Appendix A: Road Safety Audit

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A. Introduction

Cascade Lakes Highway (CLH) has become a major recreational draw with access to features including several resorts, access to the Upper Deschutes River, the High Cascade Lakes area and the Three Sisters Wilderness Area. Visitors are attracted to the scenic drive the highway itself provides and it has been designated as a byway through several agencies. Due to the increase in use by motorists and cyclists, the County, National Forest and other stakeholders have become concerned with potential safety issues. Pedestrian safety is also a concern. This portion of the plan focuses on the highway safety perspective and includes the 4 E's of highway safety: Engineering, Enforcement, Education and Emergency Services (EMS). While the primary focus of this planning study is intended to be for bicyclist safety, overall highway safety deficiencies are presented since improvements to highway safety rarely impact only one mode of transportation. Improvements to vehicular safety can have positive benefits for bicyclist safety, improvements to pedestrian safety can have positive benefits for motorist safety, and so on.

A Road Safety Audit (RSA) is a "formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users."[1] Additionally, tools exist to quantitatively measure the expected impact of safety countermeasures, such as Crash Modification Factors (CMFs). Using tools such as CMFs, a Data-Driven Safety Analysis (DDSA) approach is used to help inform and drive decisions by stakeholders to improve safety.

The goals of RSAs are to:

- Identify what elements of the highway may present a safety concern from a multimodal perspective
- Propose general and specific improvements to improve safety within the study area through:
    - Infrastructure with engineering and proven safety countermeasures
    - Enforcement practices
    - EMS
    - Education

Additionally, short, medium and long-term improvements are recommended with relative costs for each to assist the partner agencies with project selection and development.

Road Safety Audits are a collection of the thoughts, findings, observations, opinions and recommendations from the RSA team at the time of the study and field work. As conditions inevitably change after the audit, the findings, observations and recommendations may change as well. Any cost estimates associated with proposed recommendations are intended to be a ballpark, or relative cost. The preliminary cost estimates for suggested improvements could be considered at a planning and programming level, but should not be taken as true Plans, Specifications and Estimate (PS&E) level accuracy. Proposed recommendations of a higher order, such as geometric improvements, will require information from appropriate topographical survey, environmental processes, preliminary engineering and other necessary processes in order to determine a more accurate cost estimate for implementation. In no way does the RSA imply that the locations under study are unsafe for the various modes of transportation in their current configuration, nor does the RSA imply fault or that action should immediately be taken by the governing agencies of each location.

[1] https://safety.fhwa.dot.gov/rsa/

B. Existing Conditions

1. From Federal Lands Access Program (FLAP) application

The study area along the Cascade Lakes Highway corridor includes the section from milepost 21.98 through milepost 60.87 at the Klamath County line, shown in Figure 1.

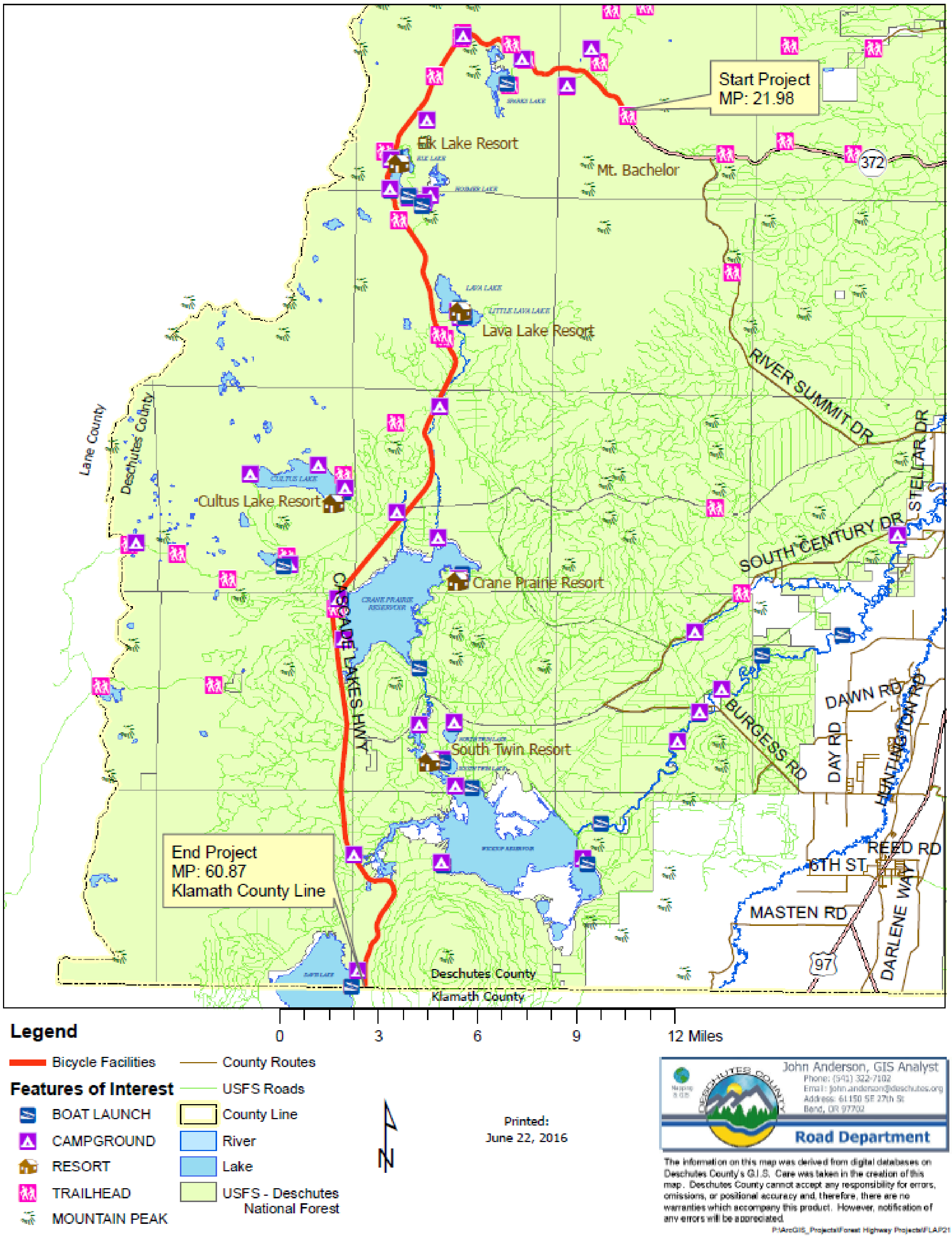

Figure 1 - Cascade Lakes Highway Study Area

The following is a summary of information that was included in the FLAP application, pertinent to highway safety:

- 2’ paved shoulders on the route
- Tight curves and sight distance issues in various sections
- No analysis relating to bicycle use has been performed
- Some pedestrian crossing conflict points could benefit from additional safety analysis
- Environmentally sensitive areas
    - Wetlands
    - Threatened and endangered species
    - Fish and wildlife habitat
    - Wildlife movement corridors
    - Possibly cultural/archeological/historical sites (unknown on FLAP application)
- There is an active and supportive local bicycling community in Deschutes County. Cyclotourism is a significant local economic generator and most weekends in the spring, summer and fall months see a cycling event in the County. Cascade Lakes Highway is frequently used for the Cascade Cycling Classic and other major cycling events. Widespread support for the analysis and planning for the facility improvements is expected.
- Pavement condition
    - Currently the Pavement Condition Index is 77-84 with most of the route at 77
    - A separate FLAP application is being submitted for a chip seal of 29 miles of the segment
- Bridges
    - Need to evaluate bridge locations with respect to safety

2. Other Data from Desktop Research

- Cross-Sectional Data
    - FLAP application indicates 2’ paved shoulders but some areas appear to have less
    - Some areas of unpaved, gravel shoulder, or at least natural flatter areas
- General alignment
    - There are some stretches of longer tangents (1-2 miles) or with gentle curvature that, combined with similar scenery in wooded areas, could lead to drowsiness. In this document, tangents are defined as straight or nearly-straight sections of highway alignment in the horizontal plane.
- Road closed in snow months
    - Gates close off road in multiple locations
- Signing
    - Some existing curve warning signing
- Striping
    - Centerline and edge line striping is present

3. Traffic Data

Deschutes County acquired traffic counts for two locations in 2013. The County and Forest Service believe that the use of the corridor has risen substantially since these counts were collected. According to Wilderness Strategy documents, from 2011 to 2016 the annual visitation in the Three Sisters Wilderness increased from under 40,000 to about 110,000 visitors.

The first site, at MP 26.22, approximately 0.2 miles west of the gate near Dutchman Flat Sno-Park, can be considered the project begin. Data was collected from 5/13/2013 through 5/20/2013 and again from 6/3/2013 through 6/17/2013. Table 1 displays the data.

DATE	DAY	ADT
5/9/2013	Thursday	
5/10/2013	Friday	
5/11/2013	Saturday	
5/12/2013	Sunday	
5/13/2013	Monday	199
5/14/2013	Tuesday	277
5/15/2013	Wednesday	223
5/16/2013	Thursday	141
5/17/2013	Friday	249
5/18/2013	Saturday	201
5/19/2013	Sunday	563
5/20/2013	Monday	302
	NO DATA	
6/3/2013	Monday	563
6/4/2013	Tuesday	605
6/5/2013	Wednesday	746
6/6/2013	Thursday	682
6/7/2013	Friday	918
6/8/2013	Saturday	1965
6/9/2013	Sunday	2243
6/10/2013	Monday	750
6/11/2013	Tuesday	517
6/12/2013	Wednesday	495
6/13/2013	Thursday	387
6/14/2013	Friday	867
6/15/2013	Saturday	1779
6/16/2013	Sunday	2090
6/17/2013	Monday	

Table 1 - MP 26.22 Traffic Counts, May-June, 2013

The average ADT for these counts is 762 vehicles per day (vpd). It can be observed that traffic greatly increased in June and especially on weekends.

The second site, at MP 31.22, approximately 1 mile north of the Elk Lake Loop Road (NF-4625), is near the south end of the area of highest use. Data was collected from 5/9/2013 through 5/21/2013 and again from 6/3/2013 through 6/17/2013. Table 2 displays the data:

DATE	DAY	ADT
5/9/2013	Thursday	44
5/10/2013	Friday	260
5/11/2013	Saturday	450
5/12/2013	Sunday	449
5/13/2013	Monday	112
5/14/2013	Tuesday	159
5/15/2013	Wednesday	144
5/16/2013	Thursday	90
5/17/2013	Friday	144
5/18/2013	Saturday	122
5/19/2013	Sunday	356
5/20/2013	Monday	260
5/21/2013	Tuesday	242
	NO DATA	
6/3/2013	Monday	296
6/4/2013	Tuesday	408
6/5/2013	Wednesday	463
6/6/2013	Thursday	406
6/7/2013	Friday	557
6/8/2013	Saturday	1260
6/9/2013	Sunday	1508
6/10/2013	Monday	459
6/11/2013	Tuesday	360
6/12/2013	Wednesday	301
6/13/2013	Thursday	260
6/14/2013	Friday	547
6/15/2013	Saturday	1193
6/16/2013	Sunday	1397
6/17/2013	Monday	452

Table 2 - MP 31.22 Traffic Counts, May-June, 2013

Excluding data from 5/9/2013, which was only a half day of collection, the average ADT for these counts is 469 vpd. It can also be observed that traffic greatly increased in June, especially on the weekends.

From the traffic data, CLH exhibits traffic patterns similar to many recreational-type highways and roads, with peaks in the summer and tourist season, especially on weekends. The peak weekend traffic was approximately three times higher than the average ADT for both locations. A seasonal ADT should strongly be considered when making design and traffic decisions that rely on traffic data (design criteria). See Traffic Data in D. 1. Recommendations for more discussion on desired traffic data to be collected.

4. Crash Data

Deschutes County provided crash data from 2009 through 2017. In addition, the Oregon Department of Transportation's (ODOT) All Roads Transportation Safety (ARTS) program was accessed through

ODOT's TransGIS site in September, 2018 to verify and augment the available crash data for the years 2012-2016. In general, crash data is known to contain errors and omissions, so the available data may not be an exhaustive list for the time periods analyzed.

Figure 2 shows the total crashes from 2009-2017 by month.

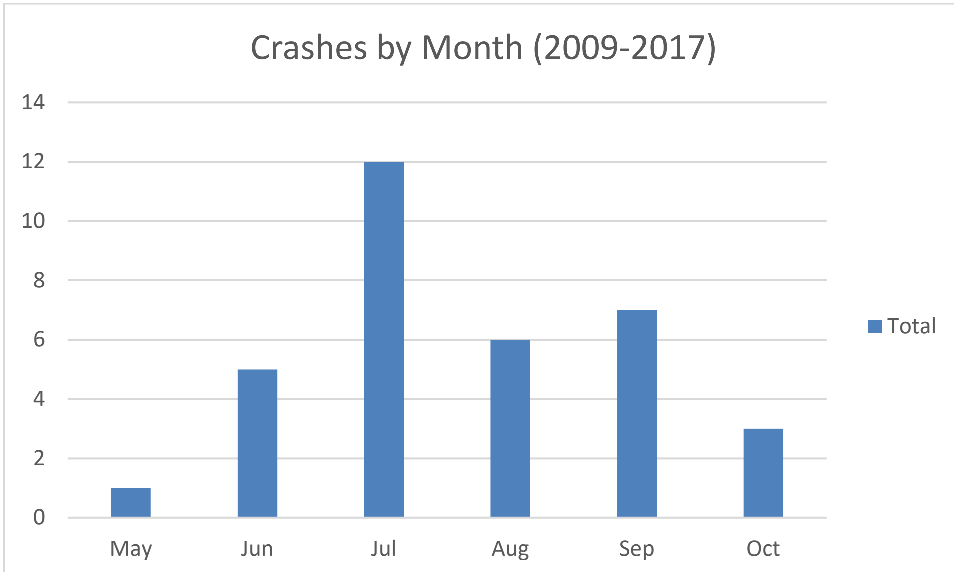

Figure 2 - Total Crashes by Month on CLH

Figure 3 shows the types of crashes by month.

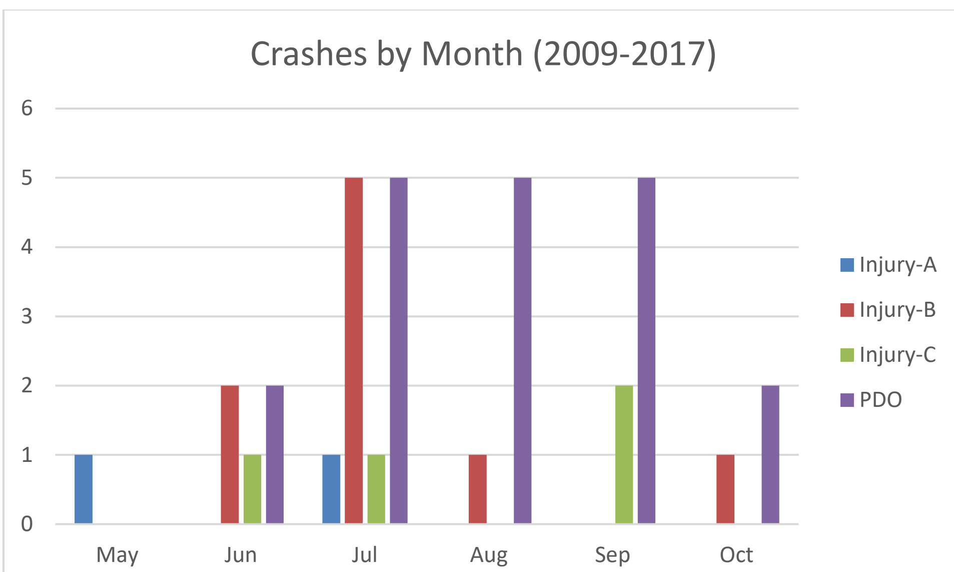

Figure 3 - Crashes by Month on CLH

See Appendix C for the raw crash data.

It can be seen from the crash data that the majority of crashes occur during the peak summer months. The crash data was also reviewed by the day of the week of its occurrence:

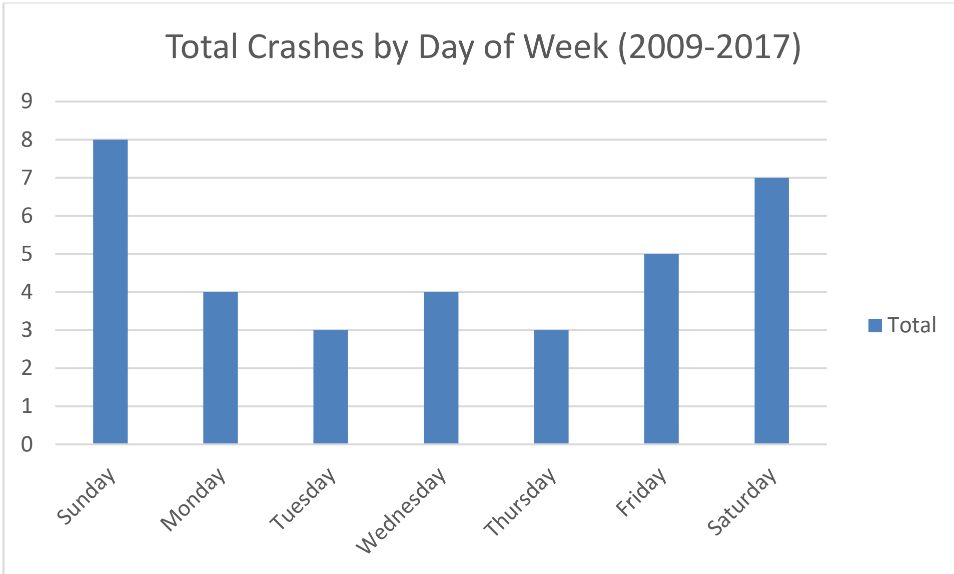

Figure 4 - Total Crashes by Day of Week on CLH

It can be inferred from the crash and traffic data that as traffic increases on weekend days, crashes are more likely to occur throughout the corridor. This correlation between expected crashes and ADT is well known in the highway safety research area.

About 25% of the crashes are animal collisions. According to the data, there are no vehicle-bicycle crashes during this time period. Most of the crashes are single-vehicle crashes. Of the multi-vehicle crashes, most occur within intersections and are likely intersection-related (involved a turning movement).

An approximate crash rate is calculated based off this data but should be used only for comparing in a relative way due to variability and error in crash data as well as traffic data. The total crash rate for the entire study area was calculated to be 0.66 crashes/million-vehicle-miles. Splitting the study into segments may give a more accurate crash rate due to there being more traffic in the northern part of the study.

From the study begin through MP 34.18, the southern end of the Elk Lake area where the highest traffic segment is believed to end, the crash rate was calculated to be 0.81 crashes/million-vehicle-miles. This was based on an estimated daily ADT of 1,043 vpd, averaged from the data set above. From the Elk Lake area through the end of the study, MP 60.87, the crash rate was calculated to be 0.59 crashes/million-vehicle-miles. This was based on an estimated daily ADT of 658, averaged from the data set above. The estimates for ADT widely vary by time of year and day of the week. In addition, it is believed that traffic has grown substantially since 2013, when the above counts were recorded. The estimated ADT values used for these crash rates attempts to represent an average ADT by time of year and by assuming that the 2013 traffic counts are the rough average of the perceived increase in traffic from 2009 to current day. Current ADT values would not be appropriate to use on the historical crash data that goes back to 2009, when traffic was likely lower than 2013 values.

By comparison, the 2016 crash rate for Century Drive, ODOT's Highway 372, from Bend to the study begin was 2.73 crashes/million-vehicle-miles[2]. The 2016 crash rate for OR-58, from the Whitehorse Campground to the Klamath County line, was 0.98 crashes/million-vehicle-miles. The 2016 crash rate for

[2] https://www.oregon.gov/ODOT/Data/Documents/Crash_Rate_Tables_2016.pdf

OR-58, from the Klamath County line to the Highway 429 junction, was 0.96 crashes/million-vehicle-miles.

The relative comparisons to highways of similar types (rural, likely more recreational type use with frequent stops to recreation areas) indicate that historical crash rates for CLH may be lower than surrounding ODOT highways. However, crash data is just one set of data to review when analyzing the safety performance of a highway. The crash rate a highway experiences in the past is rarely the crash rate the highway will experience in the future. Over time, with other variables like traffic held constant, the crashes will fluctuate around a mean and typically are location-random in nature throughout a corridor. However, if there are areas with specific safety deficiencies, these areas typically present themselves as clusters of crashes or "hot spots." With relatively low traffic and low frequency of crashes throughout CLH, clusters may be difficult to identify or may not exist. However, based on the available crash data, there appear to be some areas of higher crashes, and these will be examined throughout the study.

- Near Todd Lake intersection, including horizontal curve to west (3 crashes)
- Horizontal curves just west of Green Lakes Trailhead area (3 crashes)
- Elk Lake Resort intersection (3 crashes)

Finally, the cause or possible cause of crashes will be examined to see what countermeasures may be effective to improve motorist, and subsequently bicyclist and pedestrian, safety.

According to the Guide for the Development of Bicycle Facilities, accurate data for bicycle-related crashes can be difficult to obtain, since bicycle-related crashes are generally underreported, especially for those resulting in minor injury; crash data does not reflect near-misses; bicycle count data is lacking so it is difficult to calculate crash rates and crashes due to roadway conditions or geometry (i.e. narrow shoulders leading cyclists to off-track and crash on gravel or soil) are generally underreported or not recorded (pg. 2-23 GDBF).

5. September, 2018 Field Work

During the September 17-20, 2018 field visit, WFLHD, Deschutes County and the Forest Service discussed several specific areas of concern in addition to overall corridor concerns. This section will describe the specific findings at both the overall corridor as well as specific sites.

a) Overall Corridor

Several safety-related items were discussed at the Deschutes County office prior to reviewing the corridor in the field. The following is a summary of those safety-related items.

1) Overall Increase in Use and Wilderness Strategies

According to Deschutes County, there has been a large increase in vehicle and bicycle usage of the CLH corridor. There has been an increase in pedestrians walking along the roadway and crossing near the major trailhead areas. Trailhead locations and associated crossings across CLH are important aspects of this study. The increase in usage has been very prevalent at the Day Use areas. Anecdotally, some locals don't visit the CLH corridor anymore due to the increased use. According to the Forest Service, their Day Use areas and day use areas associated with the Cascade Lakes lodges (i.e. boat ramp parking lots, lake access) are over capacity during much of the year. Forest Service data indicates that the total wilderness area visitors by year (permit data) at the Three Sisters Wilderness (near the north end of the study area) increased from 46,999 in 2011 to 132,118 in 2016, a 181% increase in just five years. The Green Lakes trail saw 62 hikers per a typical 8-hour time period during 1991-1993 data. During 2013-2015, the same trail saw 325 hikers per a typical 8-hour period, a 424% increase.

The existing conditions and current usage throughout the CLH corridor described in this document are based on the current administration of Forest Service land. Recently, the Forest Service has proposed

Wilderness Strategies in order to mitigate the substantial increase in usage. These Wilderness Strategies are described in full in Section C of the Planning Document. The Strategies may significantly alter the existing conditions and usage as described in the Road Safety Audit. The relevant considerations from these Wilderness Strategies with respect to possible improvements to the CLH corridor are mentioned throughout this Road Safety Audit.

The overall recreational use throughout the corridor is more for fishing and hiking than hunting, according to the local agencies. A new bicycle and pedestrian multi-use path near Bend along the highway has become very popular. It currently terminates near the Forest welcome station.

2) Parking

Parking along the roadway throughout numerous sections of the corridor is a major concern. As the Forest Service Day Use area parking lots and turnouts fill up, the major increase in usage has led to visitors parking on the shoulders of CLH adjacent to these areas. The Forest Service Law Enforcement Officers (LEOs) enforce illegal parking within the Day Use areas. This is important as there may be more usable space within these lots and associated driveways where people parking along the CLH roadside could safely park instead. Overall, several of the Day Use parking lots were noted as being inefficient with respect to striping and flow.

3) Transit

The Forest Service and County have considered the use of transit to alleviate congestion throughout the CLH corridor. An Alternate Transportation Feasibility Study was completed but the study stopped at Mt. Bachelor (from the east). Transit is currently being used at Lava Lands Visitor Center, another Deschutes National Forest site, with success. This service was funded through the Federal Lands Access Program (FLAP). A 2018 FLAP application was submitted by Central Oregon Intergovernmental Council, Cascades East Transit, Mt. Bachelor and the Forest Service. This transit project would be a pilot project for 2022-2023 for providing service from Bend to Mt. Bachelor and to Devils Lake within the study corridor, with stops in between these destinations. No decisions have been made on project funding at this time. Establishing partnerships with transit services is important to the Forest Service as their mission does not necessarily include providing this type of service.

4) Bicyclist Information

Cyclists are attracted to the CLH corridor for general recreational rides as well as organized events and races. According to the agencies and stakeholders, most of the cyclists are intermediate or expert riders with respect to their level of experience. There are some specific cycling events such as the Cascade Cycling Classic, Cycle Oregon and Tour Deschutes. The CLH is not closed to vehicular traffic during these events.

During a bicyclist ride during the field review, two team members rode from Cultus Lake to Elk Lake in order to better understand the bicyclist perspective in the corridor. While this section of the CLH is relatively mild in horizontal curvature and vertical grades, it was observed that the typical roadway width for much of the corridor is difficult for cyclists to navigate within the limited paved shoulder width. At many locations the width was less than 2’ and often less than 1’.

Figure 5 - Limited Shoulder Widths Near Cultus Lake

At times, the two team members found themselves leaving the roadway and riding on the adjacent gravel shoulder. It can be difficult to return the bicycle to the roadway if there is much of a drop-off from the paved shoulder to gravel shoulder.

In addition, the two team members observed some debris on the shoulder, however, it was not excessive. It was recognized that in locations of high parking areas along the gravel shoulder, the ensuing shoulder degradation of vehicles returning to the roadway will compound bicyclist concerns at these locations. Riding on the gravel shoulder is tremendously more difficult for a bicyclist.

During the ride, the two team members were passed by several motorists. In general, motorists gave ample room for passing the cyclists. However, due to the roadway width and some areas of horizontal and vertical curvature, it can be seen from Figure 6 that conflicts can arise as vehicular and bicyclist traffic increases.

Figure 6 - Motorist Passing Bicyclists with Oncoming Vehicle on Curve

In addition, the areas of limited horizontal sight distance throughout the corridor due to horizontal curvature and vegetation and/or cut slopes is a safety concern especially for cyclists. In this photo, the cyclists are almost not visible around the curve and this would be compounded if they were riding in the opposite direction with the inside of the curve on their right:

Figure 7 - Cyclists Nearly Out of Sight Around Curve

Figure 8 - Motorist Passing Cyclists in Area of Limited Vertical Sight Distance

Figure 9 - RV Motorist Giving Ample Room While Passing Cyclists

A conversation with a Forest Service LEO, who has worked in this area for 18 years, indicated that during summer days, bicyclist traffic is anecdotally believed to be 50-100 bicyclists per day and may be up to 200 per day, excluding official cycling events. The LEO added that S. Century Dr., east of CLH, also sees a significant amount of cyclists.

