Project No. 14-26 **Copy No. ____**

CULVERT AND STORM DRAIN SYSTEM INSPECTION MANUAL

FINAL REPORT

Prepared for
NCHRP 14-26 Culvert and Storm Drain System Inspection Manual

Transportation Research Board
of
The National Academies

Jesse L. Beaver
Matthew C. Richie
Simpson, Gumpertz & Heger, Inc.
Waltham, MA

May 2016

ACKNOWLEDGMENT OF SPONSORSHIP

This work was sponsored by one or more of the following as noted:

☒ American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the **National Cooperative Highway Research Program,**

☐ Federal Transit Administration and was conducted in the **Transit Cooperative Research Program**,

☐ Federal Aviation Administration and was conducted in the **Airport Cooperative Research Program,**

☐ Research and Innovative Technology Administration and was conducted in the **National Cooperative Freight Research Program,**

☐ Pipeline and Hazardous Materials Safety Administration and was conducted in the **Hazardous Materials Cooperative Research Program,**

☐ Federal Railroad Administration and was conducted in the **National Cooperative Rail Research Program,**

which is administered by the Transportation Research Board of the National Academies.

DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES....v

AUTHOR ACKNOWLEDGEMENTS.... vi

ABSTRACT.... vii

SUMMARY....1

CHAPTER 1 - BACKGROUND....3

- Problem Statement....4
- Research Objective....4
- Scope of Manual....5
- Summary of the State of Practice....5
- Intended Users and Uses....6
- Relationship with Other NCHRP Publications....6

CHAPTER 2 – RESEARCH APPROACH....7

- Phase 1 – Literature Review....7
- Phase 2 – Develop a Catalog of Distressed Conditions....8
  - Database of Photographs....9
  - Copyright Release....9
- Phase 3 – Evaluate Inspection Techniques....9
  - Describe Best Practices for Inspection....10
  - Identify Inspection Approaches and Create Checklists....10
  - Develop Inspection Forms and Conduct Preliminary Field Inspections....11
- Phase 4 – Develop Condition Assessment Criteria....12
  - Numerical Ratings....12
  - Ratings Descriptions....13
- Phase 5 – Prepare the Culvert Inspection Manual and Final Deliverables....14

CHAPTER 3 – INSPECTION MANUAL....14

- Organization of Manual....15
- Design and Performance Characteristics....15
- Inspection Procedure....16
  - Frequency of Inspection....17
  - Types of Inspections....18
- Inspection Team and Qualifications....20
- Rating System....21
- Condition Assessment Catalog....23

CHAPTER 4 – Conclusions and Suggested Research....25

- Conclusions....25
- Suggested Future Research....25

APPENDIX A - CULVERT AND STORM DRAIN SYSTEM INSPECTION MANUAL.... A-1

LIST OF TABLES

Table 1 – Inspection Frequency (Routine Inspections) 17
Table 2 – Rating Scale and Associated Action....23
Table 3 – Rating System for Concrete Barrel....24

AUTHOR ACKNOWLEDGMENTS

The research and work product presented in this report was conducted under NCHRP 14-26 by Simpson Gumpertz & Heger Inc. The Principal Investigator for this work was Mr. Jesse L. Beaver. The Project Manager was Mr. Matthew C. Richie.

The authors wish to thank and acknowledge the contributions, valuable feedback, and insight during this project from NCHRP Project Manager Dr. Waseem Dekelbab, members of the NCHRP Project Panel, the numerous parties who contributed valuable photographs for use in the manual and condition assessment catalog, and the Simpson Gumpertz & Heger Inc. support staff who contributed to this effort.

ABSTRACT

The research presented in this report is conducted under NCHRP Project 14-26. The objective was to develop an inspection manual, primarily through an update of the 1986 FHWA manual, for assessing the condition of in-service culvert and storm drain systems to ensure system safety, functional performance, and the economical use of owner resources. The final deliverable for NCHRP 14-26 is the *Culvert and Storm Drain System Inspection Manual*. The new manual represents a complete overhaul of the condition rating system and a change to component-level rating. The new manual provides condition assessment criteria for plastic and timber pipe, and a distressed condition catalog as a photographic reference for assessing culvert and storm drain system component condition.

