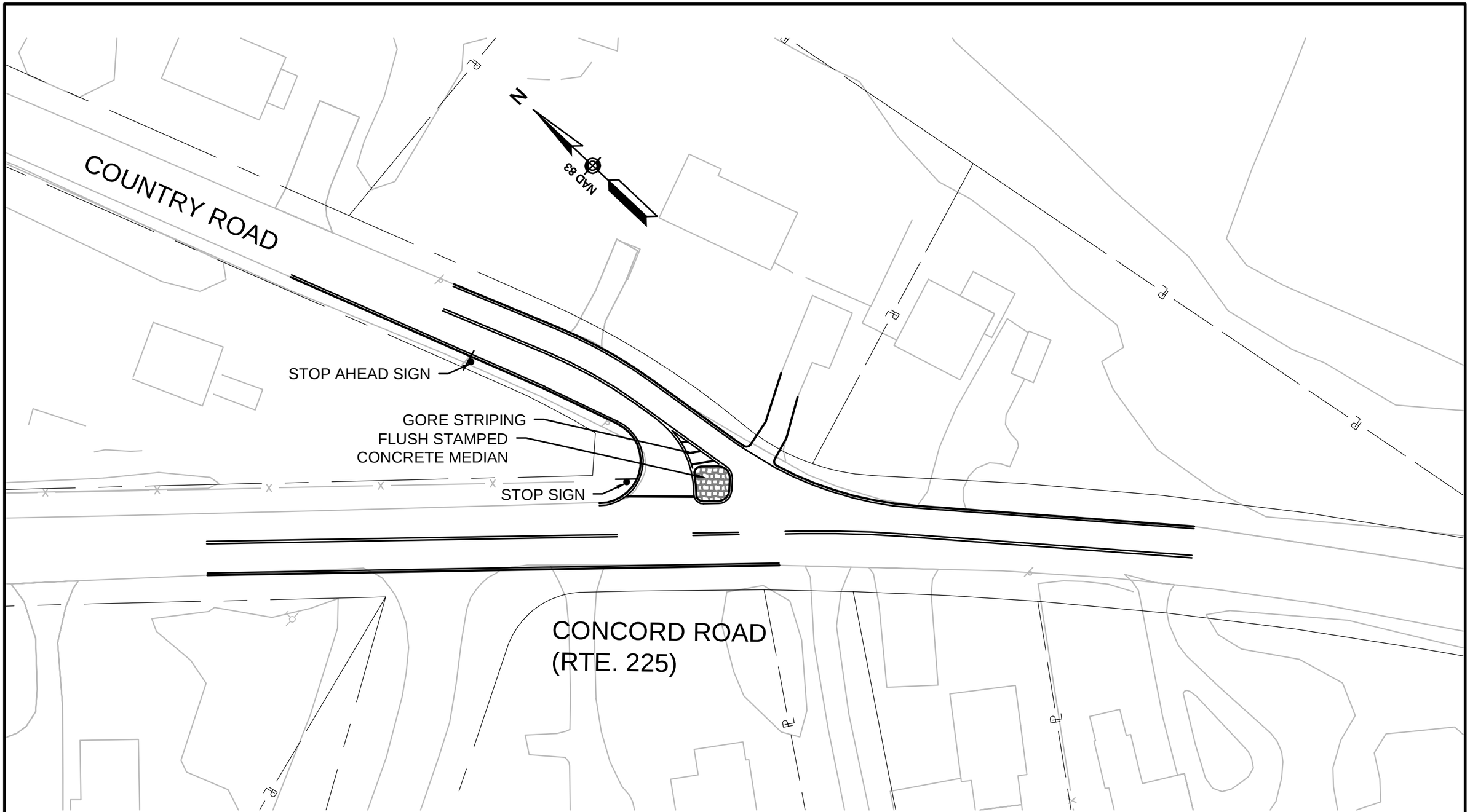
CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 2

CONCORD ROAD (RTE. 225) AT PATTEN ROAD



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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 3

CONCORD ROAD (RTE. 225)
AT COUNTRY ROAD

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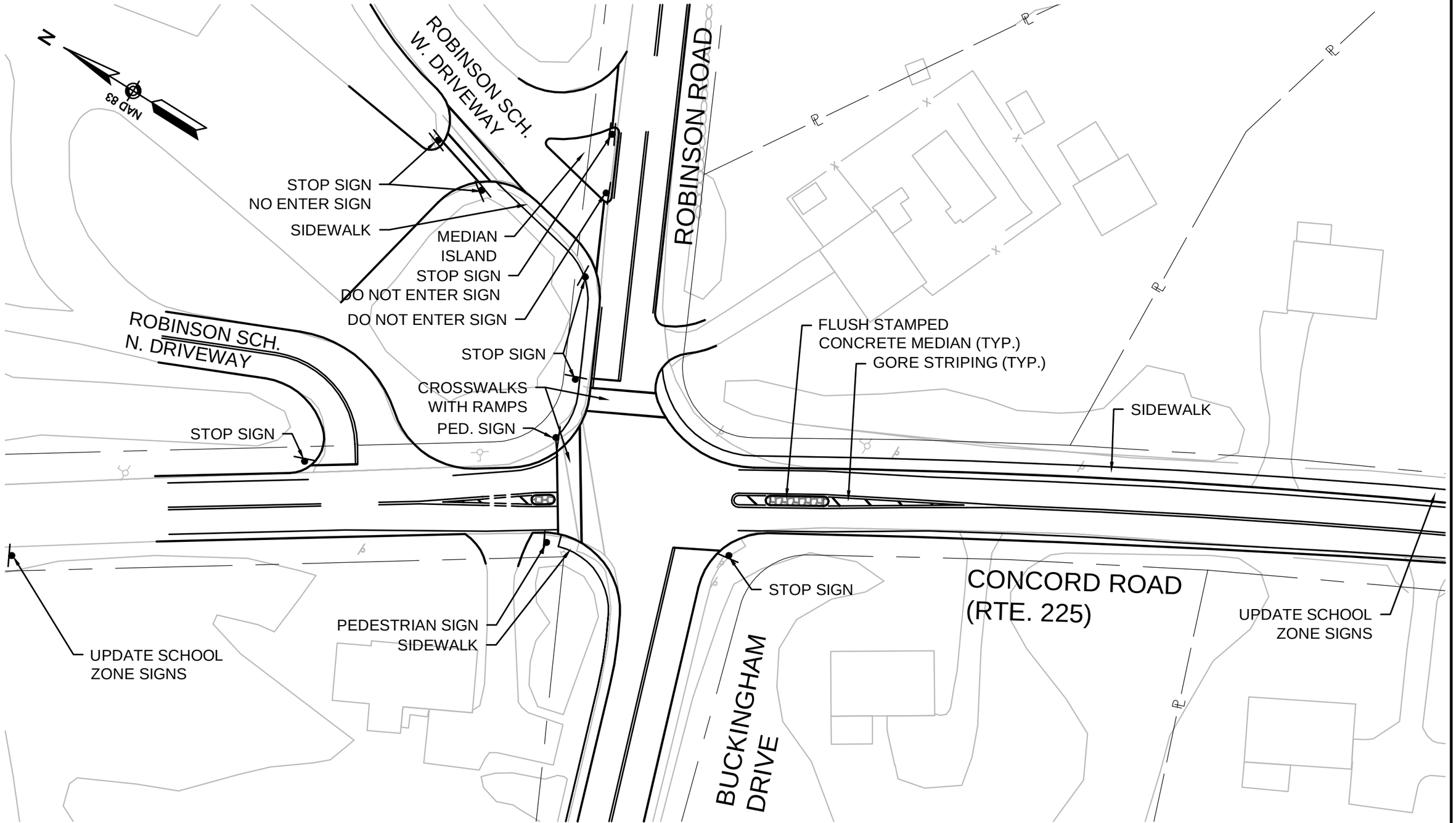

