RESEARCH

UDOT CONNECTING COMMUNITIES

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CONDITION ASSESSMENT OF HIGHWAY CULVERTS AND DETERMINATION OF PERFORMANCE MEASURES

VOLUME 1: FINAL REPORT

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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16. Abstract

The Utah Department of Transportation installed and manages over 47,000 culverts but has no comprehensive, quantitative method for evaluating the performance of these culverts. UDOT contracted with Simpson Gumpertz & Heger Inc. to 1) determine the condition of highway culverts with spans from 2 ft to 5 ft, 2) develop a system of culvert performance measures, 3) support UDOT in modifying and populating a culvert inventory and inspection database, and 4) recommend implementation of performance measures for future UDOT procedures.

272 culverts were inspected under this contract. Culvert barrel materials consisted primarily of steel, concrete, and polyethylene. Most inspected culverts had barrel span less than five feet. Culvert inspections were conducted in all UDOT Maintenance regions, in all major surface and deep soil zones, and at most elevations. UDOT culverts are performing well overall. Inspection results indicate no significant performance differential between the different barrel materials. Available data includes many concrete and metal barrels that were installed before thermoplastic barrels were used, that is, thermoplastic barrels have a shorter service life history for comparison. The problems unique to each type of culvert pipe material are discussed.

Performance measures were adopted from available references and further developed to assist in assessing both the waterway and the barrel condition of each culvert installation. Inspection results were used to determine performance ratings for culvert structural and hydraulic condition. A rating modifier for culvert importance (Importance Modifier) is proposed as a method to reduce the number of culverts that require routine monitoring and to prioritize culvert maintenance. The numeric performance ratings give equal consideration to all culvert barrel materials.

This project also evaluated, modified, and used the UDOT Culvert Database, which is composed of a database with inventory and inspection datasets and a Form program used to interface with the database. Through a cooperative effort with Utah State University the database and Form Program were upgraded to improve functionality and usability for this project.

This project also provides recommendations to improve UDOT culvert installation and maintenance procedures. The UDOT Culvert Database was also evaluated and recommendations are provided to make the Database usable by UDOT maintenance personnel for future work. References are provided to assess the different expected service life of various metal culverts and coatings.

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EXECUTIVE SUMMARY

The Utah Department of Transportation (UDOT) manages 47,000 drainage culverts along the state highways of Utah. UDOT, like other state Departments of Transportation, does not currently have procedures for monitoring the performance of these culverts or managing their maintenance. Culverts are smaller and often get less attention than bridges; however, their proper performance is equally critical to maintaining our roadways. Review of culvert performance nationally shows that failures can lead to disruption of traffic, loss of property, and have caused fatal accidents. The small size but huge inventory of culverts creates a unique management issue for UDOT. This project was developed to improve and enhance the Department policies and procedures regarding installation and performance monitoring of culverts. Recommendations are proposed to allow better evaluation of culvert performance with an emphasis on culverts classified as critical.

The objectives of this research project were to:

- determine the condition of existing highway culverts and storm drains through field surveys; excluding cast-in-place concrete culverts or culverts with spans larger than 5 ft or smaller than 2 ft,
- develop a system of qualitative and quantitative measures to assess both the short and long term in situ performance of highway culverts and storm drains, and
- support the effort of the Utah Department of Transportation to modify and populate with performance data a computerized database designed to track and monitor the performance of highway culverts and storm drains.

Utah Highway Culvert Inventory

This project focused on culverts with barrel spans between 2 ft and 5 ft. In this span range, there were 23,000 metal barrels, 6,000 concrete barrels, and 500 plastic barrels, which make up 78.8%, 19.7%, and 1.5% of the 30,000 2 ft to 5 ft span culverts, respectively, in the UDOT inventory records of culverts installed through 1998. The study subset is 63% of the entire culvert inventory (30,000 of 47,000). “Span” is defined as the unsupported distance over which the culvert must carry traffic and for circular culverts is the diameter of the pipe barrel. The findings and recommendations are generally applicable to other sizes and shapes.

Inspections conducted during this project show that the inventory is generally accurate, but not without error. Some important information, such as installation date, is not available for many of the culverts.

Utah Highway Culvert Information Storage

In collaboration with UDOT, Utah State University (USU) created a database program, the UDOT Culvert Database (UCD), to store inventory and inspection data for culverts. Simpson Gumpertz & Heger Inc. (SGH) worked with USU during this project to improve the functionality of the program. The database is designed to allow entry of inspection data into database subsets supplied to UDOT maintenance sheds that can be uploaded to a single main database of statewide inspection results.

The UCD was developed as the first step in establishing a culvert management system for Utah's culvert inventory. Its development and population with culvert information has placed Utah ahead of most states in addressing this issue, but it will not serve its purpose unless it is populated with inspection data and kept up-to-date. This project makes recommendations to simplify the database programs to reduce the amount of information collected and minimize field time and to add a rating system with an Importance Modifier that will focus attention on critical culverts.

Other State Culvert Evaluation Systems

Condition assessment and asset management of culverts are issues important to all state Departments of Transportation. Given the quantity of culverts and the potential risk of roadway disruption and property damage due to poorly maintained culverts, a systematic method to perform scheduled maintenance should be the goal of any culvert maintenance system. Culvert management activities by other jurisdictions were reviewed for guidance on how UDOT might best proceed. The National Cooperative Highway Research Program (NCHRP) released NCHRP Synthesis 303 in 2002. The synthesis describes a survey of culvert inspection and management practices used by thirty-nine state DOTs, twenty-one federal agencies, and fifteen localities. Synthesis content included specific detailed descriptions of agency management programs, examples of inspection collection forms, and discussion of data storage methods. Several key issues presented in the synthesis follow:

- no complete inventory, inspection, and management programs exist for culvert assets,
- the typical inspection schedule is "when time and funding allow",

- sixty percent of agencies keep culvert inspection data, but only 19% use these inspection results for culvert management, and
- thirty-seven percent of state DOTs have guidelines to assess pipe condition, while only 9% have guidelines for repair.

Performance Measures

Performance measures are used to objectively evaluate the current condition of culvert installations through application of relevant rating parameters. Performance measures are established based on parameters monitored during construction or during inspection of in-service culverts. Records of performance ratings over a period of time can be further used to evaluate the relative performance of different hydraulic treatments or pipe types, or to predict remaining service life.

Performance measures for existing culverts are associated with numeric ratings that indicate the level of any required action. A rating of 9 indicates a new culvert or a culvert with no apparent defects, while a rating of 0 indicates a complete failure and roadway closure. The ratings presented in the report are extensions of those initially developed by the Federal Highway Administration (1986) [4].

Culvert condition ratings are divided into two broad categories, waterway (hydraulic) performance and barrel (structural) performance. The two areas are not completely independent; however, since required actions will often be quite different for waterway or barrel issues, the differentiation is appropriate. Roadway condition may be affected by either waterway or barrel performance. Ratings are based on the state of the culvert and are modified as a function of the culvert importance. The lesser of the waterway and barrel ratings is the maintenance action rating. After modification by the importance criterion, discussed below, the action rating recommendations fall into three broad groups:

- 9, 8, 7, 6 – no immediate action required,
- 5, 4, 3 – inform supervisor; repair or maintenance required within one year, and
- 2, 1, 0 – immediate action required; road closure should be considered.

Calculations show that man-hour requirements to conduct routine inspections on each of UDOT's 47,000 culverts are significant. Modifying ratings as a function of culvert importance helps focus resources on culverts where a failure poses an increased threat to life or property or a major disruption of traffic. Importance modifiers are set based on culvert size, roadway importance, and waterway purpose. With an Importance Modifier,

a culvert with a rating of 5, which would require action under the proposed ratings above, might be upgraded to immediate action if the culvert has high importance (e.g., a large culvert carrying a stream under an interstate highway) or might be reduced to no action if the culvert has low importance (e.g., a small-diameter culvert carrying incidental drainage). A proposal for incorporation of an Importance Modifier is included in the report.

Performance Measures for New Installations

Correcting culvert problems after installation is completed is expensive. Excavating and replacing pipe under significant depths of fill often costs several times the initial cost, and often leads owners, such as DOTs, to accept defects without repair or accept repairs, such as liners, that result in a culvert with reduced capacity from the original design. This makes the control of construction practices and post-installation inspections important goals in contracting practices and an important inclusion for UDOT standard specifications. While evaluation of culverts during construction is not a focus of this project, the results from the work may be used to update the UDOT standard specifications. To that end, the authors evaluated installation practices at a culvert installation within Utah and discussed the inspection practices with the UDOT staff on-site. The following references provide considerable information on installation practices:

- *Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications* (ASTM D2321) [23],
- *Pipeline Installation* (Howard 1996) [8], and
- *Pipe Interaction with the Backfill Envelope* (McGrath *et al.* 1999) [11].

For selecting the optimum culvert materials, durability considerations are important. Overall comparison of culverts based on durability remains a controversial topic, but some guidelines are available and were used as references for the recommendations in this report, such as the AASHTO Highway Drainage Guidelines [1]. Additional information may be gleaned from the culvert condition assessments determined in this project; however, the lack of installation age for many of the inspected culverts complicates durability comparisons.

Performance Measures for Waterways

Culvert hydraulic performance is monitored through evaluation of the quality of the waterway. Prime issues include scour, erosion, and blockage by sedimentation or other debris. This report presents tabulated guidelines for rating the waterway performance

to determine the required level of corrective action. The ratings for waterways are based on roadway and side-slope condition, waterway channel and channel protection, culvert end treatment alignment, appurtenant structures, embedment and surface soils, groundwater, and surface water.

Performance Measures for Culvert Barrels

The culvert barrel is the main structural element of a culvert and provides support for the roadway and a path for the water being passed underneath. The most common culvert barrel type in the Utah Culvert Database as of 1998 was corrugated steel (72% of the total culvert inventory), followed by reinforced concrete (25%) and plastic (3%). Performance measures are presented and discussed separately for metal, concrete, and plastic pipe materials. Numeric ratings are set so that culverts require the same action response regardless of barrel material. Both the report and the UCD provide rating tables for metal, concrete, and plastic culvert barrels.

Metal culverts in Utah are predominantly corrugated steel. Metal culverts are flexible, which means that their performance is often evaluated through monitoring the culvert shape. The primary issues specific to metal culvert durability are the action of corrosion and abrasion. The metal barrel rating table includes criteria for deflection, defects in the seams, localized dents or other damage, corrosion/abrasion, joint performance, alignment, and coating performance.

Concrete culverts are the next most numerous culverts in Utah. Unlike flexible culverts, where shape is a good measure of installation and performance, concrete culverts are evaluated based on wall cracking, alignment of adjacent pipe barrels, integrity of the joints, and any other general signs of wall distress such as efflorescence, spalling, or rust stains indicating corrosion of reinforcement steel.

Plastic culverts are flexible and are inspected for many of the same features as metal pipe, except that corrosion is not an issue. However, plastic pipe walls are often constructed of relatively thin elements, which makes them susceptible to wall buckling. Additionally, stiffness and strength of thermoplastics are time dependent and cracking can occur over time. Plastic culverts are evaluated for deflection, local buckling, wall cracking, seam defects, joint defects, alignment, and durability.

Culvert Field Inspections

Field inspections of culvert condition were conducted with three levels of effort. Level 1 consisted of non–man-entry visual, qualitative inspection; Level 2 consisted of man-

entry end-to-end visual qualitative inspection, including review of pipe performance along the culvert length; Level 3 consisted of quantitative inspection that included a thorough assessment to determine extent of durability or structural issues and any quantifiable measures of the installation. All inspections were at Level 1, with upgrades to Level 2 for low-rated culverts that were safe to enter and upgrades to Level 3 where inspectors felt that features of the culvert warranted additional evaluation. Inspectors collected condition data either by notepad or by direct entry into the UCD. Criteria for selecting specific culverts for inspection were established to assure a random but complete sampling of culvert materials and installation environments.

Inspections were completed for 272 culverts, including 39 concrete culverts, 195 metal culverts, and 38 thermoplastic culverts, which are 14%, 72%, and 14%, of the inspection set, respectively, and generally representative of the relative numbers of each type of culvert in the overall inventory. Approximately 50% of the inspected culverts had 2 ft span, 30% had span larger than 2 ft but less than or equal to 5 ft, and the remainder had span either less than 2 ft or greater than 5 ft.

Inspection Results and Analysis

Overall, UDOT culverts are performing well due to generally good installation quality. This result is based on approximately equal average performance ratings wherein the typical installation age for plastic culverts was less than for metal or concrete. We attribute the installation quality to the UDOT policy of inspecting culvert installations during construction. The average ratings for all culvert barrels and waterways were 6.6 and 6.7, respectively, which indicate that no action is warranted for most culverts. However, action is recommended for ratings less than 6. This implies that many of Utah's highway culverts are approaching a level of increased inspection and consideration for repair. These ratings exclude the effect of the Importance Modifier described in the report, due to a sampling bias that resulted in many more inspections of important culverts. Only one culvert was rated as a 2, which indicates that immediate action is required, and in that case, the culvert was a 2 ft span and on a low-traffic highway. Application of the recommended Importance Modifier increased the rating for this culvert to more than 3, but resulted in three other culverts with maintenance action rating less than 3. The following paragraphs provide inspection observations.

Culvert Barrels: The average culvert barrel performance rating is 6.6, suggesting that the condition of the UDOT culvert inventory is generally good.

Metal barrels exhibited generally good condition with reduced rating primarily the result of the combined action of abrasion and corrosion, joint integrity, and deformation. Corrosion was present on the soil-side in much of the state, indicating mildly corrosive soils, and was seen at barrel ends and at locations of joint or seam leaks. We observed low frequency of barrel perforation due to soil-side corrosion. Corrosion was also present in the invert of many uncoated metal culverts. Corrosion was not found where coating integrity was maintained; however, many instances were found with peeled polymeric, cracked asphaltic, or abraded galvanized coatings. Joint integrity had significant influence on corrosion, waterway alignment, and waterway clearance of obstructions. Deformation was present near the ends of many metal barrels and at localized places in some metal barrels.

Concrete culvert barrels had overall good rating with reduced ratings primarily the result of joint integrity, barrel alignment, wall cracking, and other damage at or near end treatments. Joint integrity influenced the waterway alignment, infiltration, and exfiltration. In several cases, particularly on the western section of I-80, concrete barrels performed well while their metal end treatments experienced poor performance due to severe corrosion.

Plastic culvert barrels do not have a long history of use in Utah, but were in good condition overall where installed underground with good soil compaction. Reduced ratings were primarily due to barrel deformation, which was likely the result of poor installation quality. Many plastic culverts within the UDOT inventory are used for side and slope drains and other low-traffic applications. Internal inspection, where possible, indicated that deformation (deflection) reduces joint integrity. Most plastic culverts had small span and were therefore not frequently subjected to end-to-end interior inspection. However, no occurrences were found of barrel cracking away from the end treatments.

Many culverts have been extended as a part of roadway-widening projects. The interface where an existing culvert meets the extended portion of the culvert is often offset and in poor condition. The older sections were also often left significantly sedimented.

Waterway: Waterway performance was good overall, with an average rating of 6.7 across all UDOT culvert barrel materials. This rating indicates that no immediate action is required in most cases; however, many culverts require some type of maintenance. Waterway ratings were primarily influenced by waterway alignment (including barrel alignment and upstream/downstream alignment with the culvert barrel), obstructions

(including sedimentation and debris), end treatment undermining, and outlet scour holes. Where water was present, pH readings were collected on both the water and the surface soils. No pH results were less than 6 or greater than 8 (7 is neutral). The most significant factor causing reduction of waterway rating among the culverts studied was sedimentation. Sedimentation was present to some degree in many of the culverts inspected, was present along all or a good portion of the length of many culverts, and was severe in many of the culverts inspected. Sedimentation was common in low-slope culverts with vertical alignment below the surrounding grade.

End Treatments: End treatments for all types of culverts deteriorate more rapidly than the culvert barrel as a result of exposure to the elements and abuse from vehicles, such as mowing equipment. All end treatment materials have reduced service life relative to culvert barrels. Metal end treatments have overall fair to good performance with distress mainly in the form of corrosion, damaged coatings, and deformation. Concrete end treatments are generally in good condition. Where distress was present in concrete end sections, it consisted mainly of cracking and breaking that resulted from maintenance traffic, such as mowing, and reinforcement corrosion. In older installations, projected culvert ends were frequently broken, with exposed reinforcement and resultant waterway misalignment. Many older concrete headwall and wingwall treatments exhibited cracking and crushing. Plastic end treatments had overall poor performance and typically experienced deformation and cracking due to lateral soil load. Metal end treatments were seen to be used with good success for plastic barrels.

Roadways: Roadways were assessed to determine if pavement performance is affected by the presence of culverts. The roads were inspected for sagging, rutting, cracking, or other sign of distress over the culvert alignment. Determination of condition was made, but relation to the culvert was complicated by the lack of roadway maintenance history (i.e., recent paving operations would eliminate evidence of deterioration). Where culverts have very shallow cover, some roadways have cracking or settlement. In several instances, settlement and/or crack patterns were directly above culverts with joint infiltration. Maintenance crews should be made aware that roadway cracking could be caused by culvert distress.

Conclusions

A project to evaluate the Utah Culvert Database (UCD) and to evaluate the general condition of culverts under UDOT roadways has been completed. Field inspections show that culverts under UDOT roads are in generally good condition, but aging is evident and increased attention will be required in the future. UDOT should continue to

develop the UCD and implement other actions so that a complete approach to culvert management is in place. This will help ensure that culverts continue to perform well and that UDOT roads are safe.

UDOT Culvert Database

- The UDOT Culvert Database is a generally accurate representation of the number and type of culverts in the UDOT inventory. If UDOT maintains this database as part of its culvert management program, current errors can be corrected and the utility of the data will improve.

- The database should be modified to improve focus on important parameters and eliminate unnecessary parameters. This will reduce costs associated with culvert inspection.

- The database program should be upgraded to implement culvert management functions.

Culvert Inspection

- Ensuring proper culvert installation and monitoring culvert performance during service life are important features of a culvert management program.

- The current good condition of culverts likely follows from the UDOT policy to inspect culverts during installation. This should be continued.

- Inspection rules that will ensure regular inspection of critical culverts and at least occasional inspection of less-critical culverts are important to providing reliable and safe roadways.

Culvert Barrels

- Culvert barrels are generally performing well.

- Metal culverts and some uncoated metal end treatments along I-80 west of Salt Lake City are severely corroded. Soil-side corrosion of metal culverts is common in many parts of Utah, but this did not typically lead to culvert perforation. Metal culverts can perform well in most Utah environments when coated appropriately and installed properly. Invert corrosion due to abrasion was the most common type of distress, followed by wall deformation.

- Plastic culverts have good overall performance, although installations have not been in place for as many years as other materials.

- Concrete culverts perform well in all observed Utah environments.

Maintenance

- Sedimentation removal is the primary maintenance requirement.
- The significant predictors for culvert rating are:
    - physical blockage of waterway,
    - shape of flexible culvert,
    - degree of corrosion,
    - barrel joint integrity,
    - state of coatings,
    - roadway condition over culvert alignment and
    - scour or undermining at inlet or outlet.

End Treatments

- Culvert end treatments are installed in a more demanding environment than culvert barrels and are exposed to significant abuse due to mowing and other maintenance operations.
- Service life of end sections is reduced relative to barrels.
- Metal and concrete end treatments have fair performance while plastic end treatments have poor performance.

Recommendations

Recommendations developed during this study for the maintenance of the UDOT culvert inventory include:

- continue the practice of inspecting culverts during installation,
- at a minimum, require inspection and rating of all culverts during paving or other roadway reconstruction operations; this ensures a periodic (although perhaps irregular) evaluation of all culverts; consultants should be provided with specific forms and guidelines for conducting these inspections,
- establish a schedule and procedures for inspecting and rating critical culverts (large spans, major roadways, etc.) on a regular basis,
- apply an Importance Modifier based on culvert size, location, and function, to focus the Department's efforts onto critical culverts,
- continue to develop the UCD for use by maintenance personnel and as a management tool,

- update the UCD with inspection results to develop a record that can be used to track performance of various culvert materials and installation environments,
- emphasize clearance of sedimentation through the entire barrel length during roadway maintenance activities, and
- inform maintenance personnel that road surface distress can be an indicator of culvert distress.

1. INTRODUCTION

The Utah Department of Transportation (UDOT) manages 47,000 storm drains and culverts installed along the state highways of Utah. UDOT, like many other state DOTs, does not currently have procedures for evaluating the performance of these culverts or for applying historical performance data to the design, specification, and installation of new culverts. This project is intended to improve and expand UDOT policies and procedures regarding culvert installations, resulting in a program that allows for better evaluation of culvert performance and equal consideration of all culvert types for new installations, based on cost-effectiveness and in situ performance.

The objectives of this project were to:

- determine the condition of existing highway culverts and storm drains through field surveys that include both qualitative and quantitative evaluations, focusing primarily on culverts with spans between 2 ft and 5 ft, inclusive,
- develop a system of qualitative and quantitative measures to assess both the short- and long-term in situ performance of highway culverts and storm drains, and
- support the UDOT effort to modify and populate with performance data a computerized database designed to track and monitor the performance of highway culverts and storm drains.

During this work, we have evaluated, modified, and used the UDOT Culvert Database; developed performance measures by which culverts can be evaluated; conducted inspections to evaluate culvert conditions in Utah and to test the performance measures; and developed recommendations for UDOT culvert policies improvement.

This report presents the project findings, conclusions, and recommendations. The following chapters detail the methods used by the Utah Department of Transportation to store information about highway culverts, the field inspections conducted under this contract and the development of performance measures developed to assess culvert installations.

2. UTAH CULVERT INVENTORY

The UDOT manages 47,000 total highway culverts and storm drains. Table 2-1 provides a summary of culvert barrel material types and sizes contained in the culvert inventory dataset with records through 1998. The total culvert quantities, by barrel material, are 72% metal, 25% concrete, and 3% plastic. For this project, focus on culvert spans from 24 in. to 60 in., these ratios change to 78% metal, 20% concrete, and 2% plastic. The full database contains 432 records (1% of total) with spans between 10 ft to 20 ft and 59 records with spans greater than 20 ft. Span is defined as the unsupported distance over which the culvert must carry traffic and for circular culverts is the diameter of the pipe barrel. The inventory database has not been fully reviewed for accuracy of input data, thus some entries appear anomalous, such as plastic culverts with spans greater than 20 ft; however, the project found the database to be generally representative of the UDOT culvert inventory.

Table 2-1 – Summary of Culvert Types in UDOT Culvert Inventory Dataset through 1998

Culvert Span (in.)	Culvert Barrel Material				Total	% of Total
	Metal	Concrete	Plastic	Other		
0 to 23	9,222	4,976	1,183	82	15,463	32.9%
24 to 60*	23,288	5,829	449	2	29,568	63.0%
61 to 120	923	505	3		1,431	3.0%
121 to 240	159	269	3	1	432	0.9%
241 to 960	15	43	1		59	0.1%
Total	33,607	11,622	1,639	85	46,953	100%
% of Total	**71.6%**	**24.8%**	**3.5%**	**0.2%**	**100%**	

*This project is focused primarily on culverts in the 24 in. to 60 in. span range.