SUMMARY

In 1986, the Federal Highway Administration (FHWA) published the *Culvert Inspection Manual* as a supplement to the bridge inspector's training manual. Until now, that work remained the most comprehensive publication on the topic. Since that time, there have been significant advances in culvert and storm drain systems, inspection methods, and asset management. In particular, plastic pipe, not addressed at all in the 1986 manual, is now widely used for highway culverts and storm drains. Three decades of change created a need to develop an updated manual to provide guidance on best practices to inspect and evaluate culverts. The objective of NCHRP 14-26 was to develop an inspection manual, primarily through updating the 1986 FHWA manual, for assessing the condition of in-service culvert and storm drain systems to ensure system public safety, functional performance, and the economical use of owner resources.

The final deliverable for NCHRP 14-26 is the *Culvert and Storm Drain System Inspection Manual*. This manual represents a complete overhaul of the 1986 manual, and in particular to the condition rating system. To achieve usable results, the inspection findings must be accurate and consistent. Clear definitions are needed to show how the ratings are applied. Definitions need to be quantifiable so that they reduce opportunity for interpretation that can lead to variation between inspectors. After a detailed review of the existing rating system, the research team identified many opportunities for revision to the condition rating descriptions:

- The numerical rating system was changed to a five-point rating system from a ten-point rating system. Repeatability is key to successful implementation of a culvert and storm drain inspection and assessment system, and the ten-point scale offered unnecessary ambiguity and interpretation between ratings. The revised five-point scale also directly correlates observed conditions with recommended action.
- The format of the ratings descriptions is reorganized to a component-level evaluation, consistent with the AASHTO Bridge Element Inspection Manual. This format provides a better user experience and less confusion for the basis of a particular rating. Components are rated individually with potential distress and their associated severity rated on a scale of 1 (good condition) through 5 (failed condition).
- New materials and components have been added to the manual. Additions to the rating system include timber and plastic culvert/storm drain barrels, joints (based on AASHTO performance criteria), manholes, catch basins, and buried junctions.
- Most importantly, the new rating descriptions were developed with a focused effort on incorporating quantitative measures of distress. Research indicated that previous distress descriptors left too much room for interpretation. Adjectives such as "mild" or "significant" are now accompanied by quantitative definitions to remove ambiguity and interpretation between inspectors. The quantitative rating descriptions are based on consensus standards from a broad range of sources compiled during our literature review, including industry and manufacturer's literature, design standards, and the collective experience of the research team.

This research also developed updated inspection techniques, provided recommendations for inspection frequency, and added a catalog of distressed conditions for culvert and storm drain system distress identification. The catalog provides inspectors with a photographic condition reference for assessing the in-service performance of pipes and appurtenant structures in culvert or storm drain systems, and ultimately acts as a visual comparator for assigning a condition rating. The catalog was developed via a

photo collection campaign that reached out to over 200 contacts from all 50 states and a few international contacts, resulting in over 3,500 distressed culvert and storm drain distress photographs.

This final report summarizes the efforts and research that went into writing the *Culvert and Storm Drain System Inspection Manual* and provides the final manual as an attachment.

CHAPTER 1 - BACKGROUND

In 1986, the Federal Highway Administration (FHWA) published the *Culvert Inspection Manual* as a supplement to the bridge inspector's training manual. The manual was intended to address the global need to inventory, quantify, and rate the condition of in-service culverts. The 1986 manual has served industry well and has been adopted, in whole or part, by many municipal agencies as the basis for their agency-specific inspection manuals. This project provides an update to the 1986 manual. In particular, industry advancements in culvert materials, rehabilitation systems, inspection methods, aquatic organism requirements, environmental requirements, and storm drains systems are addressed.