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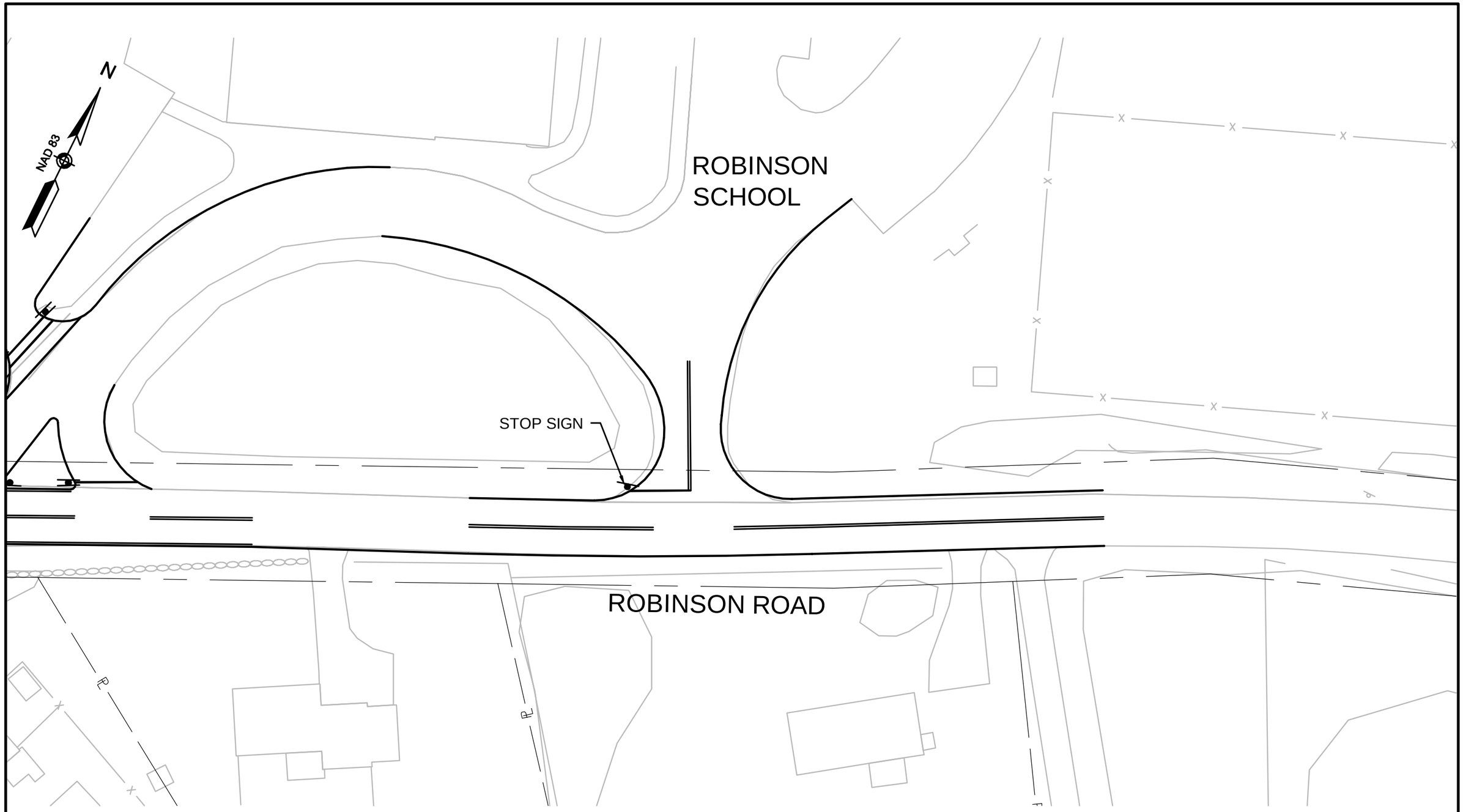
CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTIONS 4, 5 & 6

CONCORD ROAD (RTE. 225)
AT ROBINSON ROAD / BUCKINGHAM DRIVE



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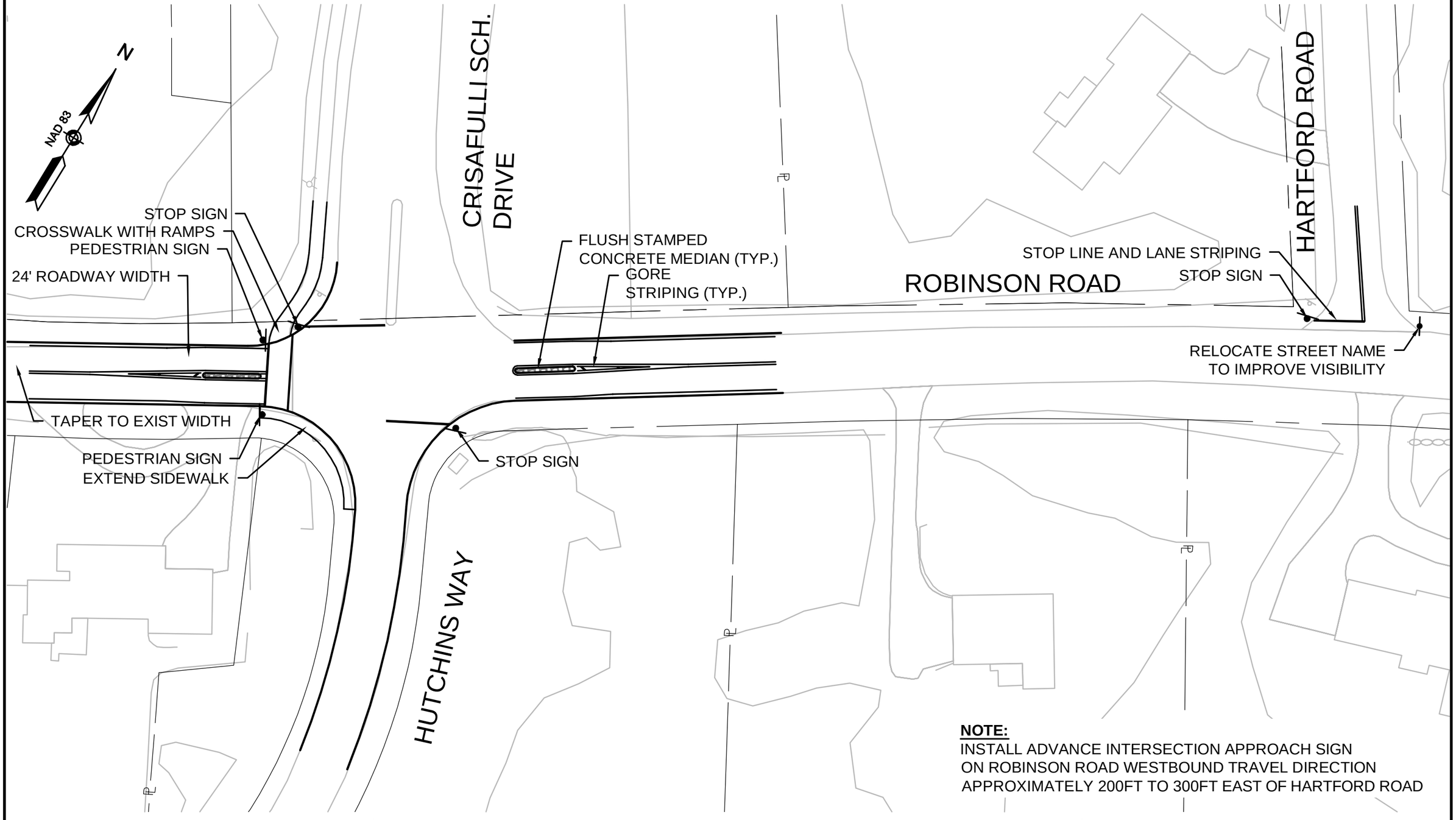
CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 7