5) Meeting with Bicycle and Pedestrian Advisory Council

WFLHD met with a representative from the Deschutes County Bicycle and Pedestrian Advisory Council (BPAC) to gain further perspectives on cycling and pedestrian use throughout the route. The council acts as an advisory group for the County when there are plans for projects and can give recommendations and agree or disagree with proposals. There are representatives from Bend and the surrounding cities on the Council.

The BPAC representative indicated that bicyclist use is higher near the north to middle sections of the study and that there is not as much use near the south end of the study. The highest concern for cyclists is the lack of shoulders, according to the representative. However, pedestrian safety is a high concern as well at several of the locations in the CLH corridor.

The representative believes that Todd Lake to Elk Lake is the most congested area and should be highest priority of this study. Throughout this section, there is mixed vehicle use and parking on both sides of the roadway can reduce the effective roadway width to 1.5 lanes. Pedestrians may cross anywhere throughout this section.

In general, the BPAC representative believes that cyclists are cognizant of their surroundings and slow down in the highly congested areas to help avoid conflict with parked vehicles, opening doors, etc. The level of cyclists are of intermediate experience and better and may ride 50-125 miles per day. To the representative's knowledge, there is no online information on cautions for the bicyclist community from a safety standpoint for the CLH corridor. Local outfitters are genuine and will give honest recommendations and advice to unfamiliar riders on possible safety concerns in the CLH corridor. There are not a lot of options for less than intermediate cyclists on the CLH corridor but one example is the area around Elk Lake. Both road bikes and mountain bikes are used in the corridor, with some trails for mountain bikers. Bend has a strong community of bicycle riders with a mix of road bike users and mountain bike users. Most in the community advocate for single-file riding on non-event rides to reduce conflict risk.

According to the representative, there are conflicts at times with vehicles with attached trailers passing cyclists that are unfamiliar with the proper way to do so. They pass and then pull back over too soon and can come close to colliding with the cyclists.

During official events, racers may be going 30-35mph throughout the corridor. Escort vehicles typically accompany these official events in the front and rear of the group. For unorganized rides, there is not one preferred pattern or loop throughout the region. A preferred direction for improvements (e.g. shoulder widening to one side only) is not believed to be advantageous according to the representative. The representative believes that cross-sectional improvements (widening the shoulders) will likely attract more cyclists and users throughout the corridor.

6) Meeting with Cascade Lakes Cabin Homeowners Association Representative

WFLHD met with a representative from the Homeowners Association for the cabins in the study area. The land is owned by the Forest Service and leased to the cabin owner. WFLHD asked this representative about the increase in use throughout the CLH corridor and the concerns that have arisen.

The representative believes that cyclotourism has grown substantially in recent time. There are official cycling events but also other events such as triathlons and relay races (on foot). There are triathlons based in Sunriver that base their races in the Cascade Lakes area and the Cascade Lakes Relay Run uses the entire stretch of CLH. There are cycle-backpackers using the area for camping trips as well.

According to the representative, there are several concerns with the CLH. The use at the Todd Lake Trailhead, Green Lakes Trailhead, Devils Lake Trailhead and Elk Lake areas has exploded in the last 3-5 years. At some of these locations, there is often parking along the roadway which leads to vehicle doors being opened into the roadway, causing concerns for cyclists. Pedestrians are walking along the roadway and roadside throughout these locations of high parking. In some turnout locations, where there are kiosks for example, vehicles are parking where they shouldn't be.

Vehicles passing one another may not be giving adequate attention to cyclists. According to the representative, vehicles and cyclists have to take special maneuvers to pass safely. The mix of trucks pulling boats, RVs, etc. is a further concern. For the cyclists especially, the narrow shoulders, steep grades (in some locations) and tight horizontal curvature in some areas is a significant concern. The representative believes a no parking ordinance and lower speed limits near high congestion areas may be a solution. According to the representative, speeds often reach 60-65mph on the tangent sections of CLH and there is a concern with the mix of slow-moving RVs or trucks pulling trailers.

7) Typical Geometry

Starting from the north, the alignment will be described in general terms. The beginning of the study is milepost (MP) 21.98 and mileposts increase in the north to south direction.

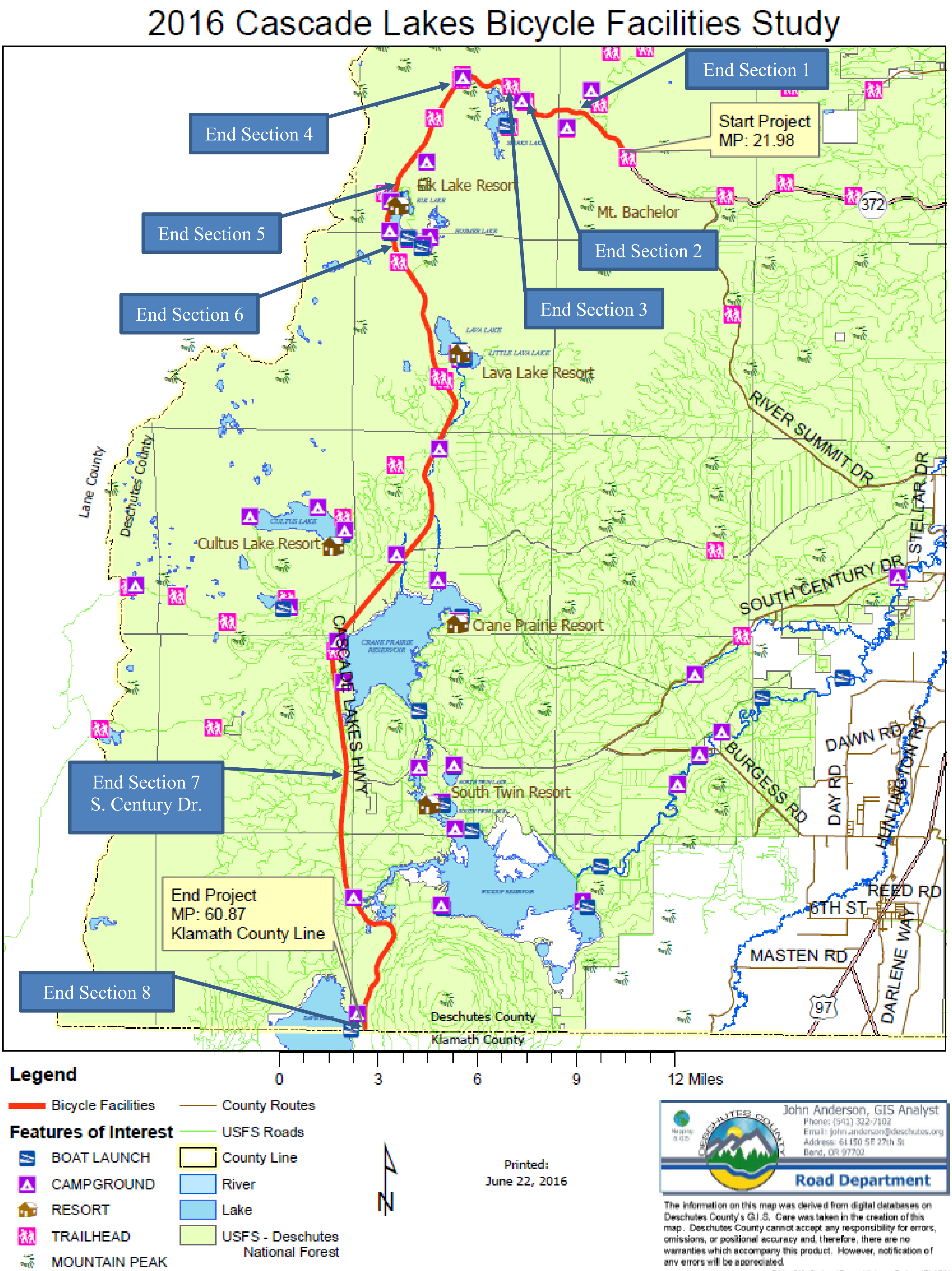

Figure 10 - CLH Study Limits by Section

Throughout Section 1, from the beginning through the Todd Lake Day Use area intersection, the horizontal alignment is on tangent or mild to moderate curvature with level to rolling vertical terrain. Paved shoulder widths are approximately 1-2’. This section is 1.7 miles, ending at MP 23.68.

From the Todd Lake Day Use Area intersection, the next section of roadway continues with similar geometrics and terrain to the flatland area near Green Lakes Trailhead, ending at MP 25.98. The horizontal alignment throughout this section has several curves with moderate curvature and back to back reverse curves. Vertically, some of the grades within this section are the steepest in the study, likely in the mountainous terrain category. A measurement in Google Earth indicates grades on the order of 7-9%. There are several areas of limited horizontal sight distance due to trees and/or cut slopes. Paved shoulder widths are approximately 1-2’. Near the end of Section 2, a recent project replaced pipe culverts with a bridge on Soda Creek (OR PFH 46 (9)).

Figure 11 - Limited Horizontal Sight Distance

From the end of Section 2, Section 3 continues through the Green Lakes Trailhead area and ends near the horizontal curve at the northwest end at MP 26.68. The horizontal alignment throughout this section is nearly tangent and the vertical grade is nearly level. Paved shoulder widths are approximately 1-2’, aside from the area near a recent bridge replacement. This is an area of substantial parking along the roadway when the Green Lakes Day Use Area parking lot fills up. The mild to flat gravel foreslope makes it easier for vehicles to park along the roadside. A recent project replaced the bridge near Green Lakes parking lot.

Figure 12 - Section 3 Typical Geometry

Figure 13 - Recent Bridge Replacement Near Green Lakes Parking Lot

From the end of Section 3, Section 4 continues through the end of the horizontal curves near Devils Lake, MP 28.48. This section contains the sharpest horizontal curves in the study (approximately 401’ and 540’ radii for example) in addition to some moderate to mild curvature. Nearly all of this section is curvilinear. There are moderate to steep vertical grades within this section as well. There are areas of limited horizontal sight distance due to vegetation and/or cut slopes. Paved shoulders are approximately 1-2’. This is an area of substantial parking near the trailhead access points (near the 401’ radius curve).

From the end of Section 4, Section 5 continues to the north side of the Elk Lake area, MP 32.28. This section contains mild horizontal curvature and generally mild vertical grades, with mostly level and some rolling terrain. Horizontal and vertical sight distance appears to meet or exceed criteria for the expected speeds. Paved shoulders are approximately 1-2’.

Figure 14 - Section 5 Typical Geometry

Section 6 is the area near Elk Lake and ends near the south end of the horizontal curve just south of the lake, MP 34.18. This section has a mild to moderate curvilinear horizontal alignment with a generally rolling vertical terrain. There are some areas of limited horizontal sight distance in this section as well. Paved shoulders are approximately 1-2’ width.

Figure 15 - Limited Horizontal Sight Distance in Section 6

Section 7 continues from the end of Section 6 and ends at the intersection with S. Century Drive, MP 51.98. This section has some long tangent and nearly tangent sections (up to nearly 4.5 miles) with some areas of mild to moderate horizontal curvature. Near some of the horizontal curves, there are some locations of limited horizontal sight distance. The vertical grades are level to rolling throughout this section. Paved shoulders are 1-2’ in width. This section contains access to several lakes, including Lava Lake, Little Lava Lake, Cultus Lake and the Crane Prairie Reservoir.

Figure 16 - Section 7 Typical Section

Section 8 continues from the S. Century Drive intersection south to the end of the study at the Klamath County line, MP 60.87. Section 8 has similar horizontal and vertical alignment characteristics to Section 7. Most of the section has long tangents or gentle horizontal curves with a moderate curvilinear section near the south end as the alignment traverses around an old lava flow. The main difference from Section 7 is that the cross-section widens and the paved shoulders are approximately 4' in width for the majority of this section.

8) Route Continuity

Agencies can use the concept of route continuity to help gauge the range of possible improvements to a given corridor or project. When studying a route, consideration needs to be given to the geometry and cross-sectional elements of the corridors adjacent to the route in study. In theory, if adjacent corridors have similar traffic and contextual characteristics (ADT, posted speed, rural, recreational road, etc.), then their geometric and cross-sectional elements are preferred to be similar as well in order to maintain driver expectations. However, other considerations such as cost, safety, environmental and other items need to be considered prior to applying a blanket approach to improving any missing links.

For CLH, on the north and east end, ODOT Highway Number 372 (no OR Route Number is posted for this highway and its name is Century Drive[3]) is adjacent to the study begin. The study begins at the end of the four-lane section of CLH and near the intersection to turn to the Mt Bachelor Resort. The portion of the CLH adjoining, but outside of, the study area extends to Bend and has approximately 12' lanes with 6' shoulders as a typical section. The posted speed limit is 55mph, there are locations of four-lane sections (for passing) and there are centerline rumble strips on this segment. According to ODOT, the AADT was 1,400 vpd as of 12/14/2017 (GIS processing date, ODOT TransGIS). To the west of the turnoff for the Mt Bachelor Resort, the ODOT data indicates the AADT is 1,000 vpd at the begin of this study, showing that the Resort is a significant traffic destination. According to ODOT, there are 100

[3] https://www.oregon.gov/ODOT/Data/Documents/Routes-to-Highway-Cross-Reference-Table.pdf

trucks per day at the beginning of the study area as well, the majority of which are single-unit (SU) trucks.

The alignment of this portion of CLH is generally smooth with some sharper horizontal curves and moderate grades, though not as sharp as some of the horizontal curves in the CLH area of study. It appears that a moderate to substantial clear zone is provided, though no data or measurements are available to determine the amount of clear zone. There are some locations of guardrail, presumably where clear zone slopes are not met.

Figure 17 - ODOT Portion of CLH - Route Continuity - Approx. 43°58'57.35"N, 121°37'19.02"W

Figure 18 - ODOT Portion of CLH - Route Continuity – Approx. 43°59'7.31"N, 121°32'34.72"W

On the south end of the CLH study, the study ends at the county line with Klamath County. The CLH continues on as Klamath County route 1352 and 1351 until it meets OR-58 (the Willamette Highway). This portion of CLH was found to have approximately 11’ lanes and 4’ shoulders. WFLHD did not drive more than a mile into this section but it was found to be similar to the area of study, especially the southern portion of CLH (south of the intersection with S. Century Drive).

Figure 19 - Klamath County Portion of CLH - Route Continuity

In fact, the portion of CLH from just south of the intersection with S. Century Drive south to the Klamath county line has been improved to include approximately 4' shoulders (described above as Section 8). Anecdotally, this is the segment with the least amount of traffic throughout the CLH corridor in Deschutes County.

Figure 20 - South of S. Century Drive along CLH (Section 8)

Another major road that intersects CLH is S. Century Drive. From CLH, this road eventually ends up in the Three Rivers and Sunriver area. A portion of this road falls under Forest Service maintenance jurisdiction and the portion closer to the Three Rivers/Sunriver area is maintained by Deschutes County. For the Forest Service portion, from S. Century Drive to approximately Burgess Rd., the traveled way width and paved shoulder width are similar to the CLH corridor north of S. Century Drive. There is significantly more vegetation encroachment on this segment leading to horizontal sight distance concerns. The centerline striping is very faint and there is virtually no edge line striping. This segment of S. Century Drive gives access to several lakes, reservoirs, resorts, campgrounds and numerous minor Forest Service roads. S. Century Drive is used by recreationalists as a way to complete a loop after CLH.

Where the County maintenance begins, the cross section is improved to approximately 4’ paved shoulders, good striping conditions and better vegetation clearing. This portion of S. Century Drive is similar to the improved portion of CLH at the southern end of the study.

9) Signing

Deschutes County has installed many advanced curve warning signs for substandard horizontal curves throughout the corridor. While the seasonal ADT is near the 1,000 vpd threshold in the MUTCD Section 2C.06 for mandating the provisions in the Section, the county has applied the provisions of the Section for many of the horizontal curves.

Pedestrian warning signing and general congestion signing are present at the Devils Lake area.

Figure 21 - Pedestrian Warning Signing north of Devils Lake

No intersection warning signs were observed during the field review (MUTCD Ref. W2-1, W2-2, etc.) at minor or major intersections throughout the corridor.

Numerous guide signs were found to be in poor condition, lacked visibility (sometimes due to vegetation or placement), appeared to be too small for visibility at high speeds and lacked advanced notice prior to the decision point.

No regulatory speed or speed limit signs were observed in the corridor. Oregon's basic rule law applies to CLH.

10) Striping

Deschutes County stripes 11' lanes throughout CLH with a 4" width as their standard. The County has been especially cognizant of passing zones near locations of driveways and approach roads in general on county roads. The County stripes annually and the timing varies but typically this is done in mid-summer. There was an edge-line striping operation going on during the team's visit.

11) Speeds

A conversation with a Forest Service LEO indicates that speeds can often reach 70+mph on portions of CLH. There are long segments of tangents or nearly tangent sections where speeds can increase. The LEO has witnessed people driving over 100mph on CLH near the road that leads to Cultus Lake. He believes the average speed for tangent segments is likely 65mph or more.

The team was passed by a vehicle traveling at a very high rate of speed while on one of the long tangents. The team estimates the speed of this vehicle to be 80mph or greater based on the team's speed at the time.

12) Maintenance

Deschutes County uses chip seals to help preserve the pavement throughout the CLH corridor. The last chip seal was constructed from Mt. Bachelor south to Elk Lake in 2015. The County considers bicyclist use on the shoulders and uses a smaller gradation of aggregate for chip seals on the shoulder portion. The County submitted a FLAP application in the 2016 Call for Projects to chip seal the remainder of CLH from Elk Lake south to the Klamath County line. In 2018, a FLAP application in the 2018 Call for Projects was submitted by the County for another chip seal on the Mt. Bachelor to Elk Lake section, with a desire to construct the project in 2020. The County plans to submit a project in the next Call for Projects to again chip seal the Elk Lake to Klamath County line section.

Snow plow operations occasionally damage signs throughout the corridor. The County strives to get these repaired or replaced as soon as practical following any damage in the spring.

At the time of the field visit, the County stated that a vegetation clearing operation was to occur that week within the corridor.

b) Todd Lake Day Use Area and Intersection with CLH

The Todd Lake Day Use Area is a popular destination that has seen an increase in usage in recent times. The parking lot for accessing Todd Lake is small (18-25 spots on an unpaved surface) and gets filled up, leading to parking along the access road (NF-370) which has caused severe congestion on NF-370 at times. According to the Forest Service, in one instance the congestion caused a jam that took an hour to clear along NF-370 as vehicles could not get by each other along the road. According to the FS, during the weekend of September 8-9, 2018, 123 vehicles attempting to access the Crater Ditch and Broken Top Trailhead (farther along on NF-370) were turned away at the Todd Lake Trailhead. These vehicles likely went to visit another area in the CLH study area. Vehicles do not park along CLH to access the Todd Lake and Broken Top Trailheads but these popular sites add to the general congestion in the CLH corridor. According to the Forest Service, the resources along the trails cannot handle any increase in use.

As mentioned in Overall Increase in Use and Wilderness Strategies, the conditions described at Todd Lake, Green Lakes, Devils Lake and the rest of the CLH corridor are based on current usage. The proposed Wilderness Strategies may significantly affect the described issues throughout and are discussed in more detail in Possible Improvements.

Figure 22 - Todd Lake Trailhead Parking Lot

At the intersection with the Todd Lake Day Use Area and the equestrian-use area on the opposite side of the highway, there is a sight-distance concern for vehicles making the turn out of the equestrian side (southwest quadrant).

Figure 23 - Todd Lake Intersection, Southwest Quadrant, Looking Northwest

Vehicles pulling horse trailers have longer functional lengths and slower accelerations which can compound the intersection sight distance concern. The horizontal alignment curves away from the intersection. Existing vegetation blocks sight distance in this direction and the other side:

Figure 24 - Todd Lake Intersection, Southwest Quadrant, Looking Southeast

To the east of the intersection, a warning sign for equestrian use is shown in Google Earth for the eastbound direction.

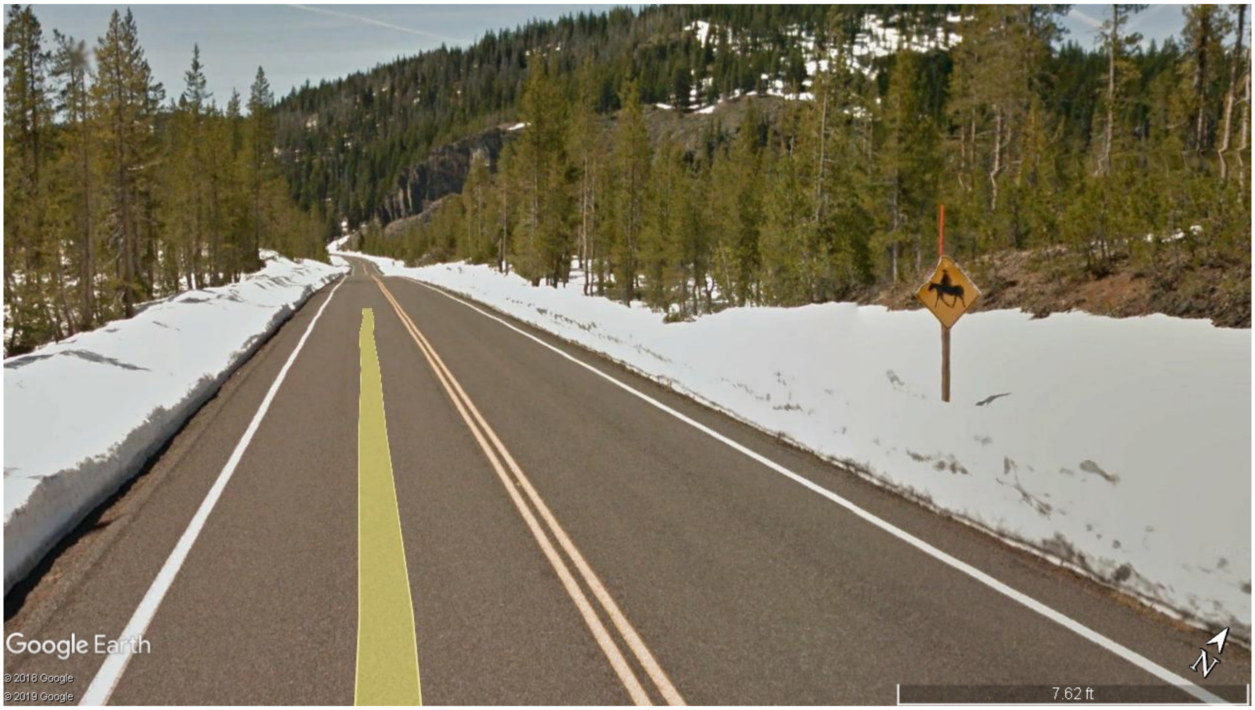

Figure 25 - Horse Warning Sign East of Todd Lake Intersection, Looking West

East of this sign, there is another equestrian warning sign for the westbound direction. This indicates a regular crossing may occur in between the two signs. There are no known issues with crossings in this area. CLH is on a tangent through here with apparent adequate stopping sight distance.

c) Green Lakes Trailhead and Parking Lot Area

The parking lot for this trailhead fills up during peak and likely even during non-peak times. When full, visitors park along CLH for up to a ½ mile each way, according to the Forest Service. The parking lot was originally designed for horse trailers and some of these spaces are still designated for vehicles with trailers or RVs. During the field visit, these spaces were being used by regular vehicles as well:

Figure 26- Green Lakes Parking Lot - RV/Trailer Spaces Used by Non-RV/Trailer Vehicles

It was noted that the Forest Service may issue citations at their discretion for this type of parking that is in violation of the posted signs.

During the team's visit on Monday, September 17, the parking lot was nearing capacity at an off-peak period. According to the Forest Service, on Saturday, September 8, the parking lot was full by 8:00am. At 3:00pm that day, 270 cars were parked in this area (approximately 103 in the parking lot and 167 along CLH).

On Sunday, September 9, the parking lot was full by 8:30am. In the afternoon, 110 cars parked in the parking lot and 116 were along CLH. It is believed that there is consistent high usage on the weekends during the summer (and even fall) months, but high weekday usage is becoming more common as well. The parking lot has 46 single parking spots for passenger cars or pickup trucks. There are six RV/trailer parking spots as well. Parking often occurs down at the bottom of the highway foreslope and occasionally events are held in the roadside vicinity along the CLH. For example, a (non-permitted) wedding was held near this area recently.

Figure 27 - Green Lakes Trailhead Area

Note the pedestrian walking along the shoulder near the Green Lakes trailhead in Figure 28:

Figure 28 - Moderate Parking along CLH Near Green Lakes

In Figure 29, note the vehicle parking right at the access road to Green Lakes Trailhead, limiting intersection sight distance for vehicles turning out of the parking lot area.

Figure 29 - Parking Near Green Lakes Access Road

d) Devils Lake Trailhead

This parking lot and trailhead area is a launch point for the South Sister hike and other trails. Recreation also occurs in and near Devils Lake, with a unofficial boat launch point within the gravel turnout on the inside of the horizontal curve along CLH.

Figure 30 - Devils Lake Overview

According to the Forest Service, on Saturday, September 8, the parking lot was full by 8:00am. At 3:15pm, the total of parked vehicles was 295, of which 96 vehicles were parked on the CLH and 199 in the parking lot.

On Sunday, September 9, the parking lot was full by 8:30am. The parking lot had 194 vehicles with 101 parked along CLH. The team discussed a desire to review the existing parking lot for ways to increase efficiencies and also review possible expansion options. The existing parking lot is unpaved so there are currently no stall lines.

Assuming most of these people are accessing the trails to the west of CLH, and a conservative vehicle occupant rate of 1.5 people per vehicle, this amounts to approximately 443 pedestrians on Saturday and 443 pedestrians on Sunday that are either walking along CLH or crossing CLH near the existing trail crossing, though some of these pedestrians are likely using the underpass. There is a large potential for conflict between pedestrians and motorists as well as bicyclists.

Figure 31 - Devils Lake Parking Lot

The sharp horizontal curve, relative to the rest of the CLH corridor, significantly limits sight distance through this area. This increases the safety hazard for the pullout on the inside of the curve, as shown in Figure 32.

Figure 32 - Pullout Near Devils Lake, Looking West

The team observed a significant pedestrian crossing near the apex of the horizontal curve. There is not a distinct pattern of pedestrian movement as parking occurs along the roadway here so crossings may happen anywhere along the horizontal curve. The team observed approximately 10 pedestrians crossing CLH in this area over approximately an hour.

Figure 33 - Pedestrian Crossing near Apex of Curve at Devils Lake

These photos show the view from the shoulder near the actual existing trail crossing. The team took sight distance measurements of 450’ to the north from this point and 425’ to the south. AASHTO stopping sight distance values for 45, 55 and 65mph are 360’, 495’ and 645’, respectively. The current speed limit, per Oregon Basic Rule, is 55mph for CLH. Currently, sight distance is not met here for this speed, however, the horizontal curve radius indicates a design speed of 35mph, as discussed in Horizontal Geometry. There are no horizontal curve warning signs for this particular curve while other higher speed curves do have horizontal curve warning signs in the corridor.