Culverts are buried pipe, box, or arch structures that are open at both ends to convey waterways under roadways. Culverts can be structurally similar to bridges, but are defined as having unsupported spans (diameter for a round pipe) less than 20 ft. Storm drains systems are closed-end conduits with in-line structures, such as junction boxes, that convey storm water runoff from roofs, parking lots, roads, walkways, and other impervious surfaces to collection and discharge points. Together, these drainage and conveyance systems protect our transportation assets from the destructive forces of water and provide means to meet environmental requirements.

Culvert and storm drain systems are vital components of transportation infrastructure assets that require periodic maintenance to achieve their design service life. Lack of appropriate maintenance is a primary cause of improperly functioning culvert systems. Age, physical damage, and environmental exposure can lead to deterioration. In addition, inadequate initial design, poor installation practices, environmental exposure, changes in land usage, and increases in traffic volume or weight can affect the performance and service life of the culvert. Failure can lead to roadway collapse or washout, area flooding, embankment erosion, or blockage to fish passages. These failures can be a heavy cost burden to transportation agencies. Resulting construction and traffic congestion can also burden local business and the traveling public, impacting the local economy.

Culverts have traditionally received less attention than bridges, leading to significant inventories with deferred maintenance needs. Each culvert and storm drain system may represent a significantly smaller investment than a bridge, however, the quantity of culvert and storm drain systems in a typical DOT (Department of Transportation) inventory is often more than a factor of 10 greater than the bridge inventory. This larger quantity raises the overall value of the culvert and storm drain inventory and increases the associated total cost of maintenance and rehabilitation and increases the importance of timely maintenance.

The National Bridge Inspection Standards (NBIS) mandate that all bridges, including culvert-like structures with total spans greater than 20 ft, are to be inspected on a maximum 2-year cycle. Conversely, culverts and storm drains have no federally mandated (or funded) minimum inspection cycle. The risk to public safety and increased repair costs can be mitigated by regular inspection and consistent assessment of culvert and storm drain system condition across the full inventory. An inspection and condition monitoring program allows for short- and long-term planning/scheduling of repairs and rehabilitation. Inspection also provides a means to meet state and federal requirements to quantify the value of infrastructure assets. Minor problems can also be identified early and corrected before they become serious. Agencies benefit economically, as preservation of culverts is typically more economical than replacement, and the level of service and reliability of the national highway system is increased.

The usefulness of the inspection information collected in the field depends on how well the inspection is conducted, the quality of the recorded data, and the consistency of condition ratings between inspectors and agency-wide. The information must be recorded in a manner that is easy to understand, furnishes an accurate assessment of condition, provides database information for interdisciplinary access and sharing, and is easily verified and updated. Quality and repeatability of the data collected is fundamental to a successful inspection program. Inspection data are used to provide the basis for agency decision-makers to prioritize and fund necessary rehabilitation programs.

To insure that a culvert or storm drain system is functioning safely, the inspection should evaluate structural integrity, hydraulic performance, and roadside compatibility.

- Structural Integrity: Structural failures can present a life threatening safety hazard or roadway closure. The identification of potential structural and material problems requires a careful evaluation of indirect evidence of structural distress as well as actual deterioration and distress in the culvert material.
- Hydraulic Performance: When a culvert's hydraulic performance is inadequate, potential safety hazards may result. The flooding of adjacent properties from unexpected headwater depth may occur. Downstream areas may be flooded by failure of the embankment. The roadway embankment or culvert may be also damaged because of erosion of embankment soils. Aquatic organism passage may also be limited.
- Roadside Compatibility: Many culverts, like older bridges, present roadside hazards. Headwalls and wing walls higher than the road or embankment surface may constitute a fixed obstacle hazard. Abrupt drop offs over the end of a culvert or steep embankments may represent rollover hazards to vehicles that leave the roadway.

The success of a culvert and storm drain inspection program hinges on the inspector's ability to effectively assess the condition of the structure and materials and to make sound evaluations that lead to consistent, accurate ratings. The inspection data collected by the inspector may be used as input to an asset management system that allows prioritization of maintenance budgets and to make other decisions that can directly impact public safety. Thus the inspection program plays the most critical role in maintaining the large number of systems in a typical agency culvert and storm drain inventory.