ROBINSON ROAD AT ROBINSON SCHOOL
EAST DRIVEWAY



NOTE:
INSTALL ADVANCE INTERSECTION APPROACH SIGN
ON ROBINSON ROAD WESTBOUND TRAVEL DIRECTION
APPROXIMATELY 200FT TO 300FT EAST OF HARTFORD ROAD

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTIONS 8 & 9
ROBINSON ROAD AT CRISAFULLI SCHOOL
DRIVEWAY AND HARTFORD ROAD

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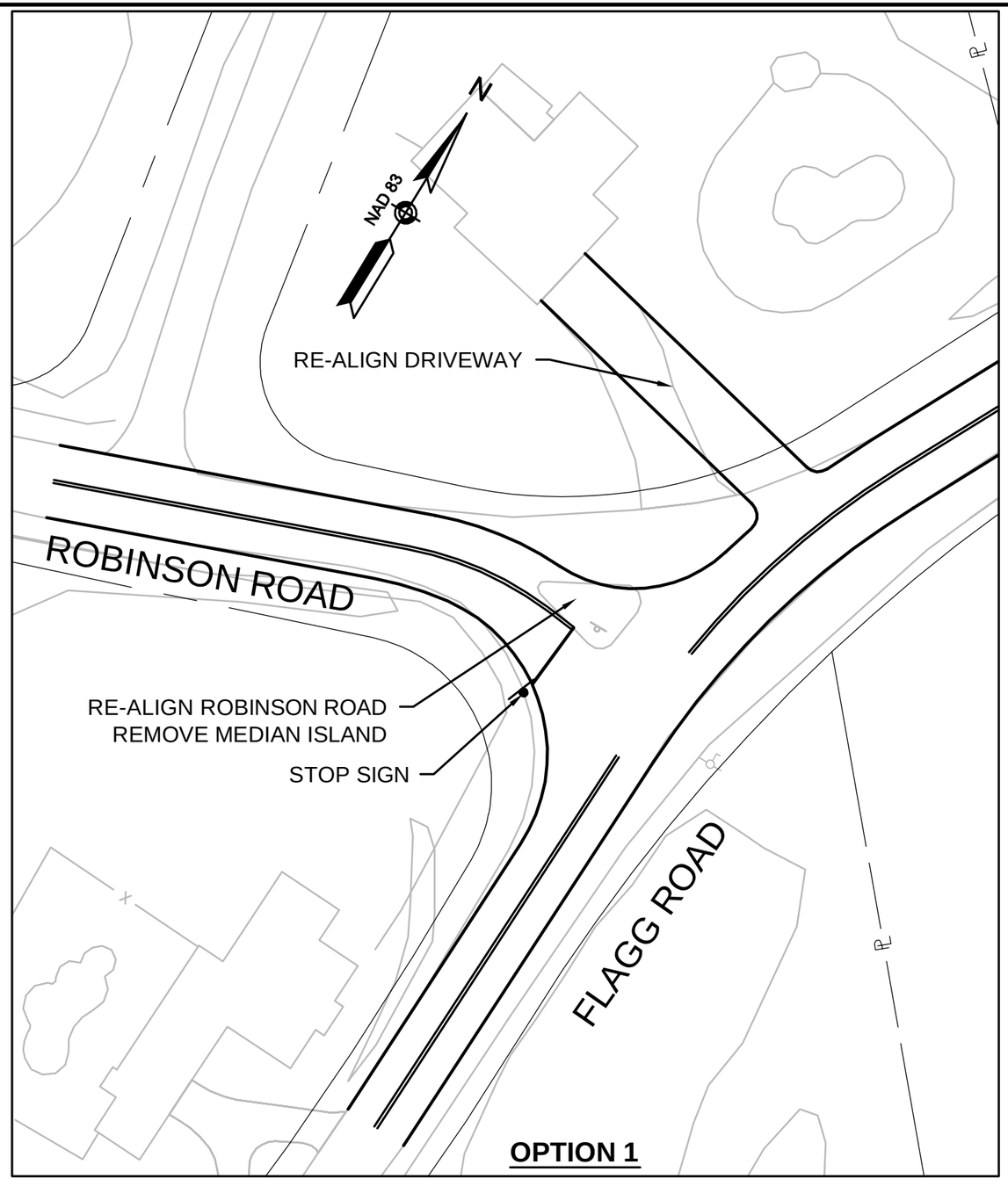