Figure 34 - Devils Lake Trail Crossing, Looking North/East

Figure 35 - Devils Lake Trail Crossing, Looking South/West

There is an existing underpass with some hiker, equestrian and snowmobile use to the southwest of the "main" crossing location on the apex of the horizontal curve. See the "Underpass" point in Figure 30. It appears that the existing underpass is greatly underutilized. The team discussed strategies to reduce or eliminate parking along the roadside in this vicinity. See Devils Lake Trailhead and Parking Lot Area for discussion.

Figure 36 - Existing Underpass Near Devils Lake

The Forest Service indicated that the beginning of the South Sister trail may be moved so that it uses the nearby existing underpass. See Devils Lake Trailhead and Parking Lot Area.

One bicyclist was observed during the team's visit. The narrow shoulder and drop-off at the edge of shoulder, especially on the pullout side, is problematic for bicycle operations. The slope of the pavement edge was not measured, however. The slope is not vertical and may be appropriate for vehicles per Safety Edge^{SM} guidance. See SafetyEdge^{SM} for more discussion.

Figure 37 - Bicyclist Observed Near Devils Lake

Figure 38 - Pavement Edge Drop-off Near Gravel Turnout at Devils Lake, Approx. 3" in Height

While at this location, Deschutes County Law Enforcement Officers stopped by and spoke with the team. According to the LEOs, speeding hasn't been an issue at this location but there are speeding concerns on the tangent sections of the CLH. The County LEOs say that it is mostly Forest Service enforcement that may ticket for CLH parking violations, however, the Forest Service stated that their enforcement staff would not ticket along CLH without County concurrence. Any major changes in County enforcement or parking restrictions along CLH in general via ordinances would likely be difficult to achieve, according to discussion among the team at this visit.

There is existing pedestrian warning signs, with supplemental 350' plaques, as one approaches from either direction to this area as well as a congestion sign:

Figure 39 - Pedestrian Warning Sign near Devils Lake

Of the available crash data, Crash 1006 occurred near the end of the 400’ radius curve on the south/west end. This was a single-vehicle, injury B crash with an animal, believed to be traveling from north to south. It is possible the horizontal curve contributed to a lack of visibility of the animal.

The team discussed strategies for improving safety at this location and is discussed in Devils Lake Trailhead and Parking Lot Area.

e) Quinn Meadows

WFLHD reviewed NF-450, an approach road that accesses the Quinn Meadows equestrian camp area. It was noted at the intersection with CLH that there was limited vertical sight distance to the south.

Figure 40 - CLH Intersection with NF-450 (Quinn Meadows), Limited Sight Distance to South

WFLHD measured approximately 750’ of intersection sight distance to the south at this location, which may be adequate for passenger cars, however, the heavy use of horse trailers in this area may require an additional time gap to make the turn out of the approach road.

f) Elk Lake

Near the north end of Elk Lake, at the intersection with NF-4625 (Hosmer Lake Rd), the team measured intersection sight distance to be approximately 650’ to the south around the horizontal curve. The critical AASHTO intersection sight distance values are 665’ and 720’ for design speeds of 60mph and 65mph, respectively. Therefore, the available sight distance here is considered marginal.

Figure 41 - NF-4625 Intersection - Sight Distance to South

WFLHD staff reviewed the main Elk Lake intersection with NF-4600 (Forest Service road names: Elk Lake Lodge to the east of CLH and the Elk Lake Trailhead to the west). This was the approximate location of three crashes according to the available crash data. Crash 01141 indicates that a motorist was traveling along the Trailhead Road and failed to stop at the stop sign for the intersection, crashing off the roadway (a single-vehicle crash). WFLHD found that the Stop Ahead sign in advance of the intersection is damaged and not retroreflective. The sign is approximately 440' from the stop sign for the intersection, which is high when compared to values for Guidelines for the Advanced Placement of Warning Signs in the MUTCD (Table 2C-4).

Figure 42 - Stop Ahead Sign on Elk Lake Trailhead Road

The stop signs at the intersection itself were found to be in good condition and highly visible. The stop bar pavement markings were in good condition as well. According to the crash data for 01141, speeding and alcohol were factors and the crash took place around noon. It is unknown if the advanced warning sign's condition, location, or sunlight factors that may have limited its visibility, may have played a role in this particular crash. It is also unknown what the condition was of the stop signs at the intersection itself, as the crash occurred on 9/19/2014.

Figure 43 - Elk Lake Intersection West Quadrant, Elk Lake Trailhead Road, Good Visibility of Stop Sign Looking East

Figure 44 - Elk Lake Intersection East Quadrant, Elk Lake Lodge Road, Good Visibility of Stop Sign Looking West

Figure 45 - Stop Sign on West Quadrant of Elk Lake Intersection, Elk Lake Trailhead Road, Manufactured May, 2018, 30" x 30"

Figure 46 - Stop Bars at Elk Lake Intersection, Elk Lake Trailhead and Elk Lake Lodge Roads, Looking East

The brown (recreational) guide signs were found to be in poor condition or hidden from view near this intersection. Some of the text is too small to be read at higher speeds.

Figure 47 - At Elk Lake Intersection, Looking North, Hidden Sign

Figure 48 - Guide Sign in Poor Condition, West Quadrant of Elk Lake Intersection, Elk Lake Trailhead Road, Looking North

In addition, the intersection sight distance on the east quadrant was found to be limited by vegetation growth along the roadside in both directions. North of the intersection, CLH curves to the east which also reduces available sight distance.

Figure 49 - Intersection Sight Distance at Elk Lake Intersection East Quadrant, Elk Lake Lodge Road, Looking South

Figure 50 - Intersection Sight Distance at Elk Lake Intersection East Quadrant, Elk Lake Lodge Road, Looking North

One other crash at this intersection involved a turning motorcycle with a vehicle, and the third crash was a deer hit. Crash 01273 is the motorcycle/vehicle crash and it appears that one of the vehicles was making a left turn into the Elk Lake resort road and the other vehicle crashed into the turning vehicle from behind. The cause according to ODOT data was "improper overtaking."

A non-MUTCD compliant "Slow 5mph" sign was noted on a tree in the eastbound direction from the intersection.

Figure 51 - Non-MUTCD Compliant Sign east of Elk Lake Intersection, Elk Lake Lodge Road, Looking East

Another custom “Slow Congested Area” sign was noted on the opposite side of the Resort approach road.

Figure 52 - Custom "Slow Congested Area" Sign with Poor Visibility, Elk Lake Lodge Road, Looking East

A third of a mile south of this intersection, there were several areas of poor horizontal sight distance observed due to the horizontal alignment and vegetation.

Figure 53 - Limited Horizontal Sight Distance in the Elk Lake Area

It is unknown if these sight distance conditions contributed to two crashes in this segment. Crash 00878 was a single-vehicle animal crash in an area with limited horizontal sight distance. Crash 01399 is a multi-vehicle crash at the NF-4600 intersection that has limited intersection sight distance to the south.

Figure 54 - CLH Intersection with NF-4600 (Point Campground), Looking South

g) Intersection with Lava Lake Road

The Lava Lake Rd. accesses Lava Lake and Little Lava Lake with a lodge, two campgrounds and three dock or boat launch areas. Therefore it appears to be a moderate to major access point relative to the CLH corridor. The intersection was observed to have limited sight distance, especially to the south.

Figure 55 - Lava Lake Rd. Intersection, Limited Sight Distance to North

Figure 56 - Lava Lake Rd. Intersection, Limited Sight Distance to South

Some of the vegetation obstructing the view is smaller, new growth along the foreslope and ditch, and the other vegetation may be mature trees outside the original CLH clearing limits.

A trailhead sign just south of the Lava Lake Rd. intersection was observed to be obstructed by vegetation. For this intersection, a small Trailhead Jct Ahead sign is provided in advance of the intersection from both directions. It may be desirable to increase their size for legibility and note the trail name(s) to provide advance guide-sign information. See Guide Signing for more discussion.

Figure 57 - Trail Head Sign South of Lava Lake Rd. Intersection, Looking South

Figure 58 - Trail Head Jct Ahead Sign South of Lava Lake Rd. Intersection, Looking South

h) Intersection with S. Century Drive

The intersection with CLH and S. Century Drive is one of the major intersections relative to the others in the corridor. WFLHD observed several concerns with this intersection, including a lack of advance guide and wayfinding signage, cluttered guide signs and poor visibility of some of the guide signs.

Approaching the intersection from the north, the first guide sign is located right at the intersection so it is easy to miss or requires a motorist to slow down from 55+mph in order to read the details.

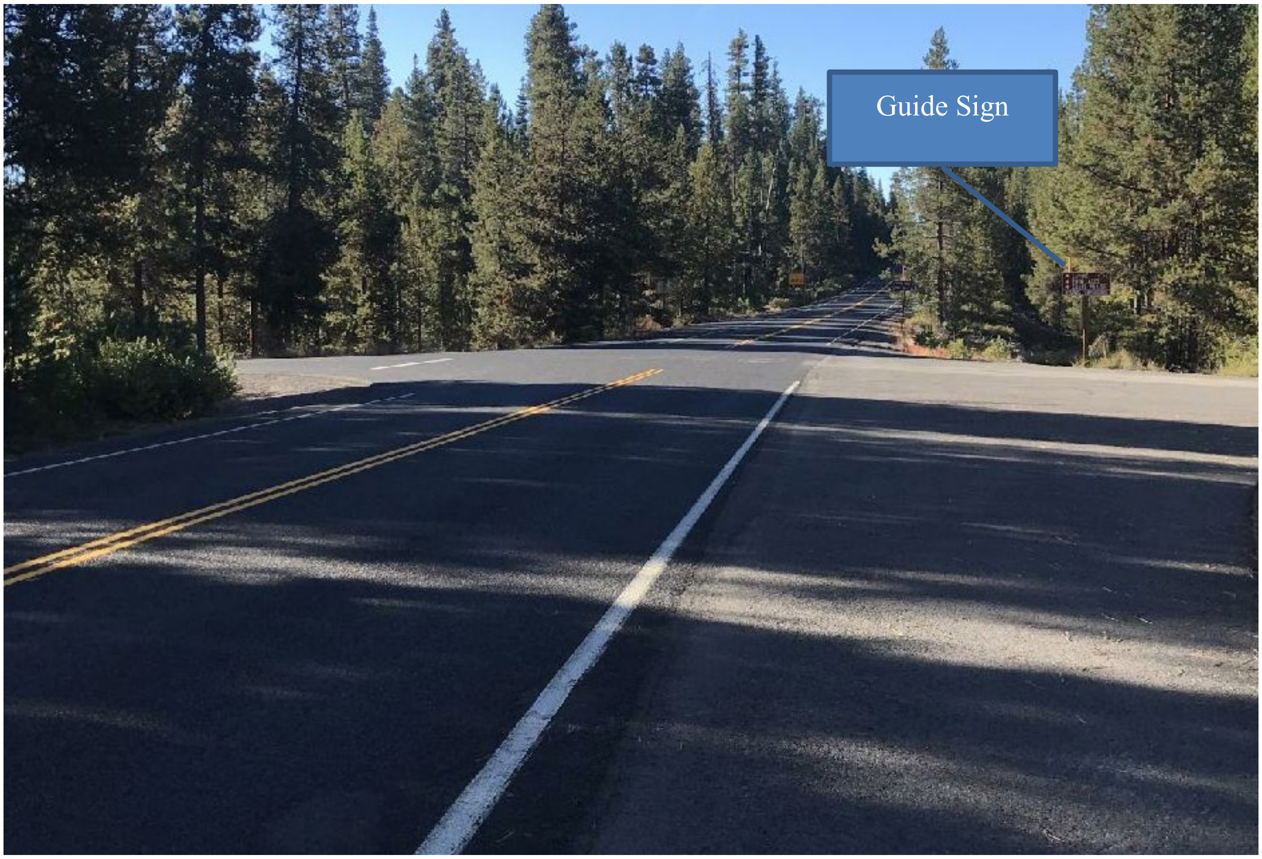

Figure 59 - Intersection with S. Century Dr., North Approach (Approx. 140' north of intersection), Looking South

There is an existing widened area to pullout here if a motorist is unfamiliar with the geography but this sign could be missed or lead to safety concerns with motorists slowing down in the roadway to read signs.

Figure 60 - Sign Assembly at Southwest Quadrant of Intersection with S. Century Dr.

The upper sign on this assembly was found to have 6" letters on the top three destinations and 5" on the "Resorts Campgrounds" line. The bottom sign was found to have 4" letter heights and be 48" x 42" overall.

From the south approach, the main sign assembly at the intersection is blocked by vegetation.

Figure 61 - CLH Intersection with S. Century Dr., South Approach, Looking North

6. Previous Improvements

Some locations throughout the CLH corridor have had improvements constructed in recent years.

a) Bridge and AOP Culvert Replacements

In approximately 1993, an overlay project was constructed from the beginning of this study through the north end of Elk Lake, a 10.7 mile project. This project also included some guardrail, culvert and signing and striping improvements. The WFLHD project number is OR PFH 46-1(4).

In approximately 2000, a second overlay project was constructed from near the south end of Davis Lake (in Klamath County) through the north end of Elk Lake to complete the overlay from the first project. These plans show that the approximately 4’ shoulders from S. Century Dr. to the south were already in place at this time. The WFLHD project number is OR PFH 46-1(5).

The Fall Creek Bridge near the Green Lakes Trailhead parking lot was replaced through the Forest Highway Program in 2017. The bridge was improved to approximately a 36’-6” roadway width (11’ lanes with 5’-7 ½” shoulders) with ODOT three-tube bridge rail and approach guardrail. The WFLHD project number is OR PFH 46(13).

Figure 62 - Recent FHWA Project near Green Lakes Trailhead

In 2016-17, the OR PFH 46(9) project replaced the pipe culverts at Soda Creek with a bridge and a single pipe culvert at Goose Creek with a larger, bottomless reinforced concrete arch culvert.

C. Possible Improvements

Design criteria that relate to highway safety are presented for discussion in relation to CLH. Next, corridor-wide improvements and countermeasures are presented. Finally, site-specific recommendations are presented that build off the overall possible improvements for the corridor. The corridor-wide improvements and countermeasures help to improve safety throughout the corridor. It is believed these improvements would help reduce the crashes that have occurred as well as help reduce future crashes.

1. Design Criteria

Reviewing current design criteria can help gain perspective on the geometric and cross-sectional elements that may be expected for a highway like Cascade Lakes Highway based on its functional classification and traffic.

a) Green Book

The *AASHTO Policy on Geometric Design of Highways and Streets* (Green Book) gives criteria for traveled way width for rural arterials in Table 7-3, which is the functional classification closest to Cascade Lakes Highway. WFLHD recommends a design speed of 60mph which is 5mph over the basic rule speed limit that applies to CLH. For a design speed of 60mph, and any traffic volume, the minimum traveled way width is 24-ft. Beyond the traveled way, shoulders are required according to the Green Book, ranging from 4-ft for under 400 vehicles per day (vpd) to 8-ft for over 2,000 vpd. This gives a range of total roadway width of 32' to 40', obviously a very wide range, with many agencies frequently opting to take documented exceptions to meeting these criteria due to financial, environmental and other constraints in order to meet federal funding requirements.

In addition, highway design methodology is likely shifting over the next five years to be more cognizant of or even require the use of performance-based design to help establish design criteria. This way, the right design features can be provided for the needs of the highway, rather than more of a blanket approach that the Green Book currently provides. This study will look at performance-based tools from a high level perspective. Further study can be done to better analyze the highway improvements from a performance-based perspective.

Design criteria (often called standards) are one important consideration, as they represent a consensus of transportation professionals who have already weighed safety, operations, environmental and financial impacts of these criteria to establish these values. However, the performance and context of an individual road or project is an important consideration as well.

b) ODOT Design Manuals and Bicycle and Pedestrian Plan

The Oregon Bicycle and Pedestrian Plan states that the vision, by 2040, is that

> "In Oregon, people of all ages, incomes, and abilities can access destinations in urban and rural areas on comfortable, safe, well-connected biking and walking routes. People can enjoy Oregon's scenic beauty by walking and biking on a transportation system that respects the needs of its users and their sense of safety. Bicycle and pedestrian networks are recognized as integral, interconnected elements of the Oregon transportation system that contribute to our diverse and vibrant communities and the health and quality of life enjoyed by Oregonians." (Executive Summary, Oregon Bicycle and Pedestrian Plan [OBPP]).

The Executive Summary goes on to mention that Oregon's bicycle tourism industry is growing, which certainly applies to CLH. The plan "recognizes the role of law enforcement agencies in enforcing rules of the road and safe operating rules" and advocates for a focus on evaluation policies and strategies to better analyze safety issues with a robust data collection plan. The plan recognizes that adequate funding is unlikely to be available for the preferred build-out of bicycle facilities. Therefore, a "strategic approach is needed to spend existing resources on the highest need and greatest value investments, leverage what is available, and to identify additional funding sources….The [plan] framework lays out priorities as follows: protect the existing system (e.g. maintenance and preservation) and address significant safety issues; add critical connections (defined in the Plan) and address other safety issues; complete the system (e.g. separation, and bicycle parking); and elaborate the system." (Executive Summary, OBPP).

The Plan states that local jurisdictions must be consistent with the contents of the Plan per Oregon Administrative Rule (OAR) 660-012. An Oregon law that also affects the direction of public agencies' investments in bicycle and pedestrian improvements is the "Bike Bill," or Oregon Revised Statute (ORS) 366.514, which requires "inclusion of facilities for pedestrians and bicyclists whenever a road, street or highway is built, rebuilt, or relocated" (pg. 13, OBPP). However, exemptions are allowed based on safety, cost and absence of need. Justification is required to document the exemptions if needed, with public review and input.

The Plan cites that in 2014, people who rode on Oregon Scenic Bikeways spent over $12 million, which supported 150 jobs, and that there are currently over 1,100 miles of bikeways across the state (pg. 22, OBPP). If CLH was designated a scenic bikeway in conjunction with appropriate facility improvements, in addition to its other scenic byway designations, it stands to reason that bicycle use would increase throughout the corridor. This would likely have positive economic effects in the region.

The Oregon Bicycle and Pedestrian Plan presents a methodology for measuring the Bicycle Level of Traffic Stress (LTS). This is a higher-level assessment than project-specific analysis that may include the Highway Capacity Manual Multimodal Level-of-Service (MMLOS), which requires traffic volume data. Similarly, there is a Pedestrian Level of Traffic Stress (PLTS). The ODOT Analysis Procedure Manual, Version 2, gives the criteria for assessing a roadway for these measures. The manual states that the original methodology was intended for urban areas, however, application of the LTS methodology on rural areas can be performed with shoulder widths and traffic volumes. The LTS Levels range from 1-4, with LTS 1 being least stressful to a bicyclist and LTS 4 being most stressful. For rural areas, due to the higher speeds and motorists being less likely to anticipate bicyclists, the minimum LTS level is 2. According to the Manual, "narrow or no shoulders and higher volumes (leading to increased overtaking conflict opportunities) will increase the stress level. Unless an adjacent separated multi-use path/bike lane is provided (LTS 1), most rural roadways do not have bike lanes and bicyclists will depend on paved shoulders" (pg. 14-19, OBPP). The Manual provides a table (Exhibit 14-11) to evaluate the LTS based on traffic volume and paved shoulder width:

Table 3 - Bicycle Level of Stress (LTS), OBPP Exhibit 14-11

Exhibit 14-11 Rural Segment Criteria with posted speeds 45 mph or greater[1,2,3] Daily Volume (vpd)			**Paved Shoulder Width**	
	0 – <2 ft	**2 - <4 ft**	**4 – <6 ft**	**≥ 6 ft**
<400	LTS 2	LTS 2	LTS 2	LTS 2
400 - 1500	LTS 3	LTS 2	LTS 2	LTS 2
1500 - 7000	LTS 4	LTS 3	LTS 2	LTS 2
> 7000	LTS 4	LTS 4	LTS 3	LTS 3

[1] Based on p1-3 & Table 1-2 from the Oregon Bicycle and Pedestrian Design Guide, 2011.

[2] Adequate stopping sight distances on curves and grades assumed. A high frequency of sharper curves and short vertical transitions can increase the stress level especially on roadways with less than 6' shoulders. Engineering judgment will be needed to determine what impact this will have on the LTS level on a particular segment. Analysis Procedure Manual Version 2 14-20 Last Updated 11/2018

[3] Segments with flashing warning beacons announcing presence of bicyclists (typically done on narrower long bridges or tunnels) may, depending on judgment, reduce the LTS by one, but no less than LTS 2.
[4] Over 1500 AADT, the Oregon Bicycle and Pedestrian Design Guide indicates the need for shoulders.

Currently, the portion of the CLH corridor with the highest congestion, from Elk Lake to the north, likely operates in the LTS 4 category (ADT in the 1,500 to 7,000 vpd range, 0-2' paved shoulders). To the south of Elk Lake, to the S. Century Drive intersection, the LTS may operate in the 2-3 range, depending on traffic on a given day. South of S. Century Drive, due to the 4' shoulders and assumed lower traffic, the LTS is likely a 2, the best available stress level for a rural area.

With possible improvements to the shoulders on the unimproved portion of the route, increasing the shoulder width to 4-6' can improve the LTS from a 4 to a 2, according to this table. Footnote 2 is very important as this table assumes adequate criteria for stopping sight distances is provided. As noted in the Existing Conditions, certain segments of CLH likely contain deficiencies in available sight distance (e.g. horizontal sight distance and intersection sight distance) which may increase the stress levels to the bicyclists in these areas.

For all intersections throughout CLH, the LTS is and will remain level 2 based on the current and future expected traffic volumes and number of lanes.

The LTS analysis can be used to identify deficiencies in a roadway or highway network on a broad scale, especially with a GIS system and in conjunction with other data. For CLH, it gives a broad-stroke perspective on how improvements to shoulder widths could improve comfort for bicyclist rides.

The OBPP Plan lists 6 performance measures to consider to evaluate a highway on page D-2:

- Safety (1): Number of pedestrian fatalities (five-year average): the average annual number of pedestrians killed in crashes with motor vehicles, over a five-year period.
- Safety (2): Number of bicyclist fatalities (five-year average): the average annual number of bicyclists killed in crashes with motor vehicles, over a five-year period.
- Safety (3): Number of pedestrian serious injuries (five-year average): the average annual number of pedestrians seriously injured in crashes with motor vehicles, in a given year.1
- Safety (4): Number of bicyclist serious injuries (five-year average): the average annual number of bicyclists seriously injured in crashes with motor vehicles, in a given year.
- Safety (5): Perceived safety of walking: the percent of the public that feels they have the necessary facilities to walk safely in their neighborhood.
- Safety (6): Perceived safety of bicycling: the percent of the public that feels they have the necessary facilities to bike safely in their community.

These performance measures should be considered by the County to help gauge the performance of their transportation system.

In the ODOT Bicycle and Pedestrian Design Guide, an appendix of the ODOT Highway Design Manual (HDM), Design Standards are given for use on Oregon highways. Local agencies are encouraged to use the dimensions and designs recommended in the Guide. The Guide adopts the AASHTO Guide for the Development of Bicycle Facilities and the AASHTO Guide for the Planning, Design and Operation of Pedestrian Facilities. The ODOT Guide contains some recommendations and best practices that exceed AASHTO or other HDM standards. For the purposes of this plan, the relevant values or recommendations that differ from or exceed AASHTO are presented. Other AASHTO guidance is presented elsewhere in this document.

The Design Guide states that “on rural roads with high bicycle use or demand, roads should include shoulders where motor vehicle speeds and volumes are high” (pg. 1-5, ODOT Bicycle and Pedestrian Design Guide). Table 1-2, from the Guide, provides rural road shoulder widths, shown in Figure 63:

Average Daily Traffic	< 400	400-1500	1500-2000	> 2000
Rural Arterials	4’	6’	6’	8’
Rural Collectors	2’	5’	6’	8’
Rural Local Roads	2’	5’	6’	8’

Figure 63 - Rural Road Shoulder Widths, Table 1-2, ODOT HDM Bike and Pedestrian Design Guide (Table 7-2 in HDM)

ODOT’s TransGIS data indicates that CLH is federally classified as a rural major collector, though Deschutes County indicates that CLH is an arterial. For the varying traffic volumes that CLH experiences, depending on the location in the corridor and time of year or day of week, there will be a range of shoulder widths from 5-8’ recommended, with 2’ shoulders possible on the southern part of the corridor. Better traffic data can help provide better guidance. The most congested portion of the corridor likely falls into the 6-8’ shoulder recommendation. The Design Guide states that if shoulders are provided for bicycle use, 6’ shoulders are recommended to allow the bicyclist to ride far enough away from the edge of pavement to avoid debris along the shoulder edge but also far enough from the traveled way to avoid conflicts. If there are “physical width limitations, a minimum 4 foot shoulder may be used” (pg. 1-8, ODOT Bicycle and Pedestrian Design Guide). The Design Guide also provides a desire to maintain a 6’ shoulder in areas of steep uphill grades. According to the Design Guide, “shoulders wider than 6 feet may be marked as bike lanes in areas of very high use, on high-speed facilities where wider shoulders are warranted, or where they are shared with pedestrians” (pg. 1-11, ODOT Bicycle and Pedestrian Design Guide).

The Design Guide states that shoulder rumble strips should not be used if they leave less than 4’ of rideable space on the shoulder.

The Design Guide references special bicycle-related signs approved for use in Oregon.[4]

The Design Guide references the Guidelines for Administration of Bicycle Racing on Oregon Roads, an older document with some important information on considerations for bicycle racing[5]. With an approval date from 1990, some of the guidance in the document should be reviewed for updates to standards such as the Manual on Uniform Traffic Control Devices (MUTCD).