The research presented in this report is conducted under NCHRP Project 14-26 *Culvert and Storm Drain System Inspection Manual*. The following sections summarize and highlight development of the manual.

Problem Statement

The Federal Highway Administration (FHWA) published the *Culvert Inspection Manual* in 1986. Since that time, there have been significant advances in culvert and storm drain systems, inspection methods, and asset management that are not reflected in the original publication. In particular, plastic pipe, not addressed at all in the 1986 manual, is now widely used for highway culverts and storm drains. Three decades of change created a need to develop an updated manual to provide guidance on best practices to inspect and evaluate culverts.

Research Objective

The objective of this research was to develop a culvert and storm drain system inspection manual as update of the 1986 FHWA *Culvert Inspection Manual*. The manual is intended to assess the condition of in-service culvert and storm drain systems to ensure system safety, functional performance, and the economical use of owner resources. The detailed objectives include:

- Create a catalog for distressed conditions,
- Add inspection techniques for new materials and components,
- Update condition assessment and rating criteria to reflect industry practices,
- Include discussion on best practices for culvert inventory management.

Scope of Manual

The scope of this manual covers the inspection and condition assessment of culvert and storm drain barrels and their appurtenant structures. Consistent condition ratings are obtained by use of ratings tables for components of culvert and storm drain systems.

Summary of the State of Practice

The state of practice for culvert and storm drain inspection, assessment, and management varies greatly across the United States. The basis for inspection frequency and level of detail collected are not consistent between transportation agencies. However, those State Departments of Transportation that use a culvert management system (approximately half) employ some or all of the following:

- Determine culverts that require regular (or any) inspection based on importance, typically identified by barrel size, functional requirements, and roadway use or traffic volume.
- Review available records and then perform field inspection to assess the current condition and performance of the culvert.
- Incorporate feedback from maintenance on poorly performing systems or from ad hoc inspections occurring during roadway construction activities.
- Rate the culvert condition based on the field inspection and flag any critical installations that may require remedial action.
- Document the culvert condition in a database.
- Identify maintenance, repair, rehabilitation, or replacement needs.
- Prioritize work relative to available funding.

Many states and counties that have culvert inspection manuals are using hybridized manuals created in house, based on rating tables from the 1986 manual, augmented to include contemporary barrel materials, inspection methods, and agency-specific inventory procedures. According to a case study by the Federal Highway Administration Shelby County Highway Division (SCHD) in Alabama has been inspecting culverts since 1994. Although it does not have its own culvert inspection manual, SCHD personnel refer to culvert inspection manuals from states like Montana and Ohio (FHWA, 2007). Najafi, Salem, Bhattachar, Salman, and Patil performed a survey of forty state departments of transportation responsible for culvert management and found that only 32% had an official culvert dictionary or literature specifying characteristics of culverts (Najafi, Salem, Bhattachar, Salman, & Patil, 2008).

Common practice for culvert and storm drain maintenance is to address culvert repair only after significant deterioration or failure has been reported. Preventative maintenance and routine inspections are not standard practice, especially for small-diameter culverts (a term which varies state to state, but is usually less than 4 ft diameter), which typically receive less attention. Development of an inventory, inspection, and maintenance program is crucial for structural health of culverts. Najafi et al. reported that while 60% of the state departments that were surveyed conducted large-diameter culvert inspections to every 2 to 5 yrs, only 48% of respondents have any formal guidelines for those inspections.

Intended Users and Uses

The intended users of the *Culvert and Storm Drain Inspection Manual* are highway agencies tasked with maintaining culvert and storm drain inventories, e.g., State DOTs, County Highway Divisions, etc. Personnel from these agencies that will benefit from use of the manual include:

- Culvert and storm drain inspectors and bridge inspection personnel responsible for inspecting structures that are designed hydraulically or structurally as culverts.
- Maintenance personnel responsible for performing scheduled maintenance on culverts and storm drains. Although bridges with spans over 20 ft usually are inspected by bridge inspectors, culverts with a total opening length less than 20 ft (single or multiple barrels) are frequently inspected by maintenance personnel.
- Consultants to highway agencies responsible for culvert and storm drain system inspection.