Table 2-2 provides a summary of culvert installation date records for all culvert spans. Within the available data, 73% (34,100 of 46,953) of the records contain no installation dates or an installation year prior to 1800 that is identified as unknown in the table. The database supplied for this study contains no entries for culverts installed after 1998, which from our understanding of recent trends, means the total amount of plastic pipe currently maintained by UDOT is underestimated.

Table 2-2 – Summary of Installation Dates for All Culverts

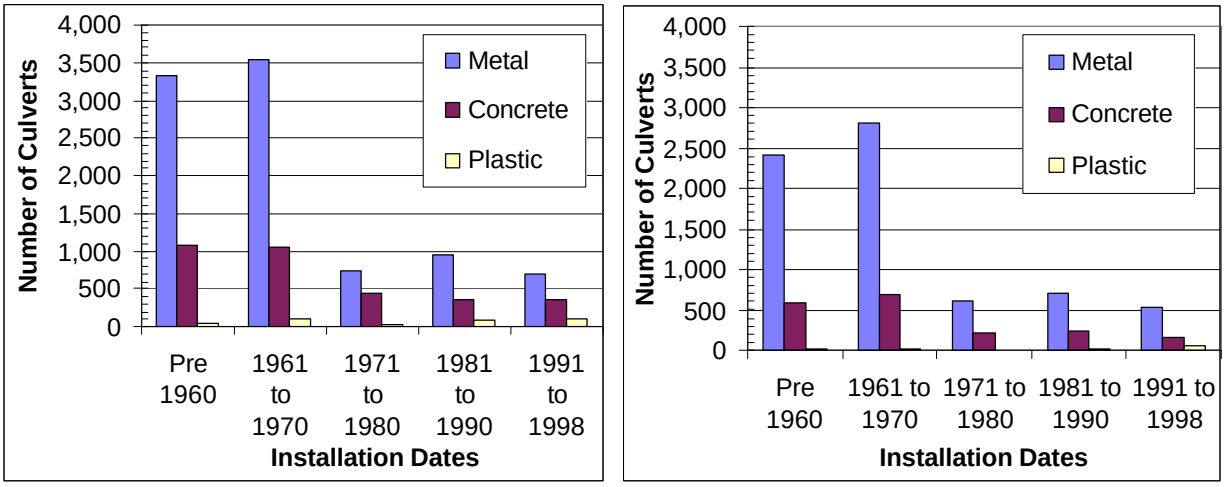
Install Date	Culvert Barrel Material				Total	% of Total
	Metal	Concrete	Plastic	Other		
Unknown	24,370	8,366	1,280	84	34,100	72.6%
Pre 1960	3,328	1,064	35		4,427	9.4%
1961 to 1970	3,541	1,052	110		4,703	10.0%
1971 to 1980	743	437	31		1,211	2.6%
1981 to 1990	938	354	85		1,377	2.9%
1991 to 1998	687	349	98	1	1,135	2.4%
Total	33,607	11,622	1,639	85	46,953	100%
% of Total	**71.6%**	**24.8%**	**3.5%**	**0.2%**	**100%**	

Table 2-3 provides a summary of culvert installation date records for culverts with span from 2 ft to 5 ft. Within this reduced set, 69% (20,501 of 29,566) of the records contain no installation dates.

Table 2-3 – Summary of Installation Dates for 2 ft to 5 ft Span Culverts

Install Date	Culvert Barrel Material			Total	% of Total
	Metal	Concrete	Plastic		
Unknown	16,224	3,960	317	20,501	69.3%
Pre 1960	2,415	579	14	3,008	10.2%
1961 to 1970	2,799	687	26	3,512	11.9%
1971 to 1980	602	214	4	820	2.8%
1981 to 1990	711	232	28	971	3.3%
1991 to 1998	537	157	60	754	2.6%
Total	23,288	5,829	449	29,566	100%
% of Total	**78.8%**	**19.7%**	**1.5%**	**100%**	

Figure 2-1 illustrates the relative quantities of culverts installed prior to 1960 and in each decade through 1998 for the culverts with installation dates. In the figure, Part a. is for all culvert records and Part b. is for culverts with span from 2 ft to 5 ft. The figure illustrates that, of the culverts with installation dates, 71% were installed prior to 1970 and have been in service for at least thirty-five years.



a. All Culvert Records b. 2 ft to 5 ft Span Culvert Records

Figure 2-1 – Summary of Installed Culverts through 1998

Attachment A.1, "Utah DOT Culvert Inventory", provides histograms that quantify available culvert inventory information for the full culvert inventory and for a reduced inventory set containing 2 ft to 5 ft span culverts. The histograms are sorted primarily by barrel material type and provide the following information:

- barrel count (number of pipe barrels used for the culvert),
- barrel lengths (longitudinal pipe run of the culvert),
- culvert crossing (typical culvert use, that is, under main roadway or side drain, etc.),
- inlet and outlet end treatment (type of end section attached to the pipe barrel),
- number of drop inlets (number of gratings/catch basins that drain into the culvert),
- installation date (year of culvert installation),
- culvert material (pipe barrel material),
- span (nominal diameter of pipe barrel), and
- culvert distribution along State Routes (number of pipes within each 10-mile length of roadway).

3. CULVERT INFORMATION STORAGE

Maintenance of real property asset information by an agency such as UDOT can be overwhelming and inefficient without a systematic methodology. For some years, UDOT has employed the Maintenance Management System (MMS) to store information for culverts and for all other owned and operated assets. While effective as a means of information storage, the MMS has limited applicability for interaction required by maintenance personnel performing regular culvert inspections. The following sections describe work by UDOT to develop a system for monitoring its culvert inventory with the ultimate goal of culvert management.

3.1 UDOT Culvert Database

To improve culvert data management, Utah State University (USU) in collaboration with UDOT created a database system, referred to herein as the UDOT Culvert Database (UCD) as one step in establishing a system for management of Utah's culvert inventory. The UCD has two components: the Form program and a database with the culvert records. The UCD Form program is compiled to run independently in a Microsoft Windows operating environment. The database is accessible either through the Form program or with Microsoft Access. The database contains two datasets: culvert inventory and culvert inspections. The culvert inventory contained in the UCD consists of culvert data extracted from the UDOT MMS in 1999. Attachment A.2, "UDOT Culvert Database", presents the components of the Form program and the data structure of both datasets in the database. An attached compact disc (Attachment A.4) contains the UCD program and datasets, a basic user's manual that was developed by USU for an earlier revision of the UCD, and photos from the field inspections.

The UCD is a work in progress. It has been functionally modified prior to and throughout this project and requires additional modification to fulfill its intended purpose. This report provides recommendations for modifications to both improve the functionality of the UCD and make it useful to typical maintenance personnel.

3.1.1 UDOT Culvert Database Form Program

The UCD Form Program accesses and modifies the culvert database. The program provides a series of five graphical windows (tabs) for entry of culvert inventory and inspection data. The tabs are named Inventory, Road Inspection, Bank Protection Inspection, Waterway Inspection, and Barrel Condition Inspection. Data is entered into the database using drop-down menus and free text entry within the tab windows. The tab windows also provide access to rating tables for the waterway and the barrel as

separate pop-up windows (see button at lower right of tab windows). Figure 3-1 through Figure 3-5 provide images of the five tab windows. Attachment A.2, “UDOT Culvert Database”, provides the respective selection data accessed in the drop-down menus within the tab windows.

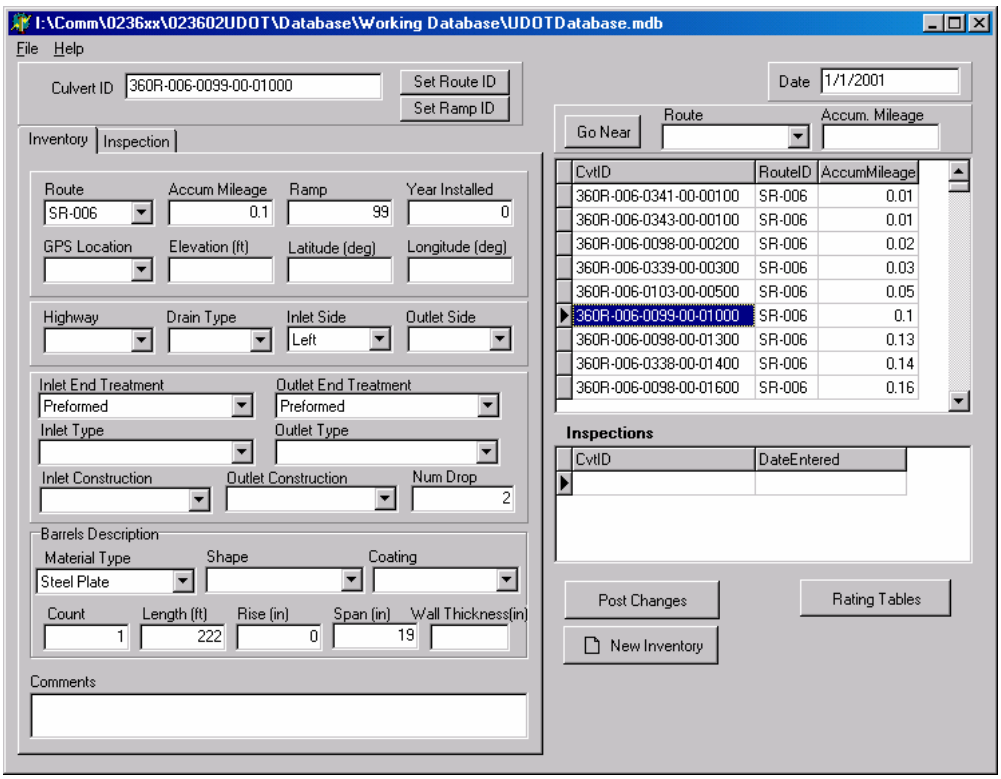


Figure 3-1 – UDOT Form Program Tab Window – Inventory

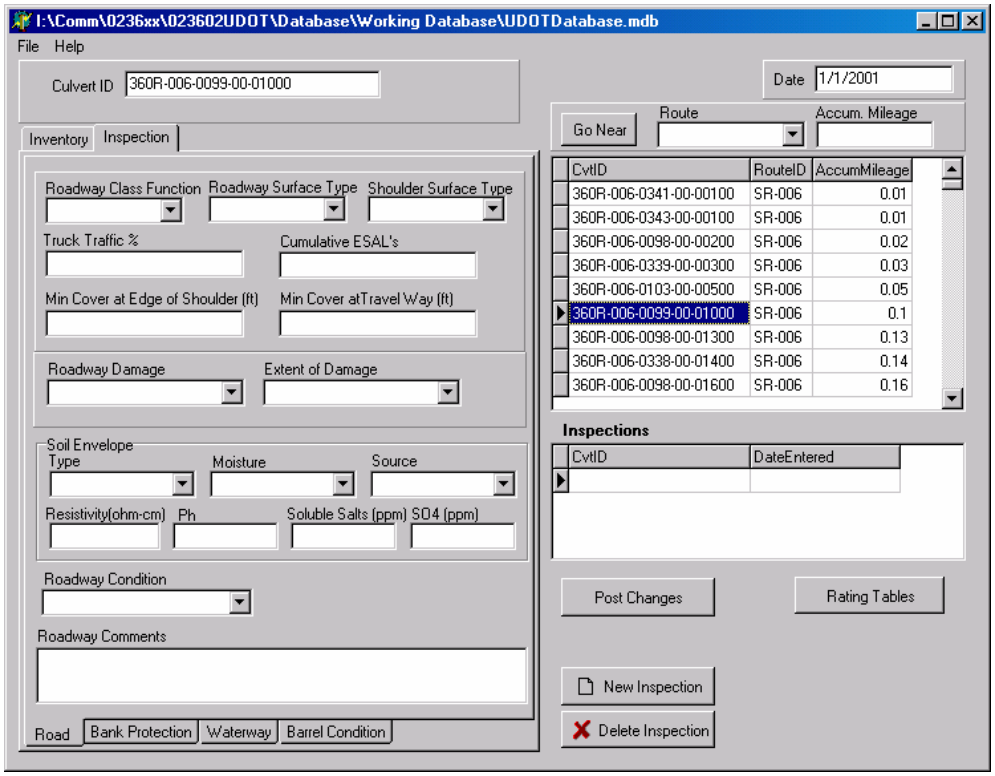


Figure 3-2 – UDOT Form Program Tab Window – Road Inspection

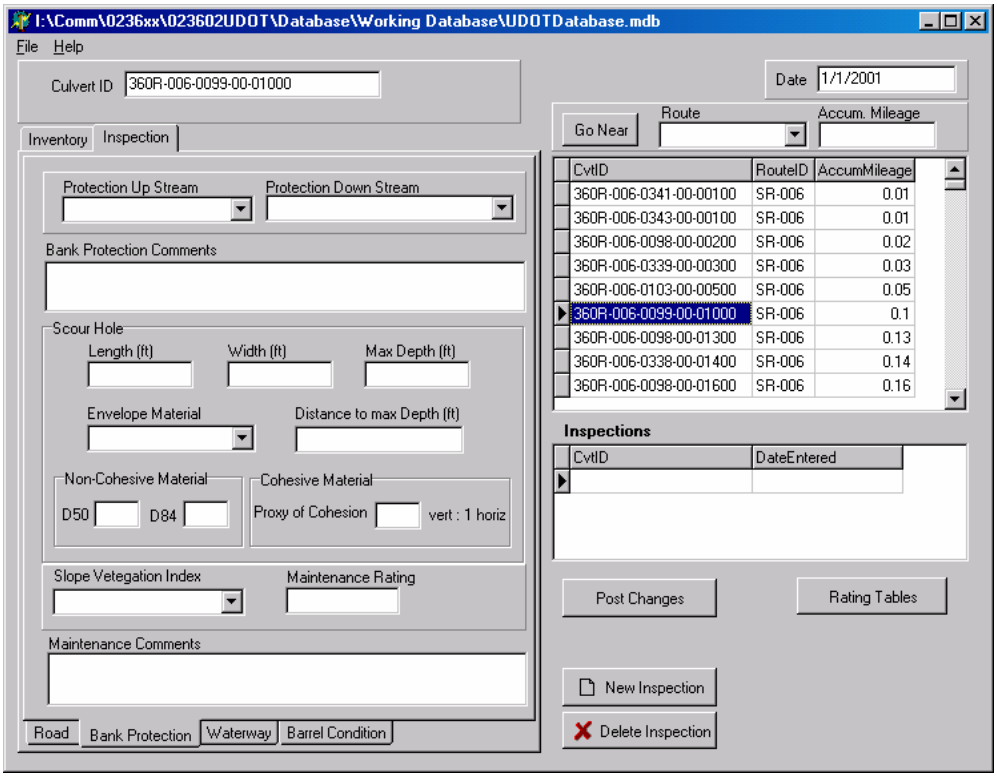


Figure 3-3 – UDOT Form Program Tab Window – Bank Protection Inspection

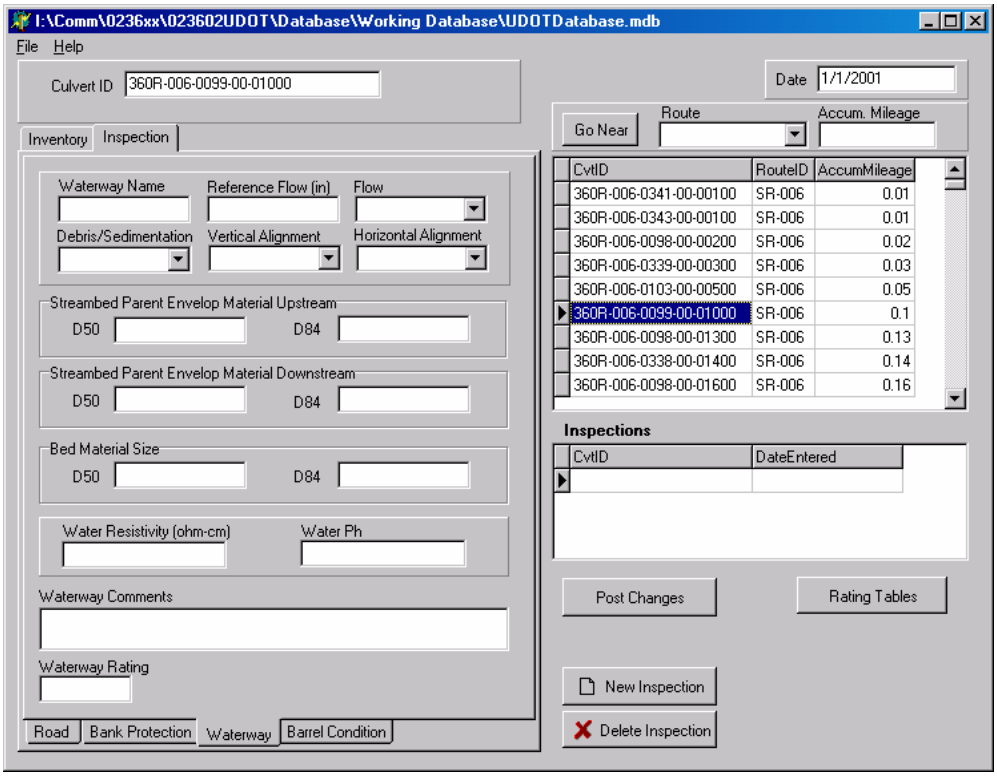


Figure 3-4 – UDOT Form Program Tab Window – Waterway Inspection

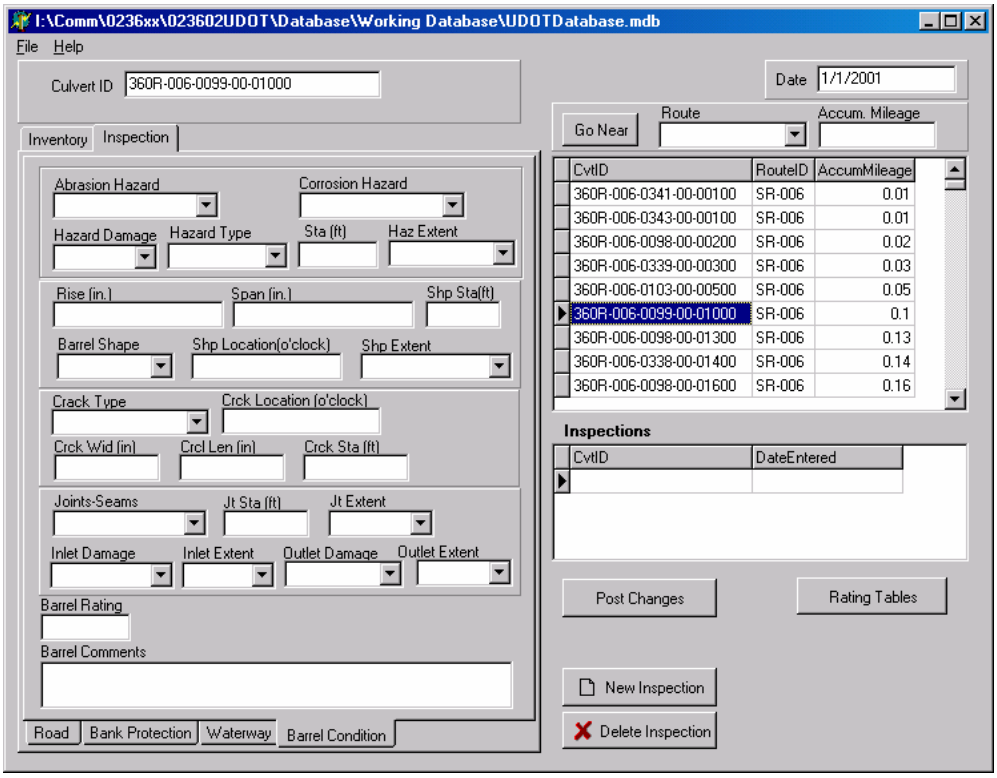


Figure 3-5 – UDOT Form Program Tab Window – Barrel Condition Inspection

3.1.2 Dataset – Culvert Inventory

The inventory dataset contains information collected within the Inventory tab in Figure 3-1 that includes culvert barrel span and rise, barrel material, installation location, type of end treatments, and other characteristics of each culvert and its installed location. The inventory is populated with approximately 47,000 culvert records in a Microsoft Access database file. These records were imported from the UDOT Asset Management MMS database in 1999. Recorded culvert spans vary from 0 in. to 960 in. (0 ft to 80 ft). For this project, records for culverts with span from 24 in. to 60 in. (2 ft to 5 ft) were extracted from the complete dataset. The total number of records in this reduced dataset is approximately 30,000. All inspection and inventory records are identified by a unique Culvert Identifier (CID) composed of the State Route (SR) and the accumulated mileage with the following format:

360H-021-0084-02900

where:

360H	=	Element number for culvert records in the MMS
021	=	Culvert located on State Route 21
0084	=	Culvert located between Reference Post 84 and 85
02900	=	Culvert located at 0.29 mi from Reference Post 84

The inventory dataset contains fifty fields, of which thirty-one are actively used in the current UCD configuration: Fifteen store data using drop-down menus, thirteen allow free text entry of inventory data, one contains the CID for each unique culvert record, one maintains information on whether the record is new or updated, and one notes the date of data entry or modification. The fields include location identifiers as well as geometric and functional parameters. Many of the fields were either partially or fully populated with data from the previously used MMS Element 360 records [6]. Populated fields are those that contain records with values other than 0, null, or N/A. Attachment A.2, “UDOT Culvert Database”, provides a complete list of fields contained in the inventory dataset.

3.1.3 Dataset – Culvert Inspection

The inspection dataset is contained in the same Microsoft Access file as the inventory dataset and contains all information obtained in culvert inspections. The inspection dataset contains individual records of culvert condition at various points in time with a unique record for each inspection of the same culvert. The inspection dataset records

use a unique CID and the date of inspection as the inspection record identifier. This allows for multiple inspection records for a single inventory record. At the start of this project, the inspection dataset was empty. The inspection dataset has now been populated with the records of the 272 inspections conducted as a part of this project. The inspection dataset contains seventy-seven fields for data. The Road Inspection tab has eighteen total fields for data entry: Eight store data using drop-down menus, and ten allow free text entry of inspection data. The Bank Protection Inspection tab has fourteen total fields for data entry: Four store data using drop-down menus, and ten allow free text entry of inspection data. The Waterway Inspection tab has sixteen fields for data entry: Four store data using drop-down menus, and twelve allow free text entry of inspection data. The Barrel Condition Inspection tab has twenty-six total fields for data entry: Fourteen store data using drop-down menus, and twelve allow free text entry of inspection data. As in the inventory dataset, three fields are used for record identification, record status, and date of record entry or modification. Attachment A.2, "UDOT Culvert Database", provides a complete lit of the fields contained in the inspection dataset.