The ODOT Highway Design Manual (HDM), Section 7.3, presents design standards for 4R or new rural arterial highways. This section references Table 7-2 in the HDM, which gives the same shoulder width standards as shown in Figure 63. In Section 7.3.2.6 Roadside Design, the HDM states that “where a barrier along a roadway is used to shield a roadside obstacle, a 2 foot shy distance from the normal edge of shoulder to the face of barrier should be used. This shy distance maintains the useable shoulder width and provides some additional distance from the traveled way and the barrier” (pg. 7-14, ODOT Highway Design Manual). The Oregon Bicycle and Pedestrian Design Guide states that “shoulders adjacent to a curb face, guardrail or other roadside barriers must be 5 feet wide, as cyclists will ‘shy’ away from a

[4] https://www.oregon.gov/ODOT/Engineering/Documents_TrafficStandards/Sign-Policy-08-Bike-Ped.pdf
[5] https://s3.amazonaws.com/imm-usac-uat-bucket-16e9mh4tuo6kc/documents/ODOT-Guidelines.pdf

vertical face" (pg. 1-8, ODOT Bicycle and Pedestrian Design Guide). Therefore, according to the Design Guide, when using guardrail or at bridge locations, it is preferred to widen the shoulder by an additional 2', regardless of the typical shoulder improvement width (e.g. 4-6' typical shoulders would become 6-8' at areas of vertical barrier). The minimum would be a 5' shoulder, however, according to the Design Guide.

c) AASHTO Roadside Design Guide

The AASHTO Roadside Design Guide (RDG) is an important guide used by highway agencies all over the country to make decisions regarding roadside safety and design. One important concept presented in the RDG is the clear zone concept. According to the RDG, "a clear zone is the unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles. The clear zone includes shoulders, bike lanes, and auxiliary lanes, except those auxiliary lanes that function like through lanes." The RDG's Table 3-1 gives suggested clear zone distances from the edge of traveled way. For CLH, this distance will vary since the foreslopes and ADT vary throughout the corridor. It is estimated that many of the foreslopes throughout the corridor are close to 1:4 or 1:3. A 1:3 slope is considered traversable but not recoverable. A 1:4 or flatter slope is both traversable and recoverable and can be counted as a clear zone per the RDG.

Assuming a design speed of 55mph, foreslopes of 1:4 and a design ADT in the 1,500-6,000 vpd range, this gives a clear zone distance of 24-30'. If a design speed of 60mph is used, the guidelines give a clear zone distance of 32'-40'.

The RDG is a set of guidelines and not design standards or criteria. Some agencies incorporate the guidelines as a set of standards (sometimes with modification of the tabulated values) for their jurisdiction. While they are not considered standards, the clear zone distances are important design aspects and can often be the difference between a severe injury or fatal crash versus an unrecorded crash because the vehicle was able to recover or get back on the roadway and drive off. In 2016, 50% of the national fatalities occurred in rural areas, even though only 30% of the total vehicle miles traveled (VMT) in 2016 were in rural areas[6]. For rural fatal crashes in 2016, 70% of drivers involved were on roadways where the posted speed limit was 55mph or higher, indicating that speed plays a significant role. According to the National Highway Traffic Safety Administration, 37% of passenger vehicle occupants killed in rural areas in 2016 were in vehicles that rolled over. The steepness of the foreslope is a key factor in rollover crashes, further demonstrating the importance of clear zone.

For CLH, the existing clear zone varies due to the foreslopes, objects within the clear zone (trees, parked vehicles, etc.). At some locations as noted in this document, substantial parking occurs along the roadway. This effectively reduces the available existing clear zone from a reasonable distance to several feet or zero in some cases if vehicles are parking right along the edge line. Additionally, during the peak season, and increasingly on non-peak days such as weekdays, the parked vehicles are lined up for thousands of feet. This means that these are not random point hazards (like a single tree within the clear zone) but rather a longitudinal, continuous hazard along the roadway. In the event of an evasive maneuver, a motorist's options are severely reduced when parking occurs along the roadside. At Devils Lake, there is tight horizontal curvature and steep grades, both of which are factors that increase the chance for a roadway departure (RwD) crash. A RwD crash is any crash that occurs when a vehicle leaves its lane (centerline to edge line) and make up the majority of rural crashes. The chances of a motorist leaving the roadway and colliding with parked vehicles is increased at Devils Lake.

[6] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812521

Furthermore, pedestrians walking along the roadway are walking in the theoretical clear zone that is preferred to be reserved for errant vehicles' use. As traffic and pedestrian use increase, the risks for collisions increase.

d) Guide to Bicycle Facilities

The *AASHTO Guide to Bicycle Facilities, 4th Edition* is the major culmination of recent guidance for agencies to develop their bicycle facilities. The guide, in combination with the MUTCD, which sets standards for pavement markings and signage, is referenced here to identify possible improvements for CLH.

Nearly all of the bicyclist trips in the CLH corridor can be considered Recreational Trips, per the Guide to Bicycle Facilities Table 2-1. Trips will include individuals or small groups as well as large groups and official events, as previously described. Most riders will be in the "Experienced and Confident" category (pg. 2-5, AASHTO Guide to Bicycle Facilities [GDBF]). The "Casual and Less Confident" riders are unlikely to feel comfortable riding on CLH, even with possible improvements such as 4-6' shoulders.

According to the Guide, the "purpose of a stand-alone bicycle plan is to identify the projects, policies, and programs that are needed in order to fully integrate bicycling as a viable mode of transportation within a community. Bicycle plans prepared by a state department of transportation (DOT) are often more focused on policy issues, while bicycle plans that are completed by local or regional agencies may focus on bicycle network planning, as well as policies and design practices that support bicycling (pg. 2-6, GDBF).

The Guide goes on state that "A good bicycle plan starts from each community's current stage—some communities may be just beginning ("starting from scratch") while others may be at a more advanced stage. It should address policy, infrastructure, and programming. For a community that is embarking upon bicycle planning for the first time, the focus may be on winning support for initial projects that will generate significant use or result in visible safety improvements, and help to build momentum for subsequent projects." The CLH corridor likely falls into this category since little planning has been done specifically for CLH. Deschutes County has a bicycle master plan in place for the County overall. The Guide advocates for a phasing plan as a strategy to improve conditions for bicycling over time since there are typically numerous constraints to achieving the desired level of improvement. This plan outlines a phasing plan in conjunction with other improvements for the CLH corridor, ranging from short-term to long-term projects. There are several factors to consider for development of the phasing plan:

- Bicycle travel demand
- Route connectivity and directness
- Crash/conflict analysis or potential for crashes
- Barriers to cycling to and beyond the corridor
- Ease of implementation
- System integration

The Deschutes County Transportation System Plan states that "Bikeways shall be designed in accordance with the current standards and guidelines of the State of Oregon Bicycle Master Plan, American Association of State Highway and transportation Officials (AASHTO) Guide for the Development of New Bicycle Facilities, and the Deschutes County Bicycle Master Plan" (pg. 95, Deschutes County Transportation System Plan).

The aforementioned Bikeway Design Standards from the DCC 17.48.050 Table B call for a minimum shoulder bikeway width of 4' with a 4' standard for an open shoulder, 5' with curb or other barrier present and 6' wide for "high use" locations.

Major factors to consider when deciding where improvements are needed for a bicycle transportation network include:

- User needs
- Traffic volumes, vehicle mix and speeds
- Overcoming barriers
- Connection to land uses
- Directness of route
- Logical route
- Intersections
- Aesthetics
- Spacing or density of bikeways
- Safety
- Security
- Overall feasibility
- Context sensitive design

These factors affect how many and what types of cyclists will use bikeway facilities.

1) Facility Types

According to the Guide, the types of possible facility types possible for CLH are listed below:

- Shared lanes (with and without wide outside lanes)
- Marked shared lanes
- Paved shoulders
- Shared use paths

The considerations for which facility type to use is a culmination of experience with data analysis, engineering judgment and budget constraints (pg. 2-16, GDBF). The Guide does not provide "strict rules" for when to choose a shared lane versus a marked shared lane, for example. The Guide lists several considerations to be used to help determine the selection of an appropriate bikeway facility:

- Road functional classification (arterial, collector, etc.)
- Traffic volume
- Speed
- Traffic mix
- Expected user types
- Road conditions
- Driveways or access points
- Topography
- Existing and proposed adjacent land uses
- Cost

Table 2-3 in the Guide outlines general considerations for each facility type. It is acknowledged that a single corridor may employ multiple facility types as needed and where appropriate.

Table 2-3 shows that for shared lanes, with no special provisions such as wider than typical lanes, are best used for minor roads with low volumes and traffic volumes generally less than 1,000 vehicles per day. Part of the CLH corridor may fall under this guidance but the highest-use area certainly exceeds the guidance here, so examining the next categories is important.

According to the Guide, shared lanes, with wide outside lanes, are best used on major roads where bike lanes are not selected due to space constraints or other limitations and are for generally more than 3,000 vehicles per day. These are typically for urban areas since a wide lane in a rural setting is typically striped to have a shoulder.

For marked shared lanes, the MUTCD recommends that the posted speed limit be 35mph or less, so this precludes their use on the CLH corridor since speeds are much higher than 35mph (Section 9C.07, MUTCD).

Table 2-3 describes bikeways on paved shoulders as being typically suitable for rural highway speeds of 40-55mph with a variable amount of traffic volume. Wider shoulders provide more roadway stability and other benefits to motorists.

Finally, of the bikeway types that may be possible for CLH, Table 2-3 describes shared use paths as being best used along greenways in linear corridors or along waterways, freeways, active or abandoned rail lines, utility rights-of-way or unused rights-of-way. It may be a short connection between neighborhoods or intersections or a longer connection between cities. The intended use provides a separated path for non-motorized users and can supplement a network of on-road bike lanes, shared lanes, bicycle boulevards and paved shoulders. The width of the shared path is an important consideration that depends on its users. Finally, a very important consideration for CLH, is that "on-road alternatives may be desired for advanced riders who desire a more direct facility that accommodates higher speeds and minimizes conflicts with intersection and driveway traffic, pedestrians and young bicyclists" (pg. 2-19). As noted elsewhere, the typical cyclists using the CLH corridor are experienced to advanced riders who want to ride with as few conflicts as possible. If a path is constructed in the higher congestion areas in the corridor, it may become a draw for less experienced cyclists and pedestrians that would not likely mix well with expert cyclists. The intermediate to advanced bicyclists that currently use CLH may prefer to use an unimproved CLH roadway over a separated multi-use path.

2) Wayfinding

Wayfinding for bicyclists can be very important for conveying where the bicyclist-designated routes are in a road or highway network. For CLH, wayfinding may not be as important, unless changes to the current use are anticipated. Most cyclists have a purpose for riding up to the CLH corridor and know where they will be riding in advance of their trip. It is possible that the side-attractions (e.g. trailheads, rides around the lakes, resorts) could warrant wayfinding for cyclists as well, but these destinations should be thoroughly signed for motorist users as well, which will also be conveyed to cyclists.

3) Data

There are technical analysis tools available that can help support bicycle planning and infrastructure decisions. However, high-quality data is typically a requisite to support these tools. Currently, there are no counts of bicycle users for the CLH corridor and traffic data is outdated, especially given the aforementioned increase in use throughout the corridor in recent years. Preferably, an agency will have a program in place to continually obtain traffic counts over time to gauge how traffic is changing and aid in planning future improvements. Beyond traffic counts, data can be collected to "analyze specific travel patterns" and monitor "compliance with traffic control devices, use of hand signals and interaction with motorists" (pg. 2-22, GDBF). Furthermore, other useful data can be collected to "analyze equipment trends such as the wearing of helmets and use of front or rear lights and reflectors" which can aid in tailoring education efforts (pg. 2-22, GDBF). Consult the Institute of Transportation of Engineers (ITE) *National Bicycle and Pedestrian Documentation Project* to review best practices for collecting data.

Analysis from tools such as the Highway Capacity Manual and Highway Safety Manual is useful for planning bicycle facilities. Due to a lack of historical data on CLH, in-depth analysis with these tools may not yield confident results. However, related analysis such as Crash Modification Factors (CMFs) can still be used to help gauge the effectiveness of improvements during a time of limited data.

For data-rich agencies, tools such as the *Pedestrian and Bicycle Crash Analysis Tool* (PBCAT) can be used to develop and analyze crash databases.

Finally, understanding bicycle travel demand is an important piece of data but difficult to obtain in many situations. The Guide's Chapter 2.6.5 outlines several methods to obtain this data, however, most are geared towards an analysis of urban growth expansion and the expected increase in bicycle travel demand. In general for CLH, surveys and public engagement may be the best way to gauge how bicyclist use may change or increase with possible improvements.

Crowdsourcing may be another avenue to help identify congestion areas and other areas of concern from a safety perspective. FHWA's Every Day Counts (EDC) innovations include "Use of Crowdsourcing to Advance Operations" which can give agencies ideas for ways to improve the flow of publicly available data relevant to agency operations.[7]

4) Bicycle Operation and Safety

Some key characteristics and criteria from Chapter 3 of the Guide will be summarized here.

The design bicycle for CLH, similar to design vehicles in roadway geometry design, is believed to be a typical road or mountain bicycle. It is assumed that other types of bicycles, such as recumbent and hand, or bicycles with trailers (such as for carrying children), are not to be the prevailing bicycle type expected throughout CLH. Some users are on camping trips or staying at the area resorts, so some cyclists will be carrying paniers or other equipment attached to their bicycle or with a small trailer. These will increase the functional width of the bicyclist with respect to their operating space. According to the Guide, the minimum operating space for a typical bicyclist is 48" and the preferred operating space is 60". The "natural side-to-side movement that varies with speed, wind, and bicyclist proficiency" contributes to the extra lateral space needed than the physical width (generally 30"). Other situations, such as steep grades, may require additional operating width. In general, an additional foot of offset is desired to fixed objects such as guardrail or bridge rails.

According to the Guide, bicyclists are typically considered vehicles in the United States and require that the cyclists follow the same rights and duties as a motorist operating a vehicle. Cyclists typically ride as far to the right as possible and this appears to be the case for cyclists of CLH based on observations.

Listed below are the broad categories of bicyclist-motor vehicle crashes according to the Guide. Understanding the causes of these crashes can assist with mitigation strategies. According to the Guide, "numerous studies of bicycle crashes in the United States conducted over the past 40 years have produced very consistent results" (pg. 3-8, GDBF). Many injury crashes that do not involve a motor vehicle are not included in state DOT crash databases. Additionally, "studies that examined hospital records have demonstrated that the majority (70–90 percent) of bicyclist crashes that are serious enough to warrant a trip to the emergency room are not the result of a collision with a motor vehicle" (pg. 3-8, GDBF). Instead, most of these crashes "result from falls, crashes with fixes objects, and collisions with other bicyclists" (pg. 3-8, GDBF).

- Urban versus Rural areas – Overtaking or being struck from behind represents a large portion of crashes on rural highways, more so than in urban areas. Overtaking crashes in rural areas are often associated with distracted drivers or drivers traveling too fast in areas with limited sight

[7] https://www.fhwa.dot.gov/innovation/everydaycounts/edc_5/crowdsourcing.cfm

distance (around curves or over the crests of hills). Serious and fatal crashes are more likely to occur in rural areas (pg. 3-8, GDBF).

- Youth versus Adult Bicyclists – bicyclists under the age of 15 are overrepresented in bicyclist-motor vehicle crashes. Adults age 25-44 are underrepresented.
- Bicyclist versus Motorist Error – Cyclists were judged to be solely at fault about 50% of the time with failure to yield, riding against traffic and stop sign violations being the most common contributing factors. Older cyclists are generally less likely to be responsible for a crash involving motorists.
- Nighttime versus Daytime – there was a relatively high incidence of crashes that occur at night and dusk, indicating that poor roadway lighting and a lack of required lighting or reflectorization on bicycles are contributing factors.

Listed below are some common contributing causes of bicyclist-motor vehicle crashes from the Guide that could apply to CLH.

- Wrong-way riding – unlikely to occur on CLH but it is possible. Remedies for this behavior include education and enforcement primarily. Additional signing can be installed but this is not likely warranted, as a well-educated bicyclist should know to ride with traffic. However, viewpoints along CLH will certainly lead some cyclists to temporarily cross over to the opposing side of the roadway at times. If used on paved shoulders, the bicycle symbol or “Bike Lane” text with or without arrows can remind cyclists of the required direction. The arrows associated with the marking clue the bicyclist in to the proper location they should be.
- Crashes at driveways, intersections and turnouts – these three categories are combined since the most appropriate treatment for CLH is to provide adequate sight distance for vehicles turning in and out of these approaches. If there’s sight distance for vehicles to see other vehicles, then there is sight distance to see bicyclists as well. Education can be a strategy to inform both motorists and cyclists to watch out for each other when making turns in and out of intersections and turnouts.
- Motorist striking bicyclist with vehicle door (“dooring”) – this occurs when the driver or passengers open doors without checking for approaching bicyclists that are passing the parked vehicle. Currently, due to the parking throughout some of the CLH corridor, this is a significant potential crash cause. Currently, education is an important countermeasure. For future cross-sectional improvements or changes to allowed parking, this is an important consideration. It is important to provide official turnouts with sufficient room for vehicles to park away from the roadway.
- Bicyclists struck from behind – From the Guide, “Overtaking crashes in rural areas are often associated with distracted drivers, or drivers driving too fast in areas with poor visibility (around curves or over the crest of a hill). Serious and fatal crashes are more likely to occur in rural areas” (Pg. 3-8, GDBF). While the specific causes vary (limited sight distance, driving too fast for conditions, motorist failing to pay attention, motorist operation error, road rage leading to risky passing maneuvers, errant bicyclist behavior, etc.), the typical ultimate engineering solution is to add paved shoulders or widen the roadway enough to include bike lanes. Other countermeasures come in the form of education or engineering with appropriate intermittent and judicious signing as well (Share the Road, Bicycle signs, etc., see Signing).
- Night-time riding – nationwide, about a third of total bicyclist crashes occur between 5:00pm and 9:00pm and about a third of the fatalities occur between 6:00pm and midnight. While it is expected that both bicyclist and motor vehicle use drop off substantially during nighttime hours on CLH, some limited use is still likely during these hours. The primary countermeasure is

education to inform bicyclists about the safety benefits of using adequate reflectors, headlights, taillights and reflective clothing and bicycle accessories. Education efforts can also inform the motorist to be extra aware of bicycles with low visibility during these hours. In some jurisdictions, the use of reflectors on bicyclists is required, and can be enforced through laws and ordinances.

- Bicycle crashes involving children – children under the age of 16 tend to be overrepresented in crashes where the bicyclist is deemed at fault. Education and enforcement are the primary countermeasures to help reduce crashes involving children bicyclists. If cross-sectional improvements to CLH are realized, children bicyclists, or more likely young adult bicyclists, may become more prevalent, though the narrow nature of the roadway and high speeds will likely deter most families from seeking the road as a riding destination. Again, education through welcome station staff, kiosks, websites, social media and Forest/County brochures can help portray the realities of CLH.

5) Design of On-Road Facilities

Chapter 4 of the Guide provides an overview of bikeway designs that "facilitate safe and convenient travel for bicyclists on roadways" (pg. 4-1, GDBF). Some of the key considerations for possible bikeway improvements to CLH are described here.

According to the Guide, "to some extent, basic geometric design guidelines for motor vehicles will result in a facility that accommodates on-street bicyclist" (pg. 4-1, GDBF). Roadway design elements such as stopping sight distance, horizontal and vertical alignment, grades and cross slopes that meet or exceed minimum design criteria for motorists will also be adequate for cyclists. Surface condition and pavement smoothness are important to a bicyclist's comfort and control. Chip seals can pose difficulties for bicyclists. Using a finer mix and covering with a fog or slurry seal can be an effective strategy, as currently employed by Deschutes County.

Coordination with other agencies is important to maximize the value provided with on-road bicycle facilities. Forest Service facilities should plan on bike racks and consider adding fix-it stations at major day-use areas. The Forest Service day-use area at Detroit Lake, OR recently completed a project in 2018 to add facilities including a fix-it station.

➢ Shared Lanes

Some of the CLH corridor may remain in its present cross-sectional form for the mid to long-term. Shared lanes may be a very appropriate way for motorists and bicyclists to share the road in many situations. There are no specific designs or dimensions for shared lanes but various design features can make shared lanes more compatible with bicycling and safer for all users. The main features that apply to CLH are providing adequate sight distance and good pavement quality. According to the Guide, "roadways that carry very low to low volumes of traffic, and may also have traffic typically operating at low speeds, may be suitable as shared lanes in their present condition. Rural roadways with good sight distance that carry low volumes of traffic and operate at speeds of 55mph or less may also be suitable as shared lanes in their present condition" (pg. 4-2, GDBF). For some cyclists, a narrow and curving rural road with low traffic volumes can be a preferable route over a high-speed, high-volume highway with good geometrics and shoulders. Some of the CLH corridor may be very suitable to remain in its present form in conjunction with some other improvements as described elsewhere.

Lane widths of 13' or less make it likely that motor vehicles will encroach at least some into the oncoming lane to pass a bicyclist with adequate and comfortable clearance (typically 3'). Relatedly, Oregon state law requires that motorists give enough distance to bicyclists when passing so that if the bicyclists were to fall towards the vehicle, the vehicle would not touch the bicyclist[8]. This law applies for speeds over 35mph.

A strategy to promote safe operations of motorists and bicyclists sharing the road can include the use of signage. See Signing.

- Paved Shoulders

According to the Guide, adding paved shoulders can "greatly improve bicyclists accommodation on roadways with higher speeds or traffic volumes, as well as benefit motorists" (pg. 4-7, GDBF). With respect to bikeways, there are key differences between bike lanes and paved shoulders. Bike lanes are travel lanes while paved shoulders are not. Paved shoulders typically can be used for parking and provide a place for disabled vehicles. According to the Guide, paved shoulders should be at least 4' wide to accommodate bicyclists and widths of 5' are recommended from the face of guardrail, bridge rail or any other vertical face (such as curbs). It is "desirable to increase the width of shoulders where higher bicycle usage is expected. Additional shoulder width is also desirable if motor vehicle speeds exceed 50mph; if use by heavy trucks, buses, or recreational vehicles is considerable; or if static obstructions exist at the right side of the roadway" (pg. 4-7, GDBF). The bicycle LOS model may be used to determine the appropriate shoulder width.

The Guide recommends providing paved shoulders on both sides of two-way highways, however, in constrained locations where pavement width is limited, it may be preferable to provide a wider shoulder on only one side of the highway instead of providing narrow shoulders on both sides. This may be beneficial on uphill roadway sections to give slow-moving bicyclists more space to reduce potential conflicts with faster moving vehicular traffic. This may also be a strategy on roadway sections with vertical or horizontal sight distance concerns. Shoulders, or wider shoulders, could be provided over the crest of vertical curves and on the inside of horizontal curves.

If rumble strips are used in conjunction with shoulder widening on CLH, the remaining clear area outside of the rumble strips within the shoulder should be a minimum of 4'. The 5' clearance to vertical obstacles such as guardrail should be maintained as well from the edge of the rumble strip, which would mean a 6' shoulder is needed at these locations. Periodic gaps in rumble strips should be provided so that cyclists can avoid debris in the shoulder, pass other cyclists, make left turns, etc. Typically this gap is 12' and is spaced at 40-60' intervals. Longer gaps should be provided on steep downgrades due to faster-moving bicyclists. The Guide also recommends that the rumble strips be 5" wide, 3/8" deep and on 11-12" center-to-center spacings. If centerline rumble strips are used, the Guide recommends that shoulder rumble strips only be used where a full-width paved shoulder of 6' or more is provided, due to concerns that motorists may shy away from using the opposing lane for passing cyclists due to the centerline rumble strips.

The Guide describes situations where retrofitting existing highways for bicycle facilities can be flexible to accommodate conditions and factors beyond the scope of the Guide. Where possible, when providing for bicyclists, the minimum paved shoulder widths should be used. However, if the preferred widths cannot be provided, it is generally preferable in retrofit situations to provide 3-4' paved shoulder than to provide a narrower paved shoulder. For example, if a 14' lane is available, a retrofit situation may call for a 10-11' lane with a 3-4' paved shoulder. By contrast, providing a 12' travel lane and 2' shoulder provides limited space to ride. Much of the CLH corridor already has 11' lanes and at least 1-2' paved shoulders, so the logical next step in a pavement action is to increase the shoulder width to at least 4', negating this retrofit scenario.

[8] https://www.oregonlaws.org/ors/811.065

Widening the roadway to add paved shoulders to accommodate cyclists should also be weighed against the likelihood that vehicle speeds will increase in conjunction.

When widening existing pavement, techniques should be considered to locate the joint so that it is not placed in the shoulder where bicyclists ride.

- Shared Use Paths

According to the Guide, shared use paths can serve a variety of purposes and travel modes but should not be used to preclude the use of on-road bicycle facilities. Instead, they should complement bikeways on the roadway network. Given this, and the lack of existing on-roadway bikeway facilities for CLH as well as concerns with maintaining such a path, they will likely be excluded from options considered in this document.

Usable width and clearance for a shared use path are the primary design considerations for shared use paths. The appropriate width is dependent on the context, volume and mix of users. Minimum values for paved with are typically 10’ for two-way traffic but typically range from 10-14’. The wider values may be needed in areas with high use or a wider variety of users.

Since shared paths are almost always used by pedestrians, they need to meet the requirements of the Americans with Disabilities Act (ADA). The grades along some of the CLH corridor would make this accommodation challenging in these areas.

Another challenge with using shared use paths is that they will be constructed on only one side of the highway, so getting users to the path may result in more crossings across CLH than were occurring before the path was constructed. For this reason as well, sidepaths, which are constructed closer to the roadway with some separation (5’ or more is recommended), would present issues with users crossing CLH in order to access the sidepath since there would be two-way traffic riding along it. Shared use paths may also attract equestrian use or all-terrain vehicles, which is not recommended to be mixed with bicycle traffic. Special care is needed at intersections due to the two-way traffic on the shared use path which may violate motorist’s expectations.

2. Geometric Improvements

a) Horizontal Geometry

Several horizontal curves are below the 2011 AASHTO Green Book criteria for a 55mph design speed. For a max superelevation rate of 6% or 8%, the Green Book tables give a radius of 1,060’ and 960’, respectively. For a 60mph design speed, and max superelevation rate of 6% or 8%, the Green Book tables give a radius of 1,330’ and 1,200’, respectively. For an example, the horizontal curve near Devils Lake is approximately 401’. Assuming full superelevation exists on the roadway throughout the curve, this geometry would meet a 35mph design speed for this curve. A 60mph design speed would be recommended for Cascade Lakes Highway overall, but there may need to be exceptions for specific areas to avoid impractical impacts. Reducing the design speed to 55mph or 50mph may be acceptable in conjunction with other countermeasures.

Improving (enlarging) substandard horizontal curves is traditionally seen as an improvement to highway safety, where motorists (vehicles, motorcycles, trucks) are the primary beneficiary. Crash modification factors are available to help gauge the level of improvement to various crash types and users. Some crash modification factors are available to gauge the benefits to vehicle-bicycle crashes as well as pedestrians (typically more for urban applications). The crash modification factor (CMF) for the current curve near Devils Lake is calculated to be approximately 1.53, which indicates a 53% increase in all crash types and severities when compared to more average curves. This is based on the CMF in Equation 10-13 from the Highway Safety Manual.

As an example, an improvement to the horizontal curvature can be analyzed with this simple CMF. If an offset alignment was a viable option here, the existing 401' radius curve could be replaced with a new alignment containing two horizontal curves, with radii of approximately 1,650' and 1,450'. This would result in CMFs of 1.08 and 1.15 for these curves, respectively, which is a significant reduction from the existing CMF. Further, more detailed analysis would be needed to evaluate the difference in the expected number of crashes that would occur over the lifetime of the project (typically 20 years).

