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Develop a Methodology for Pavement Drainage System Rating

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13. Abstract

Effective drainage is critical for preserving pavement integrity and extending service life, yet network-level methods for evaluating pavement drainage conditions remain limited. This study presents a practical methodology for assessing pavement drainage conditions using data from the Louisiana Department of Transportation and Development's (DOTD) Pavement Management System (PMS). The proposed framework evaluates three key components: (1) pavement surface drainage based on cross-slope, longitudinal grade, and rutting; (2) roadside/shoulder drainage assessed through edge drop-off data and PMS imagery for erosion, vegetation, and debris; and (3) ditch drainage evaluated through PMS imagery for sediment accumulation, erosion, and obstructions. The methodology was applied to five roadway sections to demonstrate implementation and identify correlations between drainage conditions and pavement performance. Results indicate that the pavement surface drainage rating is strongly correlated with actual pavement performance, suggesting its value as a stand-alone monitoring indicator. Fine-scale analysis (0.1-mi. resolution) proved critical for capturing localized drainage deficiencies that disproportionately affect roadway performance. The framework provides actionable

insights for maintenance prioritization and early-stage screening of operational deficiencies, although it does not evaluate hydraulic capacity or broader flood risk. Future enhancements, such as artificial intelligence (AI)-powered image analysis and Light Detection and Ranging (LiDAR)-based ditch surveys, could further improve automation, objectivity, and network-level monitoring. Overall, this study demonstrates a practical and scalable approach for integrating drainage condition assessments into network-level pavement management and supporting data-driven maintenance decisions.

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LTRC Project No. 24-2P
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Effective drainage is critical for preserving pavement integrity and extending service life, yet network-level methods for evaluating pavement drainage conditions remain limited. This study presents a practical methodology for assessing pavement drainage conditions using data from the Louisiana Department of Transportation and Development's (DOTD) Pavement Management System (PMS). The proposed framework evaluates three key components: (1) pavement surface drainage based on cross-slope, longitudinal grade, and rutting; (2) roadside/shoulder drainage assessed through edge drop-off data and PMS imagery for erosion, vegetation, and debris; and (3) ditch drainage evaluated through PMS imagery for sediment accumulation, erosion, and obstructions. The methodology was applied to five roadway sections to demonstrate implementation and identify correlations between drainage conditions and pavement performance. Results indicate that the pavement surface drainage rating is strongly correlated with actual pavement performance, suggesting its value as a stand-alone monitoring indicator. Fine-scale analysis (0.1-mi. resolution) proved critical for capturing localized drainage deficiencies that disproportionately affect roadway performance. The framework provides actionable insights for maintenance prioritization and early-stage screening of operational deficiencies, although it does not evaluate hydraulic capacity or broader flood risk. Future enhancements, such as artificial intelligence (AI)-powered image analysis and Light Detection and Ranging (LiDAR)-based ditch surveys, could further improve automation, objectivity, and network-level monitoring. Overall, this study demonstrates a practical and scalable approach for integrating drainage condition assessments into network-level pavement management and supporting data-driven maintenance decisions.

Acknowledgements

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Implementation Statement

The methodology developed in this study provides DOTD with a practical framework for assessing pavement drainage conditions at the network level using existing Pavement Management System (PMS) data. The drainage rating system can be implemented immediately by applying pavement surface drainage ratings, which demonstrated a strong correlation with actual pavement performance and can serve as an effective stand-alone monitoring tool to identify sections at higher risk of deterioration.

Roadside/shoulder and ditch drainage ratings provide additional operational insights by highlighting locations where sediment accumulation, vegetation, or erosion may impede drainage. While these evaluations currently require a manual review of PMS imagery, they can be integrated into the rating framework to guide targeted maintenance and complement surface drainage indicators. Future enhancements, such as AI-powered image analysis and LiDAR-based ditch surveys, will enable more automated, objective, and comprehensive drainage evaluations.

It is important to note that the methodology identifies operational deficiencies rather than hydraulic capacity or broader flood risk. Used as an early-stage screening tool, the framework supports proactive maintenance, extends pavement service life, and improves roadway safety, while hydrologic and hydraulic analyses remain necessary where regional flood risk influences performance.

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Introduction

In the realm of pavement engineering, the management of water and its impact on infrastructure longevity is of paramount importance. Water can lead to various degrees of damage to roadways, ranging from the formation of potholes to less visible issues such as the weakening of subsurface materials; see Figure 1 to Figure 3. One of the primary reasons for pavement failures is the weakening of the base, subbase, or subgrade when they become saturated with water. Water can seep in through unsealed pavement joints or cracks and collect beneath the pavement slabs. This accumulation of water, combined with the pressure exerted by vehicle loadings, can erode the materials underneath, creating voids and compromising the pavement's structural integrity. Additionally, inadequate surface drainage can lead to another significant issue: vehicle hydroplaning; see Figure 4. This dangerous condition occurs when water accumulates on the road surface, causing vehicles to lose traction and resulting in hazardous driving conditions and weather-related accidents.

Figure 1. Weakening of base, subbase, or subgrade

Figure 2. Potholes

Figure 3. Asphalt stripping

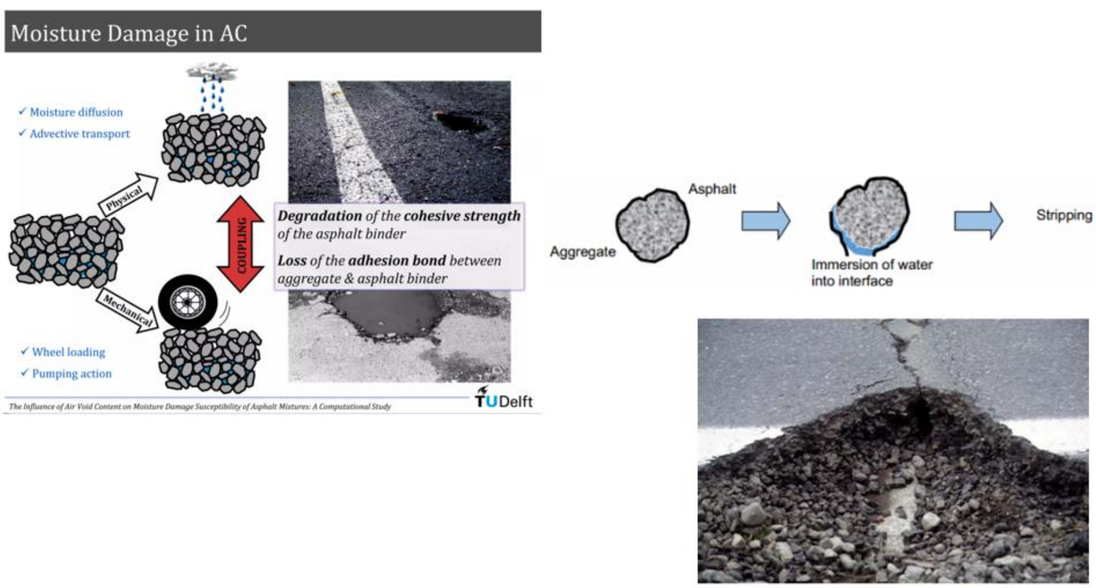


Figure 4. Hydroplaning

Water in pavements primarily comes from surface water, such as rainfall and runoff, which may enter the pavement through joints, cracks, shoulders, or backup in ditches, and from groundwater, which may enter the pavement through the rise of the groundwater table or capillary forces; see Figure 5. These water sources pose significant challenges to the durability and stability of roadways. Engineers employ various strategies to mitigate these issues, primarily through drainage systems, which consist of surface, subsurface, and roadside drainage.

Water flows across the road surface in two ways: laterally (i.e., side to side) and longitudinally (i.e., along the length of the road). Lateral drainage is achieved by crowning or by in- or out-sloping of road surfaces; see Figure 6. Longitudinal grade is of greater significance on urban roadways than on rural roadways. This is because on urban roadways, surface water is collected by curbs and gutters, then conveyed longitudinally to a drainage system.

There are two types of subsurface drainage systems: interceptor drains, typically designed to remove the water as it seeps down the pavement structure, as shown in Figure 7; and relief drains, often employed to lower the groundwater table level, as shown in Figure 8. An interceptor subsurface drainage system consists of three basic elements: a permeable base layer, a filter layer to prevent the migration of fine subgrade materials into the permeable base, and a method to remove the water from the drainage layer, such as daylighting or longitudinal/transverse pipe collectors.

Roadside drainage is designed to collect and transport water from the surface and structure of the road so that there will be no ponds on the road or backup in the ditches, as shown in Figure 9. Roadside drainage consists of following elements: foreslope, side ditches, cross drains, side drain, lateral channels, curb and gutter, drainage inlet, catch basin, storm sewer line, etc. Typically, it is more cost-effective and less risky to prevent moisture from entering and accumulating within pavements using surface drainage rather than relying on subsurface drainage for moisture removal.

Figure 5. Sources of water to a pavement [1]

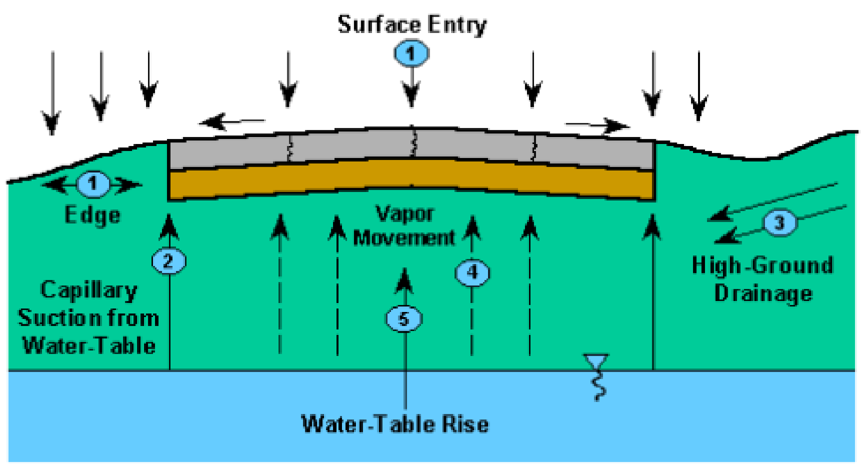


Figure 6. Typical road cross section grading [2]

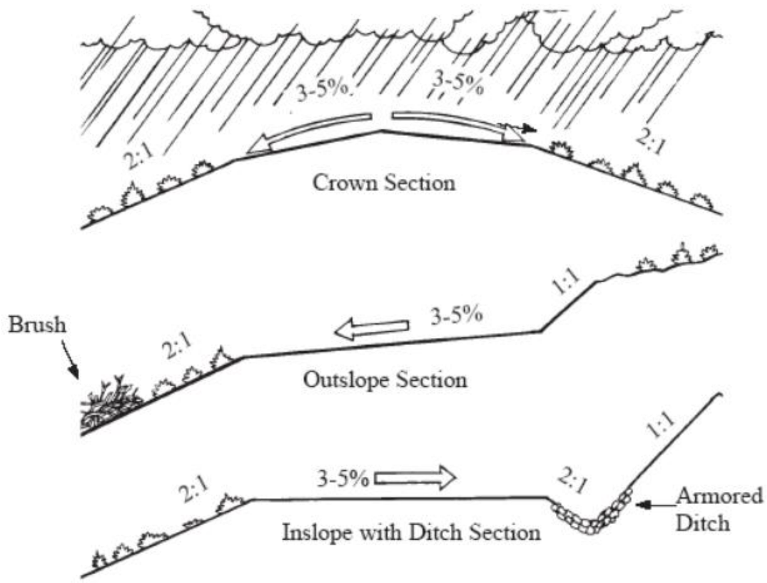


Figure 7. Typical pavement subsurface interceptor drainage system components [3]

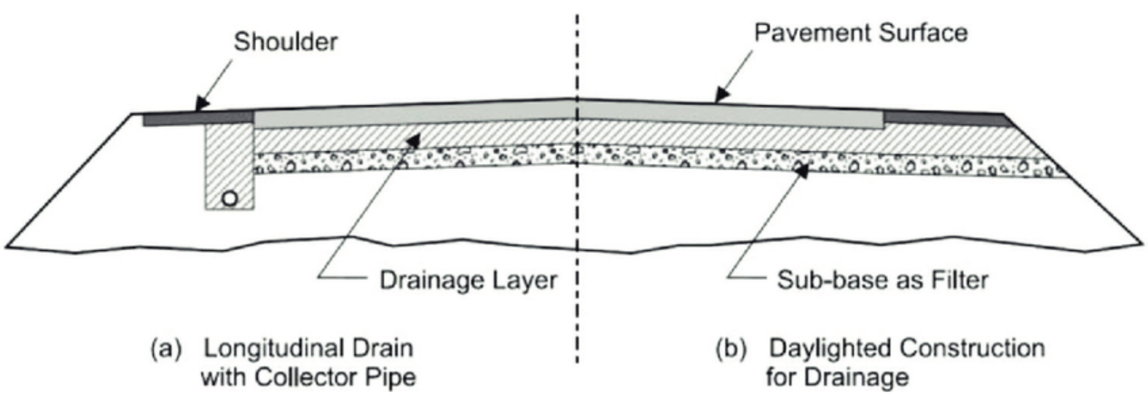


Figure 8. Subsurface relief drainage system to lower the groundwater table [4]

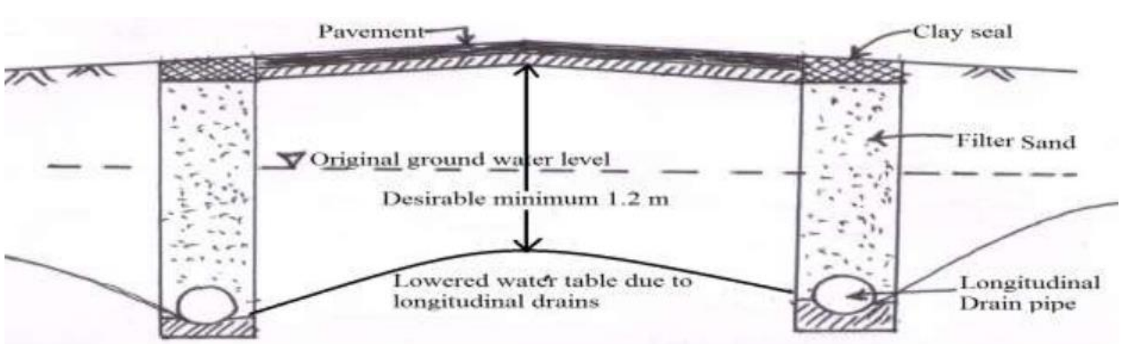


Figure 9. Roadside drainage components

The role of efficient drainage in preserving the structural integrity and functionality of road pavements cannot be overstated [5]. Proper drainage system design and maintenance play a crucial role in managing surface water, preventing it from infiltrating the pavement and undermining its structural integrity. This includes techniques such as the use of well-designed and -maintained cross slopes, ditches, culverts, and storm water management systems. Suboptimal drainage can lead to an array of issues, including but not limited to water infiltration, pavement erosion, subbase weakening, pothole formation, and even the onset of hydroplaning accidents. However, the literature review indicates that drainage condition ratings of the existing pavement at the network level are almost non-existent, largely due to the lack of practical and efficient inspection methods for network-level evaluation [6] [7].

At the Louisiana Department of Transportation and Development (DOTD), the Highway Needs Database, owned and maintained by the planning section, includes a drainage condition field that has not been updated in over 20 years. Although DOTD's maintenance division once proposed a drainage Level of Service (LOS) metric, it was never implemented. These gaps highlight a pressing need for a practical, scalable, and data-informed approach to assess drainage conditions across highway networks.

Literature Review

The importance of proper drainage in preserving pavement structural integrity and performance is well recognized [5]. Most state Departments of Transportation (DOTs) provide pavement drainage design guidance in hydraulic or roadway design manuals [8] [9] [10]. However, despite this recognition, drainage condition ratings at the network level remain largely undeveloped. Most DOTs assess surface drainage conditions only to address isolated problem areas [11].

The Connecticut Department of Transportation (CTDOT) includes drainage condition, with a weighting factor of 20%, in its asphalt pavement condition rating through an index called the drainage index (DI) [12]. However, this drainage index (DI) only considers cross-slope (SLOPAVG) and longitudinal grade (GRADE) as:

DI=8.0 if abs(SLOPAVG)>=2.0
DI=6.0 if abs(SLOPAVG)>=1.0
DI=6.0 if abs(SLOPAVG)>=0.5 and abs(GRADE)>=3.0
DI=3.0 if abs(SLOPAVG)>=0.5 and abs(GRADE)<3.0
DI=NULL if SLOPAVG is NULL
DI=3.0 if abs(SLOPAVG)>=0.5
Else DI=1.0

Recent studies have explored alternative methods for evaluating drainage. For example, Gurganus et al. [11] and Lee and Gharaibeh [6] explored the use of mobile LiDAR to capture roadway and roadside geometric features, and they developed a surface drainage rating system using those measurements for the Texas Department of Transportation (TxDOT). The rating system developed specifically applies to rural roadway sections with an unconfined edge. Data were collected on the following elements: hydroplaning speed; traveled way width; data collection lane cross-slope; roadside front slope; right roadside ditch depth; and right roadside flowline slope. Each of these elements was rated individually with a rating factor ranging from 0 to 1; see Figure 10 through Figure 15. These sub-ratings were averaged into an overall rating, which was then normalized to 100. Table 1 presents an example of such ratings.

Hydroplaning potential rating is based on the difference between the calculated hydroplaning speed (HPS) and the posted speed limit. The hydroplaning speed is calculated as:

$$HPS = SD^{0.04} P_t^{0.3} (TD + 1)^{0.06} A \quad [1]$$

$$A = \max\left[\frac{10.409}{WFT^{0.06}} + 3.507,\ \left(\frac{28.952}{WFT^{0.06}} - 7.817\right) MTD^{0.14}\right] \quad [2]$$

where,
SD is the spindown (fixed at 0.10);
P_t is the tire pressure (psi);
TD is the tire tread depth (in 1/32 in.);
WFT is the water film thickness (in.); and
MTD is the mean texture depth of pavement surface (in.).