3.2 Database Evaluation

Development of the Utah Culvert Database has placed Utah ahead of most states in addressing the issue of culvert maintenance. However, the current version of the UCD is usable by trained staff only, with little flexibility for presentation of inventory or inspection data. To make the UCD a usable tool for UDOT, the database and Form program should be streamlined to collect only the necessary inspection data, be made usable by maintenance personnel who can populate it with inspection data, and be improved to assist UDOT with culvert management decisions.

3.2.1 Inventory Data

The majority of culvert inventory data in the inventory dataset is correct and may be used for inspections and statewide analysis of culvert assets. However, the inventory data does contain incomplete entries and a number of errors. Typical incomplete entries include culvert locations, descriptions of the barrel size and material, age of installation, and end-treatment descriptions.

Culvert locations are often inaccurate; however, we believe that much of this problem derives from the mixed use of accumulated mileage versus mileage post location and the current UDOT effort to bring the two together. All culverts inspected as part of this project were located by global positioning system (GPS), which provides improved

accuracy, as well as by Route and accumulated mileage. The accuracy of the CID for culvert location varies by segment of state routes, in some locations, correlating with accumulated mileage, while in others, correlating with the reference post and longitudinal offset. In all cases, the correlation is consistent for a stretch of state region between major intersections. As the DOT aligns the reference posts to the accumulated mileage, the culvert nomenclature for each region should be verified and updated, if necessary.

The accuracy of the inventory material varies. For example, in the Cedar District of Region 4, we sought reinforced concrete culverts that were identified in the database, only to find that the culverts were metal with concrete end treatments. In a similar situation, along SR-70, where the database indicated plastic culverts, we found thermoplastic-coated metal culverts. Issues such as these likely stem from lack of inspector training.

Installation date data is often incorrect or missing entirely. This information is critical to determine culvert service performance with time.

Culvert rise and span records also contain inaccuracies. In some instances, this may be attributed to inspector uncertainty. For instance, some inspectors may be unclear whether to record the average, inside, or outside diameter for the case of corrugated wall thermoplastic pipes.

End treatments are frequently not listed at all. It is possible that the descriptions of end treatments may not have always been recorded in the original MMS records.

3.2.2 Form Program

The UCD Form program provides a good method to add data or to modify some of the data contained in the inventory and inspection datasets. However, the Form lacks several features that are advisable for culvert inspections and it contains fields that are not necessary for routine culvert inspections. The Form program is divided into several tab windows that assist in recording data. However, once recorded, there is no way to either produce a consolidated record of entered data to describe an inspection or produce a consolidated report to describe any other database contents. This indicates that the Form lacks the flexibility to fulfill a culvert management purpose. Additionally, for the Form to be usable by maintenance personnel, it would have to be debugged to limit possible errors that are easily encountered in its current configuration.

3.2.3 Suggested Modifications to the UCD

As noted in Section 4 on field inspections, filling out all the current fields is time consuming and collects much information that may not be important to the culvert rating. The number of fields should be reduced to the minimum necessary to provide a proper rating and to document culvert features.

The inventory dataset contains nineteen fields that are not currently used. Most of these fields should be eliminated, unless they represent new functionality to be incorporated into the UCD. For example, one of the currently unused fields provides for storage of data on culvert photos. This functionality should be added to both the inventory and the inspection records, so the field should not be eliminated. End-treatment descriptions should be consolidated into a single field, where there are now three fields. Attachment A.2, “UDOT Culvert Database”, provides a list of inventory fields and their use.

The inspection dataset currently contains detailed soil description fields that are not necessary for routine inspections. These fields should be eliminated, and the Form program tab windows should be reorganized accordingly. Culvert Importance Modifiers should be added to the database, and the maintenance rating, which is contained in the Bank Protection tab, should be determined automatically as the lower of the hydraulic or structural rating times the Importance Modifier. The Barrel Condition tab should be expanded to two tabs with increased description of input fields and increased flexibility for notation of barrel deficiencies. This could be accomplished by use of drop-down menus of available typical deficiencies with adjacent fields for deficiency location and severity, allowing several entries for a similar deficiency in multiple locations, which currently requires use of the barrel comments field.

A tab window should be added to provide thumbnail views of available culvert photographs with the ability to see enlarged photos. These photos should be linked to the inventory and inspection records using the CID and should be viewable using the Form program.

A procedure should be established to allow UDOT personnel to modify the selection list data for the drop-down menus in the Form program. Currently, any selection list modification requires submission to the database contractor at USU. Typical modifications might be to add end treatment descriptors like projecting, mitered, and skewed, that are not currently available in the inventory tab drop-down menus.

Management features should be added to the UCD. For the database to be of any practical use for statewide planning of culvert maintenance, the UCD must provide a reporting procedure for individual culvert inspections and for consolidated regional and statewide results. Using Microsoft Access, automatic report generation could be incorporated. UDOT staff should identify aspects of culvert inspections that are necessary to managers for creation of these inspection results.

3.3 Culvert Information Systems Used by Other Agencies

Condition assessment and asset management of culverts is an issue important to all state Departments of Transportation. Given the quantity of culverts and the potential risk of roadway disruption and property damage due to poorly maintained culverts, a systematic method to perform scheduled maintenance should be the goal of any culvert maintenance system. This section reviews culvert management activities by other jurisdictions for guidance in how UDOT might proceed in this task.

Currently, the UCD is an inspection tool without any management capabilities. Many states, including Maine, New York, California, Pennsylvania, North Carolina, Minnesota, and Connecticut, have pipe management systems established (NCHRP Synthesis 303) [12]. However, the current methods used to assess culvert conditions vary widely from state to state.

NCHRP Synthesis 303 reports that 37% of state DOTs have guidelines to assess pipe condition. A common practice is to classify culverts by span such that the details of the inspection change. For example, Maryland DOT classifies culverts with spans of 0 to 5 ft as cross-culverts and culverts with spans of 5 to 10 ft as struts, with different inspection criteria for each. In a similar manner, North Carolina is currently inventorying culvert assets by excluding any culverts with spans less than 36 in., thus significantly reducing their culvert inventory due to the large quantity of 24 in. culverts.

Several states that track culvert condition use the results of the culvert inspections to select culvert repair and rehabilitation, i.e. as input to an economic decision process, or a management tool. However, the most common method employed to maintain culverts is to use a service-life (often called useful-life) predictor and plan some type of rehabilitation or replacement at the expiration of that service life. This method leaves significant room for improvement, given the imprecise nature of service-life predictions.

The Ohio DOT created a Culvert Management Manual [22] that provides details of culvert data tracking, inspections, and condition evaluation. The manual includes similar data to the FHWA culvert inspection manual with customization for Ohio DOT's needs and provides definitions of common terminology. The manual should serve as a guide to Utah; however, the inspection and rating criteria used by Utah should be as recommended in this culvert study and not as found in the Ohio DOT publication.

In 2001, the Montana DOT conducted research to determine factors that were important to evaluate the condition of a culvert [10]. The research attempted to statistically correlate the condition of a culvert with the respective rating in each of thirty-three condition parameters. The study showed only nine parameters were statistically significant with respect to the overall rating assigned by the inspectors conducting the research. The nine parameters are:

- age of culvert,
- scour at outlet,
- evidence of major failure,
- degree of corrosion,
- invert of culvert worn away,
- sedimentation of cross section,
- physical blockage,
- joint separation, and
- physical damage.

Synthesis 303 indicates that most states perform culvert maintenance based on an as-needed, rather than preventive basis and that some include service life predictions to plan rehabilitation or replacement maintenance. This indicates that Utah is ahead of many states in its effort to manage culvert assets.

4. FIELD INSPECTIONS

4.1 Introduction

Inspections were conducted 17 – 18 December 2002, 17 – 26 March 2003, 11 – 16 July 2003, and 13 – 19 October 2003. A total of 272 culverts were inspected. SGH staff conducted all culvert inspections, with UDOT staff assistance for approximately half of the inspections. UDOT vehicles and equipment were used for all inspections. Figure 4-1 shows UDOT staff evaluating and participating in the culvert inspection process.

The project plan was to inspect a small percentage of UDOT highway culverts and use the inspection results to infer the condition of the entire culvert inventory. Inspections were conducted with three general levels of effort. All inspections were conducted at Level 1 (inlet/outlet visual, qualitative). Culverts where: 1) barrel had rating less than three, 2) end inspection suggested interior features worth inspection, 3) internal inspection wasn't prohibited in accordance with OSHA confined spaces entry regulations, and 4) culvert barrel span greater than 24 in., were upgraded to Level 2 (end-to-end visual qualitative) or, in some instances, to Level 3 (quantitative).

An overview of the field inspections in presented in this Section. Inspection results are discussed in Section 6 and provided in detail in Attachment A.3. Inspection photos are included on a CD (Attachment A.4). Description of performance measures used in the inspections is provided in Section 5.

Figure 4-1 – UDOT Staff Involved in Culvert Inspections

4.1.1 Level 1 Inspections

Level 1 inspections assessed the general structural and hydraulic condition of the culvert. The inspections were qualitative and did not include man-entry of the culvert barrel. Information was gathered using visual assessment for the inlet, outlet, roadway surface and embankment, upstream and downstream waterways, drainage area, and culvert barrel. The culvert barrel was viewed from the ends using a high-power flashlight. Inspection data was collected using a relatively quick documentation process. The data was added either directly to the UDOT Database using a laptop computer or was kept on paper for later transfer to the electronic database. Digital photographs were used to identify the culvert location, the general installation parameters, and any detected deficiencies. A handheld GPS device was used to measure the latitude and longitude coordinates of the culvert end. Confirmation of the

UDOT Database inventory data was a focus of Level 1 inspections. Excluding travel time, conducting and documenting a Level 1 inspection took about 45 minutes.

4.1.2 Level 2 Inspections

Level 2 inspections include Level 1 assessments augmented with man-entry of the culvert barrel. Level 2 activities added 1-2 hours time to inspections above that required for Level 1 activities, depending on what measurements were added.. Additional collected information included evaluation of the joints and seams for leakage, infiltration, and exfiltration, assessment of material deterioration, measurement of barrel deflection, and evaluation of waterway/barrel alignment. Data was collected in a manner similar to the Level 1 inspections and additional photographs were taken to document interior features of interest including joint deficiencies and levels of material degradation. As culverts are considered confined spaces, relevant safety precautions were observed in accordance with OSHA recommendations.

4.1.3 Level 3 Inspections

Level 3 inspections augmented data collected in Levels 1 and 2 with quantitative measures of culvert condition to determine extents of material degradation such as corrosion in metal barrels, condition of reinforcement in concrete barrels, material quality, nature of backfill materials, levels of barrel deflection along the culvert length, and quality of installations. Level 3 data collection requires an engineer experienced in culvert inspection and design procedures. Internal evaluation includes measurement as well as photographs/sketches of important features such as crack widths and various shape distortion measures. Where deemed appropriate by the inspector, samples were collected from the culvert barrel, backfill materials, and effluent water. Soil testing was also conducted to determine the pH level and the electrical resistivity.

4.2 Site Selection

To yield meaningful inspection results, culverts with predetermined characteristics had to be randomly selected for inspection. Examination of the database records showed that much of the information needed to make statistically sound culvert-sample selections was not available. For example, the installation age was not recorded for 72% of the culverts, there was difficulty locating specific culverts, and the UDOT Culvert Database has no information on culverts installed after 1998, which likely includes a significant portion of the current plastic pipe inventory. Consequently, the sampling criteria became more general and included geographic location, barrel material, barrel span, roadway importance, surface and deep soils, and age of the installation (where

available). Culvert characteristics were evaluated for matches with the selection criteria using the inventory listings in the UCD and matching culverts were selected for inspection.

The criteria for site selection evolved during the course of the project. In the December 2002 inspections, an attempt was made to use a rigorous “target and inspect” procedure; that is, the database inventory was used to identify a specific set of culverts and a corresponding driving route for the set of inspections. This procedure had limited success due to the difficulty of locating a specific culvert by highway reference posts and corresponding longitudinal offsets.

Subsequent inspections used a much more general approach that typically had inspectors looking for a culvert installation that met a set of criteria in an area in which the database showed several installations meeting that criteria; that is, if the sampling criteria was a metal culvert with span greater than 24 in. installed between 1970 and 1980, the inspectors would look along a stretch of highway where the inventory listings specified many culverts meeting that criteria. This procedure resulted in many inspections of nontargeted culverts that exhibited features of interest. The final sampling procedures could be summarized as follows:

1. Select a series of inspection routes around the state to provide geographic diversity;

2. using the inventory database to identify culverts along the routes, select location where culverts of certain sizes and material types were supposed to be present; and

3. after arriving in that area, inspect one or several culverts that had the desired characteristics.

The principal variation from this scheme was in locating corrugated HDPE culverts. These culverts constitute only 3.5% of the culverts in the inventory dataset, and many have been installed since 1998, the latest installation date of any culvert listed in the database. In addition, the December 2002 inspection trip determined that many culverts listed as plastic could not be located, and the March 2003 inspection trip indicated that many inventory records listing larger-diameter plastic culverts were in fact plastic-coated metal culverts. In view of these facts, virtually all HDPE culverts that were located were inspected.

4.3 Inspected Culverts

Inspections were completed for 272 culverts, including 40 concrete culverts, 193 metal culverts, and 37 thermoplastic culverts, which are 14.8%, 71.5%, and 13.7% of the inspection set, respectively. Inspections were conducted over most or all of twenty-three inspection days at an average rate of 12 culverts per day. Because of the need to achieve geographic diversity, culvert inspections covered long routes with considerable time spent in travel.

All culverts were inspected at Level 1. Additionally, activities consistent with Level 2 and Level 3 inspections were conducted on 96 culverts (35% of the inspection set). Overall, 60 culverts were measured for deflection; water pH was checked in twenty-three locations; soil pH was checked in thirty-two locations; and soil resistivity readings were collected in fourteen locations. Soil resistivity readings were collected in accordance with ASTM G57-95a-01, "Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method" [19]. The instrument used for the field tests was a Saturn Geo Basic Meter purchased for this project from LEM Instruments, Inc., Torrance, California. Figure 4-2 illustrates the typical test set-up, and Figure 4-3 shows a view of the resistivity meter.

Figure 4-2 – Soil Resistivity Testing by ASTM G57
SR-191 Accumulated Mileage 144.38

Figure 4-3 – Saturn Geo Basic Meter – Soil Resistivity Testing

The complete UCD inventory and inspection records from this project are provided as Attachment A.3, "Inventory and Inspection Data for 272 Inspected Culverts". All photographs taken during inspections are provided on attached CDs in jpg format. The photographs are identified using a naming convention similar to the CID:

021_01084_ML_002.jpg

where:

021 = Culvert located on State Route 21

01084 = Culvert located between Reference Post 10 and 11

ML = Culvert inlet is in median, outlet is on left side of road (right and left road sides are defined looking in the positive direction, that is, with increasing mileage or reference posts numbers.

002 = Second photo for this culvert

Table 4-1 presents a summary of the inspected culverts by span and material. The table demonstrates that more than 85% of the inspected culverts had spans within the project range of 24 in. to 60 in. As a result of the need to search for any HDPE culvert,

and the presence of large size culverts in targeted areas, culverts with spans outside the project range were frequently inspected.

Table 4-1 – All Culvert Inspections

Barrel Material	Barrel Span (in.)				Total	% of Total	Total	% of Total
	< 24	= 24	> 24 – 60	> 60			24 – 60 in.	24 – 60 in.
Concrete	4	31	5	0	40	14.8	36	15.6
Metal	6	85	89	13	193	71.5	174	75.3
Plastic	16	18	3	0	37	13.7	21	9.1
Total	26	134	97	13	270	100.0	231	100.0
% of Total	**9.6%**	**49.6%**	**35.9%**	**4.8%**	**100.0%**		**85.6%**	

Table 4-2 provides a summary of the culverts inspected by region. The culverts inspected in Regions 1 – 4 are 13%, 20%, 17%, and 50% of the total inspection set, respectively. The UDOT culvert inventory does not contain a data field that specifies the Region in which each of the culverts is located, so the relative proportions of each material within each Region are not available. However, Table 4-2 and the inspectors' review of the inventory data indicate the following:

- Only one concrete culvert was inspected in Region 4. Inspectors looked at installations listed as concrete within the region, but found that virtually all such installations were box culverts that were outside the scope of this project.

- One-third and one-half of the plastic culverts inspected in this project were located within Regions 2 and 4, respectively. These ratios are representative of the full culvert inventory. Larger quantities of plastic pipe are likely used in these regions due to the fact that Region 2 contains adverse environmental conditions (high chlorides) that discourage use of several types of metal culverts and because Region 4 is located far from any of the concrete manufacturing facilities, resulting in comparatively higher pipe-delivery costs.

- More than half of all metal culverts inspected were within Region 4. Region 4 comprises more than half of the state area, so this quantity of metal culverts is consistent with an even spread of metal culvert inspections throughout the state.

Table 4-2 – Quantity of Inspected Culverts by Region

Region	Material	Quantity	% of Total in Region	% of Total by Material	% of Total Inspected
1	Total	35	–	–	12.9%
	Metal	20	57.1%	10.4%	7.4%
	Concrete	13	37.1%	32.5%	4.8%
	Plastic	2	5.7%	5.4%	0.7%
2	Total	54	–	–	19.9%
	Metal	28	51.9%	14.5%	10.3%
	Concrete	13	24.1%	32.5%	4.8%
	Plastic	12	22.2%	32.4%	4.4%
3	Total	48	–	–	17.6%
	Metal	30	62.5%	15.5%	11.0%
	Concrete	13	27.1%	32.5%	4.8%
	Plastic	5	10.4%	13.5%	1.8%
4	Total	135	–	–	49.6%
	Metal	115	85.2%	59.6%	42.3%
	Concrete	1	0.7%	2.5%	0.4%
	Plastic	18	13.3%	48.6%	6.6%
All	Total	272	–	–	100%
	Metal	193	–	100%	71.0%
	Concrete	40	–	100%	14.7%
	Plastic	37	–	100%	13.6%

Figure 4-4 presents the locations of all inspected culverts (quantified in Table 4-2), keyed by culvert material type and overlaid on a highway map of Utah that includes boundaries of the Maintenance Regions. The figure shows that the culvert inspections sampled most regions of the state and that the majority of the inspected culverts were corrugated metal pipe, which is consistent with the UDOT culvert inventory (see Table 2-1).

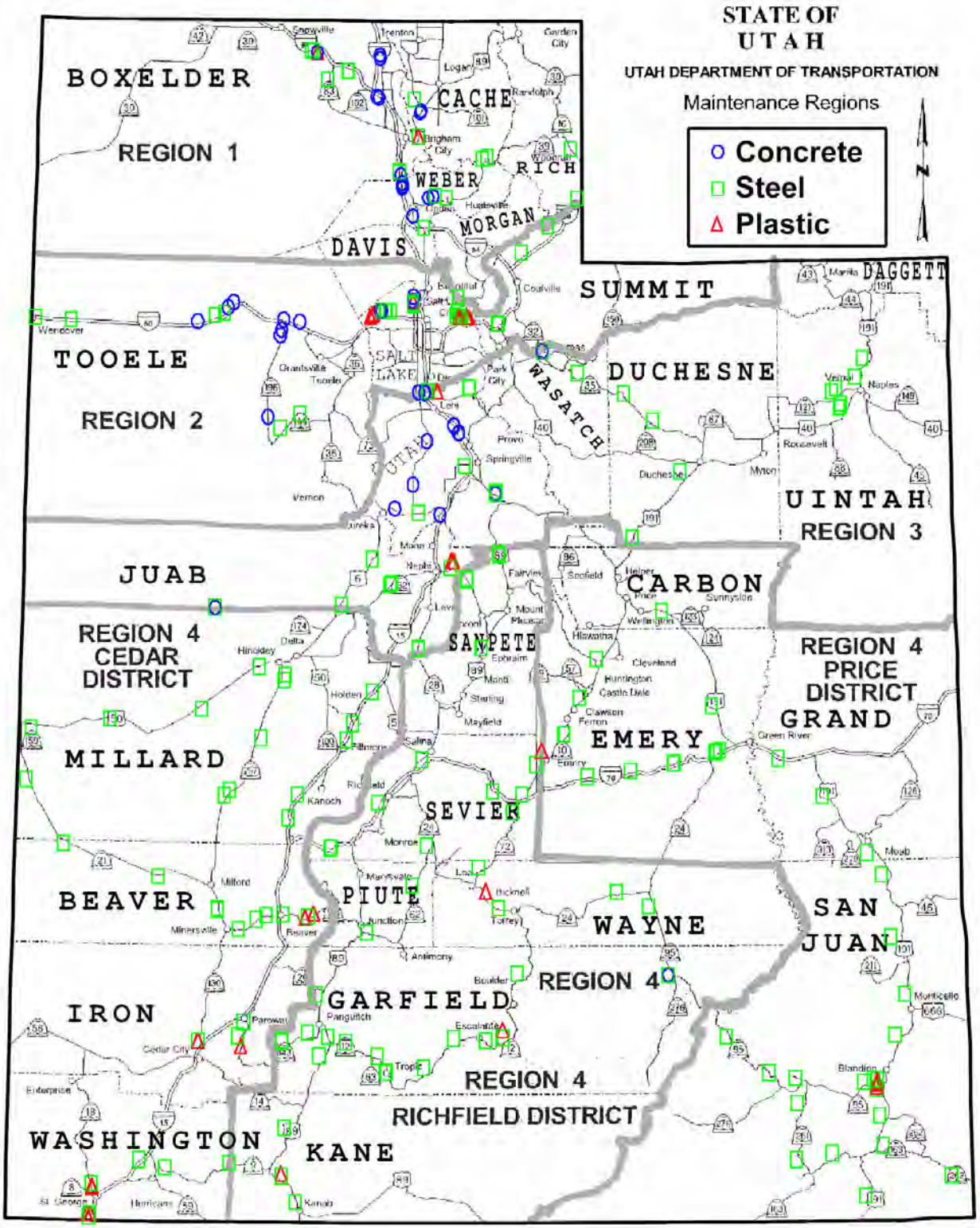
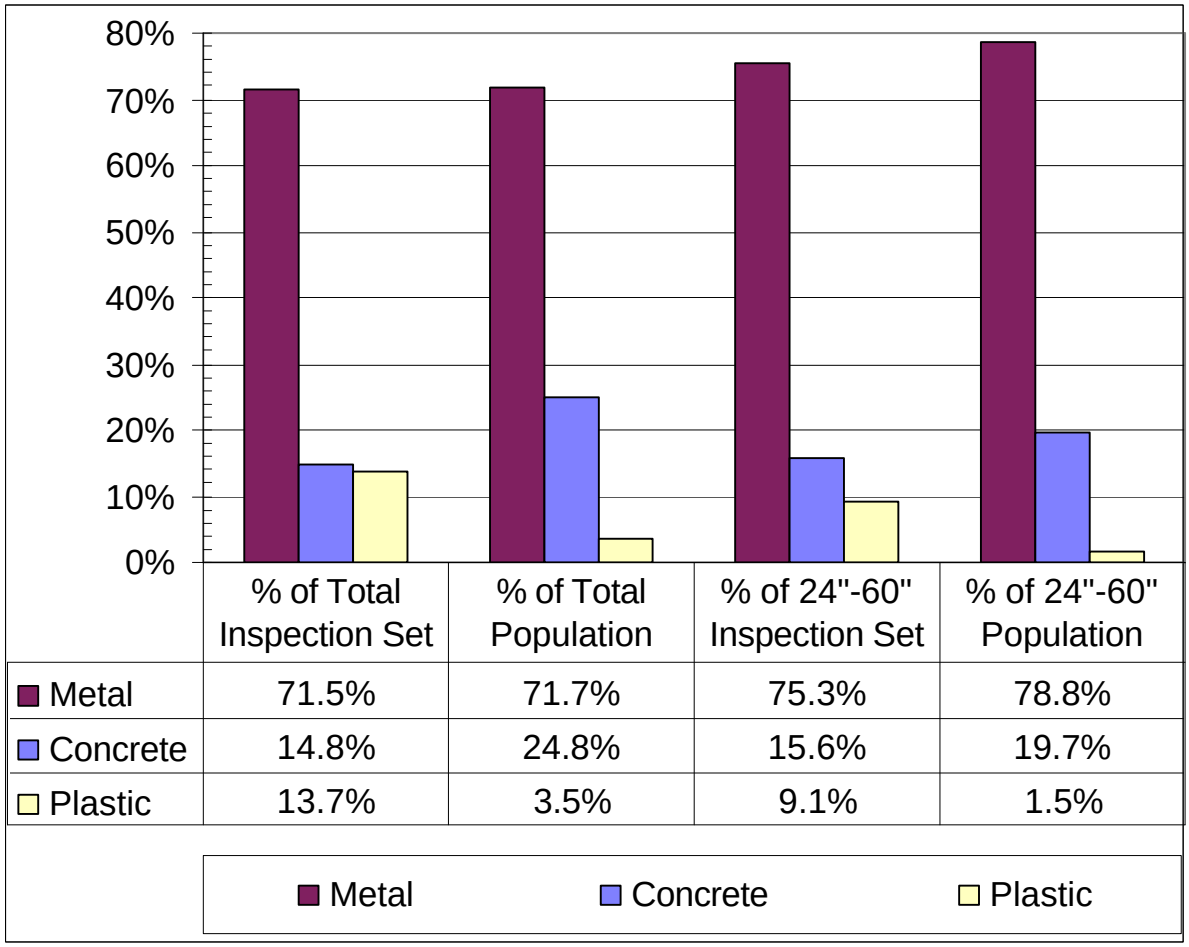