Relationship with Other NCHRP Publications

NCHRP 14-26 project work correlates with ongoing NCHRP Project 14-19 *Culvert Rehabilitation to Maximize Service Life While Minimizing Direct Costs and Traffic Disruption*. Both NCHRP 14-19 and 14-26 are useful and complementary elements in the preservation of a culvert inventory. The objective of NCHRP 14-19 is to develop a handbook that provides up-to-date guidance to assess the need for culvert rehabilitation, provide assistance in the selection and design of suitable rehabilitation options, and provide information on various methods of construction associated with culvert rehabilitation. The data collected during a culvert inspection program will directly inform the need for rehabilitation of culverts and appurtenant structures.

CHAPTER 2 - RESEARCH APPROACH

This research for NCHRP 14-26 was conducted in five phases:

- Phase 1 – Literature Review
- Phase 2 – Develop a Catalog of Distressed Conditions
- Phase 3 – Evaluate Inspection Techniques
- Phase 4 – Develop Condition Assessment Criteria
- Phase 5 – Prepare the *Culvert and Storm Drain System Inspection Manual* and Final Deliverables

Phase 1 - Literature Review

In Phase 1, we conducted a literature review which would form the foundation of the manual and future phases. The purpose of the literature review was to identify relevant sources that provide the state of practice for culvert and storm drain system inspection and asset management practices, and to identify sources for technical content necessary to update and improve the 1986 FHWA *Culvert Inspection Manual*.

The references summarized in the literature review included culvert and bridge inspection manuals from federal, state, and local agencies, storm drain system literature from environmental and transportation agencies, case studies for use of new inspection methods, journal papers describing culvert condition assessment as input to asset management, and other contemporary publications on inspection and condition assessment of culverts. We also obtained sources from past Simpson Gumpertz & Heger (SGH) projects.

The following is an abbreviated listing of agency resources referenced on this project:

- American Association of State Highway and Transportation Officials (AASHTO)
- American Society of Civil Engineers (ASCE)
- ASTM International
- Federal Highway Administration (FHWA) and Federal Lands Highway (FLH)
- International Society for Trenchless Technology
- Transportation Research Board Records (TRB), Transportation Research Laboratory (TRL), and National Cooperative Highway Research Program (NCHRP)
- Various State Highway Administrations and State Departments of Transportation (SHA and DOT)
- Various Journals, Publications, and Conference Proceedings
- Pipe Inspection organizations including NAASCO; Pure Technologies, Cues, Inc.; and RR Visual, Inc.
- Pipe Manufacturers and Pipe Trade Associations
- U.S. Geological Survey
- Various Departments of Fish & Wildlife (DFW)
- Environmental Agencies including Environmental Protection Agency (EPA), Department of Inland Fisheries and Wildlife
- University Research Publications

As part of the literature review, we identified topics that were not addressed in the 1986 FHWA *Culvert Inspection Manual* and highlighted aspects of culvert and storm drain inspection that have changed significantly since publication of the 1986 manual. We also used the literature review to identify content from the 1986 manual that was still relevant and useful for inclusion in the new manual. The literature review report introduced storm drain system terminology, typical system components, and some inspection and maintenance procedures specific to storm drain systems.

The literature review covered the following topics:

- Safety, qualifications, and equipment for the inspector.
- Culvert and storm drain system characteristics including loads and structural design.
- All typical culvert materials, including rehabilitative linings and replacement methods.
- Culvert and storm drain system components.
- Aquatic organism passage design and installation concerns.
- Inspection procedures and quality measures.
- Culvert and storm drain condition rating systems and inventory management.