Figure 10. Roadway lane width rating [11]

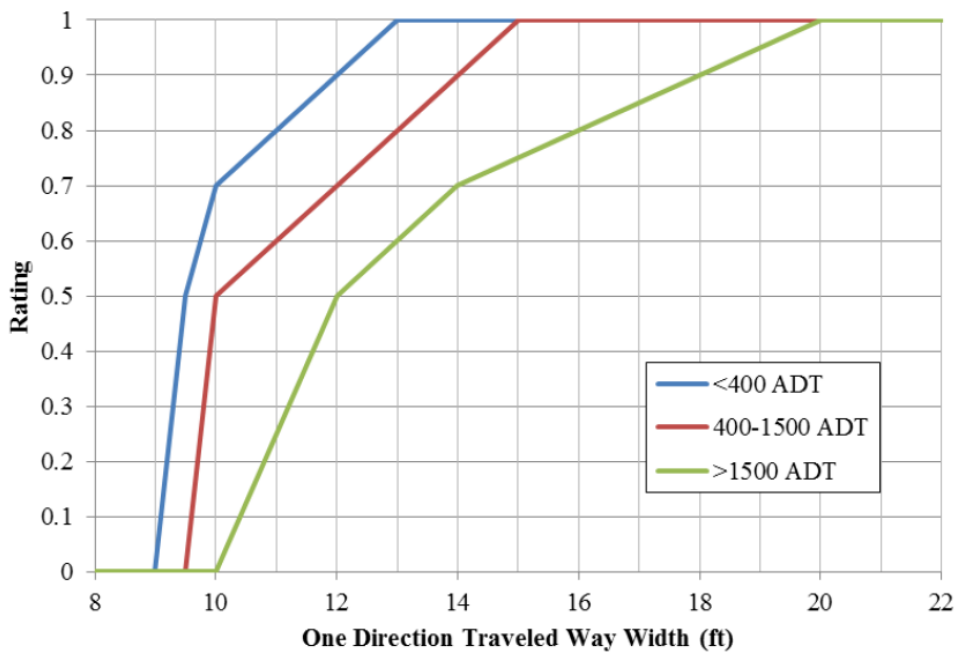
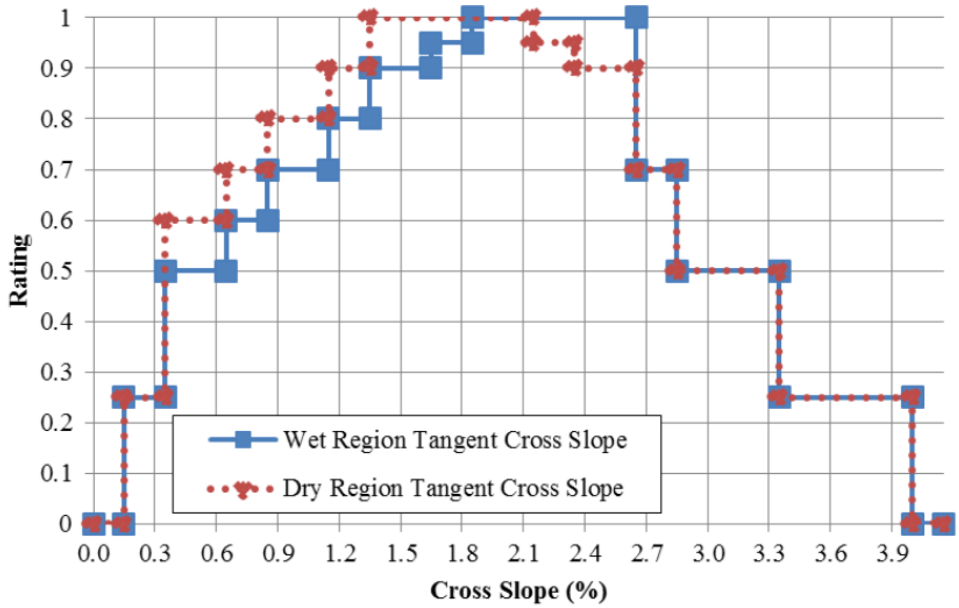
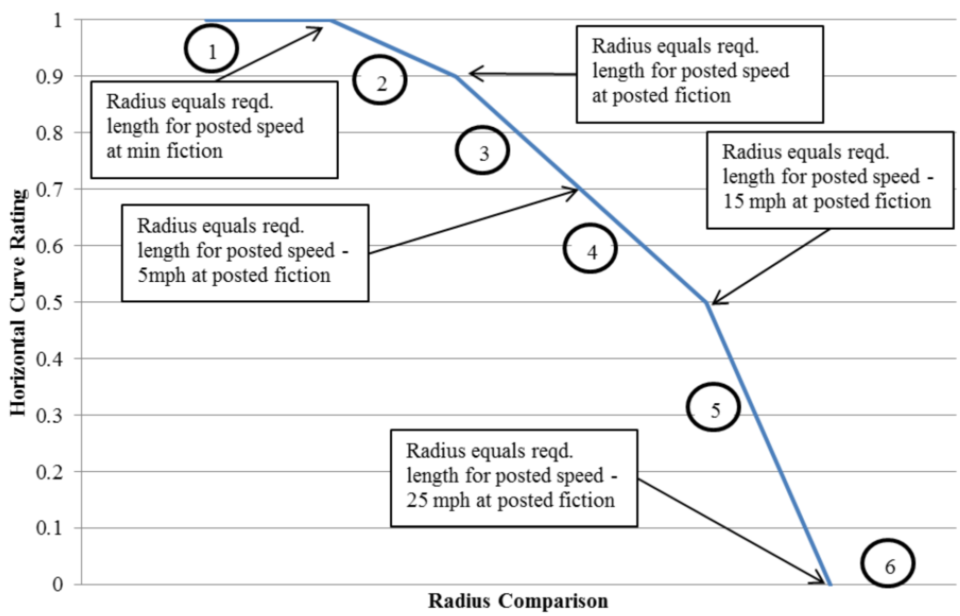


Figure 11. Travel lane cross-slope rating [11]



(a) Tangent sections



(b) Horizontal curves

Figure 12. Hydroplaning potential rating [11]

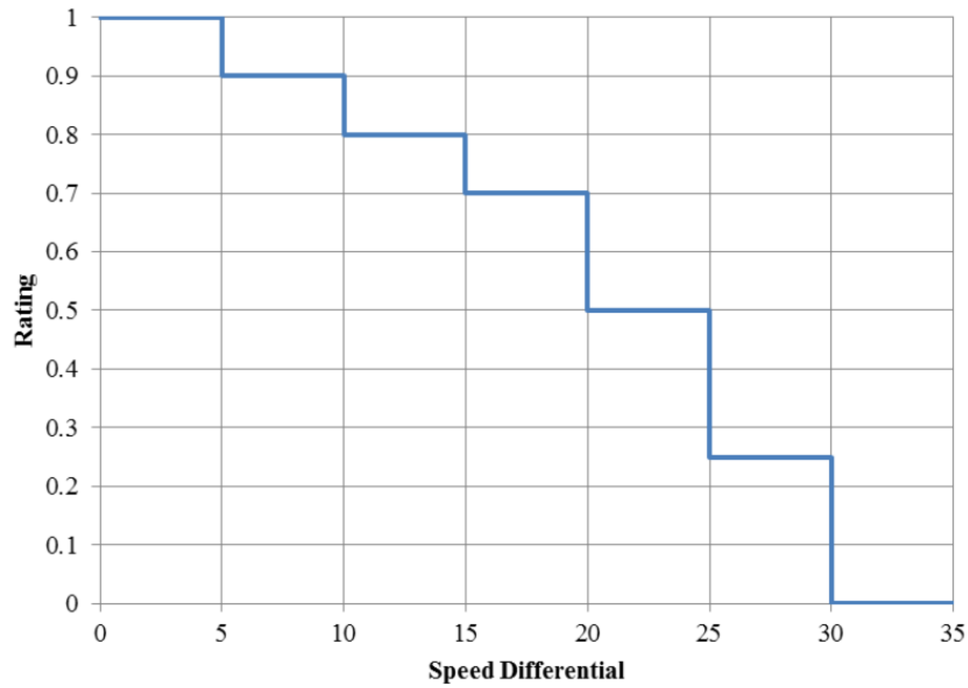


Figure 13. Front slope rating [11]

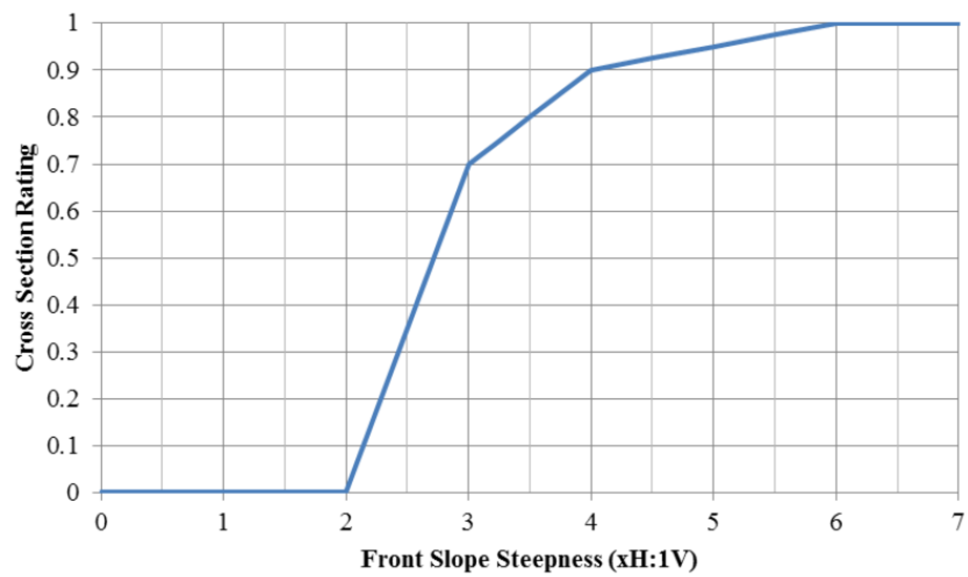


Figure 14. Ditch depth rating [11]

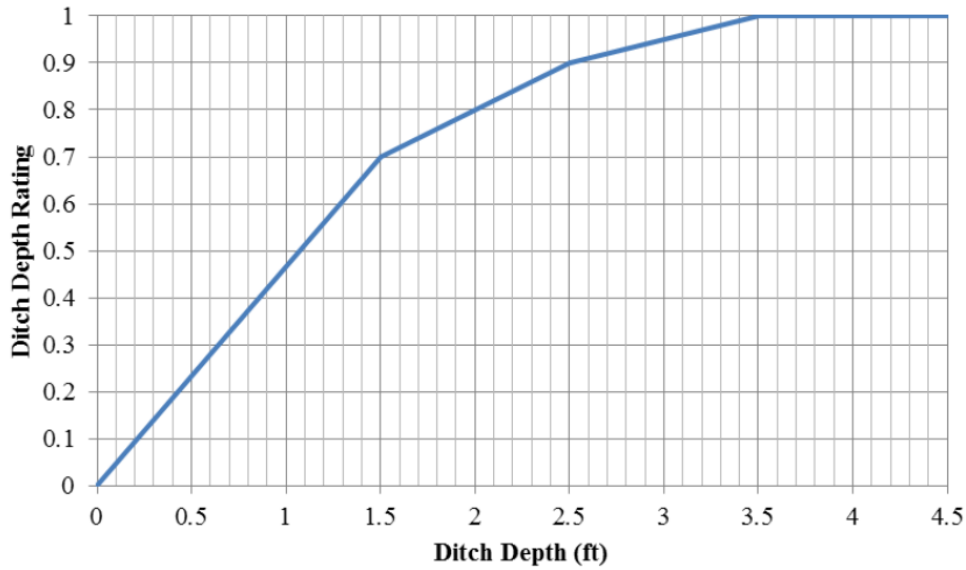


Figure 15. Ditch flowline slope rating [11]

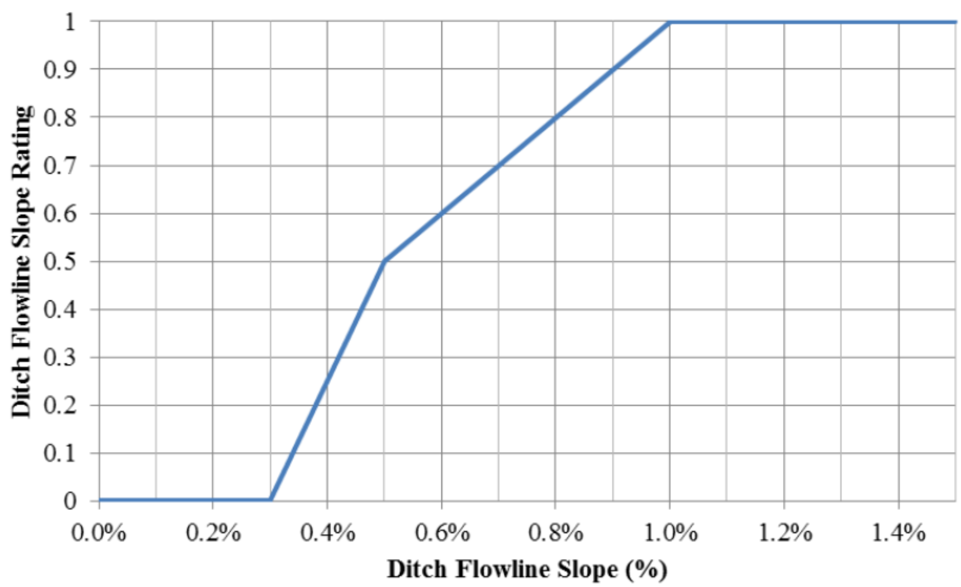


Table 1. Surface drainage rating summary [11]

					Roadway Surface				Roadside Surface						
Begin TRM	End TRM	Section	Alignment Classificaiton	Section Shape	RT Width Rating	RT Cross Slope Rating	Hydro-planing Rating	RT Roadside Shape	RT Front Slope Rating	RT Ditch Depth Rating	RT Ditch Slope Rating	Combined Paved Surface Rating	Combined Roadside Rating	Overall Drainage Rating	**Overall Rating Normalized to 100**
284.0	284.1	1	RT CURVE	RT CURVE	0.80	0.00	1.00	Primarily Ditch	0.99	0.83	1.00	0.60	0.94	0.77	77
284.1	284.2	2	TANGENT	OUT OF SHAPE	0.88	0.00	1.00	Primarily Ditch	0.99	0.83	1.00	0.63	0.94	0.78	78
284.2	284.3	3	LT CURVE	CURVE TRANSITION	0.84	0.43	1.00	Primarily Ditch	1.00	0.84	1.00	0.76	0.95	0.85	85
284.3	284.4	4	LT CURVE	LT CURVE	1.00	0.86	1.00	Primarily Ditch	1.00	0.83	1.00	0.95	0.94	0.95	95
284.4	284.5	5	LT CURVE	CURVE TRANSITION	0.78	0.43	1.00	Primarily Ditch	0.99	1.00	1.00	0.74	1.00	0.87	87
284.5	284.6	6	RT CURVE	OUT OF SHAPE	0.77	0.00	1.00	Primarily Ditch	0.98	0.88	1.00	0.59	0.95	0.77	77
284.6	284.7	7	TANGENT	TANGENT	0.81	0.78	1.00	Primarily Ditch	1.00	0.68	1.00	0.86	0.89	0.88	88
284.7	284.8	8	RT CURVE	OUT OF SHAPE	0.84	0.00	1.00	Primarily Ditch	0.94	0.61	1.00	0.61	0.85	0.73	73
284.8	284.9	9	TANGENT	CURVE TRANSITION	0.81	0.50	1.00	Primarily Ditch	0.96	0.59	0.58	0.77	0.71	0.74	74
284.9	285.0	10	LT CURVE	LT CURVE	0.98	1.00	1.00	Primarily Ditch	1.00	0.92	1.00	0.99	0.97	0.98	98
285.0	285.1	11	LT CURVE	LT CURVE	0.92	1.00	1.00	Primarily Ditch	0.99	1.00	1.00	0.97	1.00	0.99	99
285.1	285.2	12	TANGENT	CURVE TRANSITION	0.80	1.00	1.00	Primarily Ditch	1.00	1.00	1.00	0.93	1.00	0.97	97
285.2	285.3	13	LT CURVE	LT CURVE	0.82	1.00	1.00	Primarily Ditch	0.91	0.82	1.00	0.94	0.91	0.92	92
285.3	285.4	14	TANGENT	CURVE TRANSITION	0.79	0.50	1.00	Primarily Ditch	0.98	1.00	1.00	0.76	0.99	0.88	88
285.4	285.5	15	LT CURVE	LT CURVE	0.70	0.00	1.00	Primarily Ditch	0.88	1.00	1.00	0.57	0.96	0.76	76

Saarenketo [13] conducted a drainage condition survey on low-volume roads in Finland and classified drainage into three qualitative categories: Good, Fair, and Poor. Similarly, Hardy [14] recommended a two-tiered drainage survey strategy that combines coarse visual inspections at the network level (e.g., drive-by surveys for rural roads) with detailed visual surveys at the project level. Descriptions of drainage conditions were provided using the same Good–Fair–Poor scale. Most existing literature on pavement drainage focuses on hydroplaning risks and other safety concerns [5] [15] [16] [17], with limited attention to pavement structural performance [18].

Objective

The objective of this research was to explore the use of existing DOTD Pavement Management System (PMS) and LiDAR data to develop a pavement drainage condition rating index for Louisiana, with the goal of integrating drainage evaluation into the Pavement Management System (PMS) as part of the overall pavement condition assessment.

Scope

This study focused on developing a practical, network-level methodology for evaluating pavement drainage conditions using existing data from DOTD's Pavement Management System (PMS). The framework assessed three components: pavement surface drainage, roadside/shoulder drainage, and ditch drainage, based on PMS datasets and imagery. Five roadway sections (LA 441, LA 15, US 167, LA 12, and LA 397) were analyzed to demonstrate implementation potential and highlight correlations with pavement performance. The scope was limited to identifying operational deficiencies in existing infrastructure, not regional flood risk or hydraulic capacity. Exploratory use of United States Geological Survey (USGS) LiDAR and Interferometric Synthetic Aperture Radar (InSAR) data was also considered, though limitations were noted for narrow, vegetated ditches. The emphasis was on creating a scalable, fine-resolution (0.1 mi.) rating system that can be integrated into PMS workflows, with potential future enhancement through AI and LiDAR technologies.