Figure 4-4 – State Route and Maintenance Region Map with Inspected Culverts

Figure 4-5 compares the numbers of each type of culvert inspected to the inventory database content. The data demonstrates that the relative proportion of concrete, metal, and plastic culverts inspected reasonably matches the numbers of each type installed in Utah, with two comments:

- The number of concrete culverts inspected is low relative to the database population; however, we found that many concrete culverts were box culverts that are not being evaluated in this study, and the database provides no shape data to evaluate the number of circular culverts; we also found a number of culverts identified as concrete that were actually metal culverts with concrete end sections.

- Plastic culverts in the inspection set overrepresent the numbers of plastic culverts in the entire population; however, it is difficult to determine exactly how overrepresented plastic culverts are due to the lack of any culvert data after 1998 and the trend of increased usage of plastic culverts in Utah.



	% of Total Inspection Set	% of Total Population	% of 24"-60" Inspection Set	% of 24"-60" Population
Metal	71.5%	71.7%	75.3%	78.8%
Concrete	14.8%	24.8%	15.6%	19.7%
Plastic	13.7%	3.5%	9.1%	1.5%

Figure 4-5 – Comparison of Culvert Types Inspected Relative to Inventory Database

5. PERFORMANCE MEASURES AND MAINTENANCE RATINGS

Performance measures are used to objectively evaluate the future viability of systems and system elements, in this case culverts, through a process of rating parameters that are observed or measured in the field. Performance measures can be established to assess culverts during construction or based on features of culverts that have been in service for some period of time. Records of culvert condition assessments, using performance measures over a period of time, can be further used to evaluate the service life performance of different hydraulic treatments or pipe types.

Culvert performance ratings are divided into two broad categories: waterway (hydraulic) performance and barrel performance. The two areas are not completely independent; however, since required maintenance actions will often be quite different for waterway or barrel issues, the differentiation is appropriate. Roadway condition may be affected by either waterway or barrel performance.

Performance measures for barrel or waterway are quantified using a rating scale from 0 to 9. The rating values are assigned by inspectors using tables that provide rating versus limits of measurable deficiencies. Table 5-3 provides the waterway ratings. Table 5-4 through Table 5-6 provide the barrel ratings. The lower of the two ratings indicates required maintenance action. A rating of 9 implies an essentially new culvert, while a rating of 0 indicates a complete failure with the roadway closed. The rating tables are extensions of those initially developed by the Federal Highway Administration (1986). Maintenance actions based on the waterway and barrel ratings fall into the three broad groups that also use a scale of 0 to 9:

- 9, 8, 7, 6 – no action required,
- 5, 4, 3 – inform supervisor; repair or maintenance required within one year, and
- 2, 1, 0 – immediate action required; road closure should be considered.

To better describe the importance of required maintenance action, waterway and barrel ratings are modified by an Importance Modifier that is a function of the culvert barrel size, the roadway importance, and the type of waterway. Waterway and barrel performance are detailed in Sections 5.2 and 5.3, respectively. The proposed use of Importance Modifiers and maintenance action ratings for the UDOT Culvert database are described in Section 5.4.

5.1 New Construction

Correcting culvert problems after installation is expensive. Excavating and replacing pipe under significant depths of fill often costs several times the initial cost, often leading owners to accept defects without repair or accept repairs, such as liners, that result in a culvert with reduced capacity from the original design. This makes the control of construction procedures an important goal in contracting practices. While evaluation of culverts during construction is not a focus of this project, some information is presented here to provide guidance for specification writers and construction managers. References that provide excellent guidance for installation of buried pipe and culverts include:

- ASTM D2321 [23] – Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications. This standard practice is widely specified for installation of thermoplastic pipe, but the bulk of its guidance is applicable to all types of pipe.

- *Pipeline Installation* (1996) [8]. After a long career in the Bureau of Reclamation, Amster Howard assembled this guide for how to install all types of pipe.

- *Pipe Interaction with the Backfill Envelope* (1999) [11]. This FHWA study investigated the installation process and the response of corrugated steel, corrugated HDPE, and reinforced concrete pipe resulting from various installation practices. Variables included backfill type and compaction level, bedding compaction, and various methods for compacting the haunch zone.

- *AASHTO LRFD Bridge Construction Specifications* (2000) [24]. Chapters 26, 27, and 30 provide guidance on construction of metal, concrete, and thermoplastic culverts respectively. Useful recommendations include materials, assembly, and installation specifications.

For selecting the optimum culvert materials, durability considerations are a major input. Overall comparison of culverts based on durability remains a controversial topic, but some guidelines are available, such as the AASHTO Highway Drainage Guidelines.

5.1.1 Performance Measures During Construction

In many Departments of Transportation, control of installation practices during construction is increasingly being left to contractors, and the state is relying on certifications of compliance and post-construction inspections, which are described below. Whether implemented by contractors or DOT employees, items that should be monitored during construction are presented in Table 5-1. In our experience, there are

three major factors that result in poor pipe or culvert installations with the greatest frequency:

- **Management of Groundwater:** Most backfill materials need to be placed and compacted in a dry environment. Groundwater and rainfall must be properly managed to provide a dry trench during construction.

- **Backfill/Compaction Control:** All pipe systems are designed to take advantage of soil support to distribute loads and reduce the required pipe strength. Thus control of the backfill quality (usually by gradation limits) and placement (usually by in-place density tests) is essential. We have often found that construction trenches are kept so narrow that compaction at the springline level of the pipe is not possible with available equipment. Compatibility of equipment with trench conditions must be a consideration.

- **Construction Equipment:** Improper use of trench boxes, and traversing pipe with heavy equipment and inadequate cover height, will result in culvert failures. Trench boxes are placed to maintain safe working space for installation personnel, but this often requires that they be placed in areas of the structural backfill that provide significant pipe support. If spaces left by walls of the trench box are not filled with properly compacted backfill, the remaining voids can contribute to poor pipe support and performance issues. ASTM D2321 provides excellent guidance on use of trench boxes, regardless of the type of pipe installed.

Table 5-1 – Performance Measures for Culverts During Installation

Performance Area	Measure
Trench/excavation	Trench width Control of groundwater Management of precipitation Suitability of trench bottom
Backfill	Type Compaction level Placement in haunch zone Use of trench boxes
Culvert	Line and grade Joint gap Joint leakage Deflected shape Cracks
End treatments	Wing wall and head wall construction

5.1.2 Post-construction Performance Measures

The key element in construction control of culverts is to conduct a thorough inspection of the culvert within 30 days of completing construction and prior to acceptance. This inspection is important to verify that specified construction procedures have been followed and to establish baseline measurements of parameters that will be used to monitor performance during the life of the culvert. These performance measures include evaluation of structural, material, waterway, and roadway performance. A list of performance measures for flexible and rigid culverts is presented in Table 5-2; however, since items inspected at the completion of construction are the same items inspected during the life of a culvert, this subject is covered in more detail in Sections 5.2 and 5.3.

Table 5-2 – Summary of Performance Measures for Installed Culverts

Performance Area	Rigid Culverts (concrete)	Flexible Culverts (metal and thermoplastic)
Structural	Flexural cracks Radial tension cracks Diagonal tension cracks Concrete crushing	Deflection Local or general buckling Cracking
Material	Exposed reinforcement Concrete degradation	Nonstructural cracking Coating deterioration Loss of galvanizing Bolts Corrosion
Waterway	Joint performance Sedimentation/scour/water chemistry Waterway/culvert alignment (vertical and horizontal) Headwall/wingwall condition	
Roadway	Rutting Pavement deterioration Sinkholes Side slope condition	

Roadway condition in the long term provides a significant indicator of culvert performance problems that may not be otherwise detectable. For example, inspection of a culvert under dry conditions may not indicate joint leakage, but roadway settlement or cracking over this same culvert provides a strong indicator that leakage and infiltration of fines is occurring.

5.2 Waterway Performance

Long-term culvert hydraulic performance is monitored through periodic evaluation of the quality of the waterway. Prime issues include scour/erosion and blockage by debris. Table 5-3 presents guidelines for establishing the overall waterway performance ratings for the culvert. The waterway includes upstream, downstream, and passage through the barrel. The following sections offer a brief discussion of the other important factors which must be reviewed during an inspection.

Table 5-3 – Rating Guidelines for Waterway and Channel Protection

Rating	Alignment	Scour	Obstructions/Roadway/ Structure
9	Good.	No indication of bed scour or bank erosion.	No obstructions.
8	Adequate.	No indication of bed scour or bank erosion.	No obstructions.
7	Fair.	Mild bank erosion or bed scour.	Minor debris accumulation.
6	Not desirable.	Moderate bed scour or bank erosion occurring.	Minor sedimentation and debris.
5	Channel alignment beginning to change.	Significant bed scour or bank erosion requiring investigation to determine need and nature of corrective measures.	Waterway moderately restricted by trees, shrubs, or sedimentation.
4	Alignment causing embankment erosion and undercutting of structure.	Protection required due to bed scour or bank erosion.	Partial blockage of channel or culvert.
3	Scour due to alignment threatening structure of approach embankment.	The structure has been displaced or settled due to bank erosion or scour.	Mass drift accumulation has severely restricted channel or culvert opening.
2	Structure or approach weakened by scour due to poor alignment.	Structure or roadway weakened by bank erosion or bed scour; danger of collapse with next flood.	Culvert blocked by mass drift accumulation.
1	Channel directed at embankment causing server scour of approach embankment.	Structure or approach weakened; danger of immediate collapse.	Close to traffic.
0			Closed to traffic; washed out by flood action.

5.2.1 Roadway and Side Slope Condition

Roadway and side slopes should be inspected for:

- Uneven roadway surface, sag in roadway, sag in guardrail, rutting, and/or cracking. Rough or uneven roadway surfaces may indicate loss of soil through culvert joints or soil movement due to culvert barrel distress.

- Erosion or failure of side slope. Erosion of the side slope over a culvert could indicate a loss of soil through culvert joints or erosion at the culvert inlet or outlet.

Deficiencies in either the roadway or side slope should be noted and reflected in the waterway rating to influence the frequency of subsequent inspections.

Since the roadway is the most visible aspect of the culvert system, it is likely that a roadway problem could be reported without noting the existence of a culvert. It is important for roadway inspectors to determine if a culvert is contributing to the roadway performance problems. There is one reported collapse of a large-span culvert in another state where the roadway was being repeatedly paved to keep it smooth, but the condition of the culvert underneath was not evaluated. At the time of the culvert collapse, several feet of pavement had been placed over the culvert.

5.2.2 Channel and Channel Protection

The state of the channel should be inspected and documented. Measurements, sketches, and photographs should be taken as needed to show the stream alignment and location of problems such as scour. Vertical distance between the streambed and the culvert invert should also be measured where significant. The condition of the stream channel should be visually inspected for the following:

- horizontal alignment of the culvert with the stream channel that may change during high or low flows,
- vertical alignment of the culvert that can lead to scour or sedimentation problems,
- change in surrounding land use relative to prior inspections, which can dramatically change the hydraulic load and abrasion demand on the culvert and lead to erosion and scour,
- accumulation of debris and sediment which may indicate installation of the culvert at an incorrect elevation or down/upstream development, and
- scour at outlet or any undermining of inlet should be noted and measured to allow evaluation of changes over time.

5.2.3 End Treatments and Appurtenances

End treatments listed in the UDOT Database include headwall, preformed, and none. Possible treatments that are not listed in the inventory, but may actually be used, include projecting, mitered, and skewed. Appurtenant structures listed in the UDOT database include only energy dissipator and none; however, flumes, side ditches, and aprons may be present and should be noted.

Assessment of end treatments and appurtenant structures primarily involves visual inspection, although hand tools should be used such as a plumb bob to check for misalignment, a hammer to sound for defects, and a probing bar to check for scour and undermining. Similar to channel evaluation, the inspection should document the type and condition of end treatments and appurtenant structures with photographs or sketches as needed.

The defects to look for during an inspection will depend on the type of end treatment. Headwalls should be inspected for movement, settlement, cracks, deterioration, and traffic safety. All ends should be checked for undermining, scour, and evidence of piping. Energy dissipators should be evaluated for erosion or other signs of instability to service flows.

5.2.4 Soil and Groundwater

Durability is dependent in part on the chemical composition of the soil, water, and culvert system. For routine inspections, visual observations of corrosion or other items indicating severe water or soil conditions will suffice. For more detailed inspections in the case of new installations or when using durability predictor functions to determine remaining service life, in situ measurement of soil resistivity, soil pH, and reduction-oxidation potential should be made. In these cases, tests can be performed in the field, or when more precise measurements are justified, samples of soil and water should be collected for use in laboratory tests. In the absence of specific data, simplified guidelines are available for making approximate evaluations of the corrosion potential of soils; however, the accuracy of the simplified guidelines varies. AWWA Ductile-Iron Pipe and Fittings Manual of Practice [17] employs a ten-point system wherein points are given for the following evaluations of soils: resistivity, pH, redox potential, sulfides, and moisture. Pipe trade associations, such as the National Corrugated Steel Pipe Association, also publish service-life predictions based on embedment soil and flow characteristics.

5.3 Barrel Performance

The culvert barrel is the main structural element of a culvert and provides support for the roadway and a path for the water being passed underneath. Long-term performance is monitored through periodic evaluations. Performance measures are presented and discussed separately for each type of barrel material: metal concrete and plastic. Guidelines for establishing the overall Barrel Performance Rating are provided in tables for each material type.

5.3.1 Metal

Metal culverts in Utah are predominantly corrugated steel. These culverts are flexible, which means that their performance is often evaluated through monitoring deflection. Corrosion and abrasion are the chief issues for durability. Table 5-4 presents guidelines for establishing the overall Barrel Performance Ratings for corrugated metal culverts. The ratings in the table have criteria that are focused on typical Utah circular metal culverts having spans within the range studied in this project. The ratings were consolidated from tables in the FHWA Culvert Inspection Manual [4] for corrugated metal material and round or vertical elongated corrugated metal pipe barrels. The FHWA manual provides tables for other corrugated metal shapes that provide variations in the deflection limitations for various numeric ratings. Items of concern include:

- **Deflection:** Deflection is an indication of poor backfill support for a pipe. Metal pipe are ductile and are allowed to form plastic hinges, so stress is not a concern; however, if deflections reach sufficient magnitude, the pipe may collapse.

- **Seam Defects in Fabricated Pipe:** Helical seams should be inspected for cracking and separation. In bituminous-coated corrugated metal culverts, cracking in the coating may indicate seam separation.

- **Longitudinal Seam Defects in Structural Plate Culverts:** Longitudinal seams should be visually inspected for open seams, cracking at bolt holes, plate distortion around bolt holes, bolt tipping, cocked seams, cusped seams, and for significant metal loss in the fasteners due to corrosion.

- **Dents and Localized Damage:** All corrugated metal culverts should be inspected for localized damage. Pipe wall damage such as dents, bulges, creases, cracks, and tears can be serious if the defects are extensive or if the corrosion protection system is damaged.

- **Misalignment:** Misalignment may indicate the presence of serious problems in the supporting soil. The vertical and horizontal alignment of the culvert barrel should be checked by sighting along the crown and sides of the culvert. Vertical alignment should be checked for sags, faulting, and heaving. Horizontal alignment should be checked for straightness or smooth curvature for those culverts constructed with a curved alignment.

- **Joint Defects:** Typical joint defects include exfiltration, infiltration, joint separation, and other local distress.

  Exfiltration occurs when leaking joints allow water flowing through pipes to leak into supporting material. Minor leakage may not be a significant problem unless soils are quite erosive; however, if leaking joints cause piping, then serious misalignment or failure may result.

Infiltration may occur when the water table is higher than the culvert invert, allowing water and fine-grained soils to seep into the culvert. Infiltration may be detected by open joints, staining at the joints, invert soil deposits, or by depressions over the culvert. Moderate to severe infiltration can lead to loss of structural support for the pipe and possible formation of sinkholes in the roadway. Local occurrences of roadway settlement are often signs of infiltration.

Separated joints may be caused by differential settlement, undermining, improper installation, or global instability of the soil embankment. Joint separations accelerate exfiltration and infiltration, resulting in erosion of backfill materials.

- **Durability (wall deterioration):** Damage due to corrosion and abrasion is the most common cause for metal culvert replacement. Corrosion is the deterioration of metal due to electrochemical or chemical reactions. Abrasion is the wearing away of culvert materials by erosive action.

Although all corrugated steel pipes have a metallic coating for corrosion protection, extreme environmental conditions frequently require additional corrosion or abrasion protection. The National Corrugated Steel Pipe Association *CSP Durability Guide* [25] provides classifications for environmental ranges as:

- Normal Conditions: pH = 5.8 – 8.0 for R > 2,000 ohm-cm
- Mildly Corrosive: pH = 5.0 – 5.8 for R > 1,500 ohm-cm
- Corrosive: pH < 5.0 for R < 1,500 ohm-cm

where:

pH represents the hydronium ion concentration of the soil or the water on a logarithmic scale and pH = 7.0 indicates soil that is neutral.
R (resistivity) represents the resistance of water and soil to the flow of electrical current.

Inspectors should note levels of corrosion and abrasion. Relatively shallow corrosion can produce thick deposits of scale. A geologist's pick hammer can be used to scrape off heavy deposits of rust and scale to permit better observation of the metal. A hammer can also be used to locate unsound areas of exterior corrosion by striking the culvert wall with the pick end of the hammer. When severe corrosion is present, the pick will deform the wall or break through it. Protective coatings should be examined for abrasion damage, tearing, cracking, and removal. The inspector should document the extent and location of surface deterioration problems. When heavy corrosion is found, inspectors should perform pH testing and electrical resistivity measurement, and should obtain cores from the pipe wall.

Table 5-4 – Rating Guidelines–Round/Vertical Elongated Corrugated Metal Pipe Barrels

Rating	Shape	Seams and Joints	Metal
9	New.	Tight; no openings.	Near original condition.
8	Good; smooth curvature in barrel; horizontal diameter within 10% of design.	Tight; no openings.	Superficial rust; no pitting.
7	Generally good; top half of pipe smooth but minor flattening of bottom; horizontal diameter within 10% of design.	Minor cracking at a few bolt holes; minor joint or seam openings; potential for backfill infiltration.	Moderate rust; slight pitting.
6	Fair; top half has smooth curvature but bottom half has flattened significantly; horizontal diameter within 10% of design.	Minor cracking at bolts is prevalent in one seam in lower half of pipe; evidence of backfill infiltration through seams or joints.	Fairly heavy rust; moderate pitting; slight thinning.
5	Generally fair; significant distortion at isolated locations in top half and extreme flattening of invert; horizontal diameter 10% to 15% greater than design.	Moderate cracking at bolt holes along one seam near bottom of pipe; deflection of pipe caused by backfill.	Extensive heavy rust; deep pitting; moderate thinning.
4	Marginal significant distortion throughout length of pipe; lower third may be kinked; horizontal diameter 10% to 15% greater than design.	Moderate cracking at bolt holes on one seam near top of pipe; deflection caused by loss of backfill through open joints.	Pronounced thinning with some deflection; penetration when struck with pick hammer.
3	Poor shape; extreme deflection at isolated locations; flattening of crown, crown radius 20 to 30 ft; horizontal diameter in excess of 15% greater than design.	3-in long crack at bolt holes on one seam.	Extensive heavy rust; deep pitting; scattered perforations.
2	Critical; extreme distortion and deflection throughout pipe; flattening of crown, crown radius over 30 ft; horizontal diameter more than 20% greater than design.	Plate cracked from bolt to bolt on one seam.	Extensive perforation due to rust.
1	Partially collapsed; crown in reverse curve.	Failed; close to traffic.	Invert completely deteriorated.
0	Closed to traffic.	Totally failed.	Partial or complete collapse.

*See FHWA Culvert Inspection Manual [4] for other barrel shapes.