Phase 2 – Develop a Catalog of Distressed Conditions

Phase 2 developed the catalog of distressed conditions for culvert and storm drain systems. The purpose of the catalog of distressed conditions is to provide inspectors with a photographic condition reference (visual comparator) for assessing the in-service performance of pipes and appurtenant structures in culvert or storm drain systems, and ultimately for assigning a condition rating. Developing the catalog required a lengthy and labor-intensive process, which included the following steps:

- Creating a draft matrix of distress features.
- Creating a preliminary rating system for the draft matrix of distress features.
- Collecting and consolidating published typical descriptions of distress in the identified features.
- Reviewing and selecting available culvert photographs from our internal databases.
- Conducting an extensive calling campaign to request libraries of photographs that cover each distress category and with a range of severity from minor to extreme.
- Questioning inventory owners and stakeholders for other distress categories that were not yet identified in the draft matrix of distress features.
- Obtaining copyright permission in signed letter format to use the provided distressed condition photographs for the catalog of distressed conditions.
- Reviewing photographs for quality and content.
- Categorizing photographs based on distress and coordination with the draft matrix.
- Developing an in-house database system to format the catalog to show the photographs with copyright credits along with the associated condition rating and photograph distress condition narrative descriptions.
- Revising the distressed conditions listing to reflect further work on the manual and multiple oversight panel meetings.
- Revising the ratings categories to reflect oversight panel feedback from multiple panel meetings and our ongoing efforts on the manual.

We conducted an extensive search for distressed condition photographs by identifying a list of contacts that might provide suitable photographs and reaching out to them for photograph contributions. We identified contacts with a range of backgrounds and professional experience from numerous sources. Our final list included over 200 individual contacts, representing all state highway agencies and several foreign highway agencies. The contact list also included the project oversight panel members that specifically expressed interest in providing photographs. Our efforts culminated in the collection of over

3,500 usable culvert and storm drain distress photographs, but few with significant descriptive language identifying the system characteristics.

Database of Photographs

We created a photograph database system to track the large numbers of distressed condition photographs as we received them. We reviewed all photographs in the database, purged photographs that did not show distressed conditions of interest, then categorized and annotated those that were relevant. Photographs identified for inclusion in the catalog were reviewed in detail for all categories of distress. We edited and removed any information in photographs that contained closed-circuit television (CCTV) inspection notes and commentary, culvert or storm drain identification numbers, city/state identification, vehicular identifiers, notes with proprietary inspection agency terminology, and personal information as specifically requested by several photograph contributors. We also complied with all requests from contacts to remove specific information (i.e., manufacturer's identification, license plate numbers, facial characteristics, etc.). Editing was done carefully and discretely to best preserve the high quality of the photographs and to avoid distracting redactions and censor bars.

Photographs were manually sorted into folders of subject matter, distress depicted, and level of distress. Distress identifiers, such as arrows, were added where necessary. The SGH database then tagged each photograph with the source of the photograph, the corresponding attribution credit, the condition rating ascribed to the photograph and a comment describing the distress. Upon user request, the SGH database compiles and prints a fully formatted catalog of photographs organized by distressed condition, with an attribution credit and comment accompanying each photo.

Some distress categories lack photographs showing the full range of ratings; however, the general distressed condition is still well defined and the relative condition can be inferred between the distress ratings that are depicted. Once completed in Phase 2, we identified distress conditions/ratings for which we were lacking photographs. We performed a more targeted search of our internal databases and made a list of conditions to look for during the Phase 3 preliminary field investigations.

Copyright Release

The goal of this research project was to produce a culvert and storm drain inspection manual suitable for publication by AASHTO. Consequently, photographs obtained from third parties required copyright release for use in the AASHTO publication. We researched copyright law and fair use policies and reviewed copyright release forms used by AASHTO and NCHRP. We prepared a copyright release form which was distributed to all photograph contributors to be signed and sent along with photograph submissions. Photographs that were not accompanied by copyright release were not used in the catalog or the manual body. The copyright release grants permission for use by SGH, TRB, and AASHTO in publication of the *Culvert and Storm Drain System Inspection Manual* to be developed under NCHRP 14-26. A note will be added in the published manual indicating that the photographs within may not be used in any other publications.

The deliverable from Phase 2 has been incorporated as Appendix B of the manual. Additional details of work on the Catalog of Distressed Conditions are included in Phase 3.