Substantial changes to the horizontal alignment throughout the CLH corridor may not be viable due to factors such as cost and environmental impacts. Much of the horizontal alignment is near recommended values per AASHTO, or exceeds these values. However, for the Devils Lake area, this option should not be ruled out as it would help solve several issues with the existing conditions. Furthermore, what is traditionally seen as an improvement to one mode of transportation, such as how enlarging a horizontal curve radius is shown to improve safety for motorists driving the curve, there are secondary implications that must be considered. Improving the horizontal alignment can cause motorist speeds to increase their speeds when compared to the existing conditions. In other words, a curvilinear alignment can help serve to keep speeds lower, which may be more conducive to bicycle comfort. Another tradeoff, however, is that enlarging a curve radius typically increases the horizontal sight distance for motorists, which would also serve as a safety benefit to cyclists so that motorists can adequately see them and adjust speed and position on the roadway accordingly.

These tradeoffs need to be considered and weighed. There are no all-encompassing objective tools available to weigh these tradeoffs, so engineering judgment is needed. It is likely that improving curve radii, increasing horizontal sight distance and increasing the shoulder width significantly outweighs the downside of possible increased speeds throughout the corridor. Furthermore, strategies to keep speeds as intended can be employed, such as keeping lanes narrower at 11' rather than 12' per Green Book criteria.

b) Vertical Geometry

During the field review, there were some areas where the available stopping sight distance may not meet current criteria for a 60mph design speed. Further evaluation would be needed at these locations, but overall, there are not major concerns with the existing vertical geometry along CLH with respect to sight distance.

Areas of steep terrain, such as the 7-9% grades near the Green Lakes to Todd Lake segment, would likely remain in any major reconstruction project. Some flattening to a more mild grade, such as 7%, may be possible in some areas. As discussed elsewhere, the likely preferred countermeasure, rather than flattening grades, is to widen the shoulder for bicycle and motorist use in these locations.

c) Shoulder Width

As noted previously, much of the corridor currently has 1-2' paved shoulders. When looking at improvements to wider shoulders, research can help gauge the degree of difference with respect to predicted crashes. Table 4 shows the CMFs from the Highway Safety Manual for paved shoulder widths:

Shoulder Width	CMF	Improvement from 1' (Crash Reduction)	Improvement from 2' (Crash Reduction)
Existing Shoulder Width (1')	1.23	--	--
Existing Shoulder Width (2')	1.17	--	--
Widened Shoulder (4')	1.09	11%	7%
Widened Shoulder (5')	1.04	15%	11%
Widened Shoulder (6')	1.00	19%	15%
Widened Shoulder (8')	0.93	24%	21%

Table 4 - Shoulder Width CMFs from the Highway Safety Manual

The existing 1-2' shoulders increase the chances of crashes by 17-23% over the base conditions, which the Highway Safety Manual defines as 6' paved shoulders. This is why the CMF for the 6' shoulder is 1.00. These CMFs apply to all crash types and all severities for vehicular crashes. Shoulder width has a more substantial effect on specific crashes that are more attributable to the lack or presence of a shoulder, such as single-vehicle run-off-the-road (roadway departure or RwD) and multiple vehicle head-on, opposite-direction sideswipe and same-direction sideswipe crashes. These crashes make up approximately 57.4% of the default distribution of crash types based on the research in the Highway Safety Manual. For rural areas, shoulder width is one of the most important geometric characteristics.

In more advanced analysis, with better availability of data and cost estimates of specific highway alternatives, benefit/cost ratios can be calculated to help drive project decisions. Using a 3R spreadsheet tool developed by NCHRP Project 15-50, "Guidelines for Integrating Safety and Cost-Effectiveness into Resurfacing, Restoration, and Rehabilitation (3R) Projects," this Plan has estimated high level costs in order to help compare among geometric and safety-feature alternatives. The costs are not intended to be taken as programmatic estimates. Benefit/cost ratios are difficult to calculate for highways that are subject to extremely seasonal variations in traffic, such as CLH. Still, the benefit/cost ratios can be compared among alternatives to gain insight on the most cost effective options from a safety and economic standpoint. Typically, 3R projects are primarily for maintaining existing pavement, but safety improvements often can fit in to these types of projects. The widening of shoulders from 1-2' to 4-6' may be considered more of a reconstruction project (4R), but the analysis from these tools can still apply to help determine the best use of dollars to improve safety.

The effects of lane width and shoulder width with respect to frequency of bicycle crashes has been studied but only in urban areas at this time. Some lower-quality studies (meaning the correlation may have not been as strong, smaller data sets, etc.) indicate increasing the lane width by 1' can decrease all bicycle crashes (all severities) by 36%, again in urban areas[9]. The same study showed a 48% reduction in fatal and serious injury crashes by increasing the lane width by 1'[10]. Another study examined the effects of widening shoulders in urban areas on principal arterials. The study abstract states that in general, widening lanes, bicycle lanes, medians and shoulder widths resulted in a reduction in crashes up to certain limits. For traveled lanes, the limit of effectiveness was 12' lanes. For lanes wider than 12', there were mixed results for reducing bicycle crashes. Crash rates decrease for wider bicycle lanes up to 6' but then

[9] http://www.cmfclearinghouse.org/detail.cfm?facid=9239
[10] http://www.cmfclearinghouse.org/detail.cfm?facid=9242

increase for bicycle lanes greater than 6'. For shoulder widths, this study created functions for the CMFs, shown for various improvements and severities in Table 5[11]:

		CMF Calculated from Existing Shoulder Width	
CMF Type	Improved Shoulder Width	1	2
CMF (Total)	4	0.82	0.87
CMF (K, A, B, C)	4	0.82	0.87
CMF (K,A,B)	4	0.83	0.88
CMF (Total)	5	0.76	0.82
CMF (K, A, B, C)	5	0.76	0.82
CMF (K,A,B)	5	0.78	0.83
CMF (Total)	6	0.71	0.76
CMF (K, A, B, C)	6	0.71	0.76
CMF (K,A,B)	6	0.73	0.78

Table 5 - CMFs for Bicycle Crashes for Shoulder Widths on Urban Arterials (Park et al, 2016)

As shown in the table, an improvement from 1' or 2' shoulders to 4', 5' or 6' shoulders results in reductions of crashes by 18%, 24% and 29%, respectively, for total bicycle-motorist crashes of all severities. There is not much of a difference from the total crash CMF by severity when compared to the K, A, B, C or K, A, B CMFs since most crashes involving a bicyclist result in an injury (non-Property Damage Only). These are substantial improvements for the context in study. The study was on principal arterials in urban areas, with speeds ranging from 20-65mph, with 2-8 lanes and an AADT range of 1000 to 94,500 vehicles per day in Florida.

Any connections to what could be expected for CLH based on this analysis is speculative but some assumptions can be presented. It is unlikely that the CMFs would be this low for a rural, two-lane highway like CLH with low to moderate traffic. The crash history indicates that there have been no vehicle-bicycle crashes in the time period analyzed (but close calls are cited). Furthermore, it is difficult to fully assess what the potential reduction could be without bicycle traffic data.

As shown in the 3R analysis, Oregon values a K crash (fatality) the same as an A crash (serious injury). Adjusted for inflation, the costs associated with these crashes are $974,400 each. Therefore, the occurrence of K and A severity crashes greatly impacts the benefit/cost ratio for proposed improvements. In other words, an improvement that eliminates several K or A severity crashes over its design life can add up quickly on the benefit side, making the cost effectiveness of improvement more positive.

3. 3R Analysis Results for Ultimate Cross-Sectional Improvements on Existing Alignment

The results from the 3R spreadsheet analysis from the NCHRP Project 15-50 are shown for all eight sections of the CLH corridor. Some key assumptions are listed below, with a complete list of assumptions, input and the raw results in Appendix D.

[11] http://www.cmfclearinghouse.org/study_detail.cfm?stid=476

- Only the results from Improved Shoulder Width values of 4’, 5’ and 6’ are shown. Shoulder widths of 2’ and 3’ do not meet bicycle needs for the corridor. Shoulder widths of 7’ or 8’ are assumed to be beyond the scope of ultimate improvements. For reference, the ODOT state highway leading to Mt. Bachelor has 6’ shoulders and more traffic than CLH.
- Higher traffic values are used for Sections 1-6 (ending at Elk Lake). For Sections 7 and 8, the lower traffic projections are used due to less use south of Elk Lake.
- This 3R analysis does not consider the bicycle traffic variable that is a major mode for the corridor. The analysis follows Part C of the Highway Safety Manual, which contains a default crash distribution. The default crash distribution, based on the research that helped form the equations and procedures in the Highway Safety Manual, shows that vehicle-bicycle crashes make up 0.2% of the default proportion. For CLH, it can be assumed that this would likely be higher in a significant time period. From the available crash data, there have been no known vehicle-bicycle crashes to date, however, past crash data does not predict future crashes. With the high bicycle use throughout the corridor, it is likely this proportion would be higher. Without adequate data, this default distribution should not be altered beyond HSM defaults. The crash severity distribution and calibration factor (related to the default safety performance function) were also unaltered for this analysis due to a lack of data for the CLH corridor. For reference, the ODOT calibration factor for two-lane, rural, undivided highways was 0.74 according to information from 2016. This means that for Oregon two-lane rural highways, the research shows that these highways experienced 26% less crashes than the national data set used for the Highway Safety Manual. This could mean that proposed improvements will have a smaller aggregate effect on the reduction of crashes for rural highways, including CLH. However, since CLH would not have been part of the research for that calibration factor, its effects are excluded from this study.
- The alternatives including a 4’ shoulder with shoulder rumble strips were excluded since shoulder rumble strips (and likely edge line rumble strips) are not viable for bicyclists using a 4’ paved shoulder. To use shoulder rumble strips, a minimum shoulder width of 5’ is assumed.
- This analysis assumes no modifications to the horizontal or vertical alignment. Typically, 3R projects do not deviate from the existing alignment except for minor modifications or improvements. Improving the shoulder width from an existing 1-2’ to 5-6’ for example, may push the project into a reconstruction category in some views. Regardless of the type of project, the analysis here with respect to these improvements is still valid. For any significant offset alignment that may be proposed, there would be additional costs beyond the assumed values for this 3R analysis.
- A maintenance action on the existing roadway in conjunction with the improvements is assumed to be included (2” mill, 2” inlay), however, the cost for this is excluded from the analysis per the NCHRP Report since the analysis is geared towards looking at additional items to include with a regular maintenance project.
- The benefit/cost (B/C) ratios are valid to compare relative to each other within the Sections. Using estimated seasonal ADT for this analysis inflates the B/C ratio since there is no traffic for a significant portion of the year and the cost for improvements remains the same.
- The existing 11’ lanes will remain. Improving to 12’ is not as important as improving the shoulder widths. Improving shoulder width by an additional foot rather than increasing the lane width to 12’ can be shown to be a neutral change with respect to motorist safety, and arguably improves the bicyclist safety on the shoulder for a larger overall safety effect.
- Adding delineators at the roadway edge is included in the “Improve Striping/Delineation” improvement.
- The costs include pavement costs and costs of specific improvements (rumble strips, delineators, etc.) as well as incidentals for drainage, erosion control, traffic control signing and pavement markings. The Total Cost shown for each option is the construction cost for the entire Section, not a per-mile cost. A full list of assumptions are available in Appendix D.

a) Section 1

The top 10 combinations are shown in Table 6:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/Delineation	Total Benefit	Total Cost
-$409,201	0.365	11	5	1V:4H	Yes	Yes	Yes	$234,824	$644,025
-$451,949	0.353	11	6	1V:4H	Yes	Yes	Yes	$247,092	$699,041
-$484,385	0.344	11	5	1V:6H	Yes	Yes	Yes	$253,597	$737,982
-$384,764	0.338	11	4	1V:4H	Yes	No	Yes	$196,318	$581,081
-$423,219	0.338	11	5	1V:4H	No	Yes	Yes	$215,851	$639,070
-$527,907	0.334	11	6	1V:6H	Yes	Yes	Yes	$265,090	$792,998
-$465,184	0.330	11	6	1V:4H	No	Yes	Yes	$228,902	$694,086
-$426,472	0.330	11	5	1V:4H	Yes	No	Yes	$209,626	$636,097
-$468,180	0.323	11	6	1V:4H	Yes	No	Yes	$222,934	$691,113
-$457,515	0.322	11	4	1V:6H	Yes	No	Yes	$217,523	$675,038

Table 6 - Section 1 3R Analysis Results (Top-10)

It can be seen that the 5' shoulders, 1:4 slopes (no improvement over existing), with centerline and shoulder rumble strips and high-visibility/durable pavement markings had the highest B/C ratio.

The existing sideslopes along Section 1 were assumed to be 1:4. A typical with 1:4 is likely adequate in this low-fill section but flattening to 1:6 is desirable if it can fit in the budget.

b) Section 2

The top 10 combinations are shown in Table 7:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/ Delineation	Total Benefit	Total Cost
-$1,613,811	0.193	11	5	1V:3H	Yes	Yes	Yes	$385,689	$1,999,500
-$1,715,764	0.191	11	6	1V:3H	Yes	Yes	Yes	$405,838	$2,121,603
-$1,638,270	0.178	11	5	1V:3H	No	Yes	Yes	$354,527	$1,992,796
-$1,738,937	0.178	11	6	1V:3H	No	Yes	Yes	$375,962	$2,114,899
-$1,744,718	0.173	11	6	1V:3H	Yes	No	Yes	$366,159	$2,110,877
-$1,644,473	0.173	11	5	1V:3H	Yes	No	Yes	$344,301	$1,988,774
-$1,544,228	0.173	11	4	1V:3H	Yes	No	Yes	$322,443	$1,866,672
-$1,986,645	0.171	11	5	1V:4H	Yes	Yes	Yes	$410,099	$2,396,744
-$2,089,606	0.170	11	6	1V:4H	Yes	Yes	Yes	$429,241	$2,518,846
-$2,111,284	0.160	11	6	1V:4H	No	Yes	Yes	$400,859	$2,512,143

Table 7 – Section 2 3R Analysis Results (Top-10)

It can be seen that the 5' shoulders, 1:3 slopes (no improvement over existing), with centerline and shoulder rumble strips and high-visibility/durable pavement markings had the highest B/C ratio.

Flattening to 1:4 slopes is highly desired if the additional ~$400k could be spent. 1:3 slopes are traversable but not recoverable. Section 2 contains some high, steep fill slopes, so accommodating 1:4 slopes may be prohibitive for economic, environmental or slope stability concerns. Instead, guardrail could be used for a significant part of this section. A larger fill height value was used in the 3R analysis to try to account for some additional costs for walls, special cut requirements and guardrail in the results above.

c) Section 3

The top 10 combinations are shown in Table 8:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/ Delineation	Total Benefit	Total Cost
-$19,568	0.875	11	5	1V:6H	Yes	Yes	Yes	$136,869	$156,437
-$19,721	0.853	11	4	1V:6H	Yes	No	Yes	$114,425	$134,146
-$31,444	0.821	11	6	1V:6H	Yes	Yes	Yes	$144,020	$175,464
-$28,586	0.815	11	5	1V:6H	No	Yes	Yes	$125,811	$154,397
-$30,991	0.798	11	5	1V:6H	Yes	No	Yes	$122,182	$153,173
-$30,172	0.772	11	4	1V:6H	No	No	Yes	$101,934	$132,106
-$40,006	0.769	11	6	1V:6H	No	Yes	Yes	$133,418	$173,424
-$42,261	0.755	11	6	1V:6H	Yes	No	Yes	$129,939	$172,200
-$40,947	0.729	11	5	1V:6H	No	No	Yes	$110,186	$151,133
-$51,722	0.696	11	6	1V:6H	No	No	Yes	$118,438	$170,160

Table 8 - Section 3 3R Analysis Results (Top-10)

It can be seen that the 5' shoulders, 1:6 slopes (no improvement over existing), with centerline and shoulder rumble strips and high-visibility/durable pavement markings had the highest B/C ratio.

This section of CLH is relatively straightforward as it is on a tangent with low-fill and generally flat side slopes. There is a bridge towards the end of the section with approximately 5'-7" shoulders that may need modified to fully accommodate bicyclists. This cost is not reflected in Table 8 but is accounted for in the estimate in Overall 3R Analysis Discussion.

d) Section 4

The top 10 combinations are shown in Table 9:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/ Delineation	Total Benefit	Total Cost
-$1,217,635	0.222	11	5	1V:3H	Yes	Yes	Yes	$347,191	$1,564,826
-$1,295,055	0.220	11	6	1V:3H	Yes	Yes	Yes	$365,329	$1,660,385
-$1,240,440	0.205	11	5	1V:3H	No	Yes	Yes	$319,139	$1,559,580
-$1,316,703	0.204	11	6	1V:3H	No	Yes	Yes	$338,436	$1,655,139
-$1,322,380	0.200	11	6	1V:3H	Yes	No	Yes	$329,611	$1,651,991
-$1,246,498	0.199	11	5	1V:3H	Yes	No	Yes	$309,935	$1,556,432
-$1,170,615	0.199	11	4	1V:3H	Yes	No	Yes	$290,258	$1,460,873
-$1,506,548	0.197	11	5	1V:4H	Yes	Yes	Yes	$369,165	$1,875,712
-$1,584,875	0.196	11	6	1V:4H	Yes	Yes	Yes	$386,396	$1,971,271
-$1,605,178	0.184	11	6	1V:4H	No	Yes	Yes	$360,847	$1,966,025

Table 9 - Section 4 3R Analysis Results (Top-10)

It can be seen that the 5' shoulders, 1:3 slopes (no improvement over existing), with centerline and shoulder rumble strips and high-visibility/durable pavement markings had the highest B/C ratio.

Flattening the sideslopes to 1:4 or flatter is also desired if the additional ~$300k could be fit into the budget. This section contains a mix of low-fill and high-fill areas as well as through-cut areas. Slope flattening could be achieved in the lower-impact areas with solutions such as guardrail in other areas. A higher fill value was used in the analysis to account for intricate solutions that may be required.

e) Section 5

The top 10 combinations are shown in Table 10:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/ Delineation	Total Benefit	Total Cost
-$574,712	0.451	11	5	1V:6H	Yes	Yes	Yes	$472,020	$1,046,732
-$659,903	0.429	11	6	1V:6H	Yes	Yes	Yes	$496,680	$1,156,583
-$524,543	0.429	11	4	1V:6H	Yes	No	Yes	$394,618	$919,161
-$601,774	0.419	11	5	1V:6H	No	Yes	Yes	$433,883	$1,035,657
-$607,643	0.409	11	5	1V:6H	Yes	No	Yes	$421,369	$1,029,012
-$685,391	0.402	11	6	1V:6H	No	Yes	Yes	$460,117	$1,145,508
-$690,743	0.393	11	6	1V:6H	Yes	No	Yes	$448,119	$1,138,863
-$556,545	0.387	11	4	1V:6H	No	No	Yes	$351,541	$908,086
-$637,938	0.373	11	5	1V:6H	No	No	Yes	$379,999	$1,017,936
-$719,331	0.362	11	6	1V:6H	No	No	Yes	$408,457	$1,127,787

Table 10 - Section 5 3R Analysis Results (Top-10)

It can be seen that the 5' shoulders, 1:6 slopes (no improvement over existing), with centerline and shoulder rumble strips and high-visibility/durable pavement markings had the highest B/C ratio.

f) Section 6

The top 10 combinations are shown in Table 11:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/ Delineation	Total Benefit	Total Cost
-$191,895	0.681	11	5	1V:4H	Yes	Yes	Yes	$409,761	$601,656
-$218,205	0.670	11	5	1V:6H	Yes	Yes	Yes	$442,519	$660,724
-$142,722	0.669	11	5	1V:6H	Yes	Yes	No	$289,072	$431,794
-$126,757	0.660	11	5	1V:4H	Yes	Yes	No	$245,969	$372,726
-$225,413	0.657	11	6	1V:4H	Yes	Yes	Yes	$431,168	$656,581
-$171,259	0.648	11	6	1V:6H	Yes	Yes	No	$315,461	$486,720
-$253,075	0.646	11	6	1V:6H	Yes	Yes	Yes	$462,574	$715,649
-$153,515	0.641	11	6	1V:4H	Yes	Yes	No	$274,137	$427,651
-$195,302	0.637	11	4	1V:4H	Yes	No	Yes	$342,568	$537,870
-$217,368	0.636	11	4	1V:6H	Yes	No	Yes	$379,570	$596,938

Table 11 - Section 6 3R Analysis Results (Top-10)

It can be seen that the 5' shoulders, 1:4 slopes (no improvement over existing), with centerline and shoulder rumble strips and high-visibility/durable pavement markings had the highest B/C ratio.

This is a windy section along Elk Lake that had a higher crash rate, making the improvements more effective (higher B/C ratios). Improving the slopes to 1:6 is desired if the additional ~$60k could be afforded.

g) Section 7

The top 10 combinations are shown in Table 12:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/ Delineation	Total Benefit	Total Cost
-$2,363,993	0.443	11	5	1V:4H	Yes	Yes	Yes	$1,878,508	$4,242,501
-$2,070,569	0.432	11	4	1V:4H	Yes	No	Yes	$1,574,361	$3,644,930
-$2,752,963	0.426	11	5	1V:6H	Yes	Yes	Yes	$2,042,916	$4,795,879
-$2,440,329	0.419	11	4	1V:6H	Yes	No	Yes	$1,757,979	$4,198,308
-$2,801,615	0.411	11	6	1V:4H	Yes	Yes	Yes	$1,955,450	$4,757,066
-$2,478,272	0.409	11	5	1V:4H	No	Yes	Yes	$1,712,350	$4,190,622
-$2,501,668	0.399	11	5	1V:4H	Yes	No	Yes	$1,657,826	$4,159,494
-$3,195,444	0.398	11	6	1V:6H	Yes	Yes	Yes	$2,114,999	$5,310,443
-$2,856,747	0.398	11	5	1V:6H	No	Yes	Yes	$1,887,253	$4,744,000
-$2,876,699	0.390	11	5	1V:6H	Yes	No	Yes	$1,836,173	$4,712,872

Table 12 - Section 7 3R Analysis Results (Top-10)

It can be seen that the 5' shoulders, 1:4 slopes (no improvement over existing), with centerline and shoulder rumble strips and high-visibility/durable pavement markings had the highest B/C ratio.

This is a relatively mild section of alignment. Improving the slopes to 1:6 is desired if the additional ~$60k could be afforded.

h) Section 8

The top 10 combinations are shown in Table 13:

Net Benefit	B/C Ratio	Improved Lane Width (ft)	Improved Shoulder Width (ft)	Improved Slope	Install Centerline Rumble Strip	Install Shoulder Rumble Strip	Improve Striping/ Delineation	Total Benefit	Total Cost
$91,481	4.531	11	4	1V:6H	Yes	No	No	$117,391	$25,910
-$36,177	0.939	11	4	1V:6H	Yes	No	Yes	$558,783	$594,959
-$99,484	0.825	11	4	1V:6H	No	No	Yes	$469,565	$569,049
-$1,401,010	0.335	11	5	1V:6H	Yes	Yes	Yes	$705,008	$2,106,018
-$1,621,011	0.314	11	6	1V:6H	Yes	Yes	Yes	$741,999	$2,363,011
-$1,454,983	0.301	11	5	1V:6H	No	Yes	Yes	$625,124	$2,080,107
-$1,465,651	0.290	11	5	1V:6H	Yes	No	Yes	$598,910	$2,064,561
-$1,672,624	0.284	11	6	1V:6H	No	Yes	Yes	$664,477	$2,337,100
-$1,682,516	0.275	11	6	1V:6H	Yes	No	Yes	$639,038	$2,321,554
-$1,526,396	0.251	11	5	1V:6H	No	No	Yes	$512,254	$2,038,650

Table 13 - Section 9 3R Analysis Results (Top-10)

It can be seen that the 4' shoulders, 1:6 slopes (no improvement over existing), with centerline rumble strips only had the highest B/C ratio.

The shoulders would have to be widened to 5-6' to be able to use shoulder rumble strips. Increasing the shoulder width and using both rumble strip countermeasures and the improved striping/delineation countermeasures greatly increases the Total Benefit but are not nearly as cost effective as the top three options that do not widen the shoulder from the 4' width. Since traffic should be the lowest on this section, including bicycle traffic, further widening the shoulders is not likely practical.

4. Overall 3R Analysis Discussion

The results from this analysis show no or slightly diminishing returns with shoulder widths greater than 5'. Improving shoulder widths to 6' or more slightly lowers the B/C ratio for each additional foot in shoulder width. Therefore, with respect to this specific analysis, a 5' shoulder width is the best option, in conjunction with several other improvements (rumble strips and improved striping/delineation) for Sections 1-7. Section 8, with existing 4' shoulders, is the exception due to already having wider shoulders. Widening the shoulders on Section 8 by 1-2' isn't likely a practical option. As discussed above, vehicular and bicycle traffic is likely much lower on this section than other sections farther north and is less of a priority.

Again, the inherent improvements to vehicle-bicycle conflicts with a 4-6' shoulder are not fully captured in this 3R analysis. See Shoulder Width for more discussion. Additionally, the operational and "level of stress" effects of a 4', 5' and 6' shoulder for bicyclists is not taken into account with this analysis. These are important considerations that are difficult to objectify.

Table 14 shows the overall 3R cost estimate with the highest benefit/cost improvements for each section, in 2018 dollars. The totals assume a 4', 5' or 6' shoulder for the entire CLH corridor, which is not likely preferred. See Recommendations for the possible specific improvement options.

Overall 3R Cost Estimate			
Section	Highest B/C for 4' Shoulders	Highest B/C for 5' Shoulders	Highest B/C for 6' Shoulders
1	$580,000	$640,000	$700,000
2	$1,870,000	$2,000,000	$2,120,000
3	$130,000	$160,000	$180,000
4	$1,460,000	$1,560,000	$1,660,000
5	$920,000	$1,050,000	$1,160,000
6	$540,000	$600,000	$660,000
7	$3,640,000	$4,240,000	$4,760,000
8	$26,000	$2,110,000	$2,360,000
Total	$9,166,000	$12,360,000	$13,600,000
Structure Adjustments (Bridge, several culverts, 8%)	$730,000	$990,000	$1,090,000
Additional Shoulder Width at Structures (1%)	$90,000	N/A	N/A
Geometric Intersection Improvements (5%)	$460,000	$620,000	$680,000
Additional Cost Due to Location, Seasonality (20%)	$1,830,000	$2,470,000	$2,720,000
Mobilization, Survey, Testing (15%)	$1,370,000	$1,850,000	$2,040,000
Construction Engineering (5%)	$460,000	$620,000	$680,000
Preliminary Engineering (15%)	$1,370,000	$1,850,000	$2,040,000
Contingency (20%)	$1,830,000	$2,470,000	$2,720,000
Grand Total =	**$17,306,000**	**$23,230,000**	**$25,570,000**

Table 14 - Overall 3R Cost Estimate

5. Other Specific Countermeasures

This section will present several safety countermeasures that could apply at any stage of improvements to the corridor.

a) Signing

The following sections outline several signing improvements that should be considered throughout the corridor. Regular maintenance of damaged signs is strongly encouraged, along with maintenance of snow poles to help avoid damage in plowing season.