5.3.2 Concrete

Concrete culverts are classified as rigid because they do not deform appreciably under normal installation conditions. Thus, deflection cannot be measured with sufficient accuracy to assist engineers in assessing the structural state of the pipe. Inspections should note cracking, alignment, joints, and walls of the structure. General signs of wall distress such as differential movement, efflorescence, spalling, or rust stains should be noted. Table 5-5 presents guidelines for establishing the overall Barrel Performance Rating for concrete culverts. Specific items of concern are as follows:

- **Misalignment:** Misalignment may indicate the presence of serious problems in the supporting soil. The vertical and horizontal alignment of the culvert barrel should be checked by sighting along the crown and sides of the culvert and by checking for differential movement or settlement at joints between pipe sections. Vertical alignment should be checked for sags, faulting, and heaving. Horizontal alignment should be checked for straightness or smooth curvature for those culverts constructed with a curved alignment. The inspector should attempt to determine the cause of any problems found.

- **Joint Defects:** Typical joint defects include exfiltration, infiltration, cracks, and joint separation.

  Exfiltration occurs when leaking joints allow water flowing through pipes to leak into supporting material. Minor leakage may not be a significant problem unless soils are quite erosive; however, if leaking joints cause piping, then serious misalignment or failure may result.

  Infiltration may occur when the water table is higher than the culvert invert, allowing water and fine-grained soils to seep into the culvert. Infiltration may be detected by open joints, staining at the joints, invert soil deposits, or by depressions over the culvert.

  Cracks in the joint area may be caused by improper handling during installation, improper gasket placement, and movement or settlement of the pipe sections. If no differential movement between pipe sections is evident and the cracks are not open or spalling, they may be considered a minor problem. Severe joint cracks are similar in significance to separated joints.

  Separated joints may be caused by settlement, undermining, or improper installation. Joint separations accelerate exfiltration and infiltration resulting in erosion of backfill materials.

- **Longitudinal Cracks:** Cracks less than 0.01 in. wide are minor and only need to be noted. Cracks more than 0.01 in. but less than 0.1 in. in width should be noted for maintenance and evaluated for effect on structural performance. When cracks are wider than 0.1 in., measurements should be taken of fill height

and the vertical and horizontal pipe diameter, and photographs should be used to document crack location and extent.

- **Circumferential Cracks:** Cracks may also be caused by poor installation (bedding) and can occur across the bottom of the pipe (broken bell) when the pipe is only supported at the ends of each section. Cracks may occur across the top of the pipe (broken back) when settlement occurs or when the pipe is supported by hard foundation material near the pipe section midpoint.

- **Spalls:** In precast concrete pipe, spalls often occur along the edges of either longitudinal or transverse cracks or as a result of steel reinforcing corrosion when water is able to reach the steel through cracks or shallow cover. As the steel corrodes, the oxidized steel expands, causing the concrete covering the steel to spall. Spalling may be detected by visual examination of the concrete along the edges of cracks or by tapping with a hammer along cracks to locate hollow-sounding areas, which are possible incipient spalls.

- **Radial Tension Failure:** Failure of a concrete pipe wall may occur due to radial tension or “slabbing,” when the reinforcement cage straightens causing sections of concrete to “peel” away from the sides of the pipe. Fill heights should be noted in locations of radial tension failure.

- **Diagonal Tension Failure:** Failure of a concrete pipe wall may also be caused by diagonal tension or “shear,” which resembles typical concrete shear cracking and penetrates the full wall thickness at about 45° to a radial line.

- **Durability:** Durability is a measure of a culvert’s ability to withstand chemical attack and abrasion. Concrete pipes are subject to chemical attack in strongly acidic environments and may also be damaged by abrasion. Abrasion damage is a wearing away of the concrete surface by sediment and debris transport. Abrasion or surface deterioration less than 1/4 in. deep should be noted, while more severe surface deterioration should be reported for evaluation and maintenance. The condition of any linings should be noted.

Table 5-5 – Rating Guidelines – Concrete Pipe Barrels

Rating	Alignment	Joints	Concrete
9	New condition.		
8	Good; no settlement or misalignment.	Tight; no defects apparent.	No cracking, spalling, or scaling present; surface in good condition.
7	Generally good; minor misalignment at joints; no settlement.	Minor openings; possible infiltration/exfiltration.	Minor hairline cracking at isolated locations; slight spalling or scaling present on invert or crown.
6	Fair; minor misalignment and settlement at isolated locations.	Minor backfill infiltration due to slight opening at joints; minor cracking or spalling at joints allowing exfiltration.	Extensive hairline cracks, some with minor delaminations or spalling; invert scaling less than 0.25 in. deep; small spalls present.
5	Generally fair; minor misalignment or settlement throughout pipe; possible piping.	Open and allowing backfill to infiltrate; significant cracking; significant joint spalling.	Cracks open more than 0.12 in.; moderate delamination and spalling exposing reinforcement at isolated locations; large areas of invert with surface scaling or spalls greater than 0.25 in. deep.
4	Marginal; significant settlement and misalignment of pipe; evidence of piping; section dislocated about to drop off.	Differential movement and separation of joints; significant infiltration or exfiltration at joints.	Cracks open more than 0.12 in. with efflorescence and spalling at numerous locations; spalls have exposed reinforcement bars which are heavily corroded; extensive surface scaling on invert greater than 0.5 in.
3	Poor; significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred.	Significant openings, dislocated joints in several locations exposing fill materials; infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway.	Extensive cracking, spalling, and minor radial shear failure; invert scaling has exposed reinforcing steel.
2	Critical; culvert not functioning due to alignment problems throughout.		Severe radial shear failure has occurred in culvert wall; invert concrete completely deteriorated in isolated locations.
1	Partial collapse.	Close to traffic.	
0	Total failure of culvert and fill.	Close to traffic.	

5.3.3 Plastic

Plastic pipe are flexible culverts and should be inspected for many of the same features as metal pipe; however, plastic pipe are often made up of relatively thin elements, which makes them also susceptible to local buckling. Additionally, properties of thermoplastics are time dependent, and cracking can occur over time. Guidelines for establishing the overall Barrel Performance Rating for plastic culverts are provided in Table 5-6. Features to be considered during inspection follow:

- **Deflection:** Deflection is an indication of poor backfill support around thermoplastic pipe, which are flexible. Excessive deflection can lead to excessive strain in the pipe wall and eventual material yielding and/or cracking.

- **Local Buckling:** HDPE pipes can fail in a 'local buckling' mode that may be evidenced by crimping of the corrugation. Local buckling of just the liner is not considered a structural failure. Inspectors should note the location of any occurrences of bowing in the wall and provide photographs showing the location. If local buckling is present, the fill height above the pipe at the location of bowing should be noted.

- **Cracks:** Transverse or circumferential cracks may be caused by poor bedding. These cracks can occur at stress concentrations in profile-wall thermoplastic pipes. The inspector should closely observe locations with shape deviations that may indicate cracking of the thermoplastic pipe wall.

- **Seam Defects:** Seams in plastic pipe should be observed for any signs of cracking.

- **Misalignment:** Misalignment may indicate the presence of serious problems in the supporting soil. The vertical and horizontal alignment of the culvert barrel should be checked by sighting along the crown and sides of the culvert. Vertical alignment should be checked for sags, faulting, and heaving. Horizontal alignment should be checked for straightness or smooth curvature for those culverts constructed with a curved alignment.

- **Joint Defects:** Typical joint defects include exfiltration, infiltration, joint separation, and other local distress.

  Exfiltration occurs when leaking joints allow water flowing through pipes to leak into supporting material. Minor leakage may not be a significant problem unless soils are quite erosive; however, if leaking joints cause piping, then serious misalignment or failure may result.

  Infiltration may occur when the water table is higher than the culvert invert, allowing water and fine-grained soils to seep into the culvert. Infiltration may be detected by open joints, staining at the joints, invert soil deposits, or by depressions over the culvert. Moderate to severe infiltration can lead to loss of

structural support for the pipe and possible formation of sinkholes in the roadway. Local occurrences of roadway are often signs of infiltration.

Separated joints may be caused by settlement, undermining, improper installation, or global instability of the soil embankment. Joint separations accelerate exfiltration and infiltration resulting in erosion of backfill materials.

- **Durability:** HDPE is susceptible to environmental stress cracking (ESCR), which is a slow crack-growth phenomenon that may occur at stress levels below the maximum material stress limits. The interior surface should be evaluated for any noticeable cracking. Any damage located during inspection should be described and photographed.

Table 5-6 – Rating Guidelines – Plastic Pipe Barrels

Rating	Shape and Alignment	Joints
9	New or like new condition; pipe is clean, straight, and deflected 5% or less.	New; tight with no defects apparent.
8	Good, smooth curvature in barrel; no settlement or misalignment; vertical diameter within 5% of original inside diameter; no buckling of pipe surface.	Tight with no defects apparent.
7	Generally good; minor misalignment at joints; no settlement; generally smooth curvature with minor flat spots or bulges; vertical diameter between 5% and 7.5% of original inside diameter; no buckling of pipe surface.	Minor openings; possible infiltration/exfiltration of water with no soil particles.
6	Fair; minor misalignment and settlement at isolated locations; generalized flat spots or isolated areas of buckling in the liner; vertical diameter between 7.5% and 10% of original inside diameter.	Minor backfill infiltration due to slight opening at joints.
5	Generally fair; minor misalignment or settlement throughout pipe; possible piping; significant distortion at isolated locations and extreme flattening of invert; generalized liner buckling; vertical diameter between 10% and 12.5% of original inside diameter.	Open and allowing backfill to infiltrate; possible gasket displacement.
4	Marginal; significant settlement and misalignment of pipe; evidence of piping; end section or headwall dislocated; significant distortion throughout length of pipe; corrugations may show some buckling; some circumferential cracking that does not allow soil entry; vertical diameter between 12.5% and 15% of original inside diameter.	Differential movement and separation of joints; significant infiltration or exfiltration at joints; deflection caused by loss of backfill through open joints.
3	Poor; significant ponding of water due to sagging or vertical misalignment; poor shape with extreme deflection at isolated locations; general areas of flattening; circumferential cracking that does not allow soil entry; flattened crown; vertical diameter between 15% and 17.5% of original inside diameter.	Significant openings; dislocated joints in several locations exposing fill materials; infiltration or exfiltration causing misalignment and deflection of pipe and roadway settlement.
2	Critical; reverse curvature; excessive piping and loss of alignment; vertical diameter differs from original inside diameter by more than 17.5%; minor roadway subsidence.	
1	Partial collapse; holes in road surface.	Totally failed; close to traffic.
0	Pipe collapsed; road closed to traffic.	Totally failed; close to traffic.

5.4 Maintenance Action Rating System

At the present time, UDOT does not appear to have a clear vision either for monitoring and maintaining its culvert inventory or how to apply the database for this purpose. Other states are facing this same issue, as the number of culverts is enormous and a detailed inspection program covering all culverts will be extremely expensive. However, given that the consequences of failure of many culverts are small and do not involve life safety, the opportunity exists to reduce the culvert population requiring inspection by classifying culverts as critical or noncritical. NCHRP Synthesis 303 [12] indicates that such a classification is typically based solely on culvert diameter; however, other criteria are also significant, such as the importance of the roadway (e.g., interstate highway versus secondary roadway), and purpose of the culvert (main culvert under roadway, lateral culvert, side slope drain, etc.).

By establishing culvert importance criteria, UDOT can poll the database for culverts with critical features and then establish a routine monitoring and maintenance program for those culverts. Culverts classified as non-critical could be evaluated less frequently, such as during the design stage for paving or road reconstruction. This should provide for the greatest safety with the least effort.

5.4.1 Culvert Importance Modifier

All culverts have performance ratings determined based on the waterway and the barrel condition, as described in Sections 5.2 and 5.3. However, the result of interest to transportation agency decision-makers is the maintenance action required, if any, to maintain each culvert installation as a safe and functional hydraulic structure. The logical result is to use the lesser of the barrel or waterway rating to determine maintenance requirements. Since the barrel and waterway ratings do not in any way describe the relative importance of a culvert with respect to other culverts, some type of rating modifier is necessary to prioritize culvert maintenance work. The concept of an Importance Modifier is introduced as a solution to this prioritization need.

The proposed Importance Modifier is used to determine inspection frequency and the maintenance action rating based on risk and consequences of failure. The UDOT database includes 47,000 culverts, and it is not feasible to conduct routine inspections on each of these culverts. Using a culvert Importance Modifier could help focus resources on culverts where a failure would pose a serious threat to life or property or cause a major disruption of traffic. Importance Modifiers are based on culvert size,

roadway importance, and waterway purpose. Table 5-7 to Table 5-9 provide the recommended Importance Modifiers for each of these three elements.

Table 5-7 – Rating Modifiers for Culvert Importance – Roadway Class

UCD Roadway Class Function	Description	Importance Modifier[1,2]
01	Rural Interstate System	0.91
02	Rural Other Principle Arterials	0.91
06	Rural Minor Arterial System	1.00
07	Rural Major Collector	1.00
08	Rural Minor Collector	1.10
09	Rural Local System	1.10
11	Urban Interstate System	0.91
12	Urban Other Freeways & Expressways	0.91
14	Urban Other Principal Arterials	0.91
16	Urban Minor Arterial Systems	1.00
17	Urban Collector System	1.00
19	Urban Local System	1.10

[1]Lower Importance Modifier indicates higher culvert importance.
[2]Maintenance Action Rating = minimum of Barrel or Waterway Rating times the Importance Modifier

Table 5-8 – Rating Modifier for Culvert Importance - Culvert/Storm Drain Purpose

UCD Drain Type	Description	Importance Modifier[1]
Main	Under the roadway	0.91
Edge	Runs parallel to roadway, may be under shoulder lane, supports embankment	1.00
Lateral	Drains land adjacent to roadway, typically not under roadway	1.10
Slope	Drains a slope adjacent to the roadway, typically not under roadway	1.10

[1]See Notes 1 and 2 for Table 5-7.

Table 5-9 – Rating Modifier for Culvert Importance – Barrel Span and Rise

Minimum Span or Rise (ft)	Maximum Span or Rise (ft)	Importance Modifier[1]
0	2	1.10
2	4	1.00
4	10	0.91

[1]See Notes 1 and 2 for Table 5-7.

With an Importance Modifier, a culvert with a rating of 5, which would require planning for action under the proposed ratings in Section 5.4.2, might be upgraded to immediate action if the culvert has a high Importance Modifier (e.g., a culvert under an interstate highway) or might be reduced to no action if the culvert has a low Importance Modifier (e.g., a small-diameter culvert carrying lateral drainage). Several examples of this system are presented in Table 5-10.

Table 5-10 – Determining Culvert Maintenance Rating

Inspection Rating	Span or Rise Modifier	UCD Roadway Class Modifier	UCD Drain Type Modifier	Combined Importance Modifier	Maintenance Action Rating
4	0.91 (60 in. Span)	0.91 (Urban Expressway)	0.91 (Main)	0.75	3.01
4	1.00 (36 in. Span)	1.00 (Rural Major Collector)	0.91 (Main)	0.91	3.64
4	1.10 (18 in. Span)	1.10 (Rural Minor Collector)	1.10 (Slope)	1.33	5.32
8	0.91 (60 in. Span)	0.91 (Urban Expressway)	0.91 (Main)	0.75	6.01
8	1.00 (36 in. Span)	1.00 (Rural Major Collector)	0.91 (Main)	0.91	7.28
8	1.10 (18 in. Span)	1.10 (Rural Minor Collector)	1.10 (Slope)	1.33	9.00[1]

[1]Maintenance action ratings have minimum value of 0 and maximum value of 9.

Table 5-10 demonstrates that an “important” culvert, such as a large diameter culvert carrying a stream under an interstate highway would have its rating reduced by 25% while a less important culvert, such as a small-diameter culvert on a secondary road acting as a lateral drain would have its rating increased by 33%, thus not requiring additional inspection or maintenance.

The importance of a particular asset over another similar asset is a topic of significant research for the transportation industry. Methods that attempt to incorporate the economic impact on roadway users have been proposed and papers on this topic have been presented at past Transportation Research Board annual meetings [10, 20, 21, 22]. In this study, we have formulated a relatively simple recommendation for the Importance Modifier that requires modest information about each culvert installation. This system could be refined based on UDOT’s perception of the relative importance of the various use and application parameters and as management research progresses.

Modifications to the UDOT Culvert database will be needed to incorporate the Importance Modifier.

5.4.2 Maintenance Rating

After the Maintenance Rating has been determined by multiplying the Importance Modifier by the lower of the two Performance Ratings (Barrel or Waterway), the level of maintenance action required is assessed using Table 5-11. These ratings incorporate both the condition and the importance of a culvert.

Table 5-11 – Maintenance Ratings for Culverts

Adjusted Rating	Course of Action	Immediacy of Action
9	Note in inspection report only.	No repairs needed.
8		No repairs needed; list specific items for special inspection during next regular inspection.
7		No immediate plans for repair; list specific items to monitor in next regular inspection.
6		By end of next season, add to scheduled work; put on increased inspection schedule until maintenance is completed.
5	Special notification to superior is warranted.	Place in current schedule, current season; inspect at first reasonable opportunity. Increase inspection frequency.
4		Priority for current season, review work plan for relative priority; adjust schedule if possible. Increase inspection frequency.
3		High priority for current season, as soon as can be scheduled. Increase inspection frequency.
2	Notify superiors verbally as soon as possible and confirm in writing.	Highest priority, discontinue other work if required; perform emergency subsidiary actions if need (one lane traffic, no trucks, reduced speed, etc.) Increase inspection frequency.
1		Emergency actions required; reroute traffic and close roadway. Increase inspection frequency.
0		Close roadway for repairs; temporarily reroute drainage, where necessary. Increase inspection frequency.

5.5 Inspection Frequency

In addition to maintenance based on inspection results, UDOT should establish a schedule for regular culvert inspections. Federally mandated inspection frequencies for bridges, which may be differentiated from culverts by barrel span greater than 20 ft, are

at least biannual. For culverts, the large number in the UDOT inventory precludes routine inspection of each one on a schedule similar to bridges.

Conclusions drawn from the work in this project indicate that a feasible inspection plan for Utah culverts is to conduct routine inspections of important culverts at intervals of less than five years and all other culverts at intervals of less than ten years. Additionally, all culverts located under or adjacent to roadways that are being repaved or rebuilt should be inspected during the roadwork operations. Increased frequency, for important culverts with Maintenance Ratings less than 6, should be defined as biannual. Important culverts should be defined as those culverts with Importance Factors of 0.83 or less. This proposal focuses resources on critical culverts with provisions that ensure all culverts are evaluated periodically.

6. RESULTS AND ANALYSIS OF INSPECTIONS

Attachment A.3, “Inventory and Inspection Data for 272 Inspected Culverts”, provides the complete inventory and inspection data for the 272 culverts inspected in this project. The individual culvert records may be compared across the tables using the Culvert Unique Identifier (CID), which includes the State Route (SR) and the accumulated mileage of the culvert location. Specific findings and overall conclusions are described in this section of the report, illustrated with photographs.

Culverts were rated for barrel structural and waterway hydraulic condition using the performance measures described in this report. The application of Importance Modifiers and the significance of the resulting ratings are discussed in Section 6.7. The average ratings for all culvert barrels and for all waterways were both 6.7, on a scale of 0 to 9. Tables in the following sections provide culvert barrel ratings, waterway ratings, ratings by maintenance region, ratings by decade of installation, and ratings by elevation of the culvert installation. The tables show the following:

- many UDOT culverts require some level of maintenance,
- most UDOT culvert barrels do not require immediate attention,
- performance of all pipe materials is similar, except that the susceptibility of metal culverts to corrosion lowers the rating of those culverts somewhat,
- performance of waterways is similar for all culvert materials, with concrete culverts performing somewhat better than plastic or metal,
- location around the state, including UDOT Maintenance Regions and various soil zones, is not a good predictor of culvert rating,
- data collected on installation dates is sparse and inconclusive with respect to culvert durability, and
- elevation of the culvert installation is not a predictor of culvert rating or of specific maintenance problems, with several exceptions.

6.1 Culvert Barrels

Overall, culvert barrel performance is good, as evidenced by the resultant barrel ratings from the field inspections in Table 6-1. General performance descriptions and photographs of noted deficiencies are presented in the following sections for metal, concrete, and plastic barrels.

Table 6-1 – Culvert Barrel Ratings by Material

Culvert Material	Rating Range			Count*	Average Rating	Standard Deviation
	= 2	3 to 5	6 to 9			
Concrete	0	4	33	37	6.9	1.0
Metal	0	42	148	190	6.6	1.4
Plastic	0	10	27	37	6.8	1.5
Total	**0**	**56**	**208**	**264**	**6.7**	**1.3**

*272 culverts were inspected; however, some were not assigned ratings for structural performance.

Many culverts have been extended as a part of roadway-widening projects. The interface where an existing culvert meets the extended portion of the culvert is often offset and in poor condition. In several locations, the original culvert barrel was left heavily sedimented after new end extensions were installed.

6.1.1 Metal Barrels

Metal barrels exhibited overall good condition with reduced rating primarily the result of corrosion, joint integrity, and deformation. The average rating for metal barrels was 6.6, which indicates that no immediate action is required. If severe corrosion was present, it was generally in the invert. Generally light corrosion was present on the soil side of barrels, at barrel ends, and at locations of joint or seam leaks. Very little barrel perforation due to the soil-side corrosion was observed. Corrosion was not found where coating integrity was maintained; however, many instances were found with peeled, cracked, or abraded coatings. Where perforation was observed, it appeared to result from the combined action of corrosion and abrasion. Soil resistivity and pH measurements were collected at locations of severely corroded barrels. Joint integrity influenced corrosion, barrel alignment, and waterway clearance of obstructions. Deformation was present near the ends and at localized places in some metal barrels. Figure 6-1 to Figure 6-8 provide photographs of metal barrel distress observed during this project.