Phase 3 – Evaluate Inspection Techniques

Phase 3 research identified inspection approaches and practices for culvert and storm drain systems. Specific tasks for Phase 3 included:

- Describe best practices for inspection.
- Identify inspection approaches and create checklists.
- Develop inspection forms and conduct field investigations.

Describe Best Practices for Inspection

This first task in Phase 3 was to summarize the best practices for inspections. These practices were collected and described in the Phase 1 literature review and, to the extent relevant, the 1986 manual. Best practices include recommended inspection procedures, qualifications for inspectors or team leaders, inspection equipment, and aspects of safety necessary to access typical sites for routine inspections.

Work done previously by the research team indicated that culvert inspections conducted with a tiered approach lead to more-efficient inspections and improved economics of inventory management. Types of inspections detailed in the manual are based on the FHWA *Manual for Bridge Inspection* and include the Initial Inspection, Routine Inspection, In-Depth Inspection, Special Inspection, and Damage Inspection. The focus of the manual is on the Routine Inspections, which are conducted on a defined schedule and consist of the visual and non-destructive condition assessment by inspectors that may or may not be Engineers.

In the tiered inspection approach, the checklist concept can be used to determine a need for in-depth inspection beyond the initial overall site survey. For example, if preliminary visual inspection of a culvert indicates that the waterway is in excellent condition, that the barrel has no visible indicators of distress, and that the roadway/embankment grade and alignment indicate no signs of distress, person-entry inspection will not be recommended. Further, this process is codified to instruct inspectors on what aspects of the culvert system they must inspect more thoroughly following their preliminary evaluation.

Best practices for inspection scheduling and frequency are presented in terms of recommended guidelines, rather than a prescriptive inspection schedule. Our research showed that agencies responsible for culvert inventory management have a wide range of requirements for frequency of inspection. The guidance provided in this section allows agencies to balance risk of deferred maintenance with inspection frequency, based on practices used by similar agencies. For example, very small culverts may not warrant inspection and well-performing installations may allow reduced frequency of inspection. Developing a schedule for inspection frequency should carefully consider culvert location, ownership, waterway hydraulics, installation age, and consequence of failure.

The work product produced in this task is incorporated in Section 3 of the manual.

Identify Inspection Approaches and Create Checklists

Our Phase 1 literature review described inspection procedures employed by many agencies that own and manage culvert and storm drain inventories. We utilized that collected data, combined with the types of inspections established in the first task of this phase to identify best practices for the approach to culvert and storm drain system inspections. These include use of trained inspectors, the documented inspection procedure in the manual, inspection checklists for quality control, and a quality assurance system to ensure consistent and accurate inspections between inspectors.

U.S. federal regulations require individual states to develop and implement Quality Control and Quality Assurance (QC/QA) activities for bridge inspection work. While no such mandate currently exists for culvert inspection, a well-functioning quality system allows the agency to confidently make asset management decisions using the inspection results. Quality Control (QC) is the set of actions that directly control the quality of a work product by providing expectations and a system for the inspector. Quality Assurance (QA) activities are directed towards the overall assessment and management of the quality control measures. NCHRP Synthesis 375 describes the role of QA review in federal bridge inspection as "verifications of the organization and execution of bridge inspection programs. QA reviews determine whether inspection programs have qualified staff and adequate equipment. QA verifies that appropriate progress, records, identifications, and follow-up are achieved." This description is appropriate for QA systems to be used in culvert and storm drain system inspection and condition assessment.

The purpose of a QC/QA program is to set performance requirements and methods to ensure they are attained to reduce uncertainty about the quality of the end results. For culvert inspections, this consists of training inspectors, providing a manual for inspections, and implementing a series of checks that provide feedback on the accuracy and effectiveness of the system. Culverts and storm drains are inspected rapidly and visually which means variations in inspection technique, condition interpretation, and record-keeping can lead to inconsistency in component numerical rating results. Accurate and consistent inspection information is critical to a successful inventory management program. Condition assessment ratings are used to set maintenance and rehabilitation priorities in the short term and to project condition ratings for long-term prioritization. Both the short-term and long-term priorities are used for agency maintenance budgeting and to ensure protection of public safety.