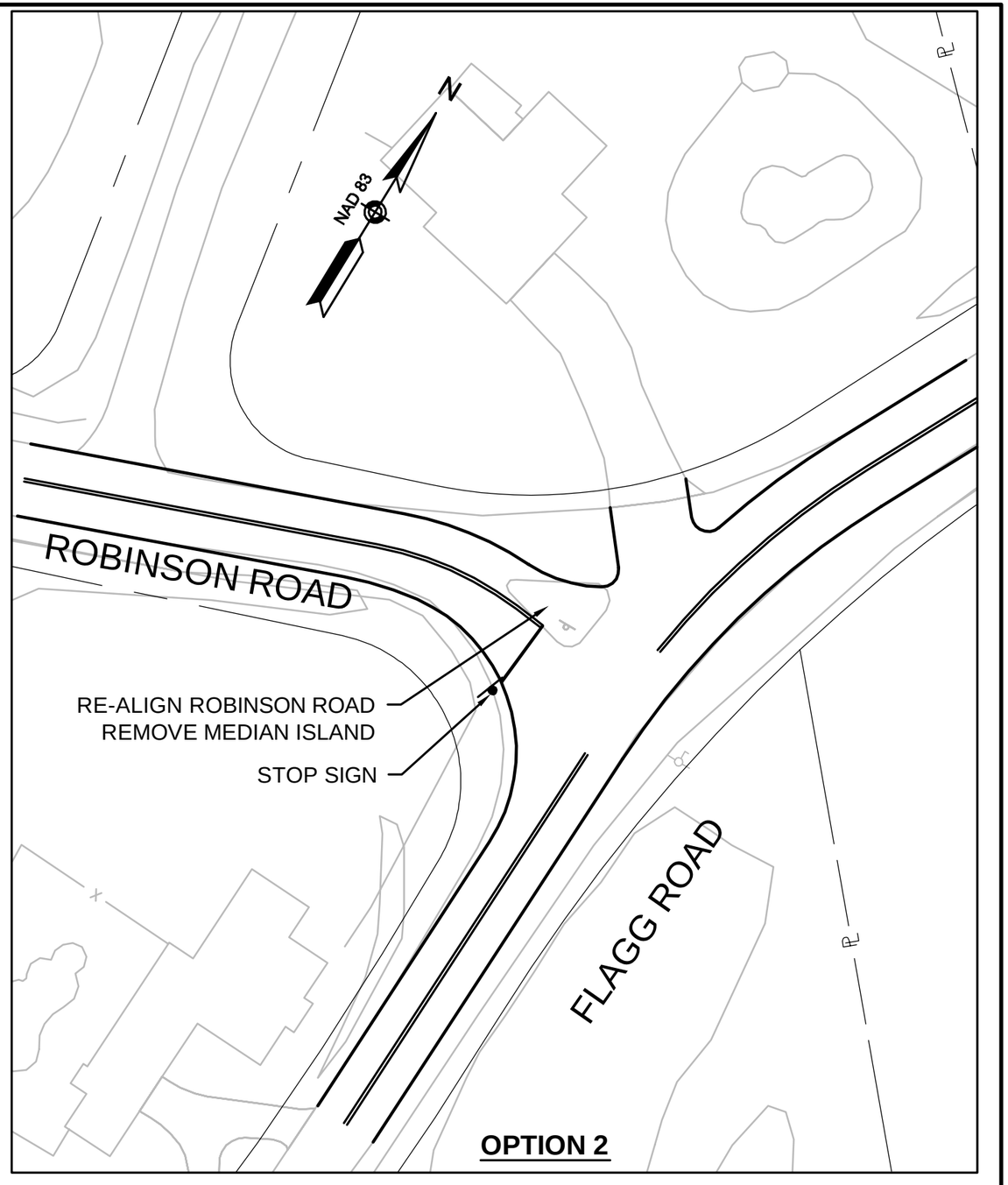

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 10

ROBINSON ROAD AT FLAGG ROAD

N

NAD 83

PATTEN ROAD

COUNTRY ROAD

INCREASE VISIBILITY
OF STREET NAME SIGN

CLEAR AND GRUB
VEGETATION

MINIMUM 7.5'
WIDTH OF CLEAR
AND GRUB

INTERSECTION AHEAD
ADVISORY SPEED LIMIT SIGN

STOP SIGN
MOVE STOP LINE CLOSER

STOP AHEAD SIGN

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 11

PATTEN ROAD AT COUNTRY ROAD

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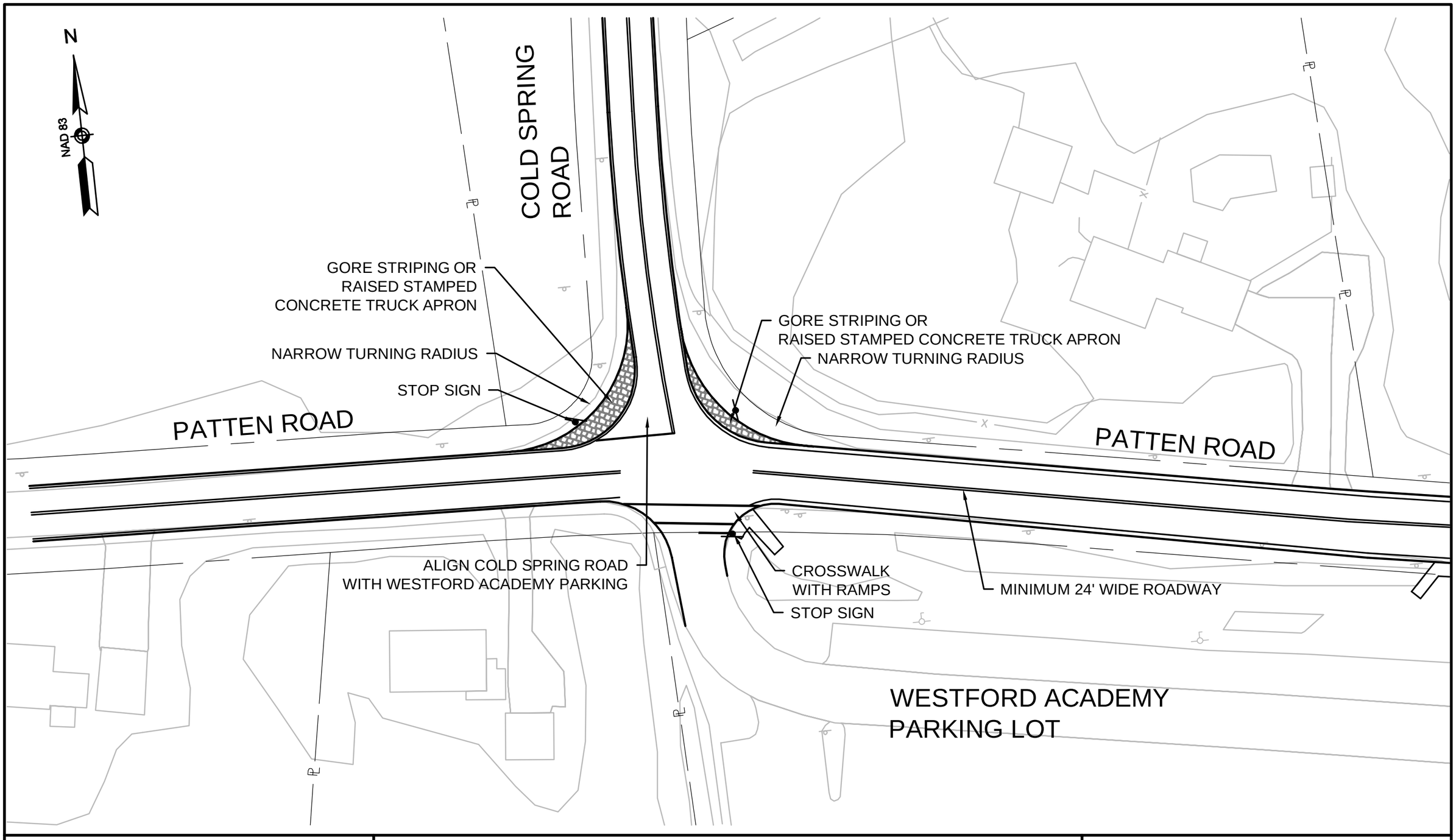