Figure 6-1 – Metal Barrel with Mild Invert Corrosion and Abrasion
SR-80 Accumulated Mileage 193.81

Figure 6-2 – Metal Barrel with Moderate Joint Infiltration and Resulting Corrosion
SR-95 Accumulated Mileage 116.73

Figure 6-3 – Metal Barrel with Moderate Local Corrosion at Peeled Coating SR-80 Accumulated Mileage 11.88

Figure 6-4 – Metal Barrel and End Treatment with Severe Corrosion SR-80 Accumulated Mileage 109.68

Figure 6-5 – Metal Barrel with Moderate Seam Infiltration
SR-80 Accumulated Mileage 193.81

Figure 6-6 – Metal Barrel with Mild Crown Flattening
SR-92 Accumulated Mileage 13.90

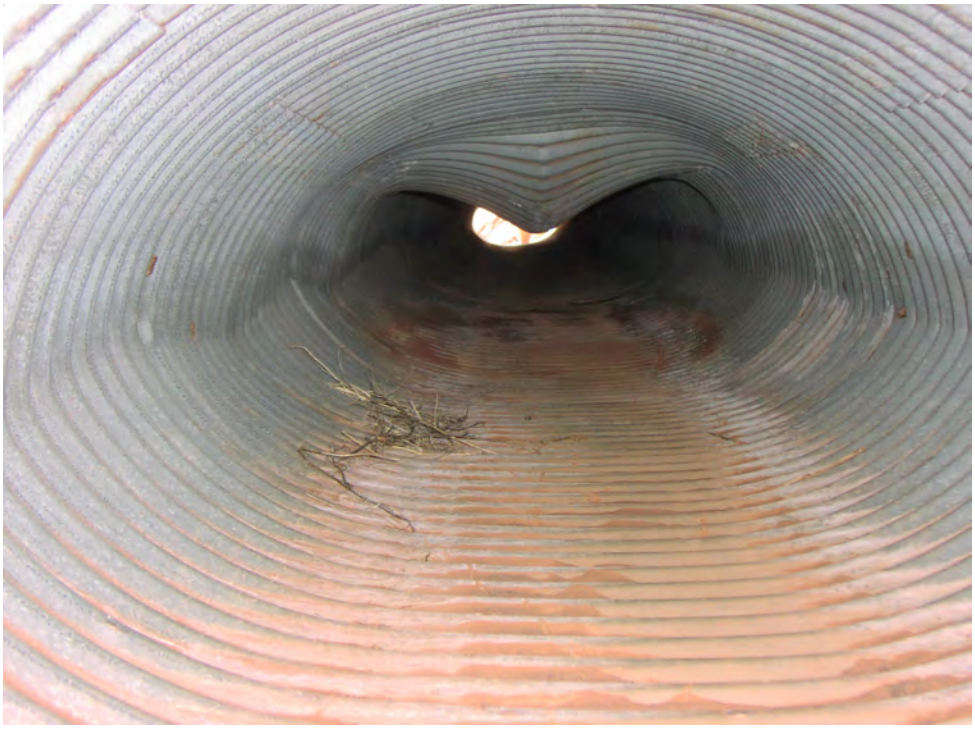


Figure 6-7 – Metal Barrel with Severe Localized Deformation
SR-95 Accumulated Mileage 90.95

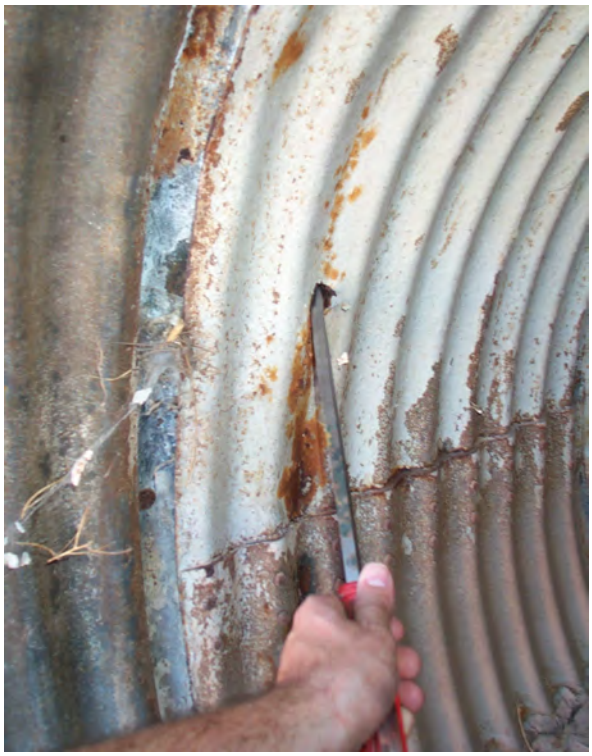


Figure 6-8 – Wall Perforation Due to Soil-Side Corrosion above Springline
SR-191 Accumulated Mileage 114.64

6.1.2 Concrete Barrels

Concrete culvert barrels had overall good ratings, with reduced ratings primarily the result of joint integrity, barrel alignment, and wall cracking. Concrete barrels had an average rating of 6.9, which is slightly greater than the average rating for all barrels. Joint integrity influenced the waterway alignment, infiltration, and exfiltration. In several cases, particularly on the western section of I-80 (salt flats), concrete barrels performed well while their metal end treatments experienced poor performance due to severe corrosion. Most structural distress in concrete culverts was observed near or at the end sections. Figure 6-9 to Figure 6-14 provide photographs of concrete barrel distress observed during this project.

Figure 6-9 – Concrete Barrel with Joint Misalignment
SR-89 Accumulated Mileage 348.47

Figure 6-10 – Concrete Barrel with Inlet Joint Misalignment and Springline Cracking SR-39 Accumulated Mileage 11.34

Figure 6-11 – Concrete Barrel with Outlet Joint Misalignment SR-13 Accumulated Mileage 30.15

Figure 6-12 – Concrete Barrel with Internal Longitudinal Crown Crack SR-91 Accumulated Mileage 18.02

Figure 6-13 – Concrete Barrel with Efflorescence Due to Wall Seepage SR-91 Accumulated Mileage 18.02

Figure 6-14 – Concrete Barrel with High Bed Load
SR-39 Accumulated Mileage 12.82

6.1.3 Plastic Barrels

Plastic culvert barrels do not have a long history of use in Utah, but were in overall good condition where installed underground with good soil compaction. Plastic barrels had an average rating of 6.8. Reduced ratings were primarily due to barrel deformation, which was likely the result of poor installation quality and the use of unlined (single-wall) corrugated pipes, which are no longer installed for highway applications. Many plastic culverts within the UDOT inventory are used for side and slope drains and other low- or no-traffic applications. Internal inspection, where possible, indicated that deformation (deflection) reduces joint integrity. Figure 6-15 to Figure 6-19 provide examples of typical plastic culvert installations and barrel distress.

Figure 6-15 – Multiple Plastic Barrel Installation on Low-Traffic Side Roadway
SR-24 Accumulated Mileage 61.15

Figure 6-16 – Typical Use of Plastic Barrel for Slope Drain
SR-12 Accumulated Mileage 70.94

Figure 6-17 – Use of Plastic Barrel for Side Foot Bridge
SR-21 Accumulated Mileage 100.70

Figure 6-18 – Very Slight Plastic Barrel Misalignment (18 in. Span)
SR-92 Accumulated Mileage 3.90

Figure 6-19 – Severe Plastic Barrel Misalignment (12 in. Span)
SR-215 Accumulated Mileage 25.65

Figure 6-20 – Ovaling of Plastic Barrel Due to Soil Cover Load (18 in. span)
SR-18 Accumulated Mileage 3.24

6.2 Waterway

Waterway performance was good overall, with an average rating of 6.7 across all UDOT culvert materials. This rating indicates that no immediate action is required in most cases; however, many culverts require scheduling for some type of maintenance. Waterway ratings were primarily influenced by waterway alignment (including barrel alignment and upstream/downstream alignment with the culvert barrel), obstructions (including sedimentation and debris), end-treatment undermining, and outlet scour holes. Where water was present, pH readings were collected. No pH results were less than 6 or greater than 8 (7 is neutral). Table 6-2 provides waterway ratings collected in the field inspections for each culvert barrel material.

Table 6-2 – Culvert Waterway Ratings by Barrel Material

Culvert Material	Rating Range			Count*	Average Rating	Standard Deviation
	= 2	3 to 5	6 to 9			
Concrete	0	8	25	33	6.5	1.6
Metal	0	29	154	183	6.8	1.4
Plastic	0	7	29	36	6.8	1.6
Total	**0**	**44**	**208**	**252**	**6.7**	**1.4**

*272 culverts were inspected; however, some were not assigned ratings for structural performance.

Waterway alignment was good in most instances. Joint misalignment caused rating reductions for metal and concrete barrels where obstructions were frequently trapped. Plastic barrels with poor barrel alignment did not show high occurrence of debris collection, likely due to the smooth interior. The horizontal alignment of culvert barrels with the upstream and downstream waterways was very good, particularly for instances with steep waterway gradient. Installations with good horizontal waterway alignment had lower frequency of pipe embedment and embankment erosion. The vertical alignment was fair to good. In some instances, pipe barrels are intentionally kept below the level of surrounding grade and partially filled with soil to permit fish passage.

Several culverts were found with moderate to severe undermining at the inlets or scour at the outlets. In one of these cases, where the undermining and scour are eroding the support of a large-diameter metal barrel with concrete headwall and wingwall end treatment, maintenance is an immediate need due to the severe extent of the undermining and the proximity to the roadway (see figures below and Section 6.7). Undermining influenced both the waterway and the barrel ratings due to the effect on

the performance and stability of the culvert end treatment as well as the effect on waterway stability due to washout of embedment soils.

The most significant factor causing reduction of waterway rating among the culverts studied was sedimentation. Sedimentation was present to some degree in many of the culverts inspected and was present along all or a good portion of the length of many culverts. In several cases, sedimentation was cleared for end extensions during road widening projects but was left in the remaining center section of the culvert length. Several of the inspected pipes were almost completely filled with sediment. Figure 6-21 illustrates the degree of sedimentation for inspected culverts as a function of the culvert location. The plot shows no particular geographic trends for sedimentation. The most common cause of sedimentation was low slope along the culvert length or the surrounding waterway.

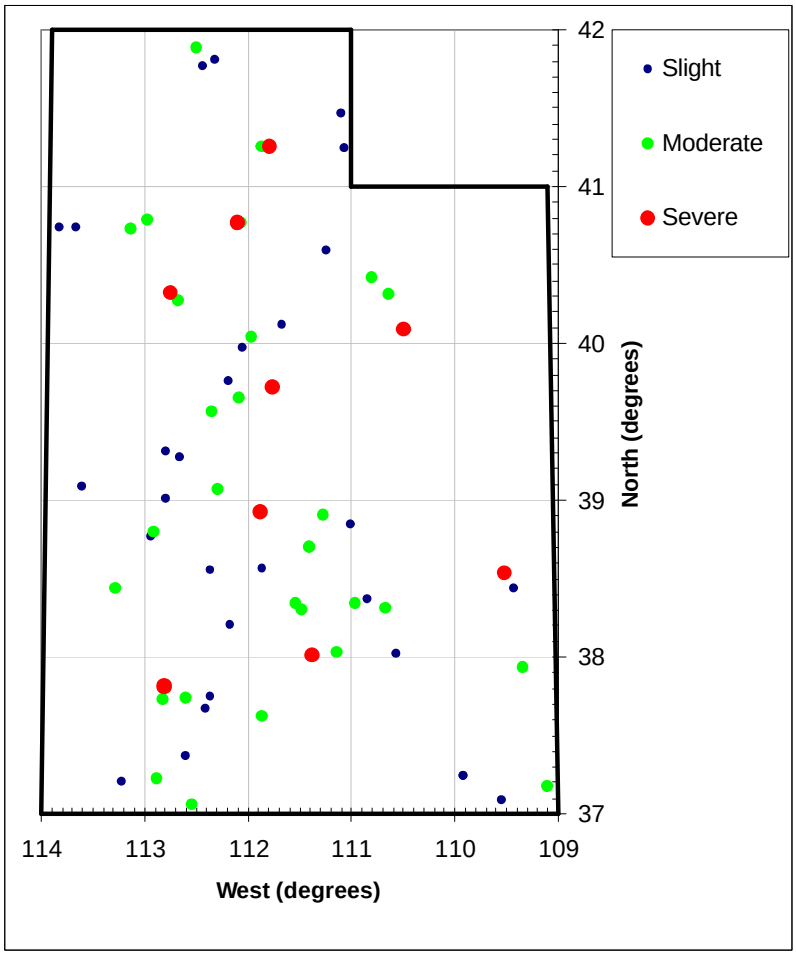


Figure 6-21 – Locations of Inspected Culverts with Slight, Moderate, or Severe Sedimentation

Figure 6-22 to Figure 6-30 provide examples of the factors that resulted in reduced waterway ratings.

Figure 6-22 – Moderate Sedimentation of Metal Culvert
SR-12 Accumulated Mileage 97.61

Figure 6-23 – Severe Sedimentation of Plastic Culvert
SR-80 Accumulated Mileage 106.10

Figure 6-24 – Severe Sedimentation of Concrete Culvert
SR-91 Accumulated Mileage 17.48

Figure 6-25 – Culvert Extension with Sedimentation Remaining in Original Barrel
SR-132 Accumulated Mileage 18.85

Figure 6-26 – Moderate Outlet Scour at Projecting Metal Culvert
SR-95 Accumulated Mileage 116.73

Figure 6-27 – Moderate Undermining of Preformed Metal End Treatment
SR-40 Accumulated Mileage 137.59

Figure 6-28 – Moderate Undermining of Concrete End Treatment
SR-12 Accumulated Mileage 52.86

Figure 6-29 – Severe Undermining of Concrete End Treatment of 12 ft Diameter Culvert
SR-10 Accumulated Mileage 21.97

Figure 6-30 – Typical UDOT Waterway Stabilization at Steep Gradient SR-70 Accumulated Mileage 15.74

6.3 End Treatments

End treatments for all types of culverts deteriorate more rapidly than the culvert barrel. This is attributed to weathering and abuse from vehicles such as mowing equipment. End treatments have shorter service life than culvert barrels.

6.3.1 Metal End Treatments

Metal end treatments have overall fair to good performance with distress mainly in the form of corrosion, damaged coatings, and deformation. Projecting ends frequently exhibited soil-side corrosion and some levels of deformation. Many metal end treatments exhibited some level of corrosion that did not impair the functionality of the culvert or the waterway. Figure 6-31 to Figure 6-34 illustrate typical end metal treatment deficiencies that resulted in reduced rating.

Figure 6-31 – Coating Cracking on Preformed Metal End Treatments
SR-215 Accumulated Mileage 24.42

Figure 6-32 – Corrosion at Peeled Coating
SR-70 Accumulated Mileage 138.54

Figure 6-33 – Soil-Side Corrosion on Projecting Ends of Metal Culverts SR-121 Accumulated Mileage 33.99

Figure 6-34 – Concrete Barrel with Corroded Metal End Treatment SR-80 Accumulated Mileage 108.70

6.3.2 Concrete End Treatments

Concrete end treatments are generally in good to fair condition. Where distress was present in concrete end sections, it consisted mainly of cracking and breaking that apparently resulted from traffic loads and initiation of drop-off due to undermining. In older installations, projected culvert ends were frequently broken, with exposed reinforcement and resultant waterway misalignment. Many older cast-in-place concrete headwall and wingwall treatments exhibited cracking with sections crushed at the corners of the walls. In no case did the damage in these end treatments significantly impair the functionality of the culvert. Figure 6-36 to Figure 6-40 illustrate typical concrete end treatment deficiencies that resulted in reduced barrel rating.

Figure 6-35 – Concrete Barrel with Longitudinal Crown Crack near End SR-39 Accumulated Mileage 11.34

Figure 6-36 – Broken End of Projecting Concrete Barrel
SR-13 Accumulated Mileage 31.16

Figure 6-37 – End Section Drop-off
SR-35 Accumulated Mileage 2.22

Figure 6-38 – Headwall Cracking over Crown of Metal Culvert
SR-15 Accumulated Mileage 23.58

Figure 6-39 – Distress in Older Wingwall – Cracking and Breaking
SR-153 Accumulated Mileage 1.09

Figure 6-40 – Cracking in Newer Wingwall
SR-21 Accumulated Mileage 84.29

6.3.3 Plastic End Treatments

Plastic end treatments had overall poor performance and typically experienced deformation due to lateral soil load. This is not a reflection of the performance of plastic barrels, for which metal and concrete end treatments were found to be used with good success. The preformed plastic ends typically experience deformation due to lateral soil load as a result of low stiffness. In some of these cases, the end of the attached plastic culverts cracks. Some newer plastic end treatments have been stiffened by bonding plastic pipe corrugations to the exterior. These modifications seem to improve the performance, but the sections are still too flexible.

Where plastic ends are projected or cantilevered, the performance varied. Typical results for single-wall plastic pipe indicate that cracking at the cantilever support is not unusual; however, this manufacturing process was abandoned some years ago, so the results do not represent double-wall plastic pipe used for new culvert installations.

Figure 6-41 to Figure 6-46 illustrate typical plastic end-treatment deficiencies that resulted in reduced barrel rating as well as successful plastic barrel installations with end treatments manufactured from metal and concrete.

Figure 6-41 – Installation of Plastic Pipe with Preformed Plastic End Treatment
SR-132 Accumulated Mileage 39.03

Figure 6-42 – Reinforcement of Preformed Plastic End Treatment by Pipe Corrugations
SR-132 Accumulated Mileage 38.42

Figure 6-43 – Typical Deformation in Preformed Plastic End Treatments
SR-80 Accumulated Mileage 105.32

Figure 6-44 – Cracking due to Deformation in Preformed Plastic End Treatments
SR-24 Accumulated Mileage 61.15

Figure 6-45 – Installation of Plastic Culvert with Preformed Metal End Treatment SR-16 Accumulated Mileage 63.13

Figure 6-46 – Installation of Plastic Culvert with Concrete End Treatment SR-24 Accumulated Mileage 61.15

6.4 Roadway

Roadways were assessed for damage above the alignment of inspected culverts. Sagging, rutting, cracking, or other signs of distress were noted, but relation to the culvert was complicated by the lack of roadway maintenance history information at the time of the inspections. Given these limitations, the roadway was assigned a general evaluation of good, fair, or poor without a specific numeric rating. "Good" indicates that no significant roadway damage is present. "Fair" indicates some type of distress such as rutting or transverse cracking. "Poor" indicates a roadway that was in need of some type of maintenance that may or may not have been related to the underlying culvert.

Roadways in Utah appear in generally good condition with respect to distress over culverts. Figure 6-47 indicates that there is a higher relative occurrence of "fair" roadway condition in the Cedar District of Region 4, which is located in the southwest portion of the state on lesser-used roadways, but no pattern is evident for "poor" roadway condition.

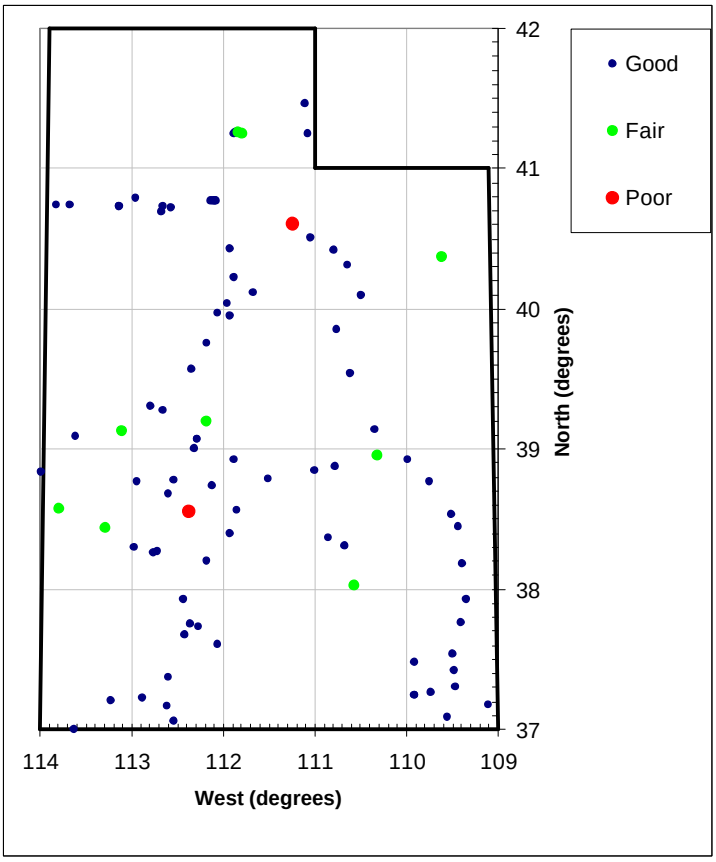


Figure 6-47 – Roadway Condition over Inspected Culverts

Where culverts have very shallow cover, some roadways have cracking or settlement that is typical at lines of stiffened support, such as above concrete culverts or at lines of flexible support such as above metal or plastic culverts. Some roadways also had crack patterns or settlement resulting from loss of support. In several instances, these crack patterns or settlement were directly above culverts with joint infiltration. Maintenance crews should be made aware that large transverse cracking of roadways could be caused by culvert distress. Figure 6-48 illustrates a crack caused by joint leakage in a culvert buried directly under the crack. Figure 6-49 illustrates typical roadway cracking for culverts with very low soil depth between the culvert top and the roadway surface. Locations of rutting and general roadway settlement also coincided with culvert distress in several instances.

Figure 6-48 – Transverse Roadway Crack over Culvert with Joint Leakage SR-23 Accumulated Mileage 4.93

Figure 6-49 – Transverse Roadway Crack over Culvert with Very Shallow Cover SR-35 Accumulated Mileage 2.74

Evaluation of the relationship between roadway cracking and barrel material type is complicated by the lack of inspection results that indicate whether the cracking is general or local above the culvert. There were 188 steel, 39 concrete, and 23 polyethylene culverts inspected under main roadways. From this set, 35 steel, 6 concrete, and 3 polyethylene culverts were under a roadway with cracking. Within these three barrel material types, the severity of roadway cracking (slight/moderate/severe), by barrel materials was: steel-14/21/0, concrete-3/3/0, and polyethylene-0/2/1. This summary does not account for the soil cover heights above each culvert installation, which is a significant factor in relating roadway cracking to culvert barrel material. For instance, the 3 polyethylene culverts includes in this list had no less than 3 ft of cover and the case with severe roadway cracking had more than 4 ft of cover, which diminishes the importance of the barrel material. These results are not of significant quantities to extract a statistically valid result about the relation between roadway cracking and culvert barrel material.

6.5 Soil Resistivity Tests, pH Tests, and Corrosion Results

Soil resistivity readings were collected in fourteen locations during inspections conducted in October 2003. Table 6-3 presents the soil resistivity readings with the

level of corrosion in the adjacent corrugated metal pipe barrels. The soil resistivity readings do not correlate well with the corrosion levels found in the pipe barrels and end treatments. This could be due to the installed time for the respective barrels or other factors such as flow patterns, the chemical composition of water or soil, or abrasion loadings.