Methodology

This study developed a practical framework for evaluating pavement drainage conditions at the network level using existing data from the Louisiana Department of Transportation and Development (DOTD). As a first step, district offices across the state were surveyed to identify common drainage issues and gauge the relative importance of different drainage elements. The methodology focused on three components: (1) pavement surface drainage assessed using PMS data such as cross-slope, longitudinal grade, and rutting; (2) roadside/shoulder drainage evaluated using PMS edge drop-off data and imagery to detect erosion, vegetation growth, and debris; and (3) ditch drainage assessed from PMS imagery to identify sediment accumulation, erosion, and obstructions. The framework was applied to five roadway sections across Louisiana, with drainage ratings generated at a fine scale (0.1-mi. resolution) to capture localized deficiencies. Additionally, exploratory analyses using publicly available LiDAR datasets and InSAR technology were conducted to assess their feasibility for roadside ditch condition evaluation.

Survey of Drainage Issues in Louisiana

To complement the technical data analysis and ensure the developed drainage rating index reflected real-world challenges and practitioner experience, a statewide email survey was conducted. The primary purpose of this survey was to gather critical qualitative and quantitative information directly from DOTD personnel across various districts. The specific objectives of this survey were:

- To ascertain the perceived importance of various roadway, roadside, and roadside drainage elements in facilitating effective surface drainage
- To identify specific road segments within the respondents' districts that are currently experiencing drainage problems
- To characterize the nature, severity, frequency, duration, and impact of these identified drainage issues

A copy of the detailed survey form is provided in the Appendix. The Google-based survey form was structured into several distinct sections to capture a comprehensive dataset:

Importance Rating

Respondents were asked to rate the importance of predefined roadway, roadside, and roadside drainage elements on a seven-point Likert-type scale, ranging from 1 ("not at all important") to 7 ("extremely important"). This quantitative rating system facilitated statistical analysis of the perceived significance of each element.

Problem Identification

This section allowed respondents to identify up to ten specific roadway segments within their district that were experiencing drainage problems. For each identified segment, detailed information was requested, including the road name, LRSID (Louisiana Roadway System Identification), and mile points; the nature of the drainage problem (encompassing issue type, severity, frequency, duration, and impact); and a selection of contributing elements via checkboxes. An "Other" option was provided for additional, unlisted contributing factors. Further questions inquired about the availability of historical flooding records, the road shape, evidence and type of erosion, and the ditch shape (V-shape, U-shape, flat, round, no ditch, other).

Open-Ended Comments

A final section provided an opportunity for respondents to offer additional comments or suggestions regarding road drainage problems, the importance of road elements, or any other related topics, allowing for the capture of unforeseen or nuanced perspectives.

Respondent Demographics

A total of 23 unique and complete responses were collected from DOTD personnel. The respondents included David North, Kyle East, Nicholas Fruge, Patrick Anthony Cusey, Clayton Cormier, Christopher Enrico Chavez, Grantt Chelette, Sam Miller, Seth Woods, Jason Robinson, Steve Christner, DeMarcion Evans, John Paul Jones, Bridget Ellerbe, Jefery Chatelain, Jonathan Lachney, David Dupree, Ennis Johnson, Gary Panteria, Jennifer Branton, Lacey McCaskill, Aaron Elisar, and Phil DiBenedetto. While specific district affiliations were not uniformly requested or provided for all respondents, the diversity of reported problem locations, which included various state routes (LA 1, LA 4, LA 12, LA 15, LA 27, LA 104, LA 347, LA 385, LA 389, LA 397, LA 433, LA 441, LA 1077), U.S. routes (US 167, US 371), and Interstate 49, suggests a reasonable geographical spread of input from across Louisiana.

Importance Ratings for Roadway Elements

Respondents rated five key roadway elements based on their importance for surface drainage. The mean ratings, calculated from the 23 complete responses, indicate a strong consensus on the critical role of geometric features and pavement surface condition in managing surface water. Figure 16 and Table 2 present the importance ratings for roadway elements. The consistently high average ratings for "cross-slope" (6.3) and "rut depth" (5.8) highlight the fundamental importance of proper geometric design and pavement surface condition in facilitating efficient surface runoff. Notably, 19 respondents rated "cross-slope" as 5 or higher, and 15 rated it 6 or higher, indicating a consensus on its extreme importance. For "rut depth," 18 respondents rated it 5 or higher, and 15 rated it 6 or higher, further emphasizing its critical role. While "cracks and potholes" received a respectable average rating of 4.73, placing it in the "moderately important" category, its rating was notably lower than the other roadway elements. This suggests that while these pavement distresses are recognized as issues that can trap water and contribute to pavement deterioration, their primary perceived role may be more related to affecting pavement structural integrity or ride quality. Their impact on overall surface drainage efficiency is often considered localized or secondary to larger-scale geometric deficiencies.

Figure 16. Importance ratings for roadway elements

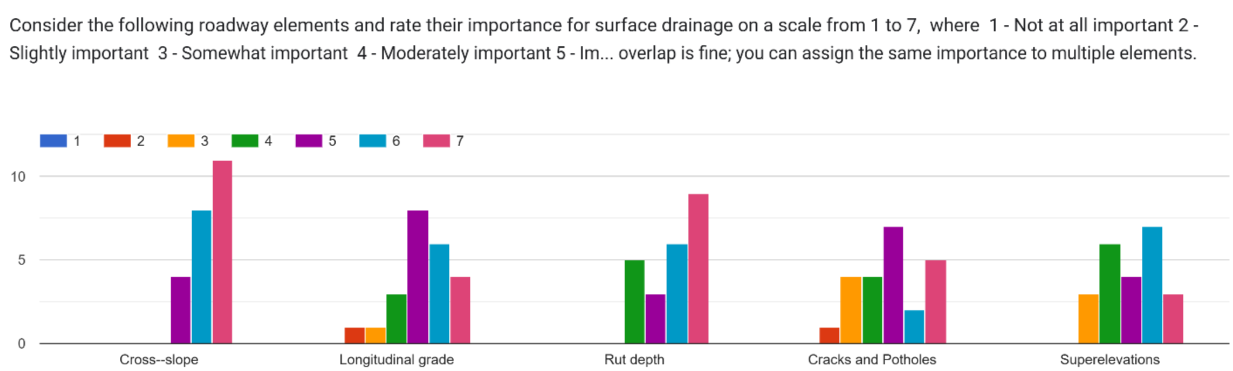


Table 2. Mean importance ratings for roadway elements

Roadway Element	Mean Rating (1-7)	Interpretation	Respondents Rating ≥ 5	Respondents Rating ≥ 6
Cross-slope	6.3	Extremely important	19/23	15/23
Rut depth	5.8	Very to Extremely important	18/23	15/23
Longitudinal grade	5.3	Important to Very important	18/23	10/23
Super elevations	5.0	Important	14/23	10/23
Cracks and Potholes	4.9	Moderately important to Important	14/23	7/23

Importance Ratings for Roadside Elements

Figure 17 and Table 3 present the importance ratings for roadside elements. This category explores elements immediately adjacent to the roadway surface that influence how water is conveyed away from the pavement. The high average rating for "high edges" (5.8) indicates their significant role in impeding water flow off the pavement surface. This is a critical factor for effective surface drainage, as water cannot shed properly if the adjacent shoulder or terrain is elevated. 20 respondents rated "high edges" as 5 or higher, and 15 rated it 6 or higher, underscoring its importance. "Barrier and rail openings" received a moderately high rating (5.4), suggesting that their proper design and maintenance are important for allowing water to pass through the roadway system. These features, being specific points designed for water passage, can become critical bottlenecks if blocked or inadequately sized. Conversely, "edge drop-offs" (4.0) and "intersection radii" (4.0) were rated lowest in this category. This implies that the impact of edge drop-offs on surface drainage is perceived as less critical than high edges. Similarly, intersection radii are primarily related to traffic flow geometry, and their influence on overall pavement surface drainage is considered minor by most respondents, although localized ponding can occur within these areas.

Figure 17. Importance ratings for roadside elements

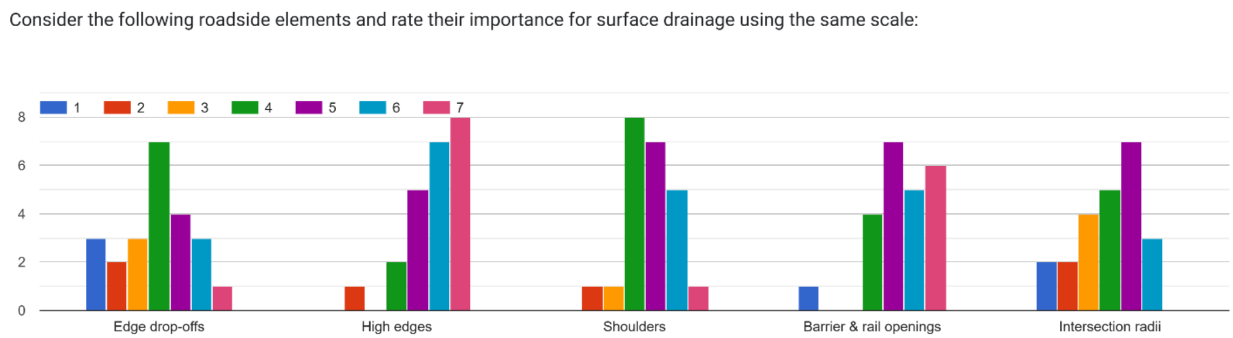


Table 3. Mean importance ratings for roadside elements

Roadway Element	Mean Rating (1-7)	Interpretation	Respondents Rating ≥ 5	Respondents Rating ≥ 6
High edges	5.8	Important to Very important	20/23	15/23
Barrier and rail openings	5.4	Important to Very important	18/23	11/23
Shoulders	4.7	Moderately important to Important	13/23	6/23
Edge drop-offs	4.0	Moderately important	8/23	4/23
Intersection radii	4.0	Moderately important	15/23	10/23

Importance Ratings for Roadside Drainage Elements

Figure 18 and Table 4 present the importance ratings for roadside drainage elements. This category focuses on engineered drainage structures specifically designed to collect, convey, and discharge storm water. "Inlets" (6.3), "curb and gutter" (6.0), "cross drain structures" (6.0), "side drain structures" (5.7), and "side ditches" (5.8) are consistently rated as extremely or very important. These elements represent the active components of a drainage system, directly responsible for collecting surface runoff from the pavement and conveying it away. Their high importance highlights their indispensable role in effective storm water management. For "inlets," 22 respondents rated it 5 or higher, and 19 rated it 6 or higher. For "curb and gutter," 20 rated it 5 or higher, and 18 rated it 6 or higher. For "cross drain structures," 21 rated it 5 or higher, and 17 rated it 6 or higher. For "side drain structures," 19 rated it 5 or higher, and 16 rated it 6 or higher. For "side ditches," 19 rated it 5 or higher, and 17 rated it 6 or higher.

"Fore slopes" (4.6) and "back slopes" (3.6) received comparatively lower importance ratings for their direct role in pavement surface drainage. This suggests that while these elements are integral to the overall right-of-way and contribute to erosion control and broader watershed management, their immediate impact on the efficient removal of water from the pavement surface is perceived as less critical than that of the engineered collection and conveyance structures.

Figure 18. Importance ratings for roadside drainage elements

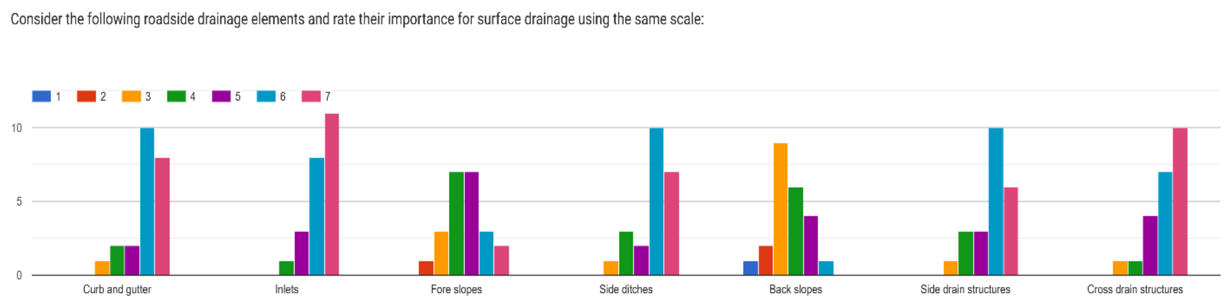


Table 4. Mean importance ratings for roadside drainage elements

Roadway Element	Mean Rating (1-7)	Interpretation	Respondents Rating ≥ 5	Respondents Rating ≥ 6
Inlets	6.3	Very to Extremely important	22/23	19/23
Curb and gutter	6.0	Very important	20/23	18/23
Cross drain structures	6.0	Very important	21/23	17/23
Side drain structures	5.7	Important to Very important	19/23	16/23
Side ditches	5.8	Important to Very important	19/23	17/23
Fore slopes	4.6	Moderately important to Important	12/23	5/23
Back slopes	3.6	Somewhat important	12/23	6/23

Other Critical Elements Identified by Respondents

Beyond the predefined categories, several respondents offered valuable qualitative information regarding other elements they deem important for surface drainage. One respondent highlighted "horizontal curvature as influencer of combination vertical, cross slope, and super." This emphasizes the complex interaction of multiple geometric parameters in curved sections of roadways, where drainage can be particularly challenging due to varying cross-slopes and super-elevations. Another critical design detail was noted as "super-elevation transitions, and preventing them from being too long which would raise the risk for areas with a 0% cross slope," which was rated as “extremely important.” This points to specific design flaws in transition zones that can create significant ponding areas on the pavement.

Broader hydrological and operational factors were also identified. "Surface elevation above MSL, detention within developments, ditch maintenance" were cited as important, indicating the influence of regional topography, the impact of adjacent land development on storm water runoff, and the ongoing operational needs for effective drainage system upkeep. The overall "roadway elevation" was independently rated as important by another respondent.

Geotechnical and environmental interactions were also recognized. One respondent noted: "Soil conditions are important because of the clay soils we have in our area causing expansion and shrinkage of the base. Also the trees along our roadways during drought seasons draw the moisture out of the base, causing cracks in the base and pavement." This highlights how subsurface conditions and vegetation can indirectly affect drainage performance by influencing pavement structural integrity and the development of distresses that trap water.

Specific pavement material properties and geometric interactions at roadway junctions were also mentioned, such as "pavement permeability (i.e., areas where higher permeability are confined within lower permeability pavement)," which received a rating of 5, and "on ramp connection onto tangent crown roadways (i.e., wider pavement with cross-slope in same direction)," which received a rating of 4. These details reveal how pavement composition and specific junction designs can create localized drainage issues. One respondent commented, “Open-Graded Friction Course (OGFC) getting clogged and creating issues during freezing temps.”

Reported Pavement Drainage Problems

A total of 19 distinct problem road segments were identified by 11 of the 23 respondents who provided specific locations. These problem locations span a wide range of Louisiana's state highway network, including various state routes (LA 1, LA 4, LA 12, LA 15, LA 27, LA 104, LA 347, LA 385, LA 389, LA 397, LA 433, LA 441, LA 1077), U.S. routes (US 167, US 371), and Interstate 49. The nature of the reported drainage problems varied, but common themes emerged. The most frequently cited issue was "roadway flooding" or "flooding over the roadway," often described as occurring during "intense events" or "heavy rain events". Some respondents specified "high frequency" of flooding, while others noted it as a "frequent occurrence" or happening "a few times per year". The impact of these events ranged from "results in closures and water on roadway" to "water rising to fog line," "adjacent property flooding," and "base failures, as well as saturation of the slope materials, resulting in slope sides and surface cracking."

Specific issues included:

- "Floods in intense events" (LA 1, Shreveport)
- “Roadway flooding, high frequency, results in closures and water on roadway" (LA 347)
- "Roadway flooding between roundabouts and adjacent properties, frequent occurrence" (LA 347)
- "Potential overtopping during high tide/southerly wind events" (LA 27)
- "Potential overtopping during typical rain event, adjacent property flooding" (LA 3092)
- "Potential overtopping, water rising to fog line, adjacent property flooding, happens during typical rain event" (LA 397)
- "Ditch erosion" (LA 12)
- “Surface flooding in outside lane" (LA 385, Ryan St)
- “Farmers have changed conditions of the farm land and drain water toward the roadway" (LA 104)
- "Flooding over the roadway" (US 167)
- "Roadway flooding, any heavy rain event, entire outside lane or both lanes" (LA 397)
- "The catch basin spacing and outflow pipe from the catch basin do not appear to be large enough and the road gets inundated with water a few times per year" (US 371)

- "High water during heavy rains, severity 4 out of 7, with 7 being most severe" (Old Minden Rd)
- "Roadway holds water during heavy rain storms" (LA 4, East Caldwell Parish)
- "Water sheet flowing across roadway" (I-49)
- "Sheet flow" (I-49)
- "Cross-slope is nominally one-way slope away from the crown of levee; due to inconsistencies in the cross-slope, water often ponds in the roadway instead of flowing to the opposite side, and down the levee. This attributes to base failures, as well as saturation of the slope materials, resulting in slope sides and surface cracking. Problem occurs with moderate rainfall (>1"), but is limited by the slope so that severe rain does not greatly increase the problem. Problem is limited to multiple small areas where cross-slope is insufficient" (LA 15)
- "Tidal issues" (LA 1)
- "Roadway flooding and stagnant water in ditches after routine rain events" (LA 441)
- "Water on roadway due to tides, direction of winds" (LA 1077)
- “Water on roadway due to tidal, wind direction; couple of times a year" (LA 433)

Identification of Key Drainage Elements and Roadway Sections for Methodology Development and Verification

This study focuses on rural roadways with ditch drainage systems. To develop the pavement drainage rating, survey results were analyzed to identify the most critical elements influencing drainage. Selection criteria required that at least 80% of respondents rate a factor as important (importance rank ≥ 5) and at least 50% rate it as very important (importance rank ≥ 6). Based on these thresholds, five key elements were identified: cross-slope, longitudinal grade, rut depth, high edge, and side ditches.

Five roadway sections (LA 441, LA 15, US 167, LA 12, LA 397) were selected to demonstrate the proposed methodology, representing a range of drainage issues identified in the survey.

Pavement Drainage System Rating Methodology

A composite drainage index (DI), which is the weighted sum of the pavement surface drainage index (DI_{PS}), roadside/shoulder drainage index (DI_{RS}), ditch drainage index (DI_{D}), and water ponding/presence index (DI_{WP}), was proposed to rate the drainage condition in this study; see Equation 3.

$$DI = w_{PS}DI_{PS} + w_{RS}DI_{RS} + w_{D}DI_{D} + w_{WP}DI_{WP} \quad [3]$$

where,
w_{PS} is the weighting factor of pavement surface drainage condition;
w_{RS} is the weighting factor of shoulder/roadside drainage condition;
w_{D} is the weighting factor of ditch drainage condition; and
w_{WP} is the weighting factor of water ponding/presence.