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 12

PATTEN ROAD AT COLD SPRING ROAD /
WESTFORD ACADEMY WEST DRIVEWAY

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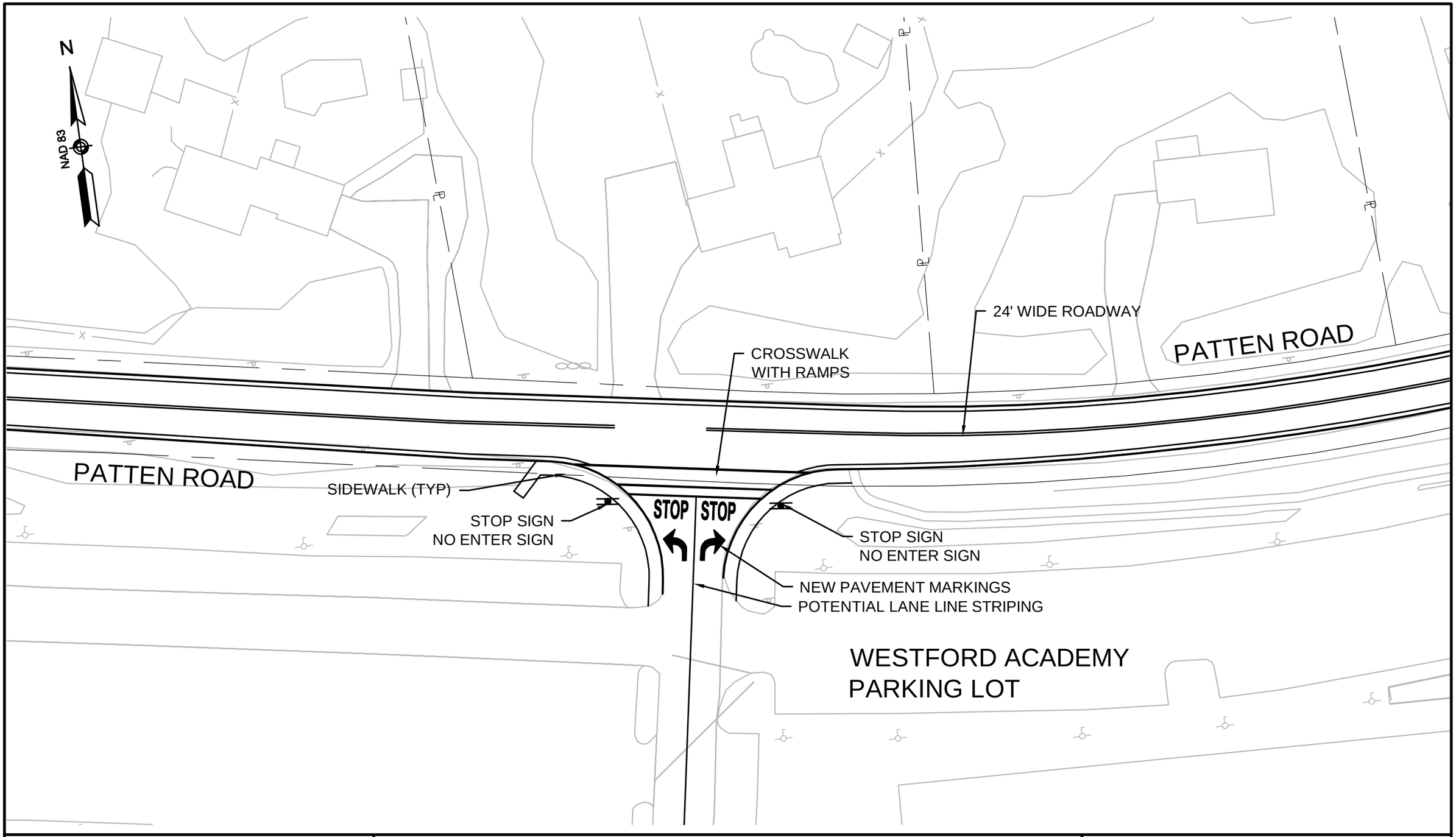

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 13

PATTEN ROAD AT WESTFORD ACADEMY
CENTER DRIVEWAY

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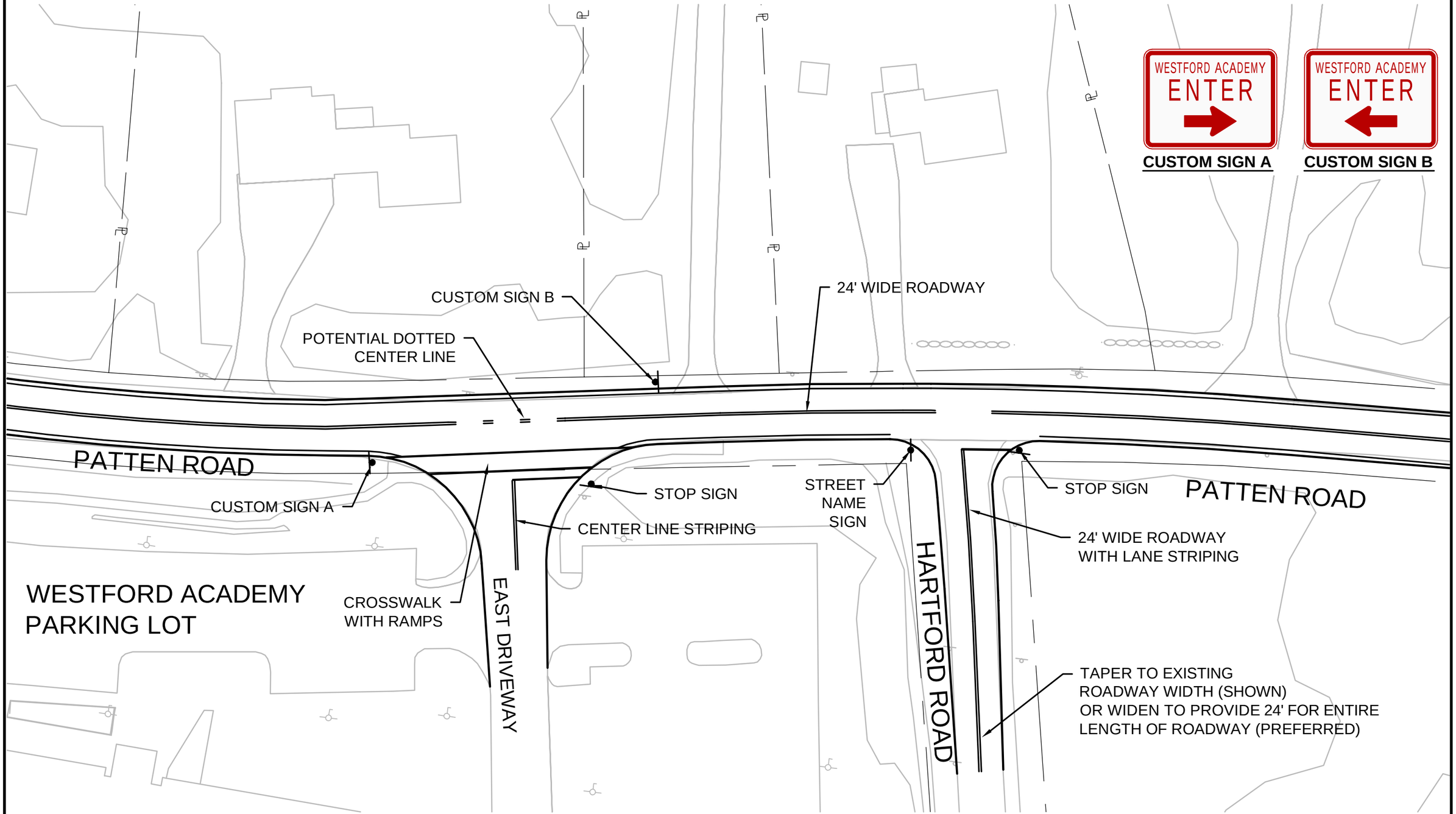

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTIONS 14 & 15

PATTEN ROAD AT WESTFORD ACADEMY
EAST DRIVEWAY AND HARTFORD ROAD

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N

NAD 83

STOP AHEAD SIGN

COLD SPRING ROAD

STOP SIGN
MAST ARM POLE

FLASHING BEACONS
(RED - N/S)
(YELLOW - E/W)

DOTTED CENTER LINE (GUIDE LINE)

INTERSECTION
AHEAD SIGN

FORGE VILLAGE ROAD

GORE STRIPING AREA

INTERSECTION
AHEAD SIGN

STOP SIGN

(← TO WESTFORD ACADEMY)