In researching QC/QA programs, we consulted many references on the topic and focused our recommendations around the FHWA Office of Bridge Technology *Recommended Framework for a Bridge Inspection QC/QA Program* and selected portions of the ISO 9001 *Quality Management System*. Implementation of the program should follow the PDCA Cycle (Plan-Do-Check-Act), which forms the basis of the ISO 9001 *Quality Management System*. While ISO 9001 certification is not a requirement of this culvert and storm drain inspection system, the principals of the PDCA tool allow for continuous improvement of the culvert inspection quality assurance process.

Develop Inspection Forms and Conduct Preliminary Field Inspections

Following consolidation of the best practices for inspection and review of available published inspection checklists, we created standard inspection forms to record inventory and inspection data in text format. Recording the inspection may be performed using paper hardcopy forms or digitally using mobile phones, tablets, or laptop computers. If hardcopy forms are used for field inspection, the data collected should later be entered into a computer database as a standardized part of the inspection. The use of computerized inventory records can greatly improve the speed at which data can be located, retrieved, and augmented with GPS location, photographs, and video.

The research team conducted several trial field inspections to determine the effectiveness of the standard inspection forms and to identify areas for improvement. Inspections were conducted primarily in Massachusetts (near the research team's home office), with additional locations in South Carolina, California, and Utah. The inspections used the draft best practices for inspection, draft checklists for data collection, and draft forms for recordkeeping. As additional inspection data, we utilized culvert and storm drain inspection results provided to us by a project panel member from Minnesota, based on the MnDOT (Minnesota Department of Transportation) HydInfra system. During our field inspection phase, we obtained additional photographs for use in the Catalog of Distressed Conditions (Appendix B of the manual).

Following completion of the trial inspections, we finalized our summary of best practices and checklists from the prior task.

The results of Phase 3 have been incorporated in Sections 2 and 3, and 5 of the manual.

Phase 4 – Develop Condition Assessment Criteria

Phase 4 produced the most significant update to the manual in the form of a complete overhaul of the 1986 manual's condition rating system. New barrel materials, older less-common barrel materials, and other components have also been added. Additions to the barrel rating system include timber and plastic. Additional components include pipe joints (based on AASHTO performance criteria), manholes, catch basins, and buried junctions.

Numerical Ratings

Numerical rating systems are used to summarize the condition of culvert and storm drain systems or individual system components. When the conditions associated with a specific numerical value are well-defined and the rating system is clearly understood by raters (inspectors) and reviewers, valuable information can be extracted from the inspection reports and used for asset management. To achieve accurate and consistent results, clear definitions were established for each rating level for each distress category. The definitions were created to be accurate and quantifiable to reduce and variation between inspectors.

After a detailed review of the existing rating system, we found many opportunities to improve the accuracy and consistency. The first major revision was a reconfiguration of the numerical ratings from a ten-point rating system to a five-point rating system. After a thorough review of the ten-point system found in the 1986 manual, and other similar older rating systems, the researchers concluded that there was not enough distinction between ratings to justify the ten-point scale. Some agencies had identified this same deficiency and used half of the numbers to 'shade' between ratings. In addition, our literature review showed recent trends supporting use of a five-point system. Repeatability is key to successful implementation of a culvert and storm drain management system, and the ten-point scale contributed unnecessary ambiguity and interpretation between ratings. Most implementations of the ten-point scales also used an accompanying table to distill the ten-point scale to five, four, or three categories of action. The revised five-point scale in the manual directly correlates observed conditions with recommended action and reduces ambiguity and variation in ratings.

A second major revision was the format of the ratings descriptions. The approach in the 1986 manual was to list the numerical rating category along with a condition description which grouped several components. This approach led to ambiguity as to which system component led to the lowest rating and frequently led to confusion in cases where one component actually had higher importance than other components in the same grouping. In light of this shortcoming, we revised the organization of the rating system to component-based ratings, with a format consistent with the AASHTO *Bridge Element Inspection Manual*. The new format provides clarity on the component that has a low rating and reduces confusion on any necessary action resulting from the ratings. Components are rated