The subsurface drainage is beneath the surface and cannot be visually inspected, so it is not explicitly included in the proposed pavement drainage system rating. Instead, the water ponding/presence rating index is included. The ponding or visible water presence is clearly related to the other three parameters. In many cases, low scores in DI_{PS}, DI_{RS}, and DI_{D} will naturally lead to a low DI_{WP} score, as water cannot drain effectively. However, the water ponding/presence plays a distinct role in the proposed drainage rating system: it reflects whether the drainage system is functioning as a whole. For example, even if ditches and shoulders appear to be in good condition, persistent ponding after storms may indicate failures elsewhere, such as downstream blockages or hidden subsurface drainage issues.

Including DI_{WP} in the rating formula offers several key benefits:

- It serves as a ground-truth checkpoint for overall drainage functionality.
- It helps identify hidden or downstream issues not visible during surface inspections (e.g., clogged culverts, subsurface drainage failures).
- It acts as a validation factor; if DI_{PS}, DI_{RS}, and DI_{D} scores are high but DI_{WP} is low, the segment should be flagged for further investigation.

Pavement Surface Drainage

Pavement Surface Drainage Rating Index (DI_{PS}) is a score used to quantify the condition of pavement surface drainage and ranges from 0 to 100. The drainage capacity of a pavement surface is primarily determined by its geometry and surface condition. Key influencing factors include cross-slope, longitudinal grade, rutting, and cracking. Cross-slope and longitudinal grade primarily affect surface runoff [6], while rutting influences water ponding and flow paths. The rating in this study mainly focuses on drainage features affecting pavement structure performance, rather than functional performance such as safety-related hydroplaning. Therefore, pavement texture, which affects water film depth, is not considered.

Pavement cross-slopes represent a balance between drainage, which benefits from steeper slopes, and driver comfort and safety, which require flatter slopes. While maximum cross-slopes are limited for safety reasons, minimum cross-slopes are necessary to ensure adequate drainage. According to the Louisiana DOTD Hydraulics Manual, the minimum cross-slope is 2.5%. Similarly, both minimum and maximum longitudinal grades are essential for proper geometric design. The manual specifies a minimum longitudinal grade of 0.5%.

Pavement surface drainage rating index (DI_{PS}) is approximated as the weighted sum of the above parameters, with the value from each ranging from 0 to 100. Instead of using the design cross-slope or longitudinal grade, the minimum required cross-slope and longitudinal grade are used to determine the Cross-Slope Index (*XSLOPE*) and Longitudinal Grade Index (*LGRADE*). This approach offers several key benefits:

- While designs can vary, the minimum required slope or grade represents the threshold necessary for adequate drainage.
- On older pavements or rural roads without formal design records, the intended slope or grade may not be known, whereas the minimum requirement is typically defined by policy or best practice.
- Using the minimum required values ensures consistent scoring across projects, even when design documentation is unavailable.

$$DI_{PS} = w_{XS}XSLOPE + w_{LG}LGRADE + w_{R}RUT \qquad [4]$$

$$XSLOPE = \text{MIN}\left(100, MAX\left(0, \left(1 - \frac{(Slope_{min} - Slope_{actual})}{Slope_{min}}\right) \times 100\right)\right) \qquad [5]$$

$$LGRADE = \text{MIN}\left(100, MAX\left(0, \left(1 - \frac{(Grade_{min} - Grade_{actual})}{Grade_{min}}\right) \times 100\right)\right) \qquad [6]$$

$$RUT = \text{MIN}\left(100, 100 - \left(\frac{Rutting}{0.125} \times 10 - 10\right)\right) \qquad [7]$$

where,
w_{XS} is the weighting factor of cross-slope;
XSLOPE is the Cross-Slope Index;
w_{LG} is the weighting factor of longitudinal grade;
LGRADE is the Longitudinal Grade Index;
w_R is the weighting factor of rutting;
RUT is the Rutting Index;
$Slope_{\min}$ is the minimum required cross-slope;
$Slope_{\text{actual}}$ is the measured cross-slope;
$Grade_{\min}$ is the minimum required longitudinal grade;
$Grade_{\text{actual}}$ is the measured longitudinal grade; and
weighting factors of 0.5, 0.25, and 0.25, are recommended for cross-slope, longitudinal grade, and rutting, respectively.

A weighting factor of 0.45 is recommended for pavement surface drainage index (DI_{PS}).

Roadside/Shoulder Drainage Index

After water has drained from the pavement surface, the shoulders or parking lanes must either direct the water to an inlet or channel it to ditches. Shoulders are typically used on rural roadways, while parking lanes and gutters are common in urban areas. The consideration of curbs, gutters, and other drainage features in urban areas is beyond the scope of this research.

A sharp or vertical edge (i.e., drop-off) between the pavement and shoulder disrupts water flow. Water strikes the edge and does not flow smoothly off the pavement, especially at low flow rates, causing temporary pooling. This can lead to localized erosion at the toe of the pavement or the upper shoulder near the edge drop-off. Shoulder erosion traps water, disrupts drainage flow by altering the slope and surface characteristics of the shoulder, and weakens the pavement.

The roadside/shoulder drainage rating index (DI_{RS}), ranging from 0 to 100, is calculated based on parameters related to pavement edge drop-off (RS_D), erosion (RS_E), and obstruction (RS_O), as shown in the equation below.

$$DI_{RS} = 100 - \left(\frac{MIN(MAX(RS_D, RS_E, RS_O), AVG(RS_D, RS_E, RS_O) + 0.85STD(RS_D, RS_E, RS_O)}{5} \times 100\right) \quad [8]$$

where,
$MAX(RS_D,\ RS_E,\ RS_O)$ is the maximum score of edge drop-off, erosion, and obstruction score;
$AVG(RS_D,\ RS_E,\ RS_O)$ is the average score of edge drop-off, erosion, and obstruction score; and
$STD(RS_D,\ RS_E,\ RS_O)$ is the standard deviation of edge drop-off, erosion, and obstruction score.

This equation ensures that a single severe defect brings attention, even if others are fine. Meanwhile, it also prevents overrating due to a single extreme value by comparing the maximum value with the average condition plus a variability allowance.

In this study, the condition of each component in the roadside/shoulder drainage rating index is classified into four categories. A description of each category and its corresponding drainage condition score is presented in Table 5.

Table 5. Roadside/shoulder condition rating scale

Score	Drop-off	Erosion	Obstruction
0	<1”	No erosion	No obstruction
1	1-2”	Minor erosion (surface only)	Light vegetation/debris, no significant flow obstruction
3	2-3”	Moderate erosions, rills (narrow, shallow channels)	Moderate vegetation/debris, partially blocking flow (~25% flow path)
5	>3”	Severe erosion, gullies (deep, wide erosion paths)	Dense vegetation/debris, obstruction to flow (~50% flow path)

A weighting factor of 0.2 is recommended for roadside/shoulder drainage index (DI_{RS}).

Ditch Drainage Index

Literature studies reveal that most drainage evaluations for ditches are based on surface symptoms, such as ponding/no ponding, erosion/no erosion, obstruction/no obstruction, etc. In many cases, excellent filed-observed conditions do not mean the ditch meets design standards. Many rural ditches are built in the field with practical experience and often lack formal design. They may function well for typical storms but fail under design storms. Therefore, the proposed ditch drainage rating index in this study adopts a hybrid approach which combines field-observed condition (D_{visual}) with hydraulic compliance ($D_{\text{hydraulic}}$), each ranging from 0 to 100.

$$DI_D = w_v D_{visual} + w_h D_{hydraulic} \quad [9]$$

where,
w_V is the weighting factor of field-observed condition; and
w_H is the weighting factor of hydraulic compliance.

Weighting factors of 0.3 and 0.7 are recommended for field-observed condition and hydraulic compliance, respectively.

The field-observed condition index (D_{visual}), ranging from 0 to 100, is calculated based on parameters related to sediment (D_S), erosion (D_E), and obstruction (D_O); see Equation 10. The condition of each component in the field-observed condition index (D_{visual}) is categorized into four classifications. A description of each category and its corresponding drainage condition score is provided in Table 6.

$$D_{visual} = 100 - \left(\frac{MIN(MAX(D_S,D_E,D_O),AVG(D_S,D_E,D_O)+0.85STD(D_S,D_E,D_O)}{5} \times 100\right) \quad [10]$$

where,
$MAX(D_S, D_E, D_O)$ is the maximum score of sediment, erosion, and obstruction score;
$AVG(D_S, D_E, D_O)$ is the average score of sediment, erosion, and obstruction score; and
$STD(D_S, D_E, D_O)$ is the standard deviation of sediment, erosion, and obstruction score.

Table 6. Ditch condition rating scale

Score	Sediment	Erosion	Obstruction
0	No visible sediment	No erosion	No flow obstruction
1	Light sediment (raises the ditch elevation by less than one-quarter of the total ditch depth)	Minor erosion (surface-level soil movement only)	Light vegetation/debris, no significant impact on flow
3	Moderate sediment (raises the ditch elevation to between one-quarter and one-half of the total ditch depth)	Moderate erosion (noticeable soil washed down into ditch, slowing flow)	Moderate vegetation/debris, partial flow obstruction (~25% of cross-section)

Score	Sediment	Erosion	Obstruction
5	Heavy sediment (raises the ditch elevation more than one-half of the total ditch depth)	Severe erosion (soil sloughing/sliding into ditch, disrupting flow or ponding)	Dense vegetation/debris, significant flow obstruction or ponding (~50% of cross-section)

The hydraulic compliance index ($D_{\text{hydraulic}}$) can be calculated with the actual and design capacity of the ditch using the following equation:

$$D_{hydraulic} = 100\,\frac{Q_{actual}}{Q_{design}} \quad [11]$$

The most commonly used equation governing Open Channel Flow is known as the Manning's equation. Manning's equation is an empirical equation that applies to uniform flow in open channels and is a function of the channel hydraulic radius (R), flow area (A) and channel slope (S).

$$Q = \left(\frac{1.486}{n}\right) AR^{\frac{2}{3}}S^{\frac{1}{2}} \quad [12]$$

The Manning's coefficient *n* represents the roughness or friction applied to the flow by the channel. It can be estimated through field inspection or photo reference. Cross-section parameters such as ditch slope, depth, width, shape, and longitudinal grade may be obtained using Light Detection and Ranging (LiDAR). However, such data were not available at the time this study was conducted. Therefore, only the visual condition rating (D_{visual}) was considered in the assessment of ditch drainage in this study.

A weighting factor of 0.2 is recommended for ditch drainage index (DI_D).

Water Ponding/Presence Index

Water ponding/presence index (DI_{WP}), ranging from 0 to 100, is used to verify field performance. It can be calculated using Equation 13. The recommended score criteria for water ponding/presence (WP) are provided in Table 7.

$$DI_{WP} = 100 - \left(\frac{WP}{5} \times 100\right) \quad [13]$$

Table 7. Water ponding/presence rating scale

Score	Water Ponding/Presence
0	No visible standing water on pavement, shoulder, or ditch
1	Localized ponding on shoulder or ditch that drains within 24 hours after rainfall; pavement mostly clear
3	Ponding remains > 24 hours after rainfall on shoulder or ditch, or localized ponding on pavement
5	Persistent ponding or standing water on multiple areas (pavement, shoulder, and/or ditch)

A weighting factor of 0.15 is recommended for water ponding/presence index (DR_{PS}).

Pavement Drainage System Rating Index

The pavement drainage system rating scale (*DI*) is divided into five categories: Excellent, Good, Fair, Poor, and Very Poor, as shown in Table 8.

Table 8. Pavement drainage system rating scale

DI	Drainage Rating	Action
100-95	Very Good	No action needed
94–85	Good	Monitor; low-priority maintenance
84–65	Fair	Schedule maintenance
64–50	Poor	Prioritize for repair
49-0	Very Poor	Immediate action; evaluate full rehab

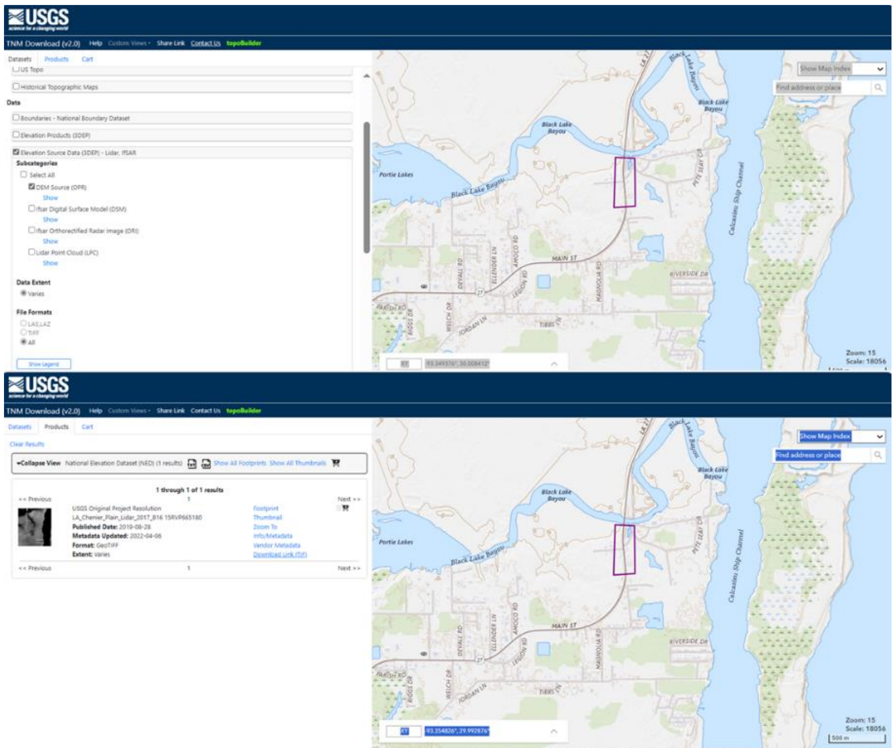
Assessment of USGS LiDAR for Roadside Ditch Geometry

As part of the effort to develop a drainage rating index for pavements in Louisiana, the research team explored the feasibility of using publicly available LiDAR data from the United States Geological Survey (USGS) to obtain geometric information regarding pavement side ditches, particularly ditch height (i.e., difference in elevation between the pavement edge and the bottom of the ditch). The USGS 3D Elevation Program (3DEP) LiDAR datasets for Louisiana were downloaded in LAS format from the National Map database; see Figure 19. The dataset specifications for our study area indicated:

- Nominal point spacing: 0.7–1.5m (~1–2 points/m^2)
- Vertical accuracy: ≤10 cm RMSEz in open terrain

All LAS tiles were re-projected to Louisiana State Plane (North or South) to match DOTD roadway GIS data. Only ground-classified points were retained for terrain modeling. Digital Terrain Models (DTM) were generated at 0.5m grid resolution.

Figure 19. Screenshot of USGS 3D Elevation Program (3DEP) LiDAR dataset example



A segment of LA 27 in Hackberry was selected to test the USGS LiDAR workflow; see Figure 20. The segment features narrow grass-lined ditches (0.4–1.0m depth) common in rural Louisiana. This pavement segment was reported to have a drainage issue by the district engineer, as indicated in the statewide survey.

Figure 20. Segment of LA 27 in Hackberry (Source: PMS images)

During the LA 27 demonstration, attempts to extract roadside ditch geometry from the USGS 3DEP LiDAR were unsuccessful. The nominal point density (≈1–2 points/m²) and resulting Digital Terrain Model (DTM) resolution (1m/pixel) produced substantial smoothing of narrow features within the roadway corridor. As a result, researchers were unable to reliably locate the roadway edge or ditch boundary from the LiDAR surface; centerline offsets and pavement edge positions could not be identified with sufficient confidence, as shown in Figure 21. Because the ditch bottom was either under-sampled or obscured by interpolation/vegetation artifacts, automated and manual cross-section extraction from the USGS data produced inconsistent and non-physical ditch depths, as shown in Figure 22. Consequently, ditch height could not be estimated from the USGS LiDAR for this segment, and the dataset is not considered applicable for quantitative ditch metrics in the drainage rating workflow.