Table 6-3 – Soil Resistivity Test Results at Corrugated Metal Culvert Installations

Soil Resistivity (ohm-cm)	State Route	Accumulated Mileage	Soil pH	Water pH	Barrel Span	Corrosion Damage
67,510	261	4.40	7	--	36	Local-Slight
67,510	261	4.401	7	--	60	Local-Slight
33,000	35	16.99	6	--	24	
12,900	35	36.10	--	--	30	Global-Slight
6,000	21	30.38	7	--	24	Global-Moderate
5,684	191	114.64	7	--	48	Global-Moderate
5,340	6	286.75	7	--	24	Global-Moderate
2,167	35	47.90	--	--	36	
1,633	191	75.74	--	--	36	
1,580	191	36.71	8	--	60	Local-Slight
1,120	24	109.31	7	6.5	24	Global-Slight
1,110	191	144.38	7	--	30	Global-Moderate
660	6	253.84	--	--	60	
590	6	151.75	7	--	36	Global-Moderate

Water pH and soil pH were collected in twenty-three and thirty-two locations, respectively, at different times of the year. Readings for pH were neutral with no individual readings less than 6 or greater than 8, where 7 is neutral. Table 6-4 presents the corrosion and abrasion levels obtained from the 193 inspected metal culverts. Testing of pH was conducted with litmus paper, which provides general results based on visual interpretation of the paper color. Readings were recorded to an accuracy of 0.5, that is, a reading near 7 could only be 6.5, 7, or 7.5. Thirty-eight percent of the inspected culverts had some level of corrosion (with abrasion), with 19% at a level of corrosion damage classified as moderate or severe. Nine percent of culverts had some level of abrasion without corrosion, with only 3% of cases having moderate or severe abrasion. Inspections indicate that typical durability concerns are the combined erosive

action of corrosion and abrasion. This is indicated by significantly higher damage levels at culvert inverts and minimal culvert perforation due to corrosion at locations other than the invert.

Table 6-4 – Abrasion and Corrosion Results from Inspections

Level of Damage		Corrosion		Abrasion	
		Count	% of Inspected	Count	% of Inspected
Global	Slight	37	19%	11	6%
	Moderate	30	16%	5	3%
	Severe	8	4%	0	0%
Local	Slight	13	7%	5	3%
	Moderate	8	4%	1	1%
	Severe	6	3%	2	1%
Total with Corrosion or Abrasion		**102**	**53%**	**24**	**12%**
Total Metal Culverts Inspected		**193**	**100%**	**193**	**100%**

6.6 Ratings by Culvert Installation Characteristics

The following sections describe the effect on culvert ratings for surface and deep soils, age of installations, elevation of installations, and by maintenance region.

6.6.1 Surface and Deep Soil Zones

We investigated the effect of surface and deep soil conditions on the culvert ratings based on UDOT maps of revegetation and geologic zones, as shown in Figure 6-50 and Figure 6-51.

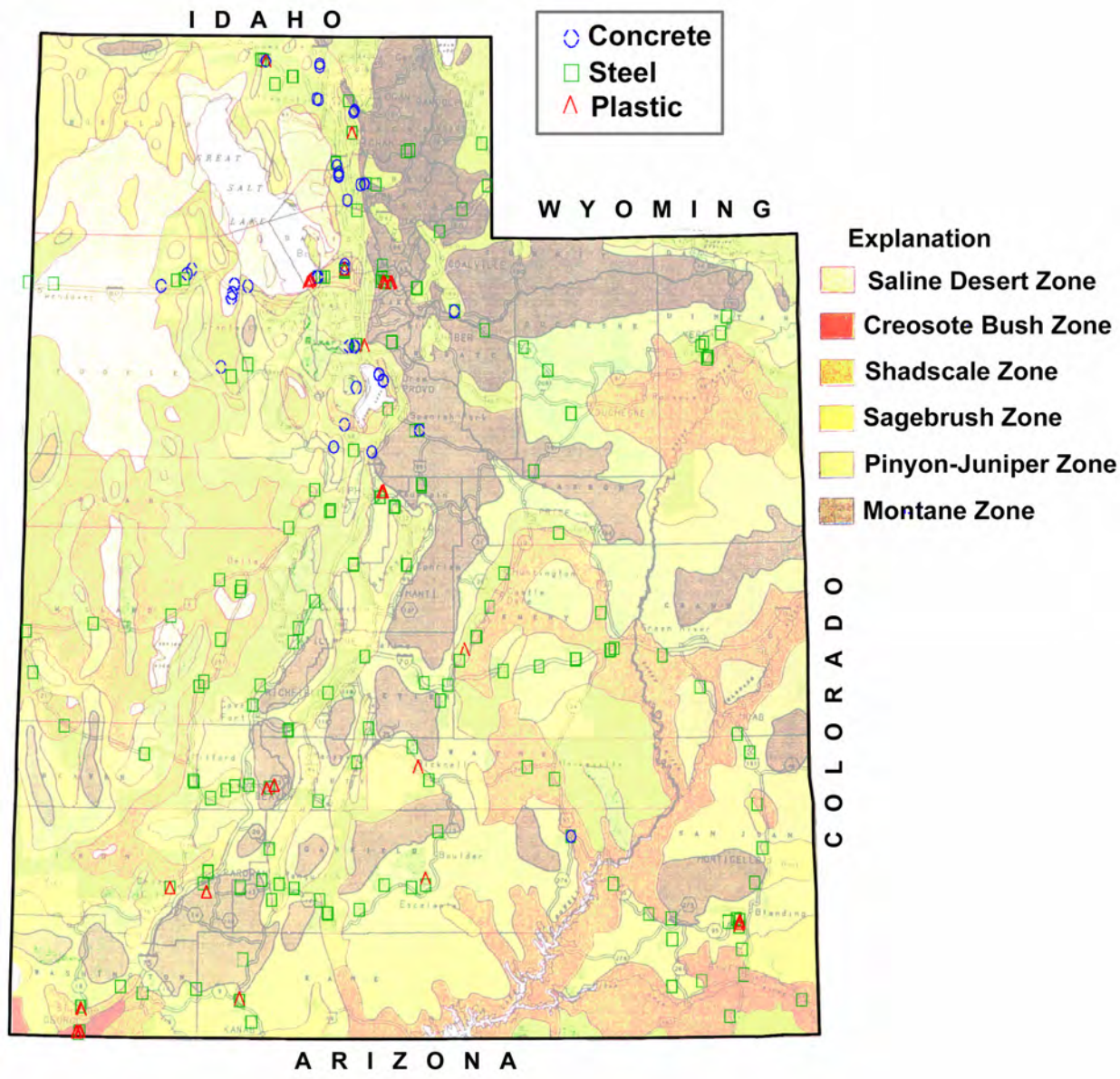


Figure 6-50 – Culvert Inspections by Utah Revegetation Zones [7]

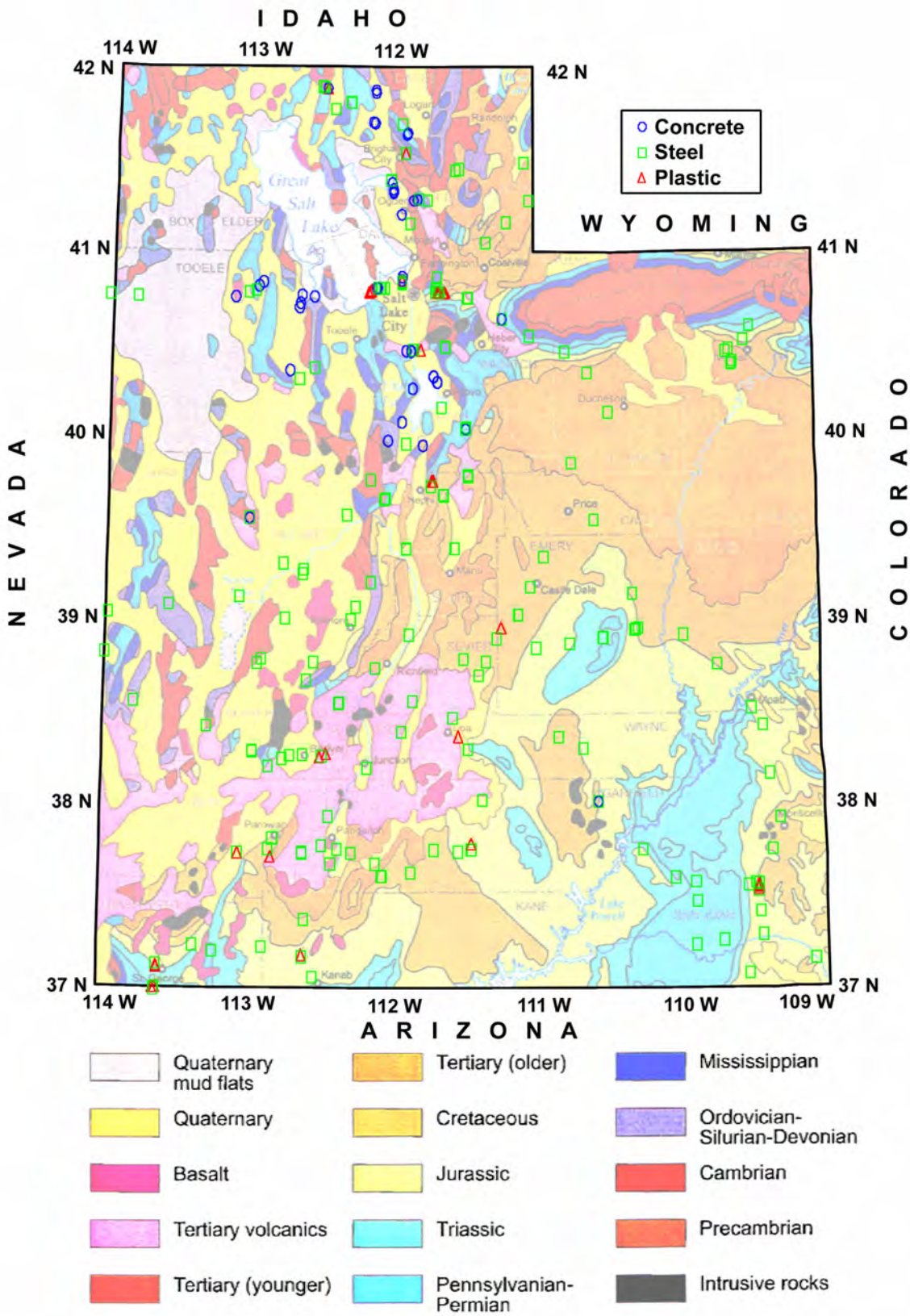


Figure 6-51 – Culvert Inspections by Utah Geologic Zones [7]

Within the revegetation zones, culvert inspections are clearly included in each of the six depicted zones. As in the inspection set in general, concrete culverts are not represented in all surface soils, appearing only in the shadscale, sagebrush, and montane zones. However, steel culverts, which are the majority of Utah culvert assets, have been inspected in all major revegetation zones. Plastic culverts, though few in number, were also inspected in all revegetation zones. Trends with respect to the deep soils (geologic zones) are similar to the surface zones, with metal culverts inspected in most geologic zones and concrete and metal represented in few geologic zones.

Figure 6-52 and Figure 6-53 show the geographic distribution of culvert ratings by plotting symbols based on barrel and waterway rating, respectively, versus culvert location coordinates on a grid roughly shaped like Utah. In all but a few cases, the waterway ratings vary little from the barrel ratings.

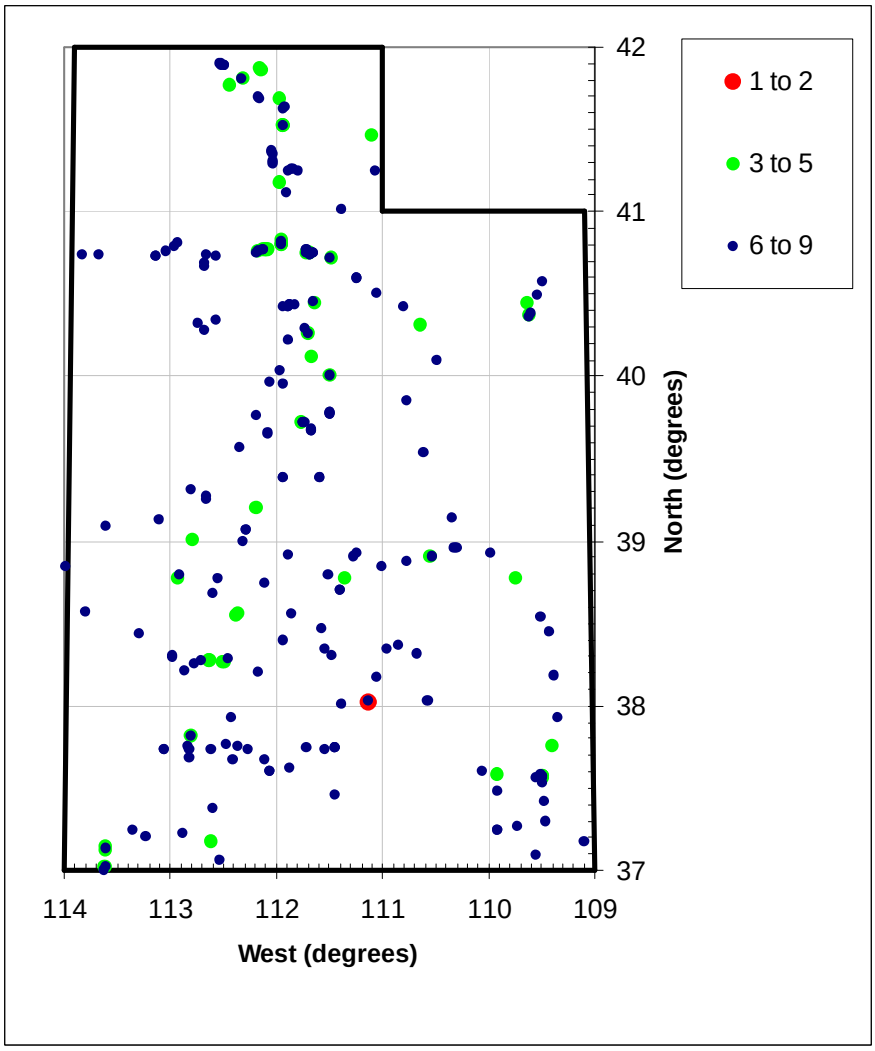


Figure 6-52 – Plot of Barrel Ratings by Culvert GPS Coordinates

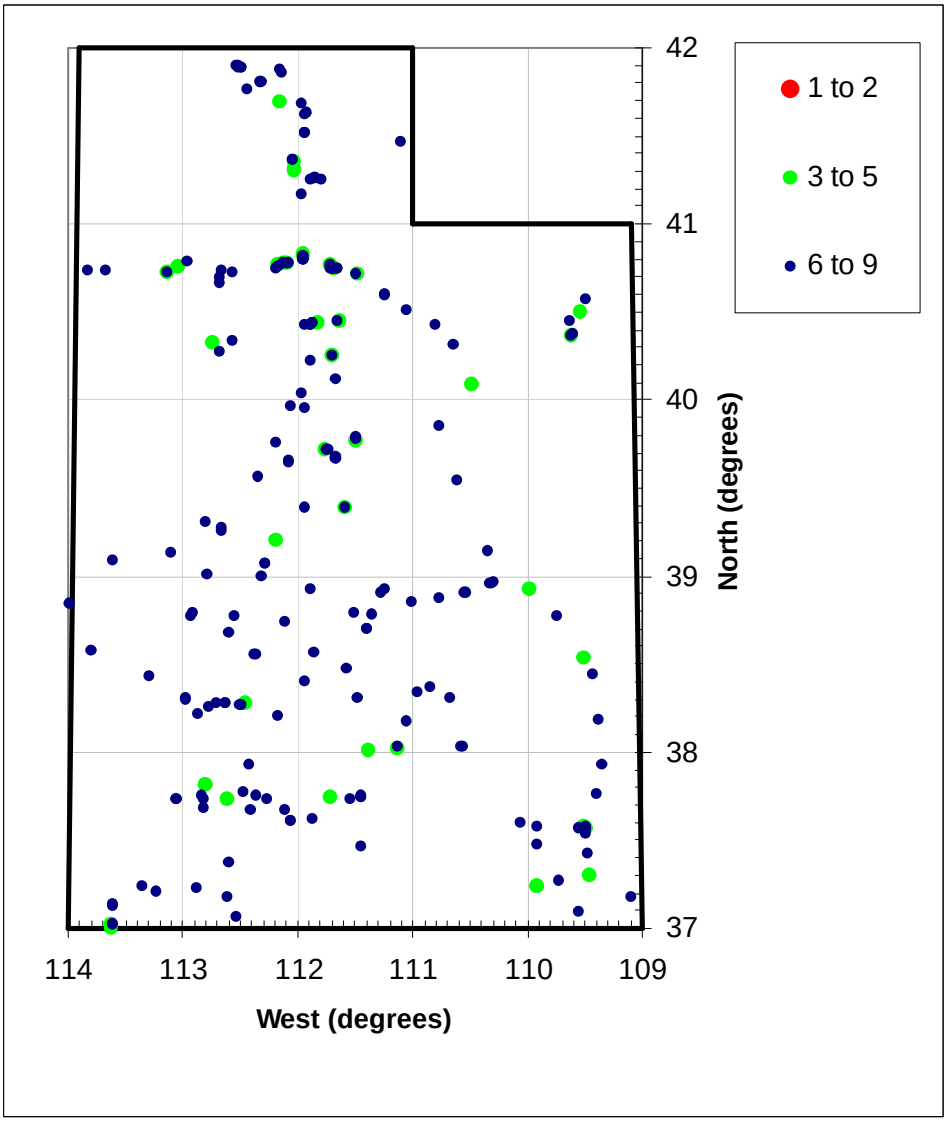


Figure 6-53 – Plot of Waterway Ratings by Culvert GPS Coordinates

Comparison of the four above figures indicates no strong correlation between the soil zones and the barrel or waterway ratings. This is also demonstrated in Section 6.6.4, where the ratings are compared by maintenance region, which can be approximately correlated with changes in general soil zones.

6.6.2 Age of Culvert Installations

Statements about culvert durability relative to age are difficult to qualify due to the small portion of inspected culverts with installation dates and the low representation of plastic culverts before 1990. Table 2-2 shows that 73% of culverts in the inventory database have no installation dates. Twenty percent of the inspected culverts had recorded

installation dates. Table 6-5 provides average barrel ratings by material and decade of installation and the culvert count represented by the ratings.

Table 6-5 – Culvert Barrel Ratings by Decade of Installation up to 1998

Barrel Material	Quantity	All	Before 1950	1950 – 1959	1960 – 1969	1970 – 1979	1980 – 1989	1990 – 1998
All	Count	55	5	6	25	2	4	13
	% of Count	100.0%	9.1%	10.9%	45.5%	3.6%	7.3%	23.6%
	Rating	6.7	7.0	7.2	7.1	4.0	5.8	6.2
	Std. Dev.	1.2	1.2	1.2	1.0	1.4	1.0	1.1
Concrete	Count	12	1	0	9	0	2	0
	Avg. Rating	7.0	7.0	–	7.1	–	6.5	–
Metal	Count	37	4	6	16	2	2	7
	Avg. Rating	6.6	7.0	7.2	7.1	4.0	5.0	6.0
Plastic	Count	6	0	0	0	0	0	6
	Avg. Rating	6.3	–	–	–	–	–	6.3

Figure 6-54 illustrates the average ratings in Table 6-5 for inspected culverts with available installation dates. The average of ratings for all culverts with installation dates is approximately equal to the average of ratings for all culverts inspected in this project.

Culverts installed between 1960 and 1969 represent half the inspected culverts with installation dates. These culverts had overall good performance as evidenced by an average rating greater than 7. The chart indicates that the culverts installed from 1970 to 1979 had poor relative performance; however, this set includes only two culverts, which represents low statistical significance. The chart indicates that culverts installed prior to 1970 appear to have better performance than those installed after 1970. This trend was apparent during inspections. In several cases, older metal culverts looked nearly new while newer metal culverts showed increased corrosion. The higher ratings for the older metal culverts may be due to use of thicker-walled or thicker-coated metal culverts that have high resistance to corrosion and deformation. Attempts were made to determine installation dates for many of the culverts that did not have this data in the inventory database, but no reliable results were obtained.

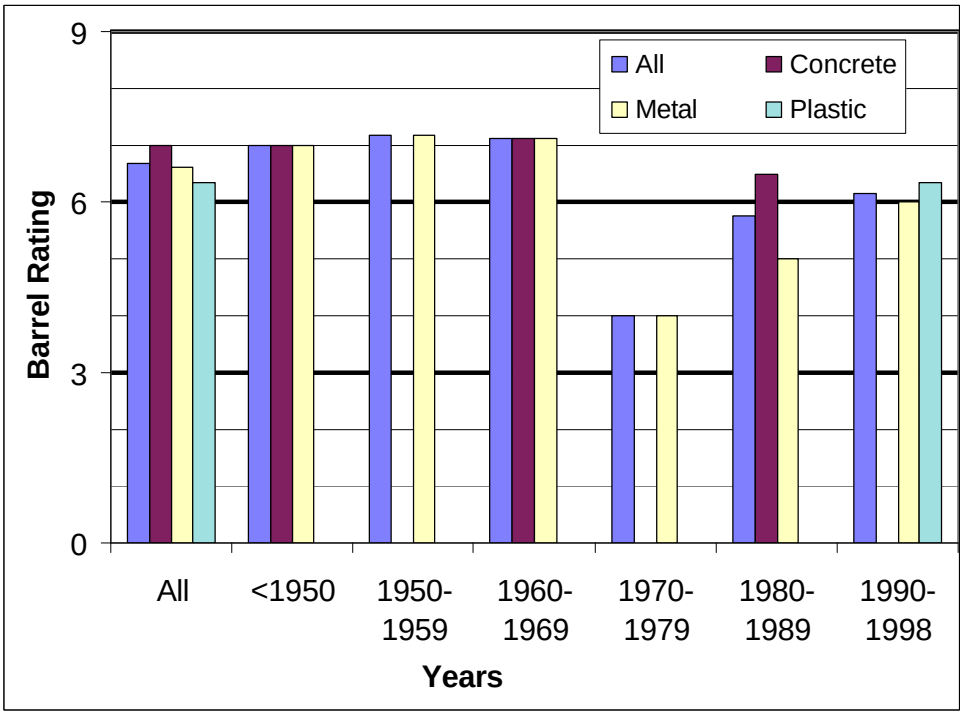


Figure 6-54 – Average Barrel Rating by Decade of Installation

6.6.3 Elevation of Installation

Figure 6-55 provides a plot of the elevations of the inspected culverts in 1,000 ft increments. The figure includes 189 culverts for which the elevation was collected by a handheld global positioning device (GPS). Some elevations in the table have very low sample size.