STOP AHEAD SIGN

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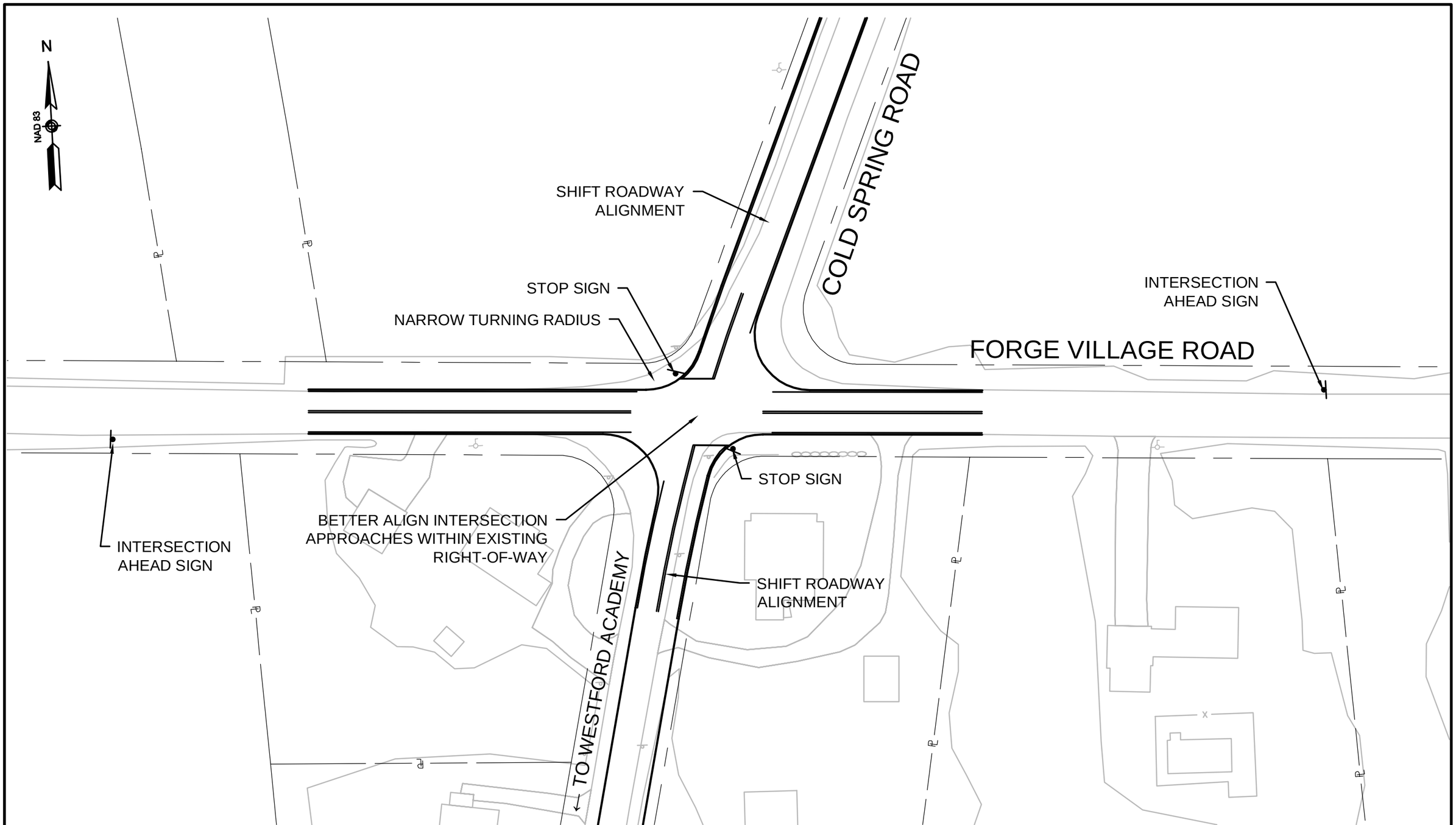
CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 16
FORGE VILLAGE ROAD AT
COLD SPRING ROAD
OPTION 1 - **FLASHING BEACONS**



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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 16

FORGE VILLAGE ROAD AT
COLD SPRING ROAD

OPTION 2 - RE-ALIGNED COLD SPRING ROAD APPROACHES

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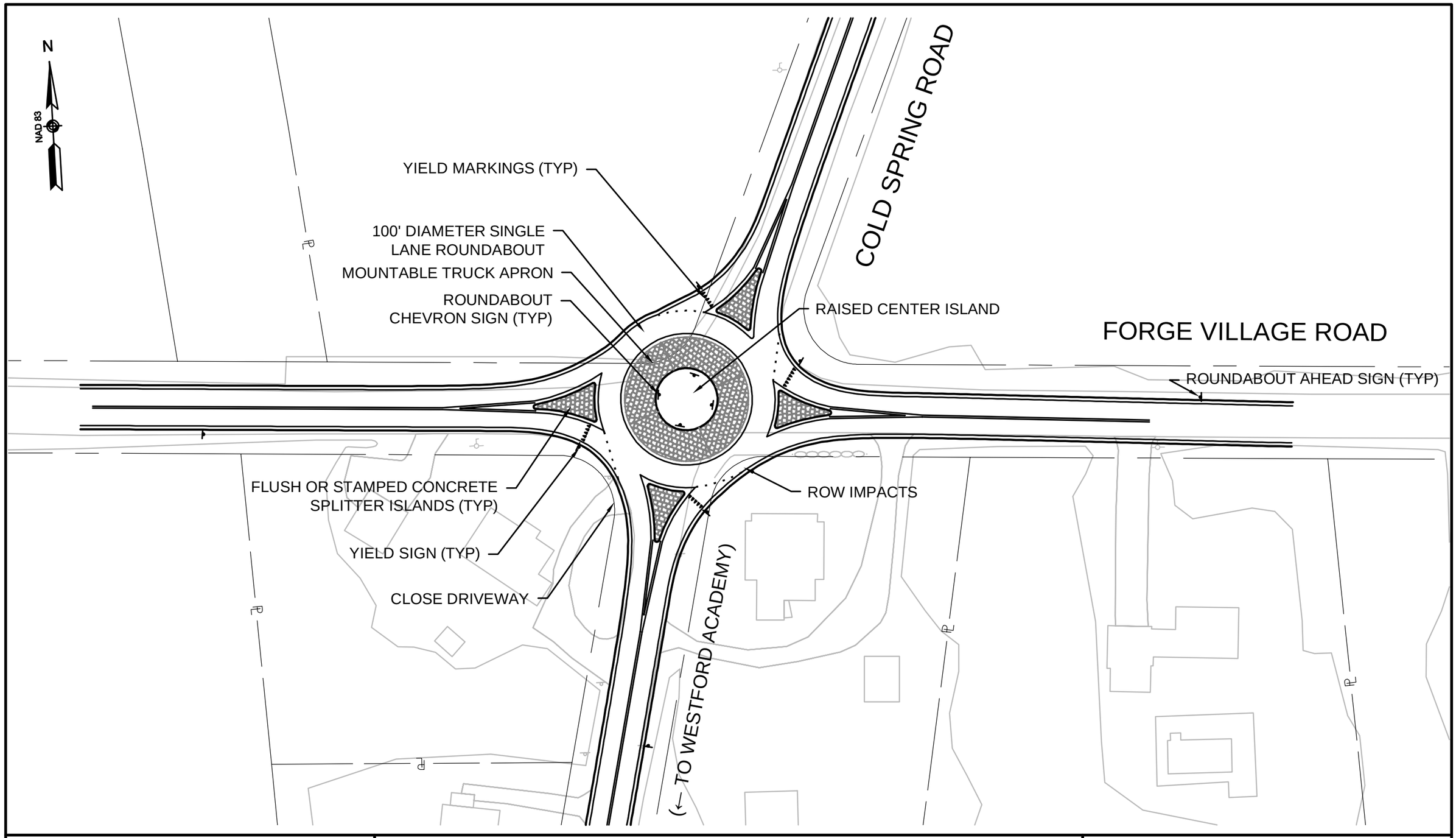