Figure 21. USGS LiDAR image of area covering LA 27

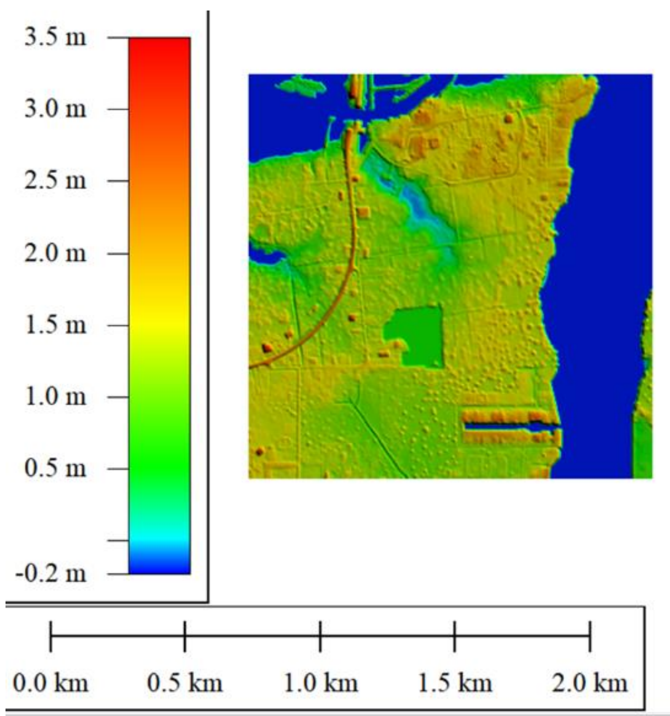
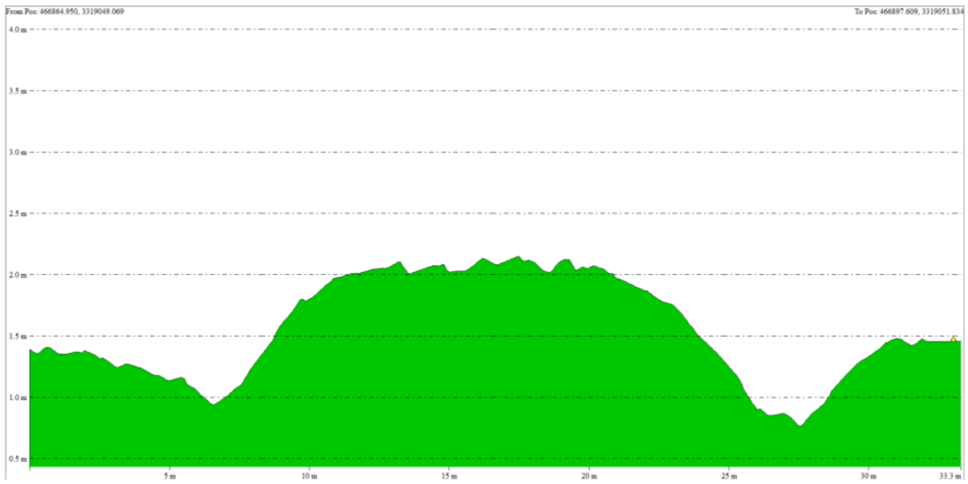
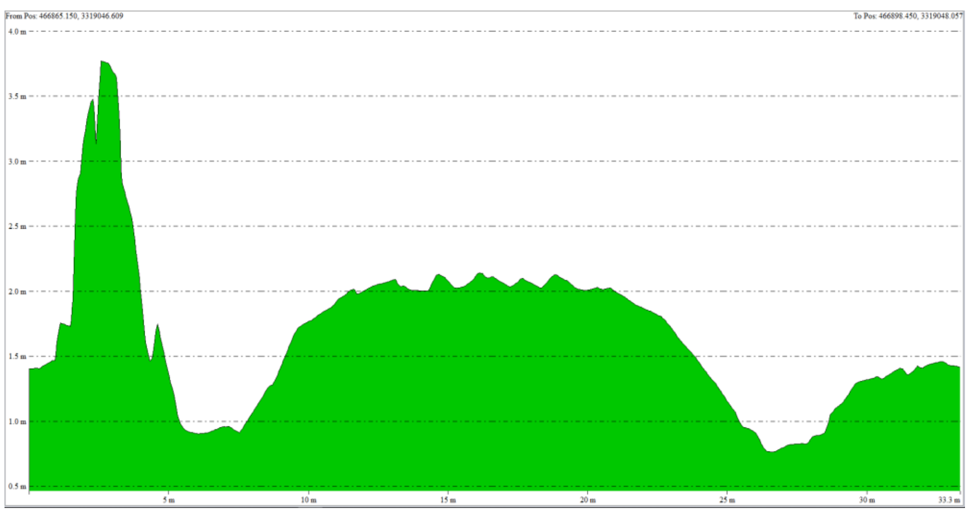


Figure 22. Roadway and ditch cross-sections at two adjacent locations



(a)



(b)

Discussion of Results

Potential Use of Remote Sensing Technologies for Ditch Condition Assessment

This study explored the feasibility of using advanced remote sensing technologies to supplement pavement drainage evaluations. A test using USGS 3D Elevation Program (3DEP) LiDAR data for a segment of LA 27 in Hackberry demonstrated that publicly available LiDAR datasets are generally too coarse for capturing the narrow roadside ditches typical of rural Louisiana. The nominal point density (≈1–2 points/m^2) and resulting Digital Terrain Model (DTM) smoothing prevented reliable identification of pavement edges, ditch boundaries, and ditch depth, rendering the dataset unsuitable for quantitative ditch measurements.

The authors also consulted with Gavin Albrow of GEOFEM to explore the potential of using InSAR technology to capture roadside ditch conditions, using LA 441 as a case study. After reviewing the InSAR data at this site, Mr. Albrow noted:

> "Given the narrow width of the roadside ditches (around 3m) and the vegetation cover along the corridor, InSAR presents some limitations in this context, particularly due to the lack of vertical displacement visibility (only ascending Line-of-Sight data is available) and coherence loss in densely vegetated areas. That said, there are a few open sections that could still be suitable for monitoring ground displacements. For more reliable assessment of ditch geometry and condition (e.g., depth, grade, slope), very high-resolution imagery or elevation data would be more appropriate."

This feedback highlights that while InSAR may provide limited insight for narrow, vegetated ditches, alternative methods, such as high-resolution imagery or mobile LiDAR-based elevation data, would be more effective for accurately assessing ditch geometry, slope, and operational condition.

Control Section 270-03

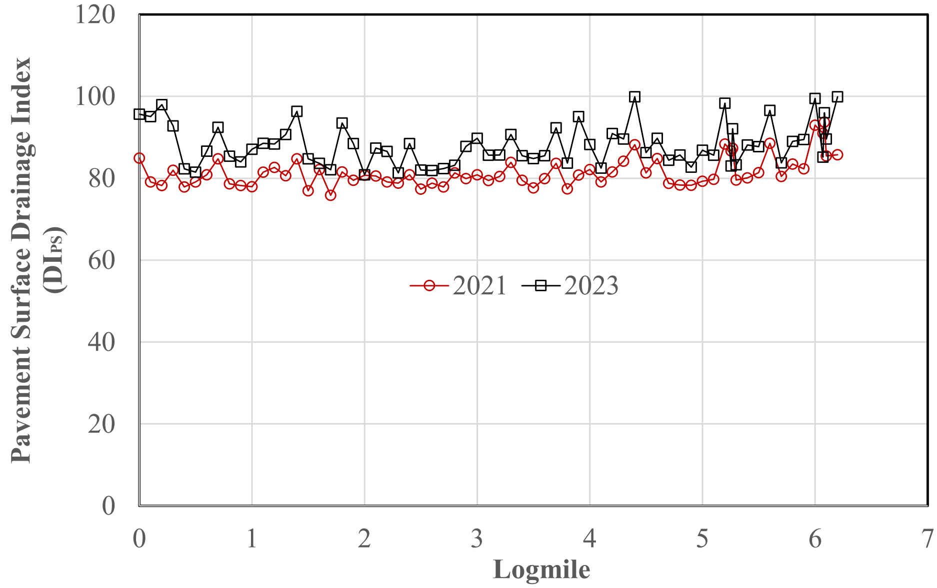
The control section 270-03 of LA 441 is located between Starns, at the western junction of LA 442, and the Saint Helena Parish line in Livingston Parish. It is classified as a minor collector with a current average annual daily traffic (AADT) of 621. This segment of roadway primarily traverses low-lying, relatively flat terrain. It is built on raised embankments with side drainage ditches, although in some areas the elevation difference between the roadway and surrounding land is minimal.

Pavement Surface Drainage

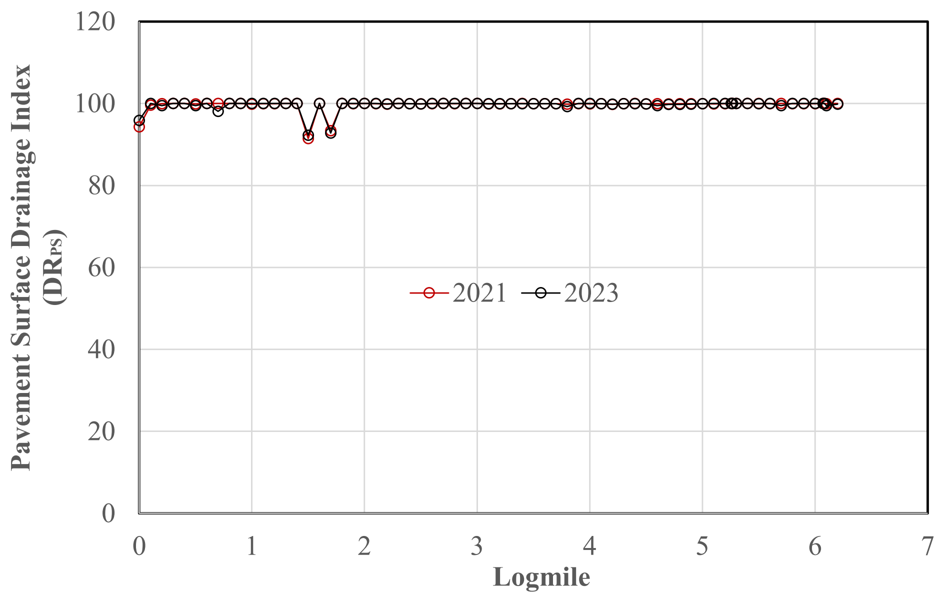
Pavement surface drainage ratings based on PMS data are shown in Figure 23a. Unexpectedly, the 2023 ratings are higher than those from 2021, despite no preservation or rehabilitation work during this period. Upon closer review, the authors found a factor-of-100 difference between the 2023 and 2021 cross-slope data, along with substantial variation in longitudinal grade data that shows no apparent correlation between the two years, as illustrated in Figure 24. The authors are working with the PMS unit to investigate and resolve these inconsistencies. However, longitudinal grade is less critical for uncurbed pavements than for curbed pavements. According to the Louisiana DOTD Road Design Manual, curbed pavements may have a flat longitudinal grade (0%).

For this reason, longitudinal grade was excluded from the pavement surface drainage rating formula in this study. Instead, weights of 0.6 and 0.4 were applied to cross-slope and rutting, respectively. The revised results are presented in Figure 23b, showing that pavement surface drainage remained in Very Good condition. A slight dip in rating at log miles 1.5 and 1.7 is due to the transition to full super-elevation on leftward curves. This is expected, as the right lane shifts from a crowned cross-slope to flat (0%), then to a super-elevated profile, and reverses this transition when exiting the curve.

Figure 23. Pavement surface drainage index for Control Section 270-03 (a) with longitudinal grade (b) without longitudinal grade



(a)



(b)

Figure 24. Cross-slope and longitudinal grade data for Control Section 270-03

DISTRICT	PARISH	ROUTE	DIRECTION	ELEMENTID	FROM_ADD	TO_ADD	XFALL	LENGTH	LEAD	CSECT	GRADE
62	32	LA 441	1	270031000	0	0.004	-0.02	0.004	2	270-03	-0.38
62	32	LA 441	1	270031000	0.004	0.008	0.01	0.004	2	270-03	-0.72
62	32	LA 441	1	270031000	0.008	0.012	0.03	0.004	2	270-03	0.24
62	32	LA 441	1	270031000	0.012	0.016	0.03	0.004	2	270-03	0.52
62	32	LA 441	1	270031000	0.016	0.02	0.04	0.004	2	270-03	1.62
62	32	LA 441	1	270031000	0.02	0.024	0.04	0.004	2	270-03	1.71
62	32	LA 441	1	270031000	0.024	0.028	0.05	0.004	2	270-03	1.74
62	32	LA 441	1	270031000	0.028	0.032	0.03	0.004	2	270-03	1.63
62	32	LA 441	1	270031000	0.032	0.036	0.03	0.004	2	270-03	1.34
62	32	LA 441	1	270031000	0.036	0.04	0.05	0.004	2	270-03	1.1
62	32	LA 441	1	270031000	0.04	0.044	0.05	0.004	2	270-03	1.27
62	32	LA 441	1	270031000	0.044	0.048	0.06	0.004	2	270-03	0.81
62	32	LA 441	1	270031000	0.048	0.052	0.06	0.004	2	270-03	0.72
62	32	LA 441	1	270031000	0.052	0.056	0.06	0.004	2	270-03	0.57

(a) 2023

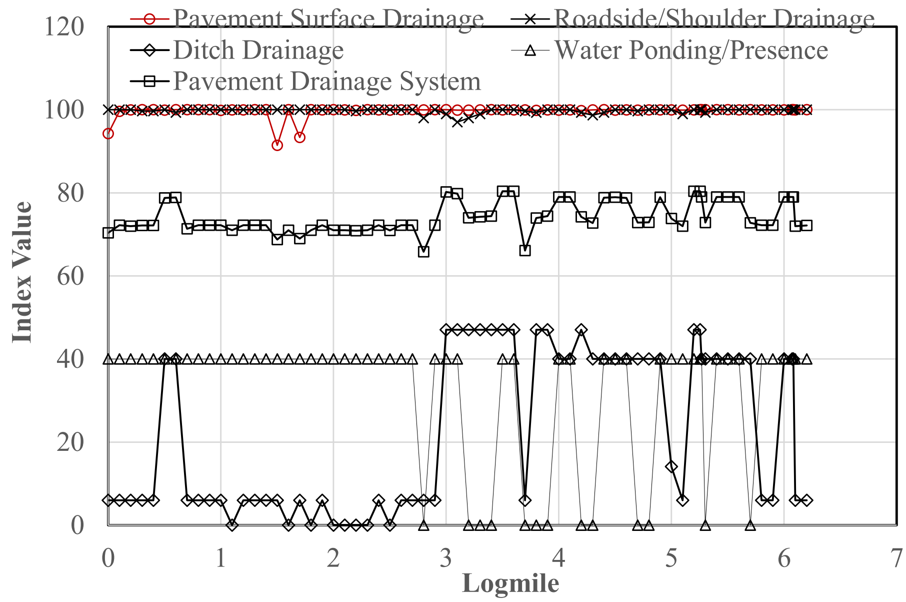
DISTRI	PARIS	ROUT	ELEMEN	DIRECTI	FROM_A	TO_AD	LENGT	LEAD	CSECT	GRAD	XFALL
62	32	LA 441	270031000	1	0	0.004	0.004	2	270-03	-0.84	-2.32
62	32	LA 441	270031000	1	0.004	0.008	0.004	2	270-03	-0.43	-0.68
62	32	LA 441	270031000	1	0.008	0.012	0.004	2	270-03	-0.64	4.48
62	32	LA 441	270031000	1	0.012	0.016	0.004	2	270-03	-0.2	3.38
62	32	LA 441	270031000	1	0.016	0.02	0.004	2	270-03	0.35	4.05
62	32	LA 441	270031000	1	0.02	0.024	0.004	2	270-03	0.57	3.55
62	32	LA 441	270031000	1	0.024	0.028	0.004	2	270-03	0.56	5.51
62	32	LA 441	270031000	1	0.028	0.032	0.004	2	270-03	0.53	3.96
62	32	LA 441	270031000	1	0.032	0.036	0.004	2	270-03	0.41	3.79
62	32	LA 441	270031000	1	0.036	0.04	0.004	2	270-03	0.27	4.81
62	32	LA 441	270031000	1	0.04	0.044	0.004	2	270-03	0.31	5.47
62	32	LA 441	270031000	1	0.044	0.048	0.004	2	270-03	0.2	5.55
62	32	LA 441	270031000	1	0.048	0.052	0.004	2	270-03	0.19	5.98
62	32	LA 441	270031000	1	0.052	0.056	0.004	2	270-03	0.2	6.22

(b) 2021

Roadside/Shoulder Drainage

Edge drop-off was rated using PMS data, while erosion and obstruction were assessed via windshield surveys using PMS right-of-way and forward-right images. This section of roadway has narrow gravel shoulders. No noticeable erosion or obstructions were observed (erosion and obstruction scores = 0). The roadside/shoulder drainage rating is presented in Figure 25.

Figure 25. Drainage index values for Control Section 270-03



Ditch Drainage

Ditch drainage conditions were evaluated through windshield surveys using 2021 PMS right-of-way and forward-right camera images. The 2023 PMS imagery revealed widespread standing water along nearly the entire section, making direct ditch condition assessment difficult. Consequently, the authors used 2021 imagery for ditch condition ratings.

Since the original ditch as-built depth is unknown, sediment levels were rated based on the proportion of side drain cross-sectional area obstructed:

- Score 1: Less than 25% filled with sediment (Figure 26a)
- Score 3: 25–50% filled (Figure 26b)
- Score 5: More than 50% filled (Figure 26c)

Figure 26. Sediment in ditches for Control Section 270-03 (Source: PMS images)

(a)

(b)

(c)

Most locations showed only minor erosion (Score 1), but some exhibited noticeable soil wash into the ditch that slowed flow (Score 3), as shown in Figure 27a, and others showed sloughing or sliding that created sediment dams (Score 5), as shown in Figure 27b.

Figure 27. Erosion in ditches for Control Section 270-03 (Source: PMS images)

(a)

(b)

Light vegetation/debris was mostly observed along the section (Score 1), with moderate vegetation/debris causing partial obstruction (Score 3) and dense vegetation/debris significantly blocking flow and causing ponding (Score 5) were seen in some locations, as shown in Figure 28a and Figure 28b, respectively.

The final ditch drainage index was presented in Figure 25.

Figure 28. Vegetation and debris in ditches for Control Section 270-03 (Source: PMS images)

(a)

(b)

Water Ponding/Presence

As noted earlier, severe standing water was observed in the 2023 PMS images, both in ditches and localized on pavement and shoulders, as shown in Figure 29. Historical weather data indicates substantial rainfall on February 9 (1.42 in.) and February 17, 2023 (1.21 in.). The PMS data was collected on February 18, less than 24 hours after the latter event. This timing provided an ideal opportunity to identify drainage deficiencies.

The findings prompted further review of the 2021 and 2019 PMS datasets, collected on April 3, 2021, and May 29, 2019, respectively.

On March 24, 2021, a heavy rainfall of 2.53 in. was recorded. Following this event, only light rain occurred on March 25 (0.29 in.) and March 26 (0.37 in.), with dry conditions thereafter. Despite this, the 2021 PMS images showed significant ditch ponding, even though the pavement and shoulders were clear, as shown in Figure 30. This suggests that poor ditch drainage, rather than residual rainfall, was responsible for water retention.

Similarly, 1.33 in. of rainfall fell on May 20, 2019, with no measurable rainfall afterward. The 2019 PMS images, collected nine days later on May 29, showed localized ponding in ditches especially near cross drains, while the pavement and shoulders remained dry; see Figure 31. Again, this supports the conclusion that persistent ditch ponding was due to drainage limitations, not rainfall.

The final water ponding/presence was rated along the section at 0.1 mile and was presented in Figure 25.