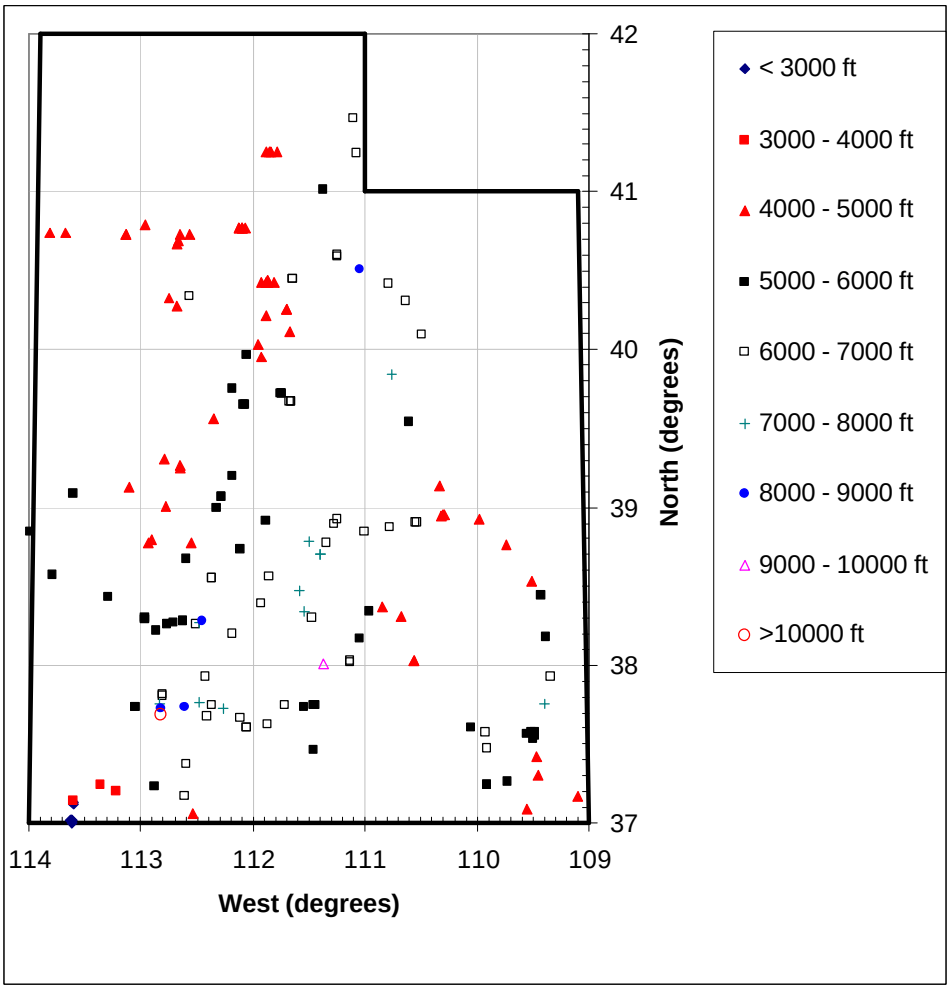


Figure 6-55 – Plot of Culvert GPS Coordinates by Elevation

Table 6-6 summarizes ratings for the culvert elevation ranges illustrated in Figure 6-55. Most ratings are in the range of 'no required action' except for a few culverts at elevations under 3,000 ft or between 5,000 to 7,000 ft.

Table 6-6 Barrel Rating Versus Culvert Elevation

Quantity	Elevation (in thousands of feet)									
	All	< 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	> 10
Culvert Count*	189	6	3	61	56	45	12	4	1	1
Max. Rating	9	7	8	9	9	9	9	7	6	8
Min. Rating	2	3	5	4	3	2	4	6	6	8
Avg. Rating	6.7	5.3	6.3	6.9	6.9	6.4	7.3	6.5	6.0	8.0
Std. Deviation	1.4	1.4	1.5	1.2	1.5	1.5	1.5	0.6	–	–

*272 culverts were inspected, but elevation was not collected for all culverts.

Table 6-7 provides the waterway rating relative to culvert elevations. The elevations at which culvert waterways have some type of maintenance action that is required are under 3,000 ft, 4,000 to 7,000 ft, and 8,000 to 9,000 ft. Figure 6-56 compares the ratings for barrels and waterways with elevation. The figure suggests that culverts at the lowest elevations and between 8,000 ft to 10,000 ft have somewhat lower ratings, but because of the limited sample size at these elevations the correlation cannot be considered strong.

Table 6-7 – Waterway Rating Versus Culvert Elevation

Quantity	Elevation (in thousands of feet)									
	All	< 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	> 10
Culvert Count	185	6	2	61	55	44	11	4	1	1
Max. Rating	9	8	8	8	9	9	9	8	5	8
Min. Rating	3	3	6	3	4	3	6	3	5	8
Avg. Rating	6.8	5.7	7.0	6.6	7.1	6.8	7.8	5.5	5.0	8.0
Std. Deviation	1.4	2.2	1.4	1.3	1.4	1.4	0.9	2.1	–	–

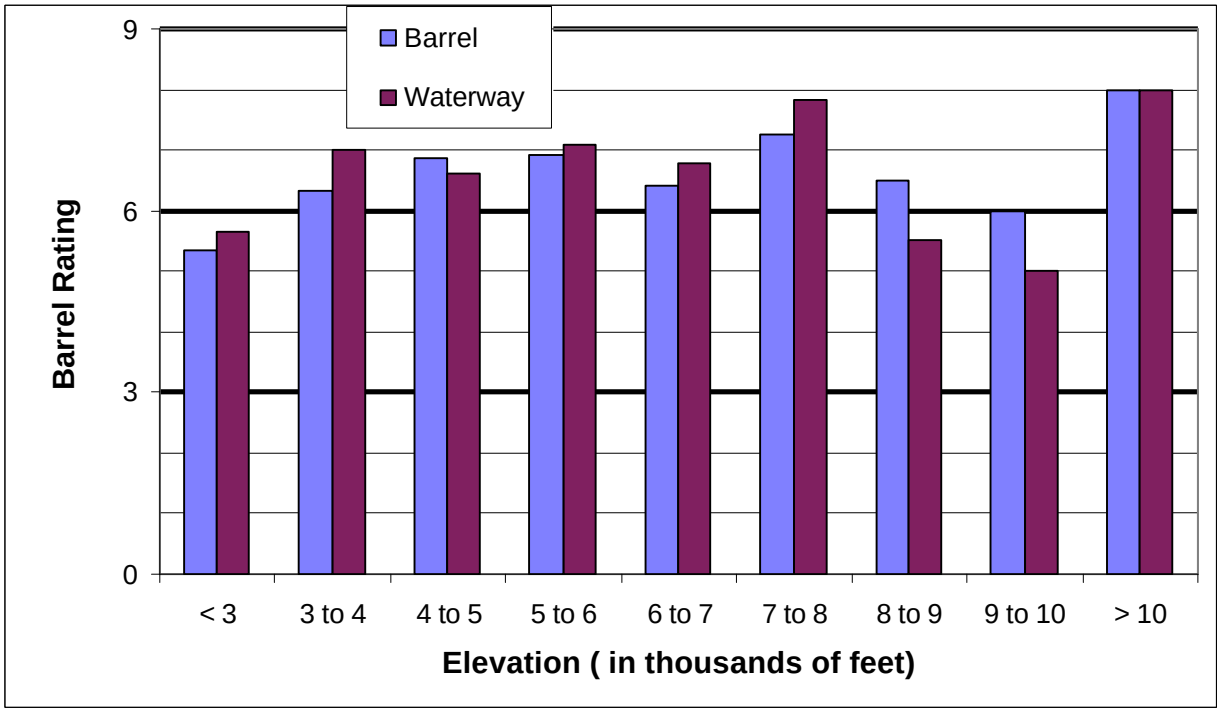


Figure 6-56 – Comparison of Barrel and Waterway Average Ratings with Elevation

6.6.4 Culvert Ratings by UDOT Maintenance Region

Table 6-8 provides the ratings by barrel material and UDOT Maintenance Region in which the culvert is located. Figure 6-57 illustrates the average barrel ratings by barrel material and by region in which the culvert is located. Performance of culverts within individual UDOT Maintenance Regions does not differ greatly from performance of culverts statewide.

Plastic barrels show a high average rating in Region 3, but a reduced rating in Region 4. Metal barrels show a marginally reduced rating in Region 2. Concrete barrels show a marginally reduced rating in Region 3. These tendencies are not extreme nor do they fit into a larger theory about installation policies for rigid versus flexible culverts and are, therefore not considered significant.

Table 6-8 – Culvert Barrel Ratings by Region and/or District and by Barrel Material

Region	Measure	Material			
		All	Metal	Concrete	Plastic
All	Count	266	190	37	37
	Rating	6.7	6.6	6.9	6.8
1	Count	35	20	13	2
	Rating	6.5	6.2	6.7	7.5
2	Count	54	28	13	12
	Rating	6.7	6.0	7.3	7.3
3	Count	48	30	13	5
	Rating	6.6	6.4	6.6	8.0
4	Count	135	115	1	18
	Rating	6.7	6.8	7.0	6.1
Cedar	Count	44	36	0	8
	Rating	6.3	6.4	–	5.8
Richfield	Count	54	48	1	4
	Rating	7.1	7.1	7.0	7.0
Price	Count	37	31	0	6
	Rating	6.7	6.8	–	5.8

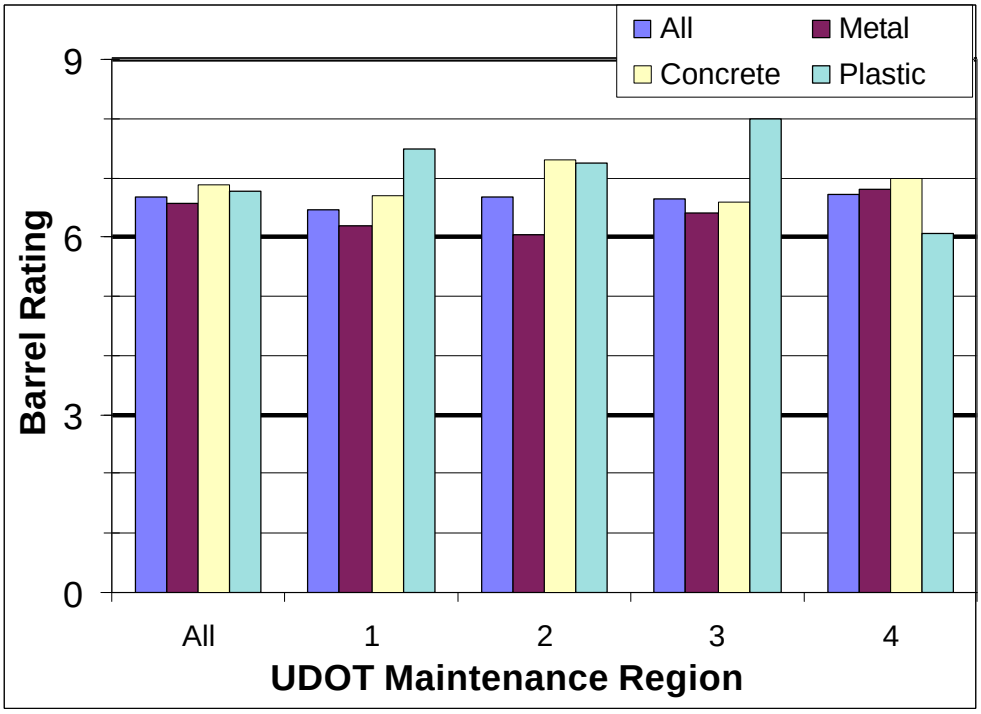


Figure 6-57 – Culvert Barrel Ratings by UDOT Maintenance Region

6.7 Culvert Maintenance Action Ratings

With inclusion of the Importance Modifiers described in Chapter 5, the average maintenance action rating for all culverts reduces from 6.2 to 5.7. Table 6-9 provides maintenance action ratings, which are the lesser of the barrel or waterway rating, with and without inclusion of the rating modifiers for culvert importance. Ratings less than 6 indicate that some type of maintenance should be scheduled. The table shows that ratings are reduced for all barrel materials. This is likely due to the following two factors:

- Ninety-four percent (257 of 272) of the culverts inspected were main drains under roadways. These culverts are of the most interest due to the direct effect on traffic and have consequent higher importance.

- Fifty-three percent (144 of 272) of inspections were conducted on main roadways, which are again of the most interest and have consequent higher importance. This resulted from the inspectors' frequent travel over main roadways to reach the limits of the state and the inspections conducted during this travel.

For reference, the Importance Modifiers for each inspected culvert, with contributing information, are provided with the inventory information in Attachment A.3, "Inventory and Inspection Data for 272 Inspected Culverts".

Table 6-9 – Maintenance Action Ratings for Inspected Culverts

Barrel Material	Inspection Ratings (Raw)			Ratings with Culvert Importance			Average Rating Reduction
	Avg.	Std. Dev.	Count*	Avg.	Std. Dev.	Count*	
Concrete	6.2	2.1	37	5.8	2.0	37	0.4 (0.1%)
Metal	6.2	1.6	190	5.6	1.6	190	0.6 (0.1%)
Plastic	6.4	1.7	37	6.1	1.7	37	0.3 (0.0%)
All	6.2	1.5	266	5.7	1.8	254	0.5 (0.1%)

*272 were inspected; however, some were not assigned ratings for structural or hydraulic performance.

Table 6-10 summarizes the culvert ratings collected during the inspections before and after modification by culvert Importance Modifiers, respectively. Again, as explained above, the effect of the Importance Modifiers is to marginally reduce average ratings. Due to this effect, evaluations of ratings in other sections of this report have neglected the Importance Modifiers to give results that are generally applicable to the entire UDOT culvert inventory rather than the main drains and those under major highways.

Table 6-10 – Average Culvert Ratings

Culvert Material	Importance Modifier	Barrel Rating				Waterway Rating			
		= 2	3 to 5	6 to 9	Count	= 2	3 to 5	6 to 9	Count
Concrete	–	0	4	33	37	0	8	25	33
	Included	0	11	26	37	2	10	21	33
Metal	–	1	41	148	190	0	29	154	183
	Included	1	88	101	190	1	73	109	183
Plastic	–	0	10	27	37	0	7	29	36
	Included	0	13	24	37	0	10	26	36
All	–	1	55	208	264	0	44	208	252
	Included	1	111	151	264	3	93	156	252

Figure 6-52 shows one metal culvert that requires immediate review due to a barrel rating of 2, prior to inclusion of Importance Modifiers that would further reduce the rating. This culvert is located on SR-10 at accumulated mileage 21.97. The culvert is 12 ft span, is located on a major highway, and has severe outlet undermining at the concrete end section (see also Figure 6-29). This culvert also has a low waterway

rating, but the end treatments are rated with the barrel and, consequently, undermining strongly influences the barrel rating. This culvert carries a major drainage channel as indicated from the size of the upstream and downstream ravines. Figure 6-58 shows the downstream ravine looking from the inside of this culvert.

Figure 6-58 – Downstream Ravine at Undermined Culvert with Rating of 2 SR-10 Accumulated Mileage 21.97

With inclusion of ratings Importance Modifiers, three additional culverts have ratings reduced to values less than 3, which indicates that maintenance is recommended for this season. These culverts have low ratings due to undermining, sedimentation, and inlet obstruction as described in Table 6-11. A photo of each of these culverts follows.

Table 6-11 – Culverts with Importance Modified Maintenance Action Rating Less than 3

State Route	Accumulated Mileage	Barrel Material	Span	Description
10	21.97	Metal	144	Severe outlet undermining
80	48.81	Concrete	24	Waterway blocked by sedimentation
15	351.45	Concrete	24	Inlet catch basin is obstructed
15	0.25	Metal	42	Inlet undermined

Figure 6-59 – Waterway Blockage by Sedimentation at Far End SR-80 Accumulated Mileage 48.81

Figure 6-60 – Outlet from Culvert with Inlet Catch Basin Obstruction
SR-15 Accumulated Mileage 351.45

Figure 6-61 – Inlet Undermining, Waterway Elevation Below Inlet
SR-15 Accumulated Mileage 0.25

7. CONCLUSIONS

A project to evaluate the Utah Department of Transportation (UDOT) Culvert Database and to evaluate the general condition of culverts under UDOT roadways has been completed. Field inspections show that culverts under UDOT roads are in generally good condition, but aging is evident and increased attention will be required in the future. UDOT should continue to develop the UDOT Culvert Database and implement other actions so that a complete approach to culvert management is in place. UDOT should also establish a regular inspection plan for culverts of high importance. This will ensure that culverts continue to perform well and that UDOT roads are safe. Specific conclusions are provided below.

7.1 UDOT Culvert Database

- The UCD provides a useful tool for culvert inventory/inspection data collection and storage for use as part of a complete culvert management program.

- The Inventory Dataset is generally an accurate representation of the number and type of culverts in the UDOT inventory. If UDOT maintains the dataset as part of its culvert management program, current errors can be corrected and the utility of the data will improve.

- The UCD contains several unnecessary fields in the Form program and the database. If UDOT maintenance personnel are to use the UCD, it will need to be streamlined to collect only the data that is required for typical inspections. This could be accomplished by removal of infrequently used fields or by relocation of these fields to a series of additional tabs for detailed inventory or inspections.

- The UCD should have photograph collection ability.

- The UCD should have the capability to produce inspection reports.

7.2 Culvert Inspection

- Ensuring that culvert installation is proper and monitoring culvert performance during service life are important features of a culvert management program.

- The current good condition of culverts likely follows from the UDOT policy to inspect culverts during installation. This should be continued.

- Inspection rules that will ensure regular inspection of critical culverts and at least occasional inspection of less-critical culverts are important to providing reliable safe roadways.

- Inspection frequency should include post-construction inspection and regular inspections at not more than five-year intervals for critical culverts, where criticality is determined from culvert Importance Modifiers.

7.3 Culvert Barrels

- Culvert barrels are generally performing well, with no significant difference in ratings for the different barrel materials.

- Plastic culverts have good overall performance, although installations have not been in place for as many years as other materials.

- Plastic culvert performance is directly influenced by installation quality.

- Metal culverts and some uncoated metal end treatments along I-80 west of Salt Lake City are severely corroded. Soil-side corrosion of metal culverts is common in many parts of Utah but was not observed to frequently lead to culvert perforation. Metal culverts can perform well in most Utah environments when coated appropriately and installed properly.

- Invert corrosion due to abrasion was the most common type of metal barrel distress.

- Concrete culverts perform well in all Utah environments.

- Many culverts have been extended as a part of roadway-widening projects. The interface where an existing culvert meets the extended portion of the culvert is often offset and in poor condition.

7.4 Waterways

- Measurements of pH in effluent water indicate no results less than 6 or greater than 8, where 7 is neutral. This indicates that the effluent waters sampled do not provide acidic attack to the culverts.

- Many culverts have been extended as a part of roadway-widening projects. In several locations, the original culvert barrel was left heavily sedimented after new end extensions were installed.

- Many culverts were sedimented, resulting in reduced the waterway capacity.

7.5 End Treatments

- Culvert end treatments are exposed to a more demanding environment than culvert barrels and are exposed to significant abuse due to mowing and other maintenance operations.

- Service life of end sections is reduced relative to barrels.

- Plastic end sections do not appear to be sufficiently stiff to resist the lateral soil load on their sides; this observation applies even to newer versions of the tapered end sections that are stiffened.

- Metal and concrete end treatments have fair performance while plastic end treatments have poor performance.

- End treatments that are buried suffer less service damage than those that are projecting.

7.6 Maintenance

- A culvert Importance Modifier was established to determine which culverts are critical and to allow prioritization of maintenance.

- Sedimentation removal is the primary maintenance requirement.

- Roadway transverse cracking may be caused by culvert distress.

- The significant predictors for culvert rating are:

    - physical blockage of waterway,
    - shape of flexible culvert,
    - degree of corrosion,
    - barrel joint integrity,
    - state of coatings,
    - roadway distress over culvert alignment, and
    - scour or undermining at inlet or outlet.

8. RECOMMENDATIONS

The following sections provide recommendations for UCD improvement or procedural modifications to improve UDOT policies for management of highway culvert and storm drain assets.

8.1 UDOT Culvert Database

- Continue to develop the Culvert Database Program as a tool to track and maintain the Utah culvert inventory.
- Modify the database and Form program to improve focus on important parameters and eliminate parameters that are not necessary. This will reduce costs associated with culvert inspection.
- Add photograph viewing and collection ability to allow documentation of culvert distress.
- Add inspection-reporting capability to produce regular inspection results in a format usable by local maintenance personnel, headquarters, and others, as needed.
- Make the Form Program friendlier to maintenance personnel and develop system to upload from local datasets to main database.
- Incorporate automated maintenance rating functionality as described in the maintenance recommendations.

8.2 Culvert Inspection

- Continue the practice of inspecting culverts during installation.
- Confirm inventory records during roadwork and modify where necessary. This was done for the 272 culverts inspected in this project.
- At a minimum, require inspection and rating of all culverts during paving or other roadway reconstruction operations; this ensures a periodic (although perhaps irregular) evaluation of all culverts; consultants should be provided with specific forms and guidelines for conducting these inspections and data must be added to the database.
- Update the culvert inspection dataset with inspection results to develop a record that can be used to track performance of various culvert materials and applications.
- Some culverts inspected during this study require immediate maintenance action.

- Establish a schedule and procedures for inspecting and rating critical culverts (large spans, major roadways, etc.) on a regular basis.

- Verify CID as means to locate culverts concurrent with the DOT effort to align reference post markers to the actual accumulated mileage.

8.3 Culvert Barrels

- Plan for replacement of heavily corroded metal culverts along I-80, west of Salt Lake City, within several years, as indicated by reduced ratings.

- Use barrel-material-specific installation instructions to ensure that installation is adequate to yield good service life for various culverts.

- Emphasize durability for culvert designs. Some of the older metal culverts show better service resistance to corrosion and abrasion. Although a certain gauge metal may be structurally adequate, thicker gauges may be appropriate for installations in corrosive environments. Alternately, thicker galvanizing may result in similar increased durability.

- Provide specific specifications for joining new culverts to existing culverts when widening roadways:

    - use a short section of pipe as the first extension. This provides two joints with rotational capacity to adapt to subsequent settlement

    - ensure that the joint collars are approved by the new pipe manufacturer for joining the specific type and sizes of the new and old pipes,

    - where possible, use pipes that will experience similar service deflections to minimize stress on the joints, and

    - if no manufactured collar is appropriate, specify installation of a concrete collar, made by wrapping the joint in a geotextile and pouring a concrete collar that covers both joints. This procedure is considered usable only for silt-tight applications.

8.4 End Treatments

- Consider specifying end treatments other than plastic for plastic pipe installations.

8.5 Waterways

- Emphasize clearance of sedimentation along the entire culvert length when this maintenance activity is conducted, such as during road-widening projects where end sections are added to the culverts.

8.6 Maintenance

- Inspectors should confirm inventory data during all roadwork operations.
- Inform maintenance personnel that road surface distress can be an indicator of culvert distress, such as leakage at joints or local culvert deformation.
- Apply an Importance Modifier based on culvert size, location, and function, to focus the Department's efforts onto critical culverts. To accomplish this goal, the UCD requires the following modifications:
    - Complete the roadway importance field for al records. This can be easily done automatically using a selection table with the database records and the known roadway classifications.
    - Add a "Culvert Importance" field to the "Bank Protection" Tab in the Form Program. Automate this field using the numeric values recommended in this report with the appropriate inventory fields.
    - Eliminate the capability to enter data in the "Maintenance Rating" field and automate this value to reflect the lesser of the "Waterway Rating" or the "Barrel Rating" times the "Culvert Importance" field described in the previous bullet.

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