1) Curve Warning Signing

Additional horizontal curve warning signing is recommended for the curves meeting the provisions of Section 2C.06 in the MUTCD. A review of the existing advisory speeds is also recommended as some of the 50-mph plaques may be high for the radius of horizontal curve present.

2) Intersection Warning Signing

As mentioned in some of the site-specific recommendations, intersection warning signage is recommended for the major intersections in the CLH corridor. Supplemental plaques may be desired to complement guide signing, recommend speeds or display the distance to the intersection.

Figure 64 - MUTCD W2-1 Intersection Warning Sign

3) Bicyclist Signing

Traditional warning signing for bicyclists is recommended at strategic locations, such as the beginning of the study area and end of the study area, with intermittent signs near major intersections, etc. The W11-1/W16-1P assembly could be used at these locations to remind motorists and bicyclists to share the road.

Figure 65 - MUTCD W11-1/W16-1P Assembly

Innovative signing solutions may be installed as well or instead of traditional signs, especially to improve bicyclist safety at key locations. Bicyclist-actuated or bicyclist-detecting flashing beacons or other digital signs could be used to alert motorists to expect bicyclists in the roadway in areas of limited sight distance or as a general warning for the next XX miles. Permanently-flashing beacons, in conjunction with bicycle warning signs, could also be used to alert motorists to expect bicyclists on the roadway. The effectiveness of permanent flashing signs is questionable. Signs that activate specifically when a bicyclist activates it or passes by (with auto detection) yield better compliance rates by motorist. However, these types of signs would be limited due to their expense and desire to maintain effectiveness. For example, they could not likely be used for every situation where there is not adequate sight distance around curves in the CLH corridor, as there are numerous locations.

The Coordinated Technology Implementation Program (CTIP) is currently funding an experimental dynamic warning system to alert motorists to the presence of bicyclists. The system combines a bicycle counter with a dynamic warning sign that flashes for a set amount of time while the bicyclists traverse a specific hazard area, depending on the site. This type of sign system could be used as an overall corridor message as well as specific areas of concern, such as locations of limited sight distance, tight horizontal geometry, steep grades, etc.

Figure 66 - Dynamic Warning System for Bicyclist Safety

Two sign systems have been installed within the Colorado National Monument area. Initial, unofficial results indicate that the signs are working as intended for both warning motorists and counting bicyclists. An information webinar and final report will be published in the near future.

ODOT plans to install a similar system, using the same bicycle counter vendor, on OR-242 on McKenzie Pass in June, 2019. However, ODOT plans to opt for flashing beacons rather than an in-sign LED lighting system, which the CTIP project is using.

Preliminarily, the team believes that an entry-to-the-corridor type sign could be used on each end. One near the beginning of the project study area, and another, likely on the north leg of the S. Century Drive intersection for motorists headed north. This southern sign location can be verified after obtaining traffic data for the corridor to determine if there is a need near the Klamath County line or not. Or, if the predominant bicyclist movement is from north to south (from Bend) along the Century Drive loop, the south entry sign may not be as necessary. This sign can warn motorists of the overall presence of bicyclists over the next XX miles and can be actuated when bicyclists ride over the loops. A selected assumed riding speed can be used to set the flashing time to take into account the time needed for a bicyclist to reach the end of the study area. The main limits for this sign should be the beginning through S. Century Drive (30 miles), since this is the portion of the corridor that does not have 4’ paved shoulders where bicycles can ride. Therefore, the entry sign can use the W11-2 bicycle warning sign and beacons with a supplemental plaque that reads:

IN ROADWAY

NEXT 30 MILES

The sign would likely flash for much of the busier summer days with higher use of bicyclists repeatedly activating the sign.

For specific areas of sight distance concerns, the same W11-2/beacons sign can be used with a supplemental plaque that reads:

IN ROADWAY

NEXT XX MILES

The miles to list in the supplemental plaque will depend on the location of each sign. For example, these signs could be placed at the beginning and end of Section 2 to cover each direction.

Figure 67 - Example of Dynamic Warning Sign Locations

This is approximately 2.3 miles in length, so the plaque could read NEXT 2 ½ MILES. The flashing time would depend on a design value for bicycle riding speed and would depend on grades, which may vary for each direction. If the design riding speed is 20 mph for example, then the beacons would need to flash for 7.5 minutes (using 2.5 miles divided by 20 mph). Each subsequent rider in that time period would restart the 7.5 minutes. When there are no riders, the beacons no longer flash and the signs are less prominent to motorists.

This is an experimental traffic control device and, like any traffic control device, should not be overused, even with the dynamic flashing feature. These signs should be reserved for where there are specific safety deficiencies such as limited horizontal sight distance where the distance does not meet 60 mph AASHTO criteria. Determining all of these areas is beyond the scope of this report and can instead be performed in preparation for a signing project. It is believed that several nearby areas should be grouped together, such as the above example in Section 2, where it is believed that there are several horizontal curves with obstructions that limit sight distance below AASHTO criteria. Again, the collection of bicycle and traffic data can help determine the highest need for these warning signs. The use of these intermittent signs in the corridor, flashing when bicycles actuate them, can help validate driver's expectations and provide frequent reminders to watch out for bicyclists when they are actually present up ahead.

For initial cost estimates of this improvement option, see Appendix E. If selected for using on CLH, the County and/or Forest should raise public awareness about the signs and post an informational flier on websites, educational material, etc.

The Oregon Bicycle and Pedestrian Plan states that segments with flashing warning beacons announcing the presence of bicyclists may, depending on judgment, reduce the LTS by one, but no less than LTS 2.

For special occasions of high bicycle use or on higher-use days (such as weekends), or in lieu of the above options, portable changeable message signs could be used instead of permanent bicyclist-related signing. An example message could be:

Phase 1: EXPECT

BIKES

ON HWY

Phase 2: NEXT

30 MILES

- Summer, 2019 Update:

Via the FLAP funding for this planning project, WFLHD procured two of the dynamic warning signs and counter systems (for counting both vehicles and bicyclists) for Deschutes County. The systems arrived in late summer, not in time for County forces to install before CLH was closed for the winter. The systems will be installed in spring, 2020 and will begin continuous data collection as well as provide the dynamic warning to motorists. See Appendix F – Dynamic Warning Sign Recommendation Memorandum for more information on the locations for installation and other details.

4) Pedestrian Signing

At locations where pedestrians may be walking along the roadway or crossing the roadway, pedestrian signing may be considered.

Rectangular rapid flashing beacons (RRFBs) are effective for gaining compliance from motorists for pedestrian crossings at uncontrolled (non-signalized) areas. Typically, they are utilized in urban areas where speeds are lower (up to 35-40mph). If a need to further improve the safety of pedestrian crossings remains at Devils Lake and Green Lakes after the Wilderness Area strategies are in effect, RRFBs may be a good option here if pedestrians can be channeled to a specific crossing location. However, lowering the regulatory speed limit must be considered in conjunction with this installation. Lower motorist speeds will help improve safety in this location as well. Several studies have examined the effect of speed on crashes involving pedestrians with respect to severe injuries and fatalities:

> "Results show that the average risk of severe injury for a pedestrian struck by a vehicle reaches 10% at an impact speed of 16 mph, 25% at 23 mph, 50% at 31 mph, 75% at 39 mph, and 90% at 46 mph. The average risk of death for a pedestrian reaches 10% at an impact speed of 23 mph, 25% at 32 mph, 50% at 42 mph, 75% at 50 mph, and 90% at 58 mph. Risks vary significantly by age. For example, the average risk of severe injury or death for a 70-year-old pedestrian struck by a car travelling at 25 mph is similar to the risk for a 30-year-old pedestrian struck at 35 mph."[12]

As can be seen, lower speeds will greatly improve pedestrians' chances of survival. Limited areas of reduced speed limits may need increased enforcement presence in order to be effective.

Besides Devils Lake and Green Lakes, in their current use pattern prior to Wilderness Area changes, there are not known pedestrian safety concerns in the CLH corridor. Pedestrians are generally limited to turnout areas, resorts and day-use parking lots and trails. Pedestrian safety concerns within day-use area access roads were not investigated in this study.

As understood by the team, the considerations for pedestrian safety would apply to equestrian use; there are no other known concerns with equestrian crossings in the corridor.

[12] http://www.pedbikeinfo.org/data/library/details.cfm?id=4714

5) *Delineators*
Roadway delineators can be an effective countermeasure to reduce roadway departure crashes, especially at night. If shoulder rumble strips can be installed with shoulder widening projects, the effect delineators have on reducing crashes is likely reduced since the rumble strips will also help motorists to correct before leaving the roadway. Before shoulder widening projects can occur, delineators are recommended if county maintenance is in agreement, since snow plow operations will likely damage many delineators each year. Delineators can provide positive guidance to motorists, especially throughout horizontal curves.

6) *Guide Signing*
As discussed throughout, all destinations throughout the corridor should be evaluated and signing improvements made to improve wayfinding and increase legibility which can have a positive effect on highway safety. For major destinations (e.g. Devils Lake, Elk Lake, S. Century Drive, etc.), additional advance signing is recommended prior to the destination (e.g. Elk Lake 1000 FT →). Signs at the turn to the destination should be evaluated for legibility with increases in font size where needed to improve readability in advance of the turn. Reducing the occurrences of motorists slowing down to read small signs or missing turns and having to turn around can reduce chances of crashes.

As discussed later in Todd Lake Intersection, decision sight distance (DSD) is recommended to be the criteria used for placing advance guide signs ahead of destinations. A consistent distance throughout the corridor is recommended.

7) *Regulatory Signing*
It is recommended that Speed or Speed Limit regulatory signs be installed at key areas throughout the corridor, such as near major destinations.

One strategy to improve future safety performance is to evaluate the use of reduced speed limits in key locations, such as near Devils Lake (see Site-Specific Recommendations). However, further engineering study is recommended, as the arbitrary lowering of posted speed limits may not achieve the desired effect of lowering speeds, as motorists typically drive the speed they feel comfortable with. If engineering study (possibly including the collection of speed data) supports lower speed limits, enforcement is often necessary.

8) *Other Signing*
Some signs, such as near S. Century Drive, are cluttered and difficult to read. With improvements to guide signing, this sign could be simplified to include the most relevant information and made larger. Other information could be given for the CLH corridor in a kiosk located in a turnout near this location. The kiosk could contain information for attractions in the area and notices regarding bicycle use in the corridor to educate motorist on safety. The Forest welcome center may be adequate for this kind of information on the other end of CLH, but another similar kiosk could be considered near the study begin as well.

b) Striping
The use of 6-inch edge lines has been shown to be an effective low-cost safety countermeasure to reduce roadway departure crashes. Widening from a 4-inch edge line to a 6-inch edge line has even been shown to reduce day-time KABC crashes in rural areas by 41.5%.[13] For all crash types and all severities, rural crashes were reduced by 12.5%.[14]

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[13] http://www.cmfclearinghouse.org/detail.cfm?facid=4741
[14] http://www.cmfclearinghouse.org/detail.cfm?facid=4736

With widened shoulders, this may further reduce the vehicle-bicycle potential for conflict as the wider stripe more strongly delineates the separation. In urban areas with bicycle lanes, wider stripes are used for this reason.

In the interim, prior to any geometric improvements, 6-inch edge lines are recommended as a new standard for Deschutes County and the Forest on annual restriping projects.

c) Rumble Strips (Traditional and Low-Noise)

1) Centerline Rumble Strips

As shown in the 3R analysis, centerline rumble strips are cost effective, high benefit/cost ratio countermeasures to improve safety. Centerline rumble strips may have helped prevent some of the crashes from occurring in the available crash history, as they are an important countermeasure to reduce roadway departure crashes. Centerline rumble strips are well-studied with generally very positive crash modification factors.

Traditional rumble strips, typically milled-in, are a proven safety countermeasure. In some locations, there are concerns regarding the amount of ambient noise that can disturb residences, campers, wildlife and other users of recreational areas near a highway. Recently, several new designs have been in experimentation to help reduce the ambient noise while still providing adequate noise and vibration within the vehicle to obtain the safety effect. These are sometimes called “mumble strips” and the indentions in the pavement are sinusoidal in form rather than the typical rectangular shape. The California Department of Transportation (CALTRANS), Oregon Department of Transportation and Washington Department of Transportation have all completed pilot projects or are using these new designs in sensitive areas with pilot policies. These designs can be used to alleviate concern with additional noise in the CLH corridor. Consult with WFLHD or these agencies directly to obtain the latest details.

An additional factor to consider is how centerline rumble strips may affect the safety of bicyclists when motorists are approaching from behind. If centerline rumble strips were installed on CLH prior to any shoulder widening, motorists would still need to move over to adequately pass bicyclists, and would cross over the centerline rumble strip. This noise can alert the bicyclist(s) ahead that a vehicle is approaching from behind and improve their awareness to their position within the roadway, possibly moving as far to the right as possible to avoid potential conflict. This may have a positive effect on vehicle-bicycle crashes. On the other hand, with the moderate to high use of bicyclists throughout the CLH corridor, passing vehicles would create noise each time they passed the bicyclists and could be detrimental to the experience in the corridor. Again, the newer designs for rumble strips have been shown to partially alleviate this.

If the shoulders are widened to 4’ or more, this effect will likely be lessened, as motorists may not always move over to the opposing lane to pass bicyclists, as there will be more separation built in to the typical roadway section.

2) Shoulder or Edge-Line Rumble Strips

Shoulder rumble strips, placed just outside the edge line pavement markings, or edge line rumble strips, which are constructed at the edge line location followed by the pavement marking application, are also both cost effective, high benefit/cost ratio countermeasures to improve safety.

Shoulder rumble strips were not included in the 3R analysis for any 4’ shoulder options since bicyclists need at least 4’ of operating width and the rumble strip reduces the available width on the shoulder. Shoulder rumble strips could be used on shoulders 5’ and greater.

Edge line rumble strips could possibly be used with 4’ shoulders if 4’ of shoulder width remained for the bicyclist, but more evaluation is needed. One additional benefit of edge-line rumble strips is that the pavement markings can better reflect light from the backside of the rumble strip. Additionally, edge line rumble strips can increase the durability and retroreflectivity of the pavement markings.[15]

For both types of rumble strips, the durability of the pavement is not in jeopardy as long as the pavement is in fair to good condition prior to the installation. Since CLH is generally plowed just once per year at the opening of the highway, rumble strips should not affect plowing performance.

d) SafetyEdge[SM]

A SafetyEdge[SM] treatment at the edge of roadway has been shown to be a significant benefit to vehicular traffic attempting to return to the roadway. For bicyclists, the Safety Edge[SM] has been shown to help them recover back to the roadway as well[16]. The SafetyEdge[SM] treatment is considered standard practice for most agencies and is a recommended countermeasure for the CLH corridor in conjunction with applicable pavement actions.

e) Vegetation Clearing

As discussed in the Existing Conditions, there are numerous areas of limited sight distance along horizontal curves and at several intersections due to trees and other vegetation obstructing the view. Vegetation removal to the original cleared areas is necessary to improve sight lines. Additional clearing within the County right-of-way along horizontal curves is strongly recommended to meet AASHTO criteria for stopping sight distance and intersection sight distance where possible.

Several areas were noted in the field review that were observed to have limited sight distance but further review is needed in the field to determine exact areas where there are deficiencies. A removal of additional trees to the clear zone limits can have a significant improvement on reducing crash severity as well. Additionally, vegetation clearing can improve the visibility of animals to motorists, which can provide more reaction time for motorists to slow down in advance of a potential animal collision. No objective data is known to quantify the effects of clearing vegetation in order to calculate a crash modification factor. It is believed that vegetation and tree removal, to improve sight distance, ensure signs are not blocked, reduce animal crashes and reduce crash severity with fixed objects (trees) within the clear zone, would result in a very high benefit/cost ratio.

f) Enforcement and Emergency Management

Regular enforcement of speeding, reckless driving and other violations is an important aspect of highway safety.

In 2016, speeding was a factor in 27% of nationwide rural traffic fatalities overall. Forty-six percent of the speeding-related fatalities in rural areas occurred on the weekend, likely when traffic is higher. Focusing enforcement activities on weekends may be the best use of resources. As noted in Speeds, anecdotal evidence suggests there is regular speeding occurring in the corridor, especially on the long tangent sections.

For fatalities involving alcohol-impaired driving, nationwide, the total number has decreased from 2007 to 2016 by 20% overall, including by 31% in rural areas. Nevertheless, in 2016, there were 5,093 alcohol-impaired driving fatalities that occurred in rural areas, 49% of the total alcohol-impaired driving fatalities. It is unknown if the CLH corridor experiences frequent drinking drivers relative to other rural and urban areas closer to residential areas and cities. Some alcohol use is expected at the resort, camping and day-use areas throughout the corridor. Without alcohol establishments such as bars and restaurants, the rate of

[15] https://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/t504039/
[16] https://safety.fhwa.dot.gov/roadway_dept/pavement/safedge/brochure/

drinking drivers may be less than other routes in Deschutes County and surrounding areas. The overall enforcement presence can help reduce drinking drivers throughout the corridor.

Restraint use has reached a rate of 89.5% in rural areas in 2016 according to NHTSA. For traffic fatalities, however, 49% of passenger vehicle occupants killed in rural areas were unrestrained. Sixty-two percent of rural pickup truck occupants killed were unrestrained, the highest percentage of any passenger vehicle occupants killed among both rural and urban areas.

In 2016, 67% of drivers killed in rural areas died at the scene, compared to 50% in urban areas. Of the 40% of all drivers killed that were transported to hospitals, 1% died en route. Of the 1% who died in route, 62% of these were drivers in rural areas. This indicates that the more remote and rural areas have longer response times by emergency management services. The CLH corridor is semi-remote relative to other recreational lands. It is recommended that Deschutes County and Deschutes National Forest regularly review and maintain their emergency management plans to best serve crashes that occur throughout the CLH corridor.[17] Through education, buckle-up campaigns can be undertaken to remind motorists of the importance of restraint use.

g) Education

The ODOT Bicycle and Pedestrian Plan provides strategies for educating travelers "on the rules of the road to promote understanding of legal rights and responsibilities and how all modes and users can safely and courteously interact with each other" (pg. 31, OBPP). The strategies that may be applicable to CLH are listed below:

- Provide education and outreach on rules of the road and personal responsibility in using the system to all road users. Identify existing materials or develop new materials as needed to address targeted audiences and seek creative distribution methods and partnerships to disseminate information to users.
- Educate motorists on the risks of distracted driving, impaired driving, and speeding to bicyclists and pedestrians.
- Educate pedestrians and bicyclists on the risks of distractions, such as texting, while walking or biking.
- Identify and share educational materials and other best practices that support safe behaviors for bicyclists and pedestrians and their interaction with other modes. Deliver materials through traditional networks such as the Transportation Options programs and others, and seek innovative new partnerships and mechanisms for delivery of materials to target audiences.
- Provide information on how to safely bike or walk when new technologies are deployed or innovations constructed, such as how to use rapid flashing beacons, and how other modes should interact with such technologies, including connected and automated vehicles.
- Identify and share best practices to encourage and provide sufficient secure and convenient bicycle parking at key destinations.
- Enhance personal security through implementation of well-lit areas, maintained vegetation, adequate opportunities to leave the facility, and other mechanisms to enhance visibility of pedestrian and bicycle facilities from the roadway and nearby land uses.
- Communicate need for enforcement of laws as they relate to pedestrian and bicycle safety and security.
- Educate and train law enforcement on risks of motor vehicle crashes to pedestrians and bicyclists.

Other general highway safety education messages such as buckle up campaigns, distracted driving awareness and drunk driving should be included.

[17] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812521

The mechanisms for outreach of educational materials could include Deschutes County and Deschutes National Forest websites, social media, visitor centers, kiosks in the corridor and portable changeable message signs at key locations in the corridor.

h) Other Strategies

The highway is closed in the winter, generally from November 1 to May 15. The team discussed possible strategies to open the highway to bicycle traffic (possibly races or similar events) prior to vehicular traffic to give cyclists more vehicle-free opportunities.

As is discussed throughout different sections of this document, a County ban on parking along CLH at undesignated areas is an option but may be difficult to pass an ordinance and would severely limit the amount of visitors that can use these areas based on the current parking lot sizes. Expansion of one or several Forest Service parking lots is also an option but may be difficult to achieve due to environmental and financial constraints as well as possible Wilderness Strategies. Finally, an expansion of one or several parking lots may not necessarily solve this parking problem, as there is a popular opinion that they cannot ever be big enough for all the desired use at some locations.

6. Site-Specific Recommendations

Three areas of site-specific recommendations are presented below. Other, more minor site-specific recommendations are presented in Recommendations.

Some of the recommendations presented are based on discussions the team had during the September, 2018 site visit. Since then, the changes resulting from Forest Wilderness Strategies may greatly affect the need for these recommendations. Therefore, options will be presented based on how the Wilderness Strategies affect the use at these sites. See Section C of the Planning Document for more discussion on Wilderness Strategies.

a) Todd Lake Intersection

The Todd Lake intersection is near the end of a horizontal curve to the west. Figure 23 and Figure 24 show the reduced intersection sight distance due to vegetation and trees growing along the roadside. Removing these trees and vegetation to establish clear sight triangles is recommended. There is no official speed data at this time for CLH, but based on anecdotal evidence from LEOs, using a design speed of 60mph is recommended rather than the 55mph basic rule speed. Chapter 9.5 in the Green Book gives criteria for intersection sight distance for various scenarios. For the Todd Lake intersection, Case B1 is the controlling case for vehicles making turns out of either approach road. Table 9-5 gives time gap values used to calculate the recommended intersection sight distance (ISD). The traffic mix along CLH is generally passenger cars (and pickup trucks) but there are significant amounts of vehicles pulling trailers especially at some locations like the equestrian area on the south approach of the Todd Lake intersection. Vehicles pulling trailers require more time to pull out of the approach and into their respective lane along mainline. Due to a high use of vehicles pulling trailers at this intersection, the “Single-unit truck” time gap value of 9.5 seconds is used to approximate this effect. The calculation from equation 9-1 gives an ISD of 838’, rounded to 840’ for design. Figure 66 shows the existing ISD to the west in red and the theoretical ISD in green (840’).

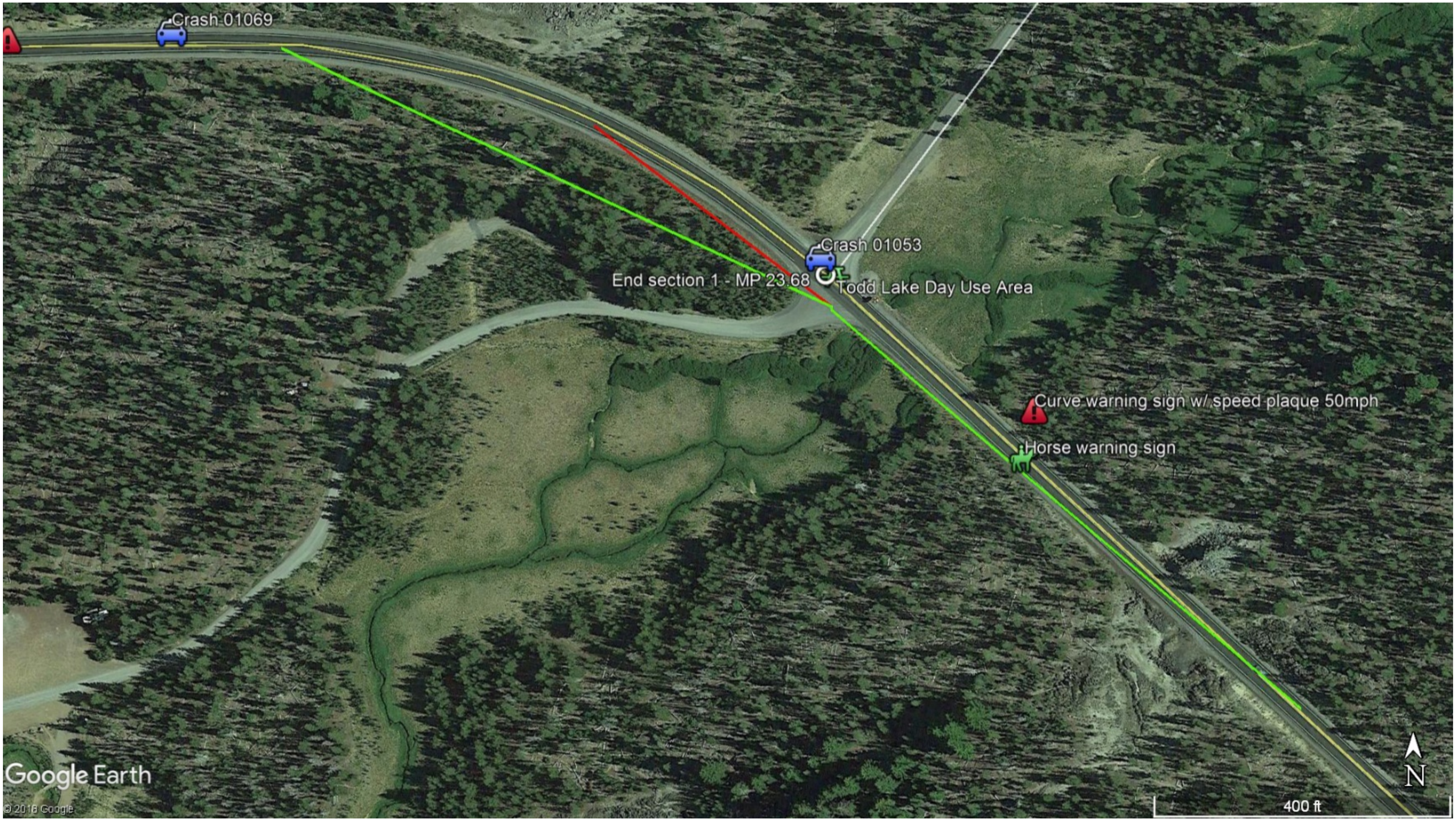

Figure 68 - Todd Lake ISD Improvements

It can be seen that substantial clearing would be needed to the west of the intersection. Some of this clearing would need to occur outside of the assumed 50’ easement from centerline of CLH. If this is not possible, it is recommended to clear as much as possible to improve ISD to the maximum extent practical. Adding warning signs as noted below is recommended in either case.

While traffic studies along CLH and at the intersections would help identify major intersections relative to the corridor, it is believed anecdotally that Todd Lake is a high-use intersection. It is recommended that W2-1 signs be added in advance of the intersection from both directions.

W2-1

Figure 69 - MUTCD W2-1

For guide (destination) signs, some upgrades are recommended in order to give better notice of destinations throughout the CLH corridor. For Todd Lake, installing a guide sign in advance of the intersection for both approaches is recommended, with the Day Use Area and Todd Horse Camp destinations included on the signs. At the intersection itself, the aesthetic “Todd Lake Day Use Area” sign appears adequate to note the intersection point for the day use area. A symbol guide sign with a directional arrow could be considered for the south approach to note the equestrian area accessed through this approach road.