Figure 29. Water ponding and presence for Control Section 270-03 (Source: PMS images from 2023 survey)

Right of way

Front right

Figure 30. Water ponding and presence for Control Section 270-03 (Source: PMS images from 2021 survey)

Right of way

Front right

Figure 31. Water ponding and presence for Control Section 270-03 (Source: PMS images for 2019 survey)

(a)

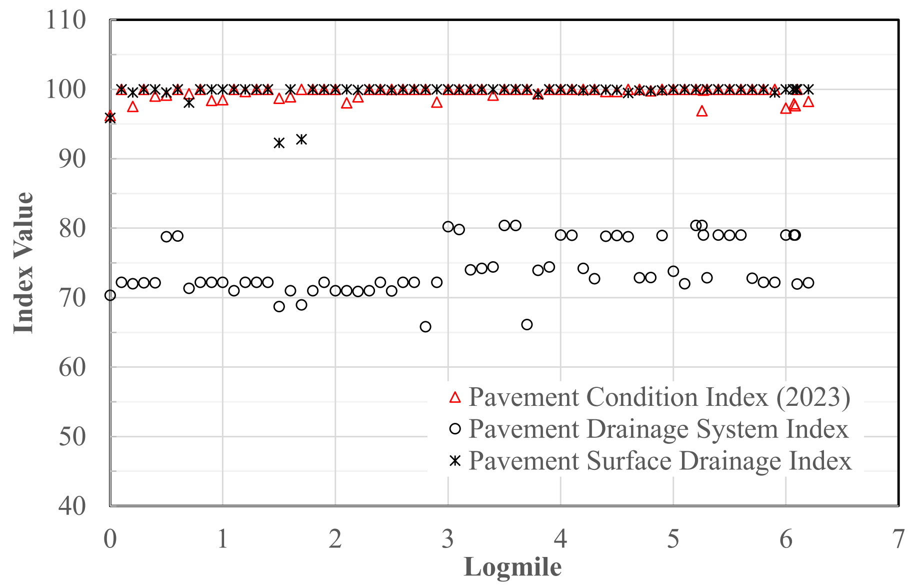
(b)

Pavement Drainage System

The final pavement drainage system rating index was presented in Figure 25 at a 0.1 mile scale. The rating index ranges from 66 to 80, falling within the Fair condition category, primarily due to poor ditch conditions and water drainage issues. The district engineer identified drainage concerns related to side ditches, cross drains, and lateral channels, which aligns with the observations made in this study.

A review of the project history shows that this pavement section was overlaid in 2019. Although the drainage condition is rated as Fair, no significant pavement distresses were observed through the 2023 PMS data collection. The Pavement Condition Index (PCI) remains above 96, as shown in Figure 32. Continued monitoring of this pavement section is recommended to assess whether any correlation emerges between the pavement performance and the drainage conditions identified in this study.

Figure 32. Pavement and drainage condition indices for Control Section 270-03



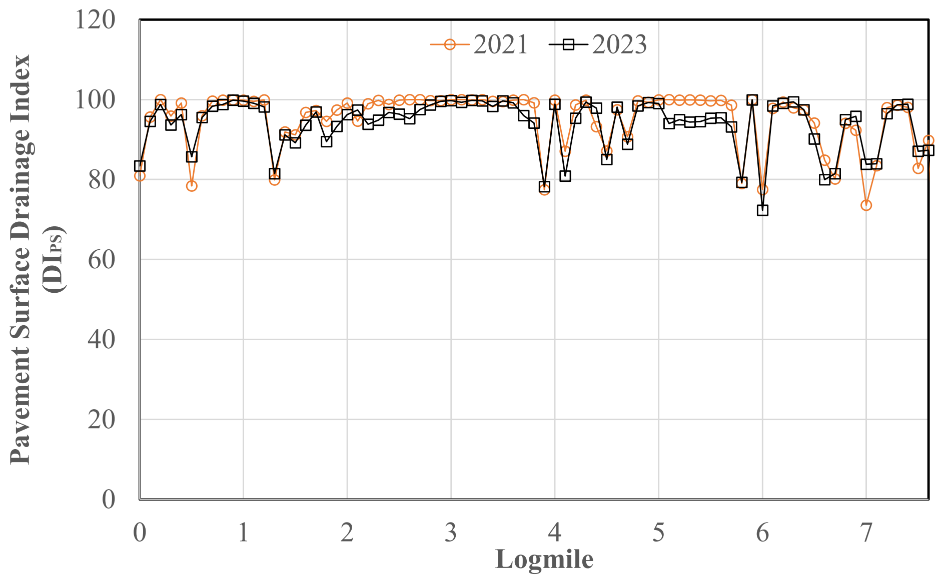
Control Section 177-04

The control section 177-04 on LA 15 extends between Shaw, at the junction with LA 910, and Deer Park, 0.18 miles northeast of the junction with LA 565, in Bossier Parish. It is classified as a major collector with a current average annual daily traffic (AADT) of 524. This segment of roadway lies along the downstream slope of a levee and relies on overland flow for drainage, as no roadside ditch is present. The roadway features a one-way cross-slope, sloping outward from the crown of the levee.

Pavement Surface Drainage

Lateral drainage is achieved by out-sloping the pavement surface away from the levee. Pavement surface drainage indices based on PMS data are shown in Figure 33. Unlike the more uniform ratings observed for Control Section 270-03, ratings for Section 177-04 vary considerably, ranging from 72 to 100. A review of the data revealed that in several locations, the cross-slope does not meet minimum requirements and even reverses direction in some areas, preventing effective drainage and promoting surface water ponding. These deficiencies are primarily located near horizontal curves where the cross-slope transitions from outslope to super-elevation (i.e., inslope).

Figure 33. Pavement surface drainage index for Control Section 177-04



Roadside/Shoulder Drainage

Edge drop-off was assessed using PMS data. Windshield surveys based on PMS right-of-way and forward-right images showed overgrown grass along the pavement edge and foreslope; see Figure 34. This dense vegetation may obstruct surface water flow, contributing to drainage issues. As such, an obstruction score of 3 was assigned.

Figure 34. Overgrown grass along the pavement edge and foreslope Control Section 177-04 (Source: PMS image)

Right of way

Front right

Ditch Drainage

As previously noted, there is no roadside ditch along this segment. Runoff drains down the levee slope through overland flow and eventually reaches a natural channel. Although no constructed ditch exists, the adjacent land functions as an infinite drainage outlet for the roadway. Therefore, the ditch drainage condition was rated as 0 across the entire section.

Water Ponding/Presence

While no ponding was visible in PMS imagery, the district reported localized surface ponding during rainfall events exceeding 1 in. As a result, a water presence score of 1 was assigned to this section.

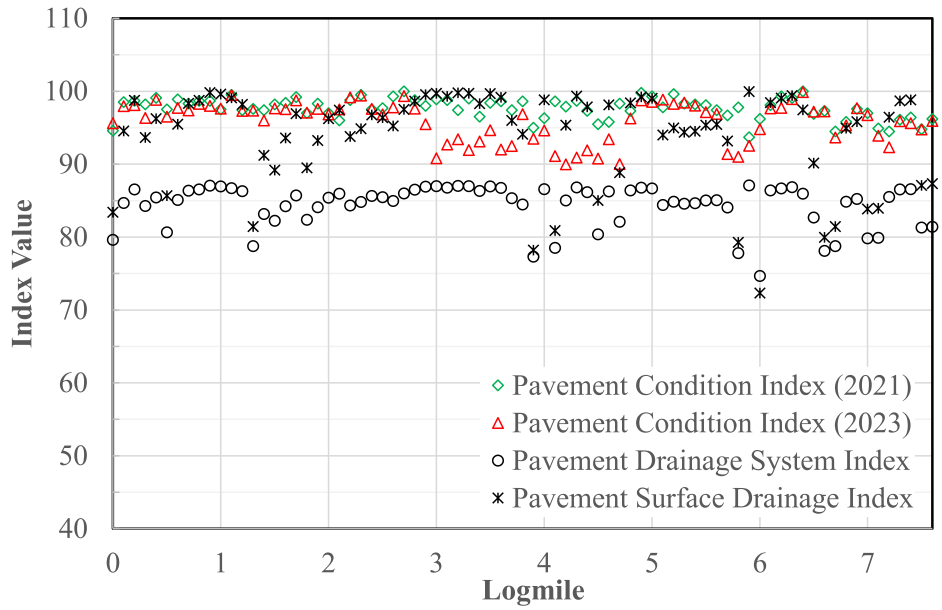
Pavement Drainage System

The final pavement drainage system rating is shown in Figure 35 at a 0.1 mile resolution. The rating index ranges from 75 to 87, indicating an overall Fair to Good condition. According to the district engineer: “The cross-slope is nominally a one-way slope away from the crown of the levee. However, due to inconsistencies in the cross-slope, water often ponds on the roadway instead of flowing down the levee slope. This contributes to base failures and saturation of slope materials, leading to slope slides and surface cracking. The issue is localized to multiple small areas with insufficient cross-slope.”

This observation is consistent with the pavement drainage ratings, which show Fair conditions in several discrete locations. A review of the project history indicates that this pavement section was overlaid in 2019. From 2021 to 2023, surface cracking-related pavement deterioration was observed between log miles 3.0 and 4.7, as shown in Figure 35. Notably, several locations within log miles 3.9 to 4.7 also exhibited Fair pavement drainage ratings. A similar pattern was observed near log mile 5.8, where both pavement deterioration and Fair drainage conditions were noted.

Together with the case study of Control Section 270-03 on LA 441, these observations suggest that the pavement surface drainage index may correlate more closely with pavement performance in the short term than the overall pavement drainage system rating index. These findings highlight the importance of continued monitoring of this pavement section’s performance.

Figure 35. Pavement and drainage condition indices for Control Section 177-04



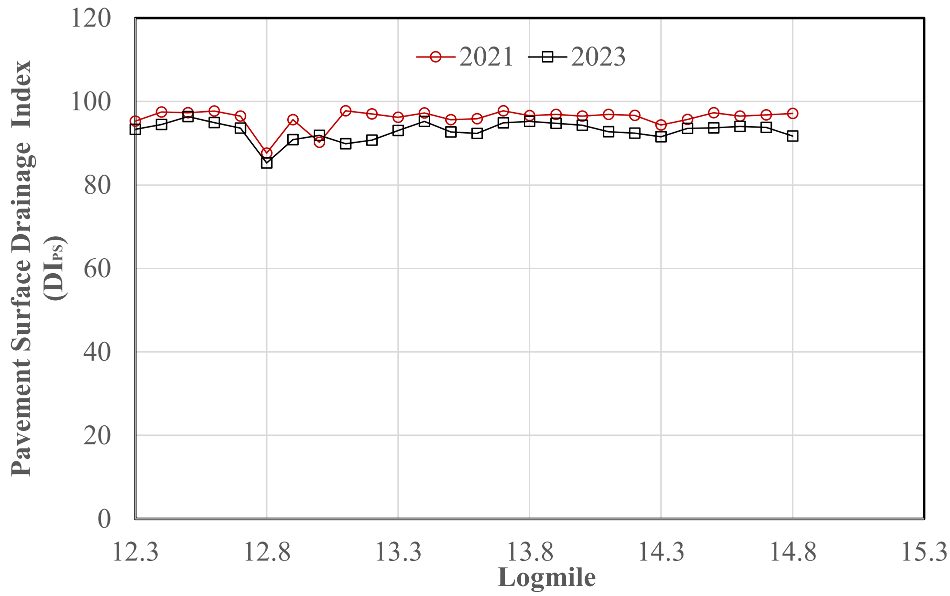
Control Section 066-07

A segment of Control Section 066-07 of US 167 from LA 748 to the St Landry Parish line in Evangeline Parish was analyzed. This roadway is classified as a minor arterial with a current average annual daily traffic (AADT) of approximately 6,500. This segment primarily traverses low-lying, relatively flat terrain with raised embankments and side ditches, though the elevation differences with adjacent land in some areas are minimal.

Pavement Surface Drainage

Pavement surface drainage ratings based on PMS data are shown in Figure 36. A decline in pavement surface drainage performance was observed from 2021 to 2023. The slight dip in the rating at log mile 12.8 corresponds to the transition to full super-elevation on leftward curves.

Figure 36. Pavement surface drainage index for Control Section 066-07



Roadside/Shoulder Drainage

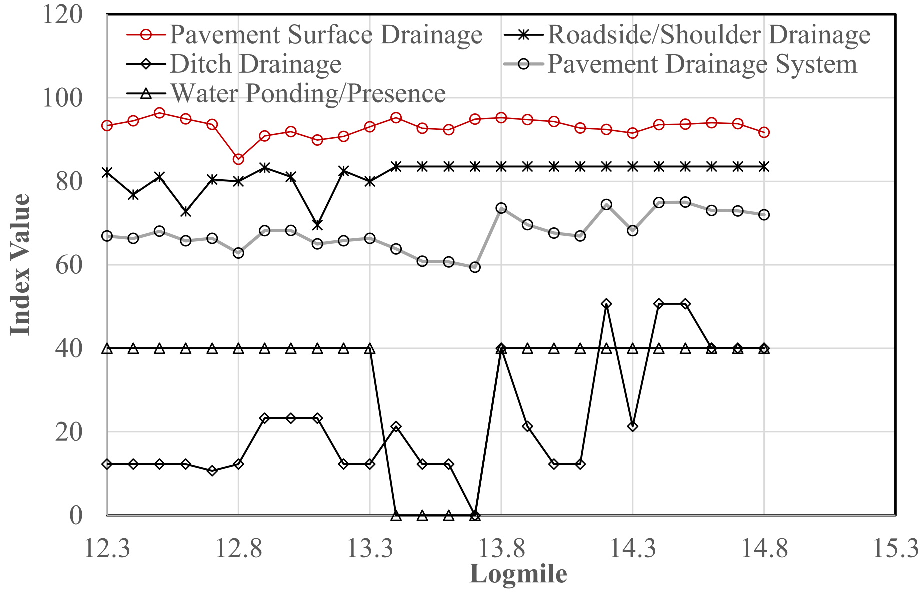
Edge drop-off was assessed using PMS data. Windshield surveys from PMS right-of-way and forward-right images indicated that shoulders were either paved or gravel, with vegetation set back from the pavement edge; see Figure 37. Accordingly, an erosion score of 0 and an obstruction score of 1 was assigned. The final roadside/shoulder drainage rating is presented in Figure 38.

Figure 37. Pavement shoulder for Control Section 066-07

Paved

Gravel

Figure 38. Drainage index values for Control Section 066-07



Ditch Drainage

Ditch drainage conditions were evaluated through windshield surveys using 2023 PMS right-of-way and forward-right camera images. As discussed earlier, sediment levels were rated based on the proportion of the side drain cross-sectional area obstructed.

Dense vegetation and debris were frequently observed along the section (Figure 39), blocking flow and causing ponding (obstruction score of 5), which complicated detailed ditch erosion assessment via PMS images (erosion score assumed as 1 here, considering the protective effect of vegetation). Nevertheless, localized issues such as the sloughing or sliding of soil into ditches due to slope failure (Figure 40), temporary damming caused by ditch erosion (Figure 41), and excess trash or debris (Figure 42) were identified in several locations, contributing to an erosion or obstruction score of 5. Each of these conditions contributes to the formation of obstructions that impede drainage flow.

The final ditch drainage index was presented in Figure 38.

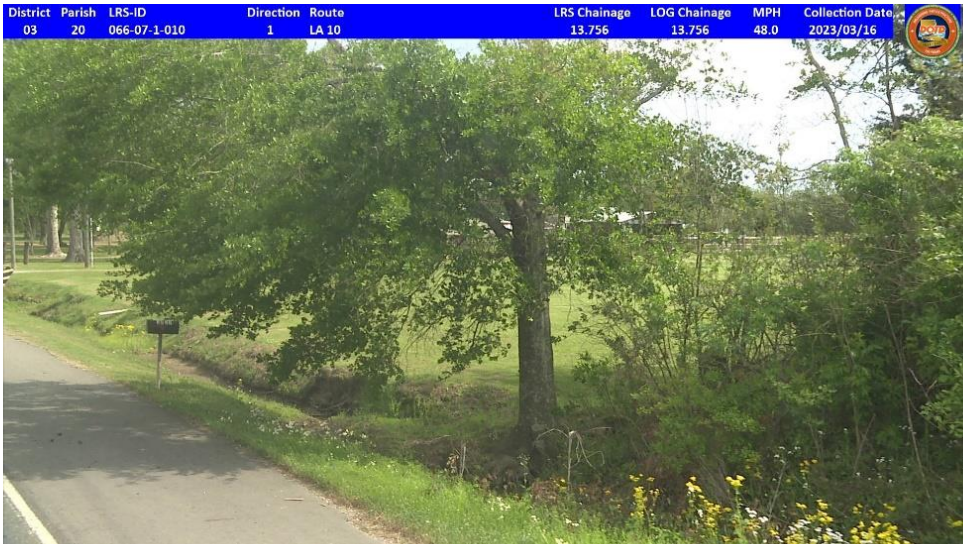
Figure 39. Dense vegetation in ditch for Control Section 066-07 (Source: PMS image)

Figure 40. Ditch slope failure for Control Section 066-07 (Source: PMS images)

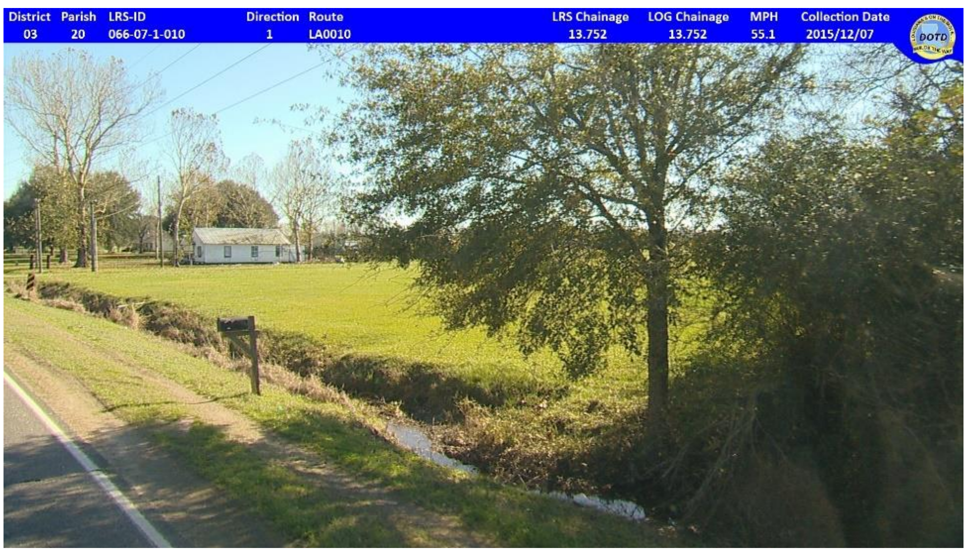
2023 PMS

2015 PMS

Figure 41. Temporary dam from ditch erosion for Control Section 066-07 (Source: PMS images)



2023 PMS



2015 PMS

Figure 42. Debris/trash in ditches for Control Section 066-07 (Source: PMS images)

2023 PMS

Image from local news station KATC [19]

Water Ponding/Presence

While no significant ponding was visible in the 2023 PMS imagery, a review of DOTD announcements and online news reports shows this section of roadway experienced flooding on September 15, 2021, December 11, 2022, and May 3, 2024.