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 16
FORGE VILLAGE ROAD AT
COLD SPRING ROAD
OPTION 3 - ROUNDABOUT

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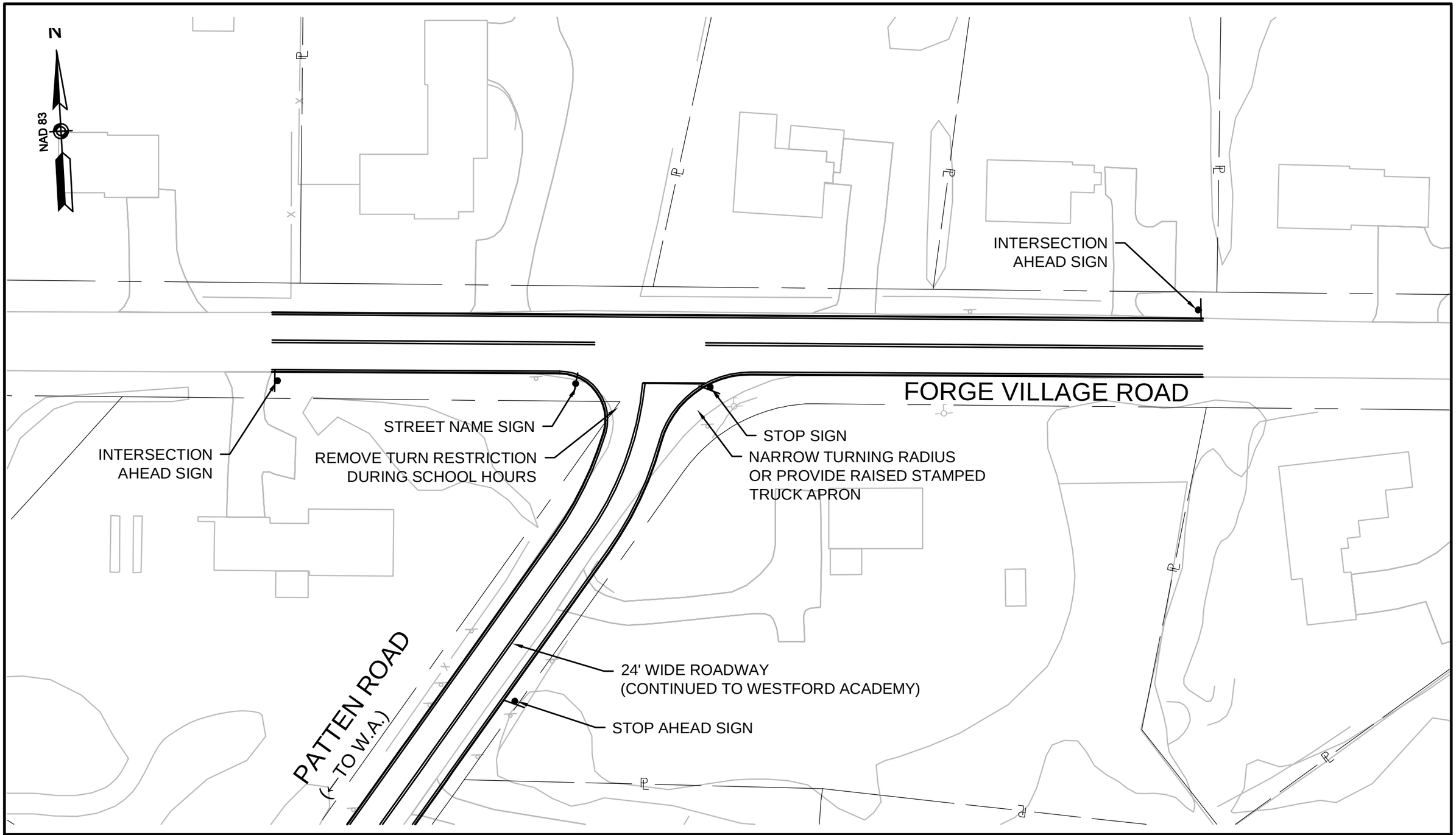

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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

INTERSECTION 17

FORGE VILLAGE ROAD AT PATTEN ROAD

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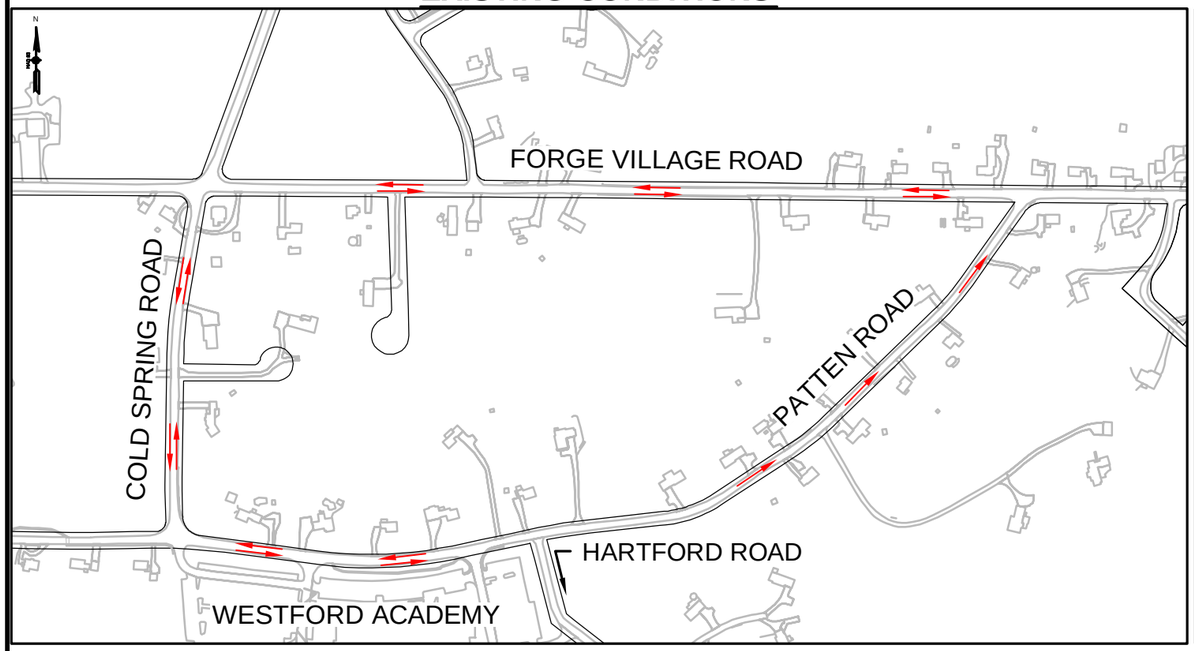
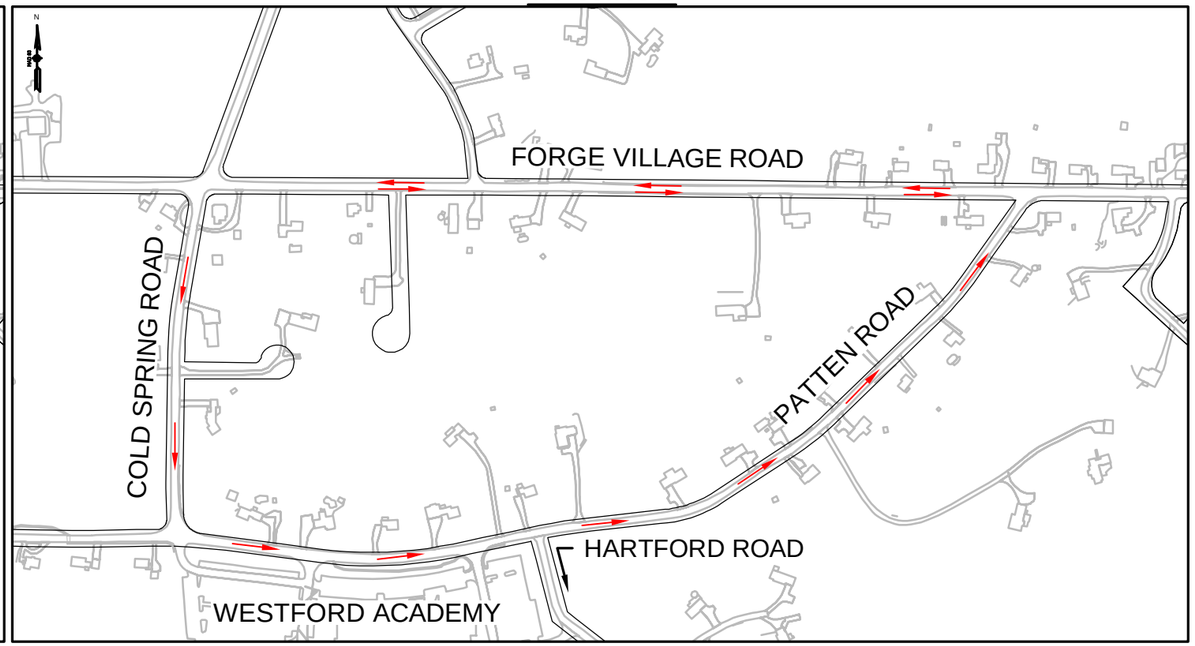
EXISTING CONDITIONS



OPTION 1



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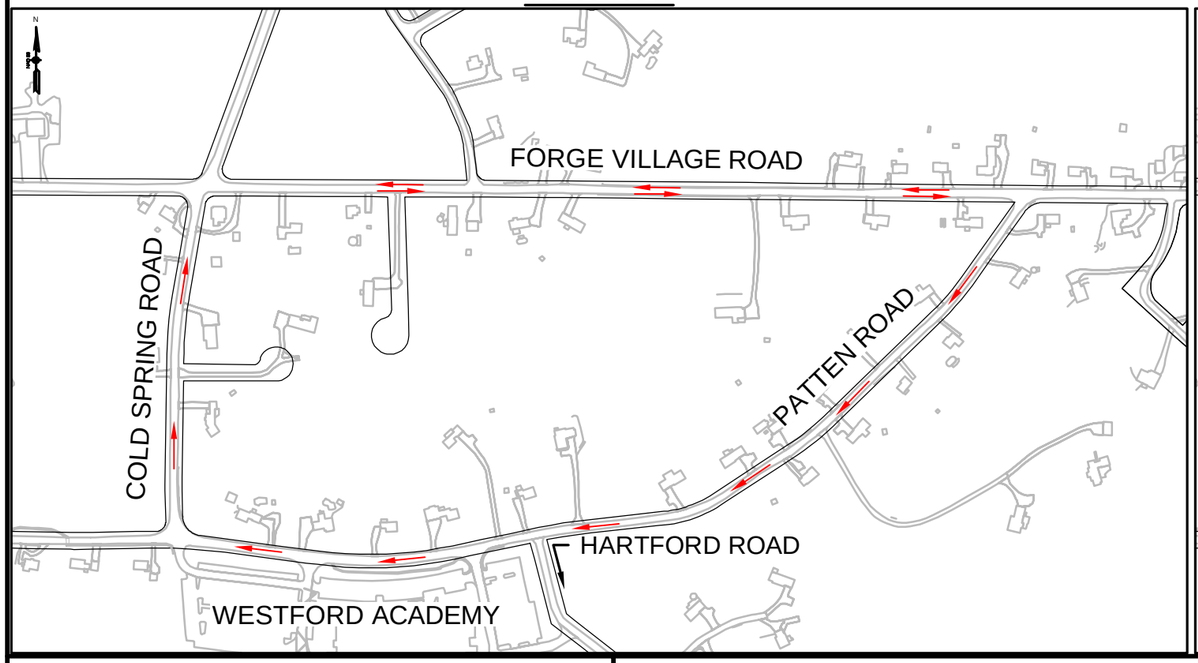
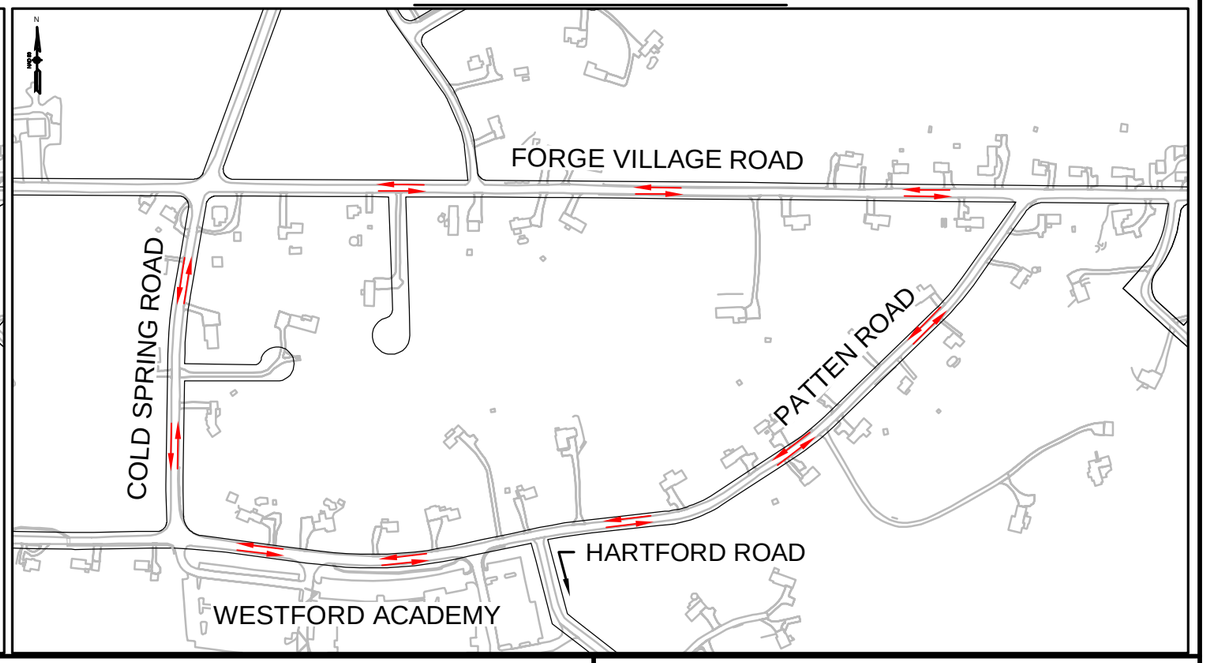


OPTION 3 - PREFERRED



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CONCEPTUAL DESIGN IMPROVEMENTS

WESTFORD SCHOOL AREA TRAFFIC REVIEW

WESTFORD, MA

PATTEN ROAD
CIRCULATION PATTERN OPTIONS
WESTFORD ACADEMY AREA