RS-064
Horse Trail

Figure 70 - MUTCD RS-064

Currently, there is an existing guide sign noting the Todd Horse Camp which may be small for expected speeds along CLH (no letter height measurements available).

Figure 71 - Existing Todd Horse Camp Sign

The concept of decision sight distance (DSD) should be considered for placement of advanced guide signs to better alert motorists of upcoming destinations and to prepare for their turning maneuver. The AASHTO Green Book Chapter 3.2.3 describes the decision sight distance concept. Due to some of the intersections that access recreational areas throughout the CLH corridor being somewhat hidden from view (e.g. Green Lakes access), these advanced traffic control devices can help advise motorists in advance and may have a positive effect on safety and general wayfinding. For a 60mph design speed, the recommended DSD from Table 3-3 is likely between 610' – 990' since a turn to an approach road does not usually require a stop (Avoidance Maneuver A in Table 3-3) and would be closer to Avoidance Maneuver C (a speed/path/direction change on a rural road). Site-specific conditions should be considered and where feasible, a uniform distance should be considered for these advanced guide signs throughout the corridor (i.e. 800' or 1000'). Simple and consistent messages are prudent uses of traffic control devices and best meet the intentions of the MUTCD.

Finally, updated traffic counts and turning movements can help establish whether or not turn lanes (left and/or right-turn lane(s)) are recommended for the intersection in medium-term improvements.

For the Todd Lake Day Use Area parking lot, some minor modifications could be examined to identify any efficiencies that can be gained within the parking lot limits. Improvements to the Forest Service roads that access the Todd Lake Day Use Area parking lot, and beyond to other hiking areas (Broken Top 370 Rd), are likely beyond the scope of potential CLH improvements.

In the case that the Wilderness Strategies do not reduce demand or are not enacted for whatever reason, other solutions may be practical to reduce congestion and prevent traffic jams along the roads at and beyond Todd Lake, using Intelligent Transportation Systems (ITS) or related systems. A vehicle counting and detection system could be installed to monitor entry traffic to the Day Use Area and display on a sign when the capacity for parking in the area has been reached. This real-time information could be available at a kiosk at the Deschutes National Forest welcome center along ODOT's Highway 372 and through web-based and/or smart phone applications that could help travelers make decisions about where to visit in the CLH corridor before even starting the trip. This could help spread out the use to other, lesser-used areas throughout the corridor as well when certain areas have high congestions.

Another non-ITS solution could be the use of Forest Service personnel or volunteers to assist with counting vehicles entering and exiting and giving travelers this information about whether the parking lot is full, etc. For either option, it may be advantageous to construct an adequate turn around near the Todd Lake intersection so vehicles can turn around before heading up to the windy Forest road and parking lot.

The ITS and vehicle-counting options are likely only relevant if demand is not reduced through the Wilderness Strategies.

b) Green Lakes Trailhead and Parking Lot Area

Assuming the Wilderness Strategies go into effect in 2020 and significantly reduce the use as expected, this will likely reduce or eliminate the issue of parking along CLH. The available permit quota at Green Lakes is planned to be 80 permits for day-use and 14 group permits for overnight. According to the data provided by the Forest Service, on September 8 and 9, 2018, there were 103 and 110 vehicles parked in the parking lot area (off the highway), respectively, on those days. A count of the individual, marked stalls indicates that there are approximately 46 single parking spots for passenger vehicles and six RV/trailer parking stalls (of which several passenger vehicles were parking in each during the visit). Therefore, much of the parking is occurring in unofficial areas within the Green Lakes parking area. The proposed quota indicates that all parking could occur within the Green Lakes parking area, off of the highway. As long as the Forest Service does not enforce parking infractions within the parking area, with vehicles parked along the access roads, etc., this may completely eliminate the parking along CLH for visitors accessing the trails here.

If the strategies do not work as intended or are not established after all, in order to reduce the amount of parking that is occurring outside of the parking lot and along Cascade Lakes Highway, it is recommended that the Green Lakes parking lot be examined to see how a reconfiguration could add spaces and increase efficiency within the existing footprint. If an opportunity comes along for an expansion of the parking lot, this should be considered as well, as the safety benefits of helping to keep vehicles from parking along CLH would be tremendous. In conjunction with possible expansion and reconfiguration, a no parking ordinance should be considered by the County to eliminate parking along the CLH roadside.

Another possible solution here could be to add turnouts along the north side of CLH near the Green Lakes parking lot with angled parking and a sidewalk on the outside of the turnouts to connect to the Green Lakes access road. It is unknown if this will require an expansion of the County's current easement in order to fit these in. Official turnouts for parking could be a substantial safety improvement over current parking patterns. A careful evaluation of available intersection sight distance at the intersection with the Green Lakes access road would be needed. Currently, parking along the roadside here could be limiting intersection sight distance for vehicles making turns out of the Green Lakes access road.

Other possible corridor-wide improvements would increase safety for this site as well, such as intersection warning signage, advanced guide signage and cross-sectional improvements. To match the Devils Lake high-use area, Congestion and Pedestrian signs could be added near the limits of parking along CLH. After Wilderness strategies go into effect, these would likely need removed if substantial parking no longer occurs along CLH.

Delineators or No Parking signs should be considered near the limits of the actual intersection on the north side of CLH in order to maintain sight lines for intersection sight distance. These may not be necessary after Wilderness strategies go into effect.

c) Devils Lake Trailhead and Parking Lot Area

For the Devils Lake area, the Wilderness Area permit quota will also significantly affect the use at this location. The Devils Lake/Wickiup trailheads will be limited to 100 day-use permits and 16 overnight group permits. According to the data provided by the Forest Service, on September 8 and 9, 2018, there were 199 and 194 vehicles parked in the parking lot area (off the highway), respectively, on those days. Since the Devils Lake parking lot area is not paved, there are no marked stalls to count. Regardless, there is apparently adequate space to handle the anticipated permit use, plus some expected use of Devils Lake itself. This is especially evident when considering that the permits are issued by individual, and typically hikers are not alone; i.e. they will be carpooling and taking up less available parking spaces than if all permittees each brought a vehicle.

A secondary proposal by the Forest Service at this location is the trail reroute of the South Sisters Climber Trail #36 to start and coincide with the Elk Devils Trail #12 before branching off to be rejoined with the rest of the South Sisters Trail. This means that the South Sisters Trail would no longer officially cross the CLH and would instead share the underpass on the Elk Devils Trail #12. Assuming this proposal proceeds to completion, this will also significantly improve the safety of hikers and pedestrians in this area. Trail users can then park in the Devils Lake parking lot and cross under CLH to access either trail.

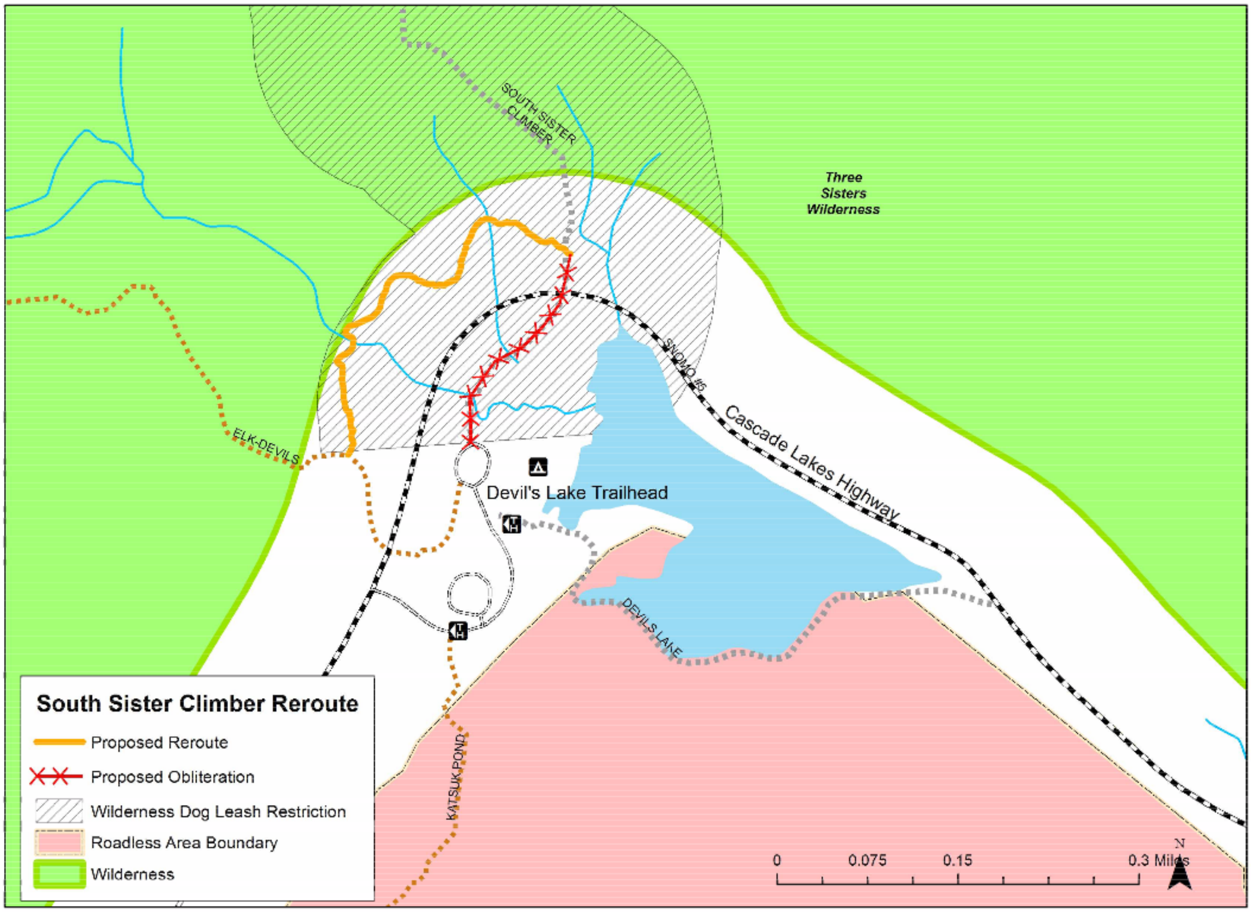

Figure 72 - Deschutes National Forest South Sister Climber Trail Reroute Proposal [18]

While the proposed Wilderness Area strategies will likely nearly eliminate parking along CLH to access the trails as well as pedestrians crossing across the highway, there is still a chance that trail users will inadvertently or deliberately park along CLH to access the trails based on previous experience or a desire to park as close to the trails as possible. There is still a chance that there will be pedestrian crossings as well with the large turnout located on the inside of the curve, etc. The team offers strategies to reduce this likelihood.

1. Install signage in this area to require day-use hikers, overnight hikers and Devils Lake day-use users to use the official Devils Lake parking lot.
2. Establish No Parking areas with signs throughout this area to eliminate parking from unofficial areas such as shoulders. Parking could still be allowed along paved turnouts and possibly along a portion of the turnout along the inside of the 400' radius curve.
3. Install guardrail on the outside of the horizontal curve, continue through the underpass (where there is existing guardrail) and extend a bit beyond to physically eliminate parking on this side, approximately 6-7' from the traveled way. Installing guardrail here could be justified by the existing assumed speed limit, curvature of the road and foreslopes outside of the shoulder.
4. Install guardrail on the inside of the curve as well to physically prevent parking where desired. Guardrail near the existing north end of the lake could be justified due to the permanent body of

[18] https://www.fs.usda.gov/project/?project=49620

water within the clear zone of the highway, which is a warrant according to the AASHTO Roadside Design Guide.

As discussed in Devils Lake Trailhead, the turnout on the inside of the curve is a safety concern itself due to inadequate sight distance when exiting the turnout. The strategies mentioned above may be used to limit or eliminate parking here. An unofficial boat launch (for non-motorized boats) is located at the north end of Devils Lake. Additional measures beyond the above to address this turnout could include:

1. Installing traditional delineators, breakaway bollards or removal breakaway bollards (to uninstall/reinstall for snow seasons) to explicitly delineate where parking can occur based on the best areas of sight distance, or physically eliminate parking. It may be difficult to completely eliminate the use of the north end of the lake for boat access but discouraging or eliminating the parking along the turnout may nearly eliminate this use.
2. Reduce the speed limit through this area to 35 mph for example. The speed limit could coincide with the available intersection sight distance along the turnout. Additional vegetation clearing may be considered as well along the inside of the curve. A reduced speed limit may alleviate the concern along the turnout enough so that parking here is no longer a concern. Enforcement would be required, though the existing horizontal curve helps to self-govern speeds within the curve limits. If the Wilderness Area strategy and trail reroute proposals do not go through, with a reduced speed limit, a rectangular rapid flashing beacon (RRFB) could be a viable countermeasure to reduce vehicle-pedestrian conflicts at the South Sisters trail crossing. Careful consideration would be necessary to promote the device’s use by pedestrians, including possible physical barriers like guardrail to channel pedestrians to the official crossing. At a 35mph speed limit, more traditional crossing treatments, such as crosswalks and pedestrian signing at the crosswalk, are also viable options.

With or without the Wilderness Area strategies and trail reroute proposal going forward, as mentioned previously, a mid- or long-term bypass of this area could be explored as the most extreme option to alleviate many of the issues with this area. A concept of what this might look like is shown as a green line:

Figure 73 - Devils Lake Reroute Concept

A reroute could mean that the existing highway and parking lot could remain with no to little improvements, since parking along existing CLH would no longer be nearly the safety concern. This would remove parking and pedestrian conflicts from mainline CLH and the existing highway could be accessed as an approach road with one or two intersections along the new alignment. For this type of planning study, a very high level estimate can be considered based on a per-mile construction cost basis. New construction, in moderate to complex terrain, may be on the order of $3 million per mile. The example shown in Figure 71 is just under 1 mile along the green alignment.

If there are no alterations to the posted speed limit, horizontal curve warning signs are recommended to be installed here for the sharp horizontal curve.

D. Order of Priority for Site-Specific Recommendations

Funding sources are limited. The strategic investment into prioritized projects, leveraged where possible among agencies, is important to achieving the goals for multi-modal transportation over time. Therefore, this section is dedicated to prioritizing and ranking improvements to the CLH corridor from all applicable perspectives (economic, safety, social, environmental, etc.).

The ODOT Bicycle and Pedestrian Plan states that local government (Oregon cities and counties) roadway spending for 2013 was estimated at $231.8 million for roadway capital and $23 million for bicycle and pedestrian capital (pg. C-5, OBPP). Appendix C of the Plan lists Revenue Funding Mechanisms that could be utilized to allocate for bicycle and pedestrian improvements. Table 7 in that Appendix can be used to collect funding mechanism ideas.

1. Recommendations

Since the study began to develop this Plan, several changes have occurred that affect the recommendations for short and mid-term solutions to meet the goals of the Plan. These are discussed in more detail in previous sections and Section C of the Planning Document. Due to changes in the Wilderness Strategy, the specific safety concerns at the Green Lake and Devils Lake areas may be substantially mitigated due to a limit on use quotas available, beginning in 2020. At Devils Lake, a proposed trail reroute, which makes the existing underpass part of the official trail for South Sisters, should help improve the safety of pedestrians using the trail. In light of these developments, the team offers multiple solutions and considerations for future improvements that will depend on how the use changes over the next few years. Relatedly, the traffic on CLH is likely to be affected with the reduction in available quotas. A change in traffic volume and traffic patterns may affect the long-term solutions as well but it is likely the ultimate shoulder width recommendations remain as described. However, the extent of the shoulder width recommendations may change as traffic patterns are reevaluated. It is also conceivable that a No Parking County ordinance will no longer need to be considered throughout the CLH corridor once traffic is spread throughout the corridor. Limited parking along the shoulder throughout the corridor is unlikely to be a major concern once the currently congested areas are mitigated.

In order to best improve safety in the near-term and mid to longer term, the following sequence of improvements is recommended in the Improvement Matrix shown in Table 15.

The relative costs are subjective but for CLH are considered to be approximately $0-50k for Very Low, $50-100k for Low, $100k-1M for Medium and $1M+ for High. The timeline to implement the improvement is also somewhat subjective and the assumed timeline is shown for each category. Some of the Very Low cost improvements are considered very low cost since they are a small increase on a regular effort or countermeasure already in place, such as annual striping maintenance.

The green, yellow and red colors indicate whether the team feels the improvement is worth pursuing on the path to improving highway safety and bicycle facilities throughout the CLH corridor. Green indicates that the team believes this to be an effective improvement and part of the sequence of improvements. Yellow indicates that either the improvement is believed to be marginally effective, more data is needed in order to better evaluate or the effects of the Wilderness Strategies need to commence first. Red indicates that the team believes this improvement is not an effective improvement to support the overall goals for CLH.

Each improvement will be described following the Improvement Matrix, with some high level cost estimates based on the 3R analysis for the geometric improvement (shoulder widening) options and some other specific cost estimates located in Appendix E.

Relative Cost	Timeline to Implement: Near-Term (0-5 years)	Mid-Term (5-10 years)	Long-Term (10+ years)
Very Low	NV1: Vegetation clearing (maintenance of original cleared areas); Improved/ additional guide, warning and regulatory signing; 6-inch edge line striping	MV1: Increased enforcement presence, especially during peak times	LV1: Increased enforcement presence, especially during peak times
Very Low	NV2: Increased enforcement presence, especially during peak times; educational outreach strategies	MV2: Educational outreach strategies	LV2: Educational outreach strategies
Very Low	NV3: Maintain good crash records; set simple performance goals	MV3: Maintain good crash records, monitor performance goals	LV3: Maintain good crash records, monitor performance goals
Very Low	NV4: Minor improvements at Devils Lake along CLH to limit parking.		
Very Low	NV5: Moderate improvements at Devils Lake along CLH to limit parking.		
Low	NL1: Additional clearing along curves, intersections; traditional bicycle warning signing	ML1: Collect regular traffic data at key locations	LL1: Collect regular traffic data at key locations
Low	NL2: Centerline rumble strips and delineators.		
Low	NL3: Collect regular traffic data at key locations		
Low	NL4: Dynamic warning signs for bicyclists.		
Medium	NM1: Transit Pilot Project	MM1: Parking lot expansion of Green Lakes and Devils Lake	
Medium	NM2: Parking lot enhancements (revise existing layouts to be more efficient)	MM2: Additional congestion management/ITS solutions	
Medium	NM3: Improvements at Devils Lake along CLH to limit parking, reduce speeds and improve crossing safety.		
High		MH1: Widen to 4' shoulders from begin through Elk Lake with minor areas of realignment	LH1: Widen to 4' shoulders from Elk Lake south to S. Century Dr.
High		MH2: Widen to 5' shoulders from begin through Elk Lake with minor areas of realignment	LH2: Widen to 5' shoulders from Elk Lake south to S. Century Dr.
High		MH3: Widen to 6' shoulders from begin through Elk Lake with minor areas of realignment	LH3: Widen to 6' shoulders from Elk Lake south to S. Century Dr.
High		MH4: Bypass of existing Devils Lake alignment.	

Table 15 - CLH Improvement Matrix

Near-Term, Very Low Cost (NV1) – Vegetation Clearing (Maintenance), Improved/Additional Signing, 6-inch Edge Line Striping:

- Clear vegetation back to original cleared areas to improve sight distance throughout the corridor.
- Evaluate all guide signing in the corridor. Replace signs too small for 60mph operating speeds. Add advance guide signing for major destinations in a consistent manner.
- Add warning signage for remaining horizontal curves not meeting 55mph posted speeds per MUTCD. Add intersection warning signage for major intersections. In advance of any special innovative bicycle warning signage, install traditional standard MUTCD bicycle/Share the Road warning sign assemblies at key locations in the corridor.
- Add Speed or Speed Limit signs at key locations (near major destinations/approach roads, begin/end of jurisdictional limits). Consider temporary speed drops at Devils Lake and Green Lakes until Wilderness Strategies go into effect.
- Make 6-inch edge line striping the new standard for CLH.
- Consider removing sign panels for winter to avoid damage from plow operations in spring.

Near-Term, Very Low Cost (NV2) – Increased Enforcement, Educational Strategies:

- Utilize County and Forest Law Enforcement Officers especially during peak times. Increase presence when feasible. Increased enforcement is intended to help manage motorist speeds and manage compliance with various regulations (Wilderness Area enforcement, any illegal parking, etc.).
- Review existing educational materials as related to highway safety from both the County and Forest resources. Team up together and with other advocacy groups (BPAC, bicycle groups, trail maintenance/hiking organizations, resort HOA, RV touring, fishing/hunting groups, etc.) to provide campaigns, materials and disseminate information to a variety of audiences. Use social media, websites and occasional changeable message signs in the corridor.

Near-Term, Very Low Cost (NV3) – Crash Records, Performance Measure Goals:

- Work with County and Forest LEOs to ensure a process is in place to collect adequate crash data and store records for easy access and retrieval. The format that ODOT uses for crash data collection is preferred for consistency with state records.
- Set simple performance measures with an end goal of zero fatal and serious injury crashes by a certain date in the future. Some examples are listed in ODOT Design Manuals and Bicycle and Pedestrian Plan. See the OBPP for a full list of possible measures. Monitor performance measures annually and communicate with elected officials on the status of measures and goals.

Near-Term, Low Cost (NV4) – Minor Improvements to Limit Parking Near Devils Lake along CLH:

- As discussed in Devils Lake Trailhead and Parking Lot Area, implement the desired minor modifications (signing) to limit parking along CLH as needed once Wilderness Area Strategies go into effect. This may require a county ordinance and county and/or Forest enforcement.

Near-Term, Low Cost (NV5) – Moderate Improvements to Limit Parking Near Devils Lake along CLH:

- [Dependent upon the final outcome and effects of Wilderness Strategies. Similar to NM3 but focused on short-term measures] Reduce parking limits with bollards, delineators or similar barriers placed at areas most undesirable for parking (e.g. along turnout on inside of horizontal curve). Guardrail may be used as well.
- See Appendix E – Cost Estimates for the various options with preliminary cost estimates.

Near-Term, Low Cost (NL1) – Vegetation Clearing (Additional), Traditional Bicycle Signing:

- Determine areas where additional vegetation clearing, beyond the original cleared limits, will increase sight distance along horizontal curves and near intersections to meet AASHTO recommendations for a 60mph design speed, or as high as practical. Some areas of concern are noted throughout this study but an extensive evaluation should be performed. Additionally, identify where additional vegetation clearing can be accommodated to meet clear zone guidelines, especially in higher-risk areas such as the outside of horizontal curves. Clear and grub this vegetation.
- Install traditional (static, not flashing) bicycle warning signs at key locations throughout the corridor.

Near-Term, Low Cost (NL2) – Centerline Rumble Strips, Delineators:

- Install centerline rumble strips and post-mounted delineators throughout the entire CLH corridor. Use ODOT delineator standard drawings to keep consistent with other ODOT state highways. These typically decrease the spacing between delineators on sharper horizontal curves. If desired, utilize lower-noise, "mumble" strips as are being experimented with in California, Oregon and Washington state.

Near-Term, Low Cost (NL3) – Traffic Data:

- Using traditional traffic counting methods or innovative methods (intermittent or permanent stations), conduct traffic data collection on a regular basis. See Traffic Data for more information on the locations the team believes are most important at this time as well as the frequency of collection.

Near-Term, Low Cost (NL4) – Dynamic Warning Signs for Bicyclists:

- Install several dynamic warning signs at key locations throughout the corridor as described in Bicyclist Signing. These could be installed before or after the collection of vehicular and bicyclist traffic data throughout the corridor. If continuous counters such as the type used in the CTIP project are installed, these signs can be added on to the system at a later date. Preliminary cost estimates are provided in Appendix E.

Near-Term, Medium Cost (NM1) – Transit Pilot Project:

- Evaluate the effectiveness (ridership, reduction in congestion) of the proposed transit program in the corridor. Depending on the effectiveness, consider continuing the transit program into future years. (A FLAP application for a transit pilot project is currently under consideration for funding).

Near-Term, Low Cost (NM2) – Parking Lot Enhancements:

- [Dependent upon the final outcome and effects of Wilderness Strategies.] Revise the parking lots and access roads as desired at Todd Lake, Green Lakes and Devils Lake. This could include paving areas at Todd Lake and Devils Lake within the existing footprint and adding striping to maximize efficiency for all users (including equestrian use at Devils Lake). Signs may be needed to direct users such as RVs and trailers to appropriate areas. The goal here would be to ensure as many vehicles can park within the parking lots as possible and off of CLH.

Near-Term, Medium Cost (NM3) – Improvements at Devils Lake along CLH to Reduce Parking, Lower Speeds and Improve Crossing Safety:

- [Dependent upon the final outcome and effects of Wilderness Strategies and other possible options that may have been tried, such as NV4 and NV5.] If the strategies do not proceed or do not have the intended effect on parking along CLH, implement a permanent speed reduction within the Devils Lake area, coupled with physical barriers such as guardrail to limit parking, channel pedestrians to one crossing location and install high visibility crossing signage, crosswalk markings and possibly a rectangular rapid flashing beacon (RRFB).
- Several of the options in this area, and referenced in the Appendix E – Cost Estimates, could be combined and tried, working from least costly and impactful to more costly.

Mid-Term, Very-Low Cost (MV1) – Continue Increased Enforcement:

- Continuation of NV2. Use traffic and crash data to best focus efforts and locations.

Mid-Term, Very-Low Cost (MV2) – Continue Educational Outreach:

- Continuation of educational outreach strategies from NV2. Use traffic and crash data to best focus efforts and locations.

Mid-Term, Very-Low Cost (MV3) – Continue Crash Records, Performance Measure Goals:

- Continuation of NV3. Evaluate performance goals and adjust based on safety performance and traffic data.

Mid-Term, Low Cost (ML1) – Continue Traffic Data:

- Continuation of NL3. Adjust frequency and locations as needed.

Medium-Term, Medium Cost (MM1) – Parking Lot Expansion at Green Lakes and Devils Lake:

- [Dependent upon the final outcome and effects of Wilderness Strategies.] Expand high-use parking lots in the corridor such as Green Lakes and Devils Lake to add capacity to parking areas and reduce parking on CLH.

Medium-Term, Medium Cost (MM2) – Congestion Management, ITS Solutions:

- [Dependent upon the final outcome and effects of Wilderness Strategies.] Utilize state-of-the-art technology to monitor use throughout the corridor in real time and provide information via media to help users make decisions about destinations.

Medium-Term, High Cost (MH1) – Widen to 4’ Shoulders from Begin to Elk Lake:

- Construct 4’ paved shoulders as an upgraded typical section from the begin of the study through Elk Lake with minor areas of realignment. Add a foot of shoulder width in front of guardrail and any other structures to meet AASHTO guidelines for shy distance. Improve side slopes where possible and increase horizontal sight distance as needed along the curves that do not meet AASHTO criteria. Install additional guardrail as needed where slopes cannot meet clear zone guidelines. Install centerline rumble strips if not already installed, post-mounted delineators and high-type pavement markings. Adjust structures and extend or replace culvert as needed.
- Install left-turn and right-turn lanes as warranted by current traffic counts at major destinations (Green Lakes, etc.).