For the September 2021 flood, the road was closed and inundated on September 15 following a heavy rainfall of 4.15 in. recorded in the past 24 hours from 11:53 AM by the nearest National Weather Service station at Lafayette Regional Airport. Although only light rain

(0.45 in.) followed on September 16 and no measurable rainfall occurred afterward, it still took until September 20 for water to fully recede, indicating limited drainage capacity.

For the December 2022 flood, DOTD [20] announced that "US 167 is closed at a point approximately 1.3 miles north of the St. Landry/Evangeline Parish line due to roadway flooding," which corresponds to a log mile of approximately 13.6. This suggested a localized drainage issue.

For the May 2024 flood, the road was closed on May 3 and reopened on May 6. On May 3, only 0.32 in. of rain in the past 24 hours from 11:53 AM were recorded at the Lafayette Regional Airport station, but DOTD [21] cited "high water as a result of severe weather conditions." This may have been due to localized heavy rainfall not detected by the station roughly 30 miles away. A moderate rainfall of 0.84 in. was recorded on May 4, with dry conditions afterward. The three-day closure suggests either more intense local rainfall occurred than measured, or that poor drainage slowed water removal.

Based on this information and 2015-2023 PMS images, the final water ponding/presence was rated along the section at 0.1 mile and was presented in Figure 25.

Pavement Drainage System

The final pavement drainage system rating index was shown in Figure 38 at a 0.1 mile scale. The index ranges from 59 to 75, placing the section in the Poor to Fair category, primarily due to inadequate ditch conditions and water drainage issues. The district engineer also noted drainage concerns related to longitudinal grade and roadway elevation.

Project history indicates this section received a 2 in. preventive maintenance overlay in 1996. Despite the Poor to Fair drainage system rating, the pavement surface drainage condition remains in Good to Very Good condition. After 27 years of service since the last overlay, the Pavement Condition Index (PCI) for Control Section 066-07 (log mile 12.3 to 14.8) is still above 68, which is considered Fair under the DOTD PCI scale; see Figure 43.

Overall, while the poor drainage system rating has had a limited effect on long-term pavement performance, localized impacts are evident at the 0.1 mile scale; see Figure 44. For example, the pavement is in Poor condition near log mile 13.5–13.6, corresponding directly to poor drainage system conditions.

Figure 43. Variation of PCI with time for Control Section 066-07

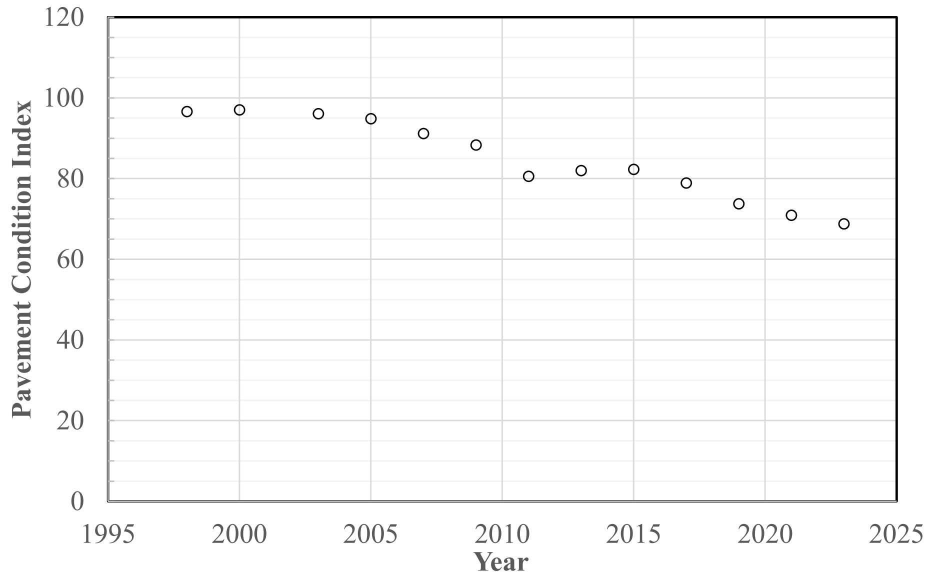
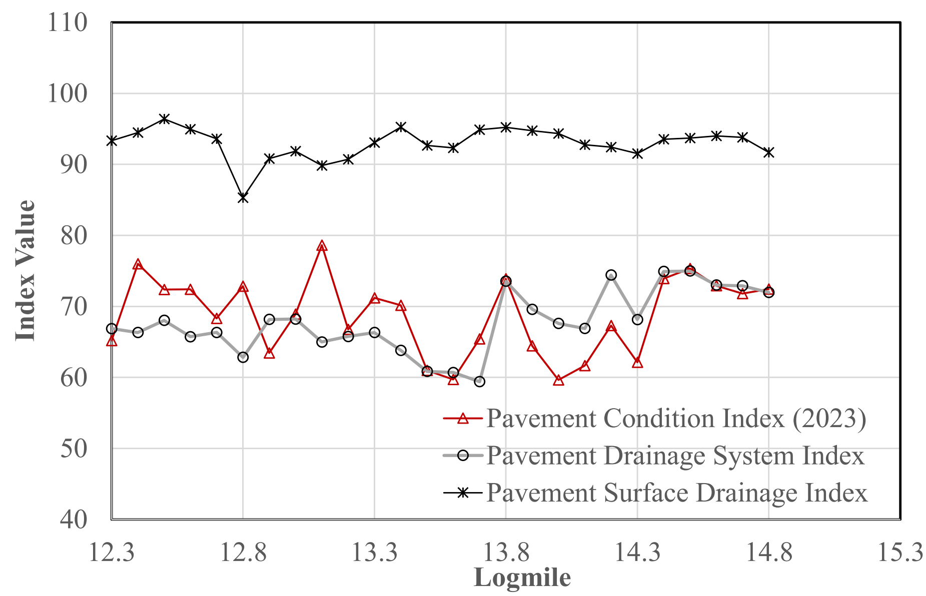


Figure 44. Pavement and drainage condition indices for Control Section 066-07



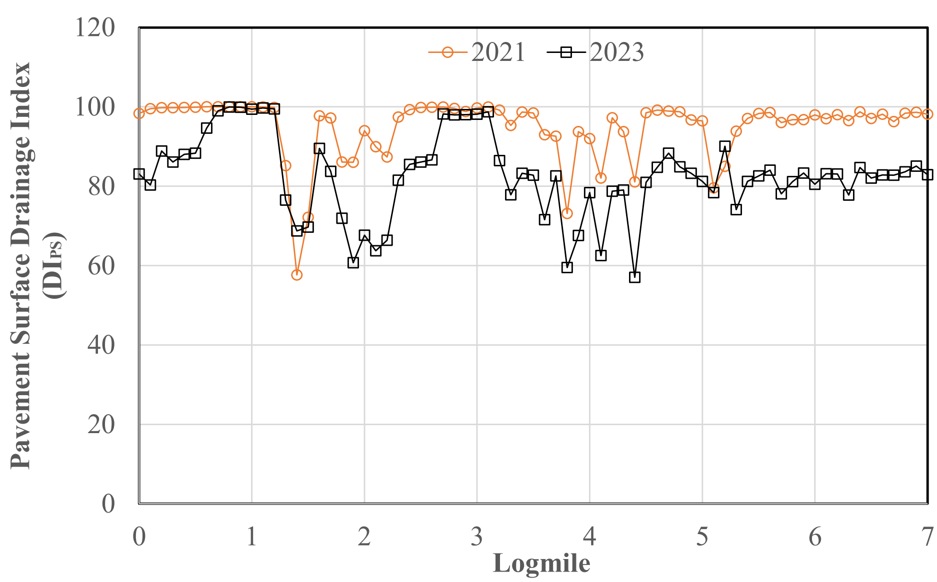
Control Section 012-04

The Control Section 012-04 of LA 12 is in Calcasieu Parish. It is a minor arterial with an AADT ranging from 3,500 to 12,000 vehicles, depending on the location. The roadway traverses low-lying, gently rolling terrain and is constructed on raised embankments with side ditches. Across most of the section, the elevation difference between the roadway and adjacent land remains minimal.

Pavement Surface Drainage

Figure 45 presents pavement surface drainage ratings from 2021 to 2023, showing marked declines in several sub-segments. Ratings vary considerably along the section with log miles 1.3-2.3 and 3.3-7.0 specifically rated Fair to Poor.

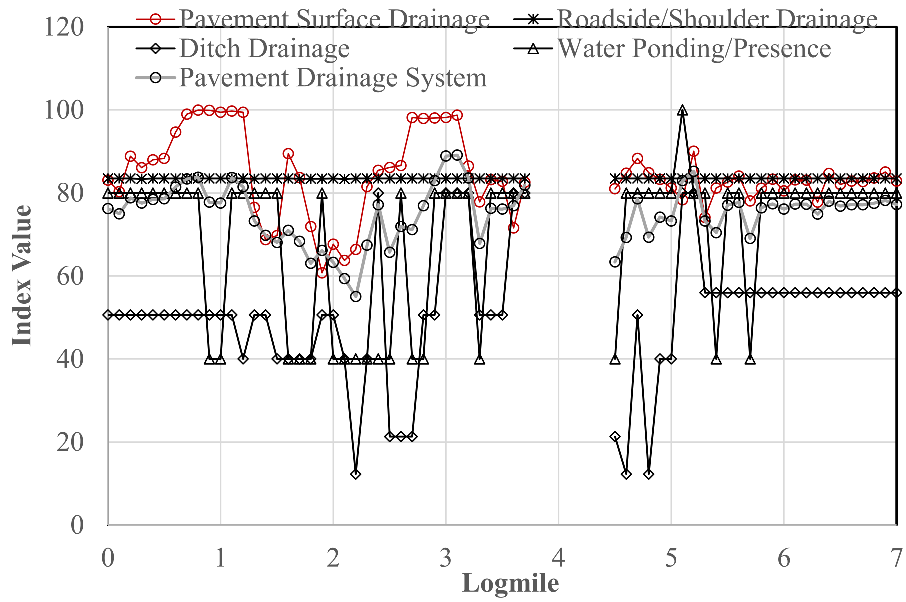
Figure 45. Pavement surface drainage index for Control Section 012-04



Roadside/Shoulder Drainage

Edge drop-off was evaluated using PMS data. Shoulders are mostly paved; the erosion score is 0, and obstruction score is 1. The urban segment at log mile 3.8 to 4.4 with curb and gutter was excluded. The final roadside/shoulder drainage rating is presented in Figure 46.

Figure 46. Drainage index values for Control Section 012-04



Ditch Drainage

Ditch drainage conditions, taken from 2023 PMS imagery, revealed light to moderate vegetation. Several segments of roadway exhibited erosion-related issues, including sloughing or soil sliding into the ditches. The final ditch drainage index is presented in Figure 46.

Water Ponding/Presence

Persistent ditch ponding was observed in ditches in 2023 PMS images, which were collected on February 6. Historical weather data indicate that 1.35 in. of rainfall occurred on January 30, 2023. Following this event, only light rainfall was recorded on February 2 (0.71 in.) and February 3 (0.26 in.), with dry conditions thereafter.

The final water ponding/presence was rated along the section at 0.1 mile intervals and is presented in Figure 46.

Pavement Drainage System

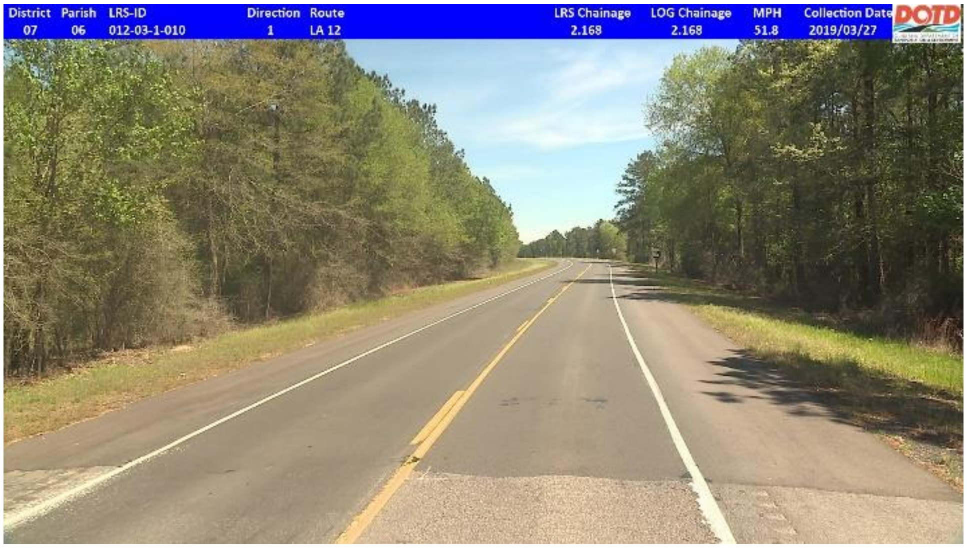
The final pavement drainage system rating index, shown in Figure 46 at a 0.1 mile scale, ranges from 55 to 89, reflecting conditions from Poor to Good. This variability results from differences in both ditch conditions and pavement surface drainage. The district engineer also reported drainage concerns related to ditch erosion.

The segment from log mile 0.0 to 2.3 was cold planed and overlaid in 1995. Although no additional projects are documented, PMS images suggest that maintenance activities were carried out in 2019, as evidenced by a noticeable color change in the pavement surface; see Figure 47. The significant improvement in PCI further supports this. Within this segment, the sub-segment from log mile 1.3 to 2.3 shows relatively poor surface and system drainage, resulting in faster pavement deterioration compared to the remainder of the segment; see Figure 48. Notably, the initial pavement condition of this sub-segment after maintenance was not as good as that of the adjacent sections.

The segment from log mile 2.3 to 3.8 was cold planed and overlaid in 2020. Although the pavement surface drainage condition from log mile 2.3 to 2.6 and 3.2 to 3.7 declined significantly between 2021 and 2023, the overall pavement condition remains uniform and in Very Good condition; see Figure 48. Continued monitoring is recommended to determine whether a correlation develops between pavement performance and the observed drainage deficiencies.

The segment from log mile 4.8 to 7.1 was cold planed and overlaid in 1998. By 2023, both the pavement drainage system and pavement surface drainage were still in Fair condition; see Figure 48. After 25 years of service, the average PCI for this segment of Control Section 193-31 remained above 80, indicating that the pavement is rated in Fair condition but is near the threshold for Good condition.

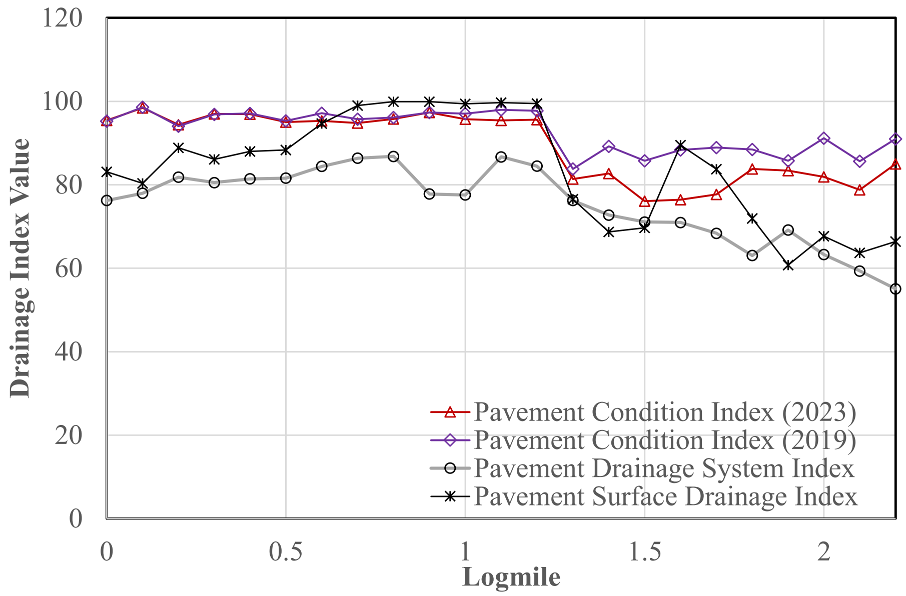
Figure 47. Pavement maintenance for Control Section 012-04 (Source: PMS images)



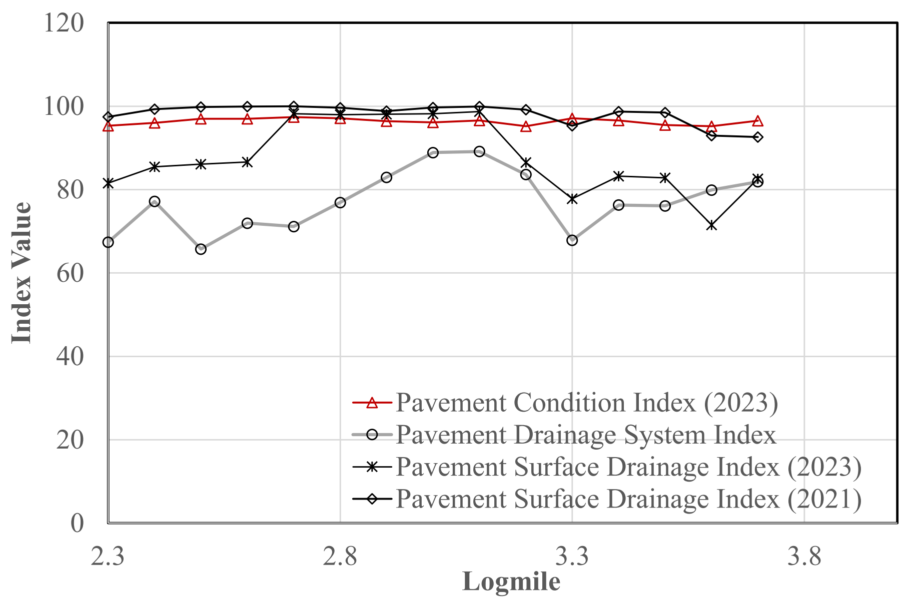
(a)

(b)

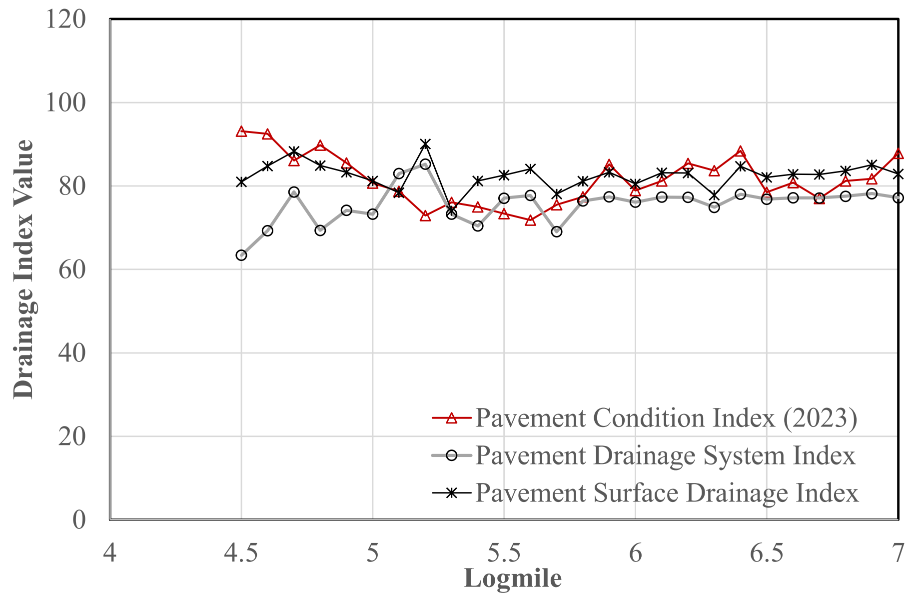
Figure 48. Pavement and drainage condition indices for Control Section 012-04



Log mile 0 to 2.3



Log mile 2.3 to 3.8



Log mile 4.5 to 7.1

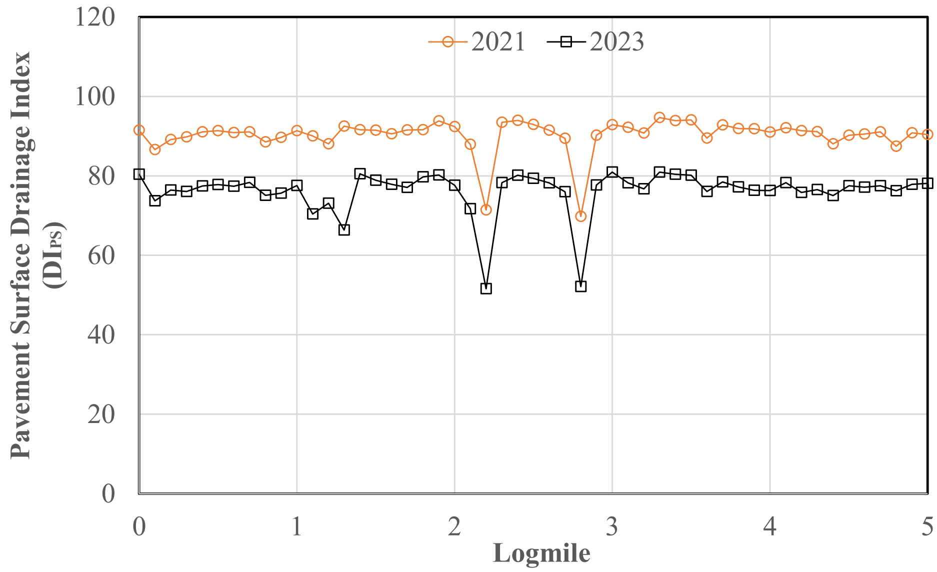
Control Section 193-31

A segment of Control Section 193-31 of LA 397, from log mile 0 to 5.1 in Calcasieu Parish, extends between the junction of LA 14 and the junction of US 90. It is classified as a minor arterial with an AADT ranging from 2,793 to 8,604. The roadway is built on raised embankments with side ditches, though elevation differences are minimal.

Pavement Surface Drainage

Ratings mostly declined from Good in 2021 to Fair in 2023, with dips near rail crossings at log miles 2.2 and 2.8; see Figure 49.

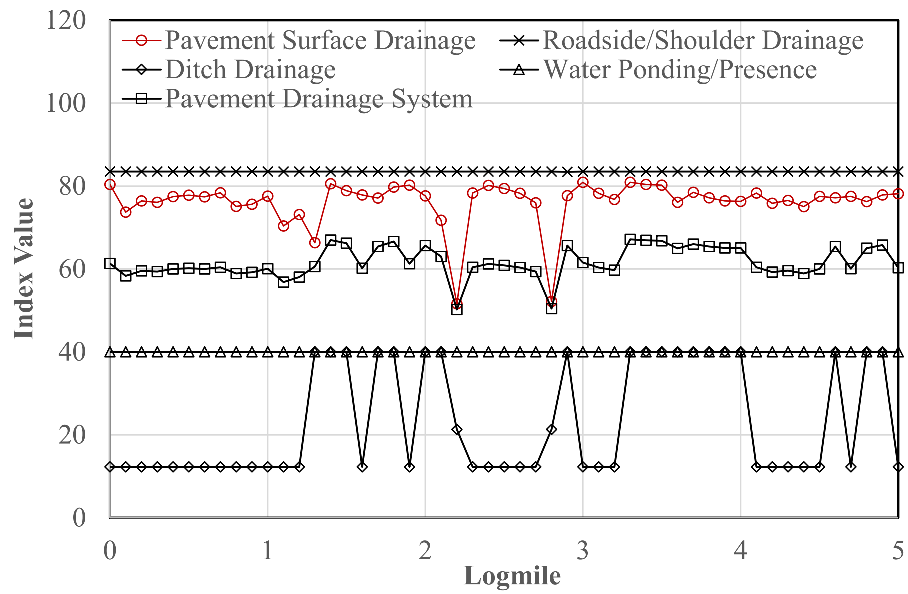
Figure 49. Pavement surface drainage index for Control Section 193-31



Roadside/Shoulder Drainage

Shoulders are paved with vegetation set back. The erosion score is 0, and the obstruction score is 1. Results are shown in Figure 50.

Figure 50. Drainage index values for Control Section 193-31



Ditch Drainage

Windshield surveys indicated moderate to heavy vegetation, obstructing flow and causing ponding. No erosion was observed. Final ratings are shown in Figure 50.

Water Ponding/Presence

Significant standing water was observed in roadside ditches in the 2023 PMS images. Historical weather data shows that 0.77 in. of rainfall occurred on February 9, 2023, with PMS data collected the following day.

Similarly, the 2021 PMS dataset, collected on May 30, 2021, revealed ditch ponding. The Lake Charles area experienced widespread flooding from May 17–20, 2021, followed by light rainfall on May 21 (0.88 in.) and May 22 (0.49 in.), with dry conditions afterward.

The final water ponding/presence was rated along the section at 0.1 mile and is presented in Figure 50.

Pavement Drainage System

The final pavement drainage system rating index, shown in Figure 50 at 0.1 mile scale, ranges from 50 to 67, placing this section in the Poor to Fair category. This rating reflects deficiencies in both ditch conditions and pavement surface drainage. The district engineer also reported drainage concerns associated with side drains and cross drains.

Project history indicates that this segment was cold planed and overlaid in 2005. By 2023, both the drainage system rating and pavement surface drainage remained in the Poor to Fair range. As part of the state highway system, LA 397 uses a trigger PCI value of 64 to define Poor pavement condition. After 18 years of service, the PCI for control section 193-31 had declined to approximately 66 (Figure 51), suggesting the pavement is nearing the end of its functional service life. A notable drop in condition between 2021 and 2023 corresponds with the deterioration of pavement surface drainage, which shifted from Good to Fair during this period.

One exception is the segment from log mile 1.1 to 1.5, which is in Very Good condition (Figure 52) due to the construction of new left-turn lanes near E. McNeese Street in 2022 to alleviate congestion and improve traffic flow. The project also included an overlay at the intersection, which enhanced pavement condition locally. However, according to the 2023 pavement surface drainage rating index**,** this overlay did not address or improve the underlying pavement surface drainage deficiencies.

Figure 51. Variation of PCI with time for Control Section 193-31

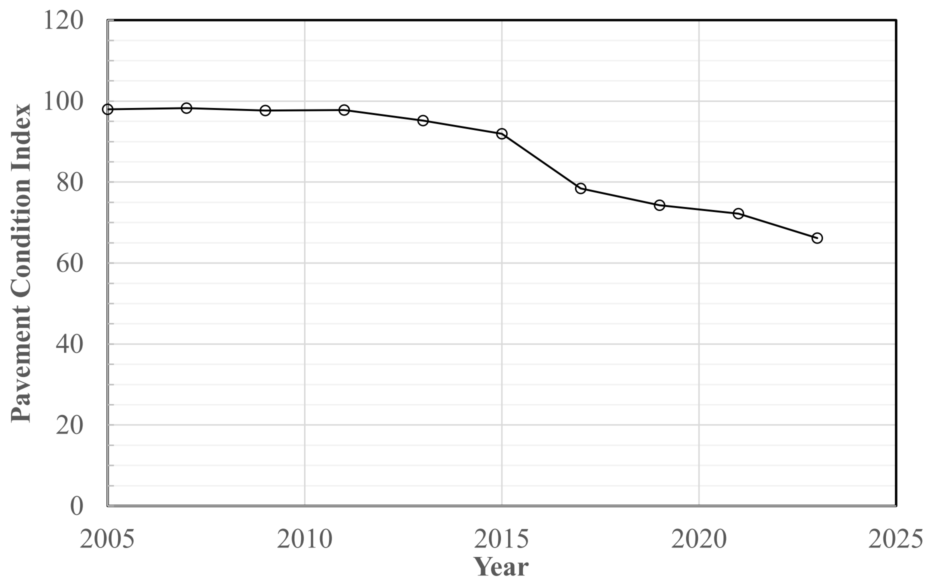
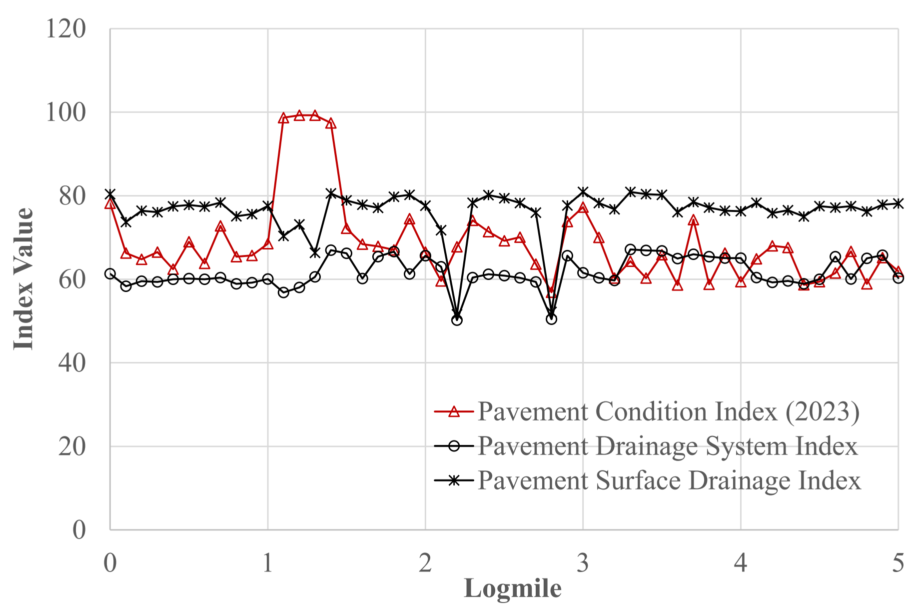


Figure 52. Pavement and drainage condition indices for Control Section 193-31



Conclusions

This study developed a practical methodology for evaluating pavement drainage conditions at the network level, with particular applicability to rural roadways, using data from DOTD's Pavement Management System (PMS). The proposed rating framework includes three components:

1. Pavement surface drainage, based on PMS data such as cross-slope, longitudinal grade, and rutting.
2. Roadside/shoulder drainage, assessed using edge drop-off data and PMS imagery for erosion and vegetation/debris.
3. Ditch drainage, evaluated from PMS imagery for sediment accumulation, erosion, and obstructions.

Five roadway sections (LA 441, LA 15, US 167, LA 12, and LA 397) were analyzed to demonstrate the methodology. Importantly, the framework evaluates how existing drainage infrastructure functions under observed conditions; it does not assess hydraulic capacity, storm intensity, or broader flood risk. Thus, drainage condition ratings should be viewed as an initial diagnostic tool for identifying areas requiring further hydraulic investigation.

Key conclusions from the study include:

- The proposed rating system offers actionable insights for pavement maintenance and can be implemented immediately using existing PMS Datasets.
- The pavement surface drainage condition rating exhibited a strong correlation with actual pavement performance, suggesting its value as a stand-alone monitoring indicator applicable to both rural and urban roadways.
- Sediment accumulation, vegetation/debris, and erosion reduce ditch capacity. While flooding cannot be fully prevented during major rainfall events, proper maintenance facilitates faster water recession, reducing roadway closures and structural damage.
- The water ponding/presence index in this study depends on the timing of PMS image collection, recent rainfall, and precipitation intensity. To improve reliability, this information can be supplemented with input from DOTD districts, as district personnel are most familiar with recurring ponding issues along their roadways.

- Fine-scale (0.1 mi.) analysis is critical, as small areas of poor drainage can disproportionately impact roadway serviceability.
- The proposed framework identifies operational deficiencies in roadside and pavement drainage, but does not account for hydraulic capacity limitations or regional flood risk. In such cases, the condition rating should be treated as the first stage of analysis, with follow-up investigations required to address watershed-scale drainage and flood mitigation.
- Exploratory use of USGS 3DEP LiDAR and InSAR highlighted limitations; low point density and vegetation effects prevent reliable ditch geometry assessment.
- AI-powered image analysis and high-resolution LiDAR-based ditch surveys could enable more automated, repeatable, and comprehensive drainage evaluations.
- Consistent collection of cross-slope, longitudinal grade, and horizontal curve data across many years is essential for the successful implementation of the proposed rating methodology.

Overall, this study demonstrates that drainage conditions can be integrated into network-level pavement management. While the methodology does not replace hydraulic design or flood risk modeling, it provides a practical and scalable means of monitoring how well the existing drainage infrastructure is functioning. Used as an early-stage screening tool, it can help DOTD prioritize maintenance, identify critical sections, and implement proactive drainage improvements.

Recommendations

Based on the findings of this study, the following recommendations are proposed for DOTD to enhance pavement drainage monitoring and maintenance:

- Adopt the proposed pavement drainage rating framework to systematically assess operational deficiencies in pavement surface, roadside/shoulder, and ditch drainage at the network level. This framework provides actionable insights for maintenance prioritization and early-stage screening.
- Implement the rating system in a phased approach**:**
  - **Phase I—Immediate Implementation:** Incorporate the pavement surface drainage rating into the PMS as part of the overall pavement condition assessment, using existing datasets (cross-slope, longitudinal grade, rutting). This component has demonstrated a strong correlation with actual pavement performance and can serve as a stand-alone monitoring tool to identify sections at higher risk of deterioration.
  - **Phase II—Expanded Implementation:** Incorporate additional operational insights by manually reviewing PMS imagery to evaluate erosion, sediment accumulation, vegetation, and debris. Include these ratings in the overall drainage system assessment to guide targeted maintenance activities. At this stage, only the visual condition (D_{visal}) is considered.
  - **Phase III—Advanced Implementation:** In future stages, integrate AI-powered image analysis and high-resolution LiDAR surveys to enable automated, repeatable, and comprehensive evaluations of drainage conditions. This will improve efficiency, consistency, and network-level monitoring.
- Conduct ratings at a 0.1 mi. resolution to capture localized drainage deficiencies, which can disproportionately affect pavement performance and serviceability.
- Maintain consistent PMS data collection. Ensure accurate and repeatable measurement of cross-slope, longitudinal grade, and horizontal curves over many years, as these are critical for the successful implementation of the rating methodology.
- Plan for periodic updates. Regularly update the drainage ratings to track changes over time, inform maintenance planning, and proactively mitigate operational deficiencies before they affect pavement performance.

- Use drainage ratings as an early-stage diagnostic tool. While the methodology identifies operational deficiencies, it does not account for hydraulic capacity or broader flood risk. For areas with potential regional flood impacts, complementary hydrologic and hydraulic analyses should be conducted.

Acronyms, Abbreviations, and Symbols

Term	Description
A	flow area
AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	annual daily traffic
AI	artificial intelligence
cm	centimeter(s)
CTDOT	Connecticut Department of Transportation
D_E	erosion score of ditch
D_O	obstruction score of ditch
$D_{hydraulic}$	hydraulic compliance index of the ditch
D_S	settlement score of ditch
$D_{visual}DI$	field-observed condition index of the ditch drainage index
DI_D	ditch drainage index
DI_{PS}	pavement surface drainage index
DI_{RS}	roadside/shoulder drainage index
DI_{WP}	water ponding/presence index
DOT	Department of Transportation
DOTD	Louisiana Department of Transportation and Development
DTM	digital terrain model
FHWA	Federal Highway Administration
$Grade_{min}$	minimum required longitudinal grade
$Grade_{actual}$	measured longitudinal grade
HPS	hydroplaning speed
in.	inch(es)
InSAR	Interferometric Synthetic Aperture Radar
LGRADE	longitudinal grade index
LiDAR	Light Detection and Ranging
LOS	level of service
LRSID	Louisiana Roadway System Identification
LTRC	Louisiana Transportation Research Center
m	meter(s)
MSL	mean sea level

Term	Description
MTD	mean texture depth
n	Manning's coefficient
OGFC	open-graded friction course
PCI	Pavement Condition Index
PMS	Pavement Management System
Q	hydraulic capacity of the ditch
R	hydraulic radius
RS_D	edge drop-off score
RS_E	erosion score of roadside/shoulder
RS_O	obstruction score of roadside/shoulder
RUT	rutting index
S	channel slope
$Slope_{min}$	minimum required cross-slope
$Slope_{actual}$	measured cross-slope
SD	spindown
TD	tire tread depth
TxDOT	Texas Department of Transportation
USGS	United States Geological Survey
WFT	water film thickness
W_D	weighting factor of ditch drainage
$W_{hydraulic}$	weighting factor of hydraulic compliance
W_{LG}	weighting factor of longitudinal grade
W_{PS}	weighting factor of pavement surface drainage
W_R	weighting factor of rutting
W_{RS}	weighting factor of roadside/shoulder drainage
W_v	weighting factor of field-observed condition
W_{WP}	weighting factor of water ponding/presence
W_{XS}	weighting factor of cross-slope
W_P	water ponding/presence score
XSLOPE	cross-slope index
3DEP	3-D elevation program

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Appendix

The appendix to this final report is available upon request by contacting ltrcpublications@gmail.com.