- 3R Analysis cost:

MH1 Costs	
Sections Included	Highest B/C for 4' Shoulders
1	$580,000
2	$1,870,000
3	$130,000
4	$1,460,000
5	$920,000
6	$540,000
Subtotal =	$5,500,000
Structure Adjustments (Bridge, several culverts, 8%)	$440,000
Additional Shoulder Width at Structures (1%)	$55,000
Geometric Intersection Improvements (5%)	$275,000
Additional Cost Due to Location, Seasonality (20%)	$1,100,000
Mobilization, Survey, Testing (15%)	$830,000
Construction Engineering (5%)	$275,000
Preliminary Engineering (15%)	$825,000
Contingency (20%)	$1,100,000
Grand Total =	**$10,400,000**

Table 16 - MH1 Costs from 3R Analysis

Medium-Term, High Cost (MH2) – Widen to 5' Shoulders from Begin to Elk Lake:

- Construct 5' paved shoulders as an upgraded typical section from the begin of the study through Elk Lake with minor areas of realignment. Improve side slopes where possible and increase horizontal sight distance as needed along the curves that do not meet AASHTO criteria. Install additional guardrail as needed where slopes cannot meet clear zone guidelines. Install centerline rumble strips if not already installed, post-mounted delineators and high-type pavement markings. Install shoulder rumble strips or edge line rumble strips. Possible structure adjustments and culvert extensions or replacements.
- Install left-turn and right-turn lanes as warranted by current traffic counts at major destinations (Green Lakes, etc.).
- 3R Analysis cost:

MH2 Costs	
Sections Included	Highest B/C for 5' Shoulders
1	$640,000
2	$2,000,000
3	$160,000
4	$1,560,000
5	$1,050,000
6	$600,000
Subtotal =	$6,010,000
Structure Adjustments (Bridge, several culverts, 8%)	$480,000
Additional Shoulder Width at Structures (1%)	N/A
Geometric Intersection Improvements (5%)	$300,000
Additional Cost Due to Location, Seasonality (20%)	$1,200,000
Mobilization, Survey, Testing (15%)	$900,000
Construction Engineering (5%)	$300,000
Preliminary Engineering (15%)	$900,000
Contingency (20%)	$1,200,000
Grand Total =	**$11,290,000**

Table 17 - MH2 Costs from 3R Analysis

Medium-Term, High Cost (MH3) – Widen to 6' Shoulders from Begin to Elk Lake:

- Construct 6' paved shoulders as an upgraded typical section from the begin of the study through Elk Lake with minor areas of realignment. Improve side slopes where possible and increase horizontal sight distance as needed along the curves that do not meet AASHTO criteria. Install additional guardrail as needed where slopes cannot meet clear zone guidelines. Install centerline rumble strips if not already installed, post-mounted delineators and high-type pavement markings. Install shoulder rumble strips or edge line rumble strips. Possible structure adjustments and culvert extensions or replacements.
- Install left-turn and right-turn lanes as warranted by current traffic counts at major destinations (Green Lakes, etc.).
- 3R Analysis cost:

MH3 Costs	
Sections Included	Highest B/C for 6' Shoulders
1	$700,000
2	$2,120,000
3	$180,000
4	$1,660,000
5	$1,160,000
6	$660,000
Subtotal =	$6,480,000
Structure Adjustments (Bridge, several culverts, 8%)	$520,000
Additional Shoulder Width at Structures (1%)	N/A
Geometric Intersection Improvements (5%)	$320,000
Additional Cost Due to Location, Seasonality (20%)	$1,300,000
Mobilization, Survey, Testing (15%)	$970,000
Construction Engineering (5%)	$320,000
Preliminary Engineering (15%)	$970,000
Contingency (20%)	$1,300,000
Grand Total =	**$12,180,000**

Table 18 - MH3 Costs from 3R Analysis

Medium-Term, High Cost (MH4) – Bypass of Devils Lake:

- [Dependent upon the final outcome and effects of Wilderness Strategies.] However, this could be an option in either situation. Construct a bypass of the Devils Lake area as described in Devils Lake Trailhead and Parking Lot Area. A high-level estimate of $3M per mile (for construction costs) is assumed, with approximately 1 mile in length to complete this bypass. This could also be an option in the Long-Term.

Long-Term, Very Low Cost (LV1) – Continue Increased Enforcement:

- Continuation of MV1. Use traffic and crash data to best focus efforts and locations.

Long-Term, Very Low Cost (LV2) – Continue Educational Outreach:

- Continuation of educational outreach strategies from MV2. Use traffic and crash data to best focus efforts and locations.

Long-Term, Very Low Cost (LV3) – Continue Crash Records, Performance Measure Goals:

- Continuation of MV3. Evaluate performance goals and adjust based on safety performance and traffic data.

Long-Term, Low Cost (LL1) – Continue Traffic Data:

- Continuation of ML1. Adjust frequency and locations as needed.

Long-Term, High Cost (LH1) – Widen to 4' Shoulders from Elk Lake to S. Century Dr.:

- Construct 4' paved shoulders as an upgraded typical section from the Elk Lake through S. Century Dr. with minor areas of realignment. Add a foot of shoulder width in front of guardrail and any other structures to meet AASHTO guidelines for shy distance. Improve side slopes where possible and increase horizontal sight distance as needed along the curves that do not meet AASHTO criteria. Install additional guardrail as needed where slopes cannot meet clear zone guidelines. Install centerline rumble strips if not already installed, post-mounted delineators and high-type pavement markings. Possible structure adjustments and culvert extensions or replacements.
- Install left-turn and right-turn lanes as warranted by current traffic counts at major destinations (S. Century Dr., etc.).
- 3R Analysis cost:

LH1 Costs	
Sections Included	Highest B/C for 4' Shoulders
7	$3,640,000
8	$26,000
Subtotal =	$3,670,000
Structure Adjustments (Bridge, several culverts, 8%)	$290,000
Additional Shoulder Width at Structures (1%)	$40,000
Geometric Intersection Improvements (5%)	$180,000
Additional Cost Due to Location, Seasonality (20%)	$730,000
Mobilization, Survey, Testing (15%)	$550,000
Construction Engineering (5%)	$180,000
Preliminary Engineering (15%)	$550,000
Contingency (20%)	$730,000
Grand Total =	**$6,920,000**

Table 19 - LH1 Costs from 3R Analysis

Long-Term, High Cost (LH2) – Widen to 5’ Shoulders from Elk Lake to S. Century Dr.:

- Construct 5’ paved shoulders as an upgraded typical section from the Elk Lake through S. Century Dr. with minor areas of realignment. Improve side slopes where possible and increase horizontal sight distance as needed along the curves that do not meet AASHTO criteria. Install additional guardrail as needed where slopes cannot meet clear zone guidelines. Install centerline rumble strips if not already installed, post-mounted delineators and high-type pavement markings. Possible structure adjustments and culvert extensions or replacements.
- Install left-turn and right-turn lanes as warranted by current traffic counts at major destinations (S. Century Dr., etc.).
- 3R Analysis cost (note that Section 8 will maintain the existing 4’ shoulder width; costs are to install rumble strips and other countermeasures):

LH2 Costs	
Sections Included	Highest B/C for 5' Shoulders
7	$4,240,000
8	$26,000
Subtotal =	$4,270,000
Structure Adjustments (Bridge, several culverts, 8%)	$340,000
Additional Shoulder Width at Structures (1%)	N/A
Geometric Intersection Improvements (5%)	$210,000
Additional Cost Due to Location, Seasonality (20%)	$850,000
Mobilization, Survey, Testing (15%)	$640,000
Construction Engineering (5%)	$210,000
Preliminary Engineering (15%)	$640,000
Contingency (20%)	$850,000
Grand Total =	**$8,010,000**

Table 20 - LH2 Costs from 3R Analysis

Long-Term, High Cost (LH3) – Widen to 6’ Shoulders from Elk Lake to S. Century Dr.:

- Construct 6’ paved shoulders as an upgraded typical section from the Elk Lake through S. Century Dr. with minor areas of realignment. Improve side slopes where possible and increase horizontal sight distance as needed along the curves that do not meet AASHTO criteria. Install additional guardrail as needed where slopes cannot meet clear zone guidelines. Install centerline rumble strips if not already installed, post-mounted delineators and high-type pavement markings. Possible structure adjustments and culvert extensions or replacements.

- Install left-turn and right-turn lanes as warranted by current traffic counts at major destinations (S. Century Dr., etc.).
- 3R Analysis cost:

LH3 Costs	
Sections Included	Highest B/C for 6' Shoulders
7	$4,760,000
8	$26,000
Subtotal =	$4,790,000
Structure Adjustments (Bridge, several culverts, 8%)	$380,000
Additional Shoulder Width at Structures (1%)	N/A
Geometric Intersection Improvements (5%)	$240,000
Additional Cost Due to Location, Seasonality (20%)	$960,000
Mobilization, Survey, Testing (15%)	$720,000
Construction Engineering (5%)	$240,000
Preliminary Engineering (15%)	$720,000
Contingency (20%)	$960,000
Grand Total =	**$9,010,000**

Table 21 - LH3 Costs from 3R Analysis

a) Shoulder Widths

The preferred shoulder widths for each section of the CLH corridor will be the most impactful decision for the long-term vision of the corridor. The team offers several options of ultimate shoulder improvements with a summary of the points discussed previously throughout this document. There are no preferred shoulder widths at this time because additional traffic data is needed to validate the use and need throughout the corridor. The following options are considered the reasonable menu of options based on the analysis performed to date throughout this document.

Option 1:

1. MH3: construct 6’ shoulders from the begin of study through Elk Lake. Estimated cost = $12.2M
2. LH2: construct 5’ shoulders from Elk Lake through S. Century Dr. Estimated cost = $8.01M
3. S. Century Dr. to end of study – maintain 4’ shoulders with minor improvements from other alternatives.

Option 1 Total Cost = $20.2M (2018 dollars)

Option 2:

1. MH2: construct 5’ shoulders from the begin of study through Elk Lake. Estimated cost = $11.29M
2. LH2: construct 5’ shoulders from Elk Lake through S. Century Dr. Estimated cost = $8.01M
3. S. Century Dr. to end of study – maintain 4’ shoulders with minor improvements from other alternatives.

Option 2 Total Cost = $19.3M (2018 dollars)

Option 3 Sequence:

1. MH2: construct 5’ shoulders from the begin of study through Elk Lake. Estimated cost = $11.29M
2. LH1: construct 4’ shoulders from Elk Lake through S. Century Dr. Estimated cost = $6.92M
3. S. Century Dr. to end of study – maintain 4’ shoulders with minor improvements from other alternatives.

Option 3 Total Cost = $18.21M (2018 dollars)

Option 4 Sequence:

1. MH1: construct 4’ shoulders from the begin of study through Elk Lake. Estimated cost = $10.4M
2. LH1: construct 4’ shoulders from Elk Lake through S. Century Dr. Estimated cost = $6.92M
3. S. Century Dr. to end of study – maintain 4’ shoulders with minor improvements from other alternatives.

Option 4 Total Cost = $17.32M (2018 dollars)

The four options, containing three different shoulder widths, proposed throughout the study area are the culmination of the analysis and study throughout this document based on a variety of sources. While 4’ shoulders are the minimum width to meet AASHTO guidelines for bicycle use, if the 5’ or 6’ widths are pursued, a performance-based design is strongly recommended in order to maximize funding, implementation schedule and resources. The overarching variable that feeds the shoulder width dimension, as described previously, is traffic (both vehicular and bicyclists). For an example of a performance-based design, Option 1 steps down (narrows) in shoulder width throughout the corridor which aligns with the assumed drop in traffic and recreational use throughout the corridor from north to south. While vehicular traffic may drop throughout the corridor, bicyclist traffic may remain relatively constant through S. Century Drive. Still, the vehicular-bicyclist conflict potential is believed to drop throughout the corridor. The traffic and use will be verified through additional traffic counts in the future.

Other discussion to support a future final recommendation includes:

- The begin through Elk Lake section contains some of the most hazardous horizontal geometry and steep vertical geometry. The safety performance of this section will benefit from wider shoulders (specifically, wider than the minimum 4’ for AASHTO bike shoulders, therefore the 5’ or 6’ options) due to the resulting increase in horizontal sight distance, a wider shoulder for bicyclists to negotiate steep grades and additional shoulder width for the recovery of errant vehicles. This benefit carries more weight due to the unlikelihood of any major horizontal and vertical alignment improvements in these locations. Major alignment improvements in these locations would require significantly higher cost, environmental impacts and intricate geotechnical solutions, among other considerations.

- According to the Oregon Bicycle and Pedestrian Plan, the recommended improvements will reduce the Level of Stress for bicyclists from Level 3 or 4 (depending on ADT data per location) to Level 2 for shoulder widths of 4-6'. According to this criteria, shoulder widths greater than 6' would not improve the Level of Stress for bicyclists in the section with highest traffic. To achieve Level 2, adequate stopping and horizontal sight distance is needed, and wider shoulders in the 5-6' range would help improve horizontal sight distance in order to meet AASHTO stopping sight distance criteria in the section with sharpest horizontal geometry.
- According to the Oregon Bicycle and Pedestrian Design Guide, based on the traffic counts and assumed growth in the corridor, for Rural Arterials, the recommended shoulder widths are 6-8'. For Rural Collectors, the recommended shoulder widths are 5-8' depending on traffic. The Design Guide states that 6' shoulders are recommended if the shoulders are provided for bicycle use with a desire to maintain a 6' shoulder in areas of steep uphill grades, which is also cited in the AASHTO Guide to Bicycle Facilities. Option 1 would construct 6' shoulders in the area of the steepest grades in the corridor to satisfy this recommendation.
- If a 6' shoulder is selected for the highest use section (study begin through Elk Lake), this reduces the need to widen at vertical obstruction locations, such as guardrail installations, per guidance in the ODOT Design Manual for shy distance. Due to the terrain, this section will also likely contain significant guardrail in order to keep cut and fill limits to a minimum in order to construct the wider shoulders. If a 5' shoulder is selected, this is the minimum width given to reduce bicyclists from shying away from the barrier. For all shoulder widths, it is preferred to widen the shoulder by an additional 2' at locations of vertical obstructions, so this recommendation will be evaluated for feasibility when scoping these future projects.
- If 6' shoulders are selected, this will allow the use of rumble strips on the shoulder. For 5' shoulders, rumble strips or stripes can still be explored, with a possible modification to the strip width in order to maintain the 4' clearance along the shoulder for bicyclist use. Rumble strips or stripes will not be viable on shoulders of 4' width.
- If 6' shoulders are selected for the first section, this matches the shoulder width on the adjoining ODOT section of Cascade Lakes Highway, where use is believed to be higher than the area under study.
- The proposed shoulder widths are believed to be in alignment with the Bikeway Design Standards from the Deschutes County Code 17.48.050, where 4' is the minimum, 5' is needed where curb or barrier is present and 6' is used in "high use" locations. Subjectively, the begin through Elk Lake section may be considered high use due to the higher seasonal vehicular traffic mixed with significant bicyclist traffic.
- The Guide for Bicycle Facilities states that it is "desirable to increase the width of shoulders where higher bicycle usage is expected. Additional shoulder width is also desirable if motor vehicle speeds exceed 50mph; if use by heavy trucks, buses, or recreational vehicles is considerable; or if static obstructions exist at the right side of the roadway" (pg. 4-7, GDBF). A 6' shoulder width is believed to satisfy this guidance.
- Wider shoulders, specifically of 6' width, are recommended by the Guide for Bicycle Facilities when using centerline rumble strips, another recommended countermeasure for CLH.
- For example, when examining Option 1, for the proposed 5' shoulder width section, it can be seen that it is approximately $1M to increase the shoulders to 6' in this section as well, making the total $9,010,000 instead of $8,010,000. This could be considered as more accurate traffic data is obtained in order to see if this additional cost is beneficial to users. However, in a performance-based approach, the line must be drawn somewhere in order to realize cost savings. The $970k may be better spent on other countermeasures or improvements throughout the CLH corridor, or another County route.
- As can be seen from the results of the 3R analysis for all shoulder width improvement projects (4-6'), there are no project options that reach a benefit/cost ratio of 1.0 or better, which is commonly

considered the minimum ratio needed to justify a project. However, as discussed in Overall 3R Analysis Discussion, the possible vehicle-bicycle conflicts are not fully accounted for in this analysis, the operational improvements for both bicyclists and vehicles are not accounted for and the "level of stress" a bicyclist feels is not accounted for in these ratios. On the other hand, these benefit/cost ratios are calculated based on traffic data that is assumed to be present all year long, which is not the case with CLH, so the true benefit/cost ratios would be lower based on the methodology used. Regardless, it can be difficult to find projects in highway engineering with significant geometric or cross-sectional improvements that can calculate a benefit/cost ratio at 1.0 or above. Often, traffic along the route where improvements are being considered has to be substantially higher than many rural two-lane highways in order for the aggregate safety impacts to be large enough to tip the ratio to 1.0 and above. However, benefit/cost ratios are never the sole reason to pursue or reject a possible project.

- There is a recreational and mobility aspect to this project that is difficult to quantify as well. Through the team's conversations during field review, the team heard that there are people who would like to use the corridor but do not currently feel comfortable doing so, based on the existing conditions. With the implementation of some of the possible improvements described in this report (shoulder widths but also others), this would hopefully allow all desired use to occur throughout the corridor with improvements to the safety performance for all users.

The menu of options for shoulder width improvements come with a significant cost that is unlikely to be able to be borne by Deschutes County alone. Outside sources of funding that include federal funding, such as the FLAP program, would likely be needed in order to make projects such as these a viable option. The FLAP program requires a minimum match from local agencies, which in Oregon is currently 10.27%.

At the high end of the shoulder width options, this would put the approximate local investment at $1.25M for MH3 and $820,000 for LH2 to complete the shoulder projects, which is still a significant investment for a county.

If the minimum shoulder width options were used throughout the corridor instead, the costs are $10.4M for MH1 and $6.92M for LH1 in order to bring the corridor to 4' shoulder widths throughout. This would put the approximate local investment at $1.07M for MH1 and $711,000 for LH1, which is still a significant county and/or local match investment.

b) Traffic Data

As mentioned throughout the RSA, additional traffic data for motorists and bicyclists at minimum is desired at key locations throughout the corridor. Counting traditional vehicle groups (i.e. passenger cars, light trucks, heavy trucks, RVs, motorcycles, bicyclists, etc.) is desired to obtain better data on the users of the corridor.

The proposed Wilderness Strategies are going to significantly alter the traffic patterns throughout the CLH corridor. The permit quotas apply to the busy season, defined as the Friday before Memorial Day through September 30. It is possible that visitors attempting to avoid the quotas will attempt to make their trips outside of this season, which could lead to similar issues in the existing conditions outside the quota season. However, the weather and time of year is not as conducive to hiking and camping trips outside of the peak season. With major reductions at Todd Lake, Green Lakes and Devils Lake, some of that traffic will be spread throughout the rest of the CLH corridor, as intended by the Forest Service. Some of the existing traffic may no longer visit the CLH corridor at all. This further strengthens the need for accurate traffic data over the next few years once the strategies go into effect to best evaluate the new traffic patterns and tailor future projects accordingly. It is possible the recommendations in this document could be altered to fit the new data.

Obtain traffic counts at key locations for both motorists and bicyclists for both 2019 and the year that Wilderness Area strategies become effective to gauge traffic impacts. This will help verify that the areas of widened shoulders is reasonable from a performance perspective. The team recommends obtaining counts at these key locations:

1. Study Begin
2. Todd Lake Intersection
3. Green Lakes Intersection
4. Devils Lake Intersection
5. Elk Lake Resort Intersection
6. S. Century Dr. Intersection

The counts at each intersection will include turning movements and through movements so that the traffic between each node is recorded, which will cover the entire CLH corridor.

Traffic count collection should be designed to account for the peaks and valleys of traffic depending on the day of the week, time of year, etc. while being cognizant of events that may cause spikes in use above typical use, like bicycle racing events. The team encourages the use of automated traffic counters in order to collect as much data as possible to develop accurate average values.

It is likely that the bicyclist traffic will continue to remain at its current use or grow, regardless of the Wilderness Area strategies. With motorist traffic spreading out to other areas throughout the CLH corridor, the vehicle-bicycle conflict areas may spread out as well. New “hot spot” safety areas may arise. The current lower-traffic sites south of Elk Lake may see their traffic increase, including on the long tangents where speeds were believed to be higher. It is desired that speed data be collected as well, whether in conjunction with traffic counts and/or enforcement actions, but this data is not as important as collecting representative traffic data over time.

If funding allows, it would be best to count traffic in 2019, before Wilderness Area Strategies go into effect, and then again in 2020 to determine the effects the strategies are having. Beyond 2020, count collection could be reduced to every 2 years for the short-term, then every 5 years or as it can be fit into the County’s budget.

Innovative technology is available to continually count bicycle traffic in conjunction with bicycle warning signs warning motorists of bicyclists ahead in the roadway at key areas. The NCHRP Report, Methods and Technologies for Pedestrian and Bicycle Volume Data Collection: Phase 2, presents important findings from a comparison of available counting methods for bicyclists and pedestrians.[19] Some of the bicycle counter options include:

- Eco Counter (inductive loop system) as a continually counting, permanent system; can tie-in to dynamic warning sign (see Bicyclist Signing). The vendor states that the system can be installed with another set of inductive loops to also count vehicles.
- Other inductive loop systems as continually counting, permanent systems.
- Bicycle-specific pneumatic tubes as mobile, temporary systems.
- Magnetometer systems.

[19] https://www.nap.edu/download/24732

Another source of data are mobile technology platforms such as Strava, Inc., which makes user data available for purchase. This would not give a total count of bicyclists in the CLH corridor, but could provide insights into destinations and travel times throughout the corridor.[20]

1) Summer, 2019 Update

Deschutes County, in partnership with the City of Bend, OR, obtained counts for several locations along CLH during the summer of 2019. Appendix G – 2019 Traffic Data contains the complete dataset. The data contains both vehicular and bicyclist counts for Thursday, July 25, 2019 through Thursday, August 1, 2019. However, data collection ended at approximately 9am on August 1, so this data is excluded from the following tables.

Vehicular Data		East of Green Lakes Intersection	South of Elk Lake Resort Intersection	North of S. Century Dr. Intersection	South of S. Century Dr. Intersection
	Day of Week	Daily Traffic	Daily Traffic	Daily Traffic	Daily Traffic
7/25/2019	Thursday	1699	772	518	571
7/26/2019	Friday	2299	1552	971	904
7/27/2019	Saturday	3411	2170	1102	1084
7/28/2019	Sunday	3154	2074	1305	1186
7/29/2019	Monday	1805	1018	554	564
7/30/2019	Tuesday	1802	946	469	547
7/31/2019	Wednesday	1803	960	507	572
Resultant ADT =		2282	1356	775	775
Saturday/Sunday ADT =		3283	2122	1204	1135
Fri/Sat/Sun ADT =		2955	1932	1126	1058
M-Th ADT =		1777	924	512	564

Table 22 - July, 2019 Traffic Data

[20] https://altaplanning.com/wp-content/uploads/Innovative-Ped-and-Bike-Counts-White-Paper-Alta.pdf

Bicyclist Data		East of Green Lakes Intersection	South of Elk Lake Resort Intersection	North of S. Century Dr. Intersection	South of S. Century Dr. Intersection
	Day of Week	Daily Bicyclists	Daily Bicyclists	Daily Bicyclists	Daily Bicyclists
7/25/2019	Thursday	13	8	8	5
7/26/2019	Friday	1	8	3	9
7/27/2019	Saturday	2	10	5	4
7/28/2019	Sunday	2	7	1	0
7/29/2019	Monday	0	13	5	5
7/30/2019	Tuesday	0	6	1	2
7/31/2019	Wednesday	0	10	1	1
Resultant ADT =		3	9	3	4
Saturday/Sunday ADT =		2	9	3	2
Fri/Sat/Sun ADT =		2	8	3	4
M-Th ADT =		3	9	4	3

Table 23 - July, 2019 Bicyclist Data

It appears that the pneumatic tube at the Green Lakes intersection did not capture bicyclists accurately after July 25. This is evident by the drop-off in recorded bicyclists (shaded in yellow), as well as the higher counts at the Elk Lake intersection, which is farther into the corridor and presumably experiences less vehicular and bicyclist traffic at this location than Green Lakes. The data for this location should probably be omitted from any analysis.

This data helps to provide a rough baseline and update of traffic values from previous years (see Traffic Data). The limited data sets from 2013 and 2019 appears to show a substantial increase in use between these years. The weekend traffic is significantly higher as expected. The 2019 data did not include any data during holidays or other known major events in the corridor, therefore, it will be important to look for these traffic increases in future data collection efforts (such as with the dynamic warning signs/counters that will collect continuous data). Also, it appears that traffic decreases as expected from north to south. The 2019 traffic data from the begin of this study through Elk Lake appears to be on par with many state highways in Oregon during the summer season, which validates many of the concerns and recommended countermeasures discussed in this document. However, it will be important to examine the effects of the Wilderness Area Strategies on traffic in the coming years.

E. Conclusions

While the Cascade Lakes Highway corridor has not experienced known crashes between vehicles and bicyclists, there is an increasing potential for these conflicts that may continue to rise in the future. Deschutes County and Deschutes National Forest are commended for taking proactive steps to increase safety for all users on their facilities, rather than waiting for crashes to occur.

The recommendations outlined in this Road Safety Audit are intended to assist Deschutes County and Deschutes National Forest with their next steps in the planning process for multimodal transportation and safety improvements to the Cascade Lakes Highway corridor.

F. References

1. Crash Modification Factor Clearinghouse. USDOT & University of North Carolina Safety Research Center. 2018. http://www.cmfclearinghouse.org/
2. Draft Decision Notice, Central Cascades Wilderness Strategies Project. USDA Forest Service. November, 2018. https://www.fs.usda.gov/nfs/11558/www/nepa/105465_FSPLT3_4483291.pdf
3. Guide for the Development of Bicycle Facilities, 4th Edition. AASHTO, 2012.
4. Guidelines for Integrating Safety and Cost-Effectiveness into Resurfacing, Restoration, and Rehabilitation (3R) Projects. NCHRP Project 15-50. 2018.
5. Highway Safety Manual, 1st Edition. AASHTO. 2010.
6. Manual on Uniform Traffic Control Devices (MUTCD). Federal Highway Administration, 2009.
7. Oregon Bicycle and Pedestrian Plan. Oregon Department of Transportation, May 19, 2016. https://www.oregon.gov/ODOT/Planning/Documents/OBPP.pdf.
8. Oregon Department of Transportation Bicycle and Pedestrian Design Guide. Appendix L of the ODOT Highway Design Manual. Third Edition, 2011. https://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/HDM_L-Bike-Ped-Guide.pdf.
9. Oregon Revised Statute 2017 ORS 811.065. Oregon Revised Statute. https://www.oregonlaws.org/ors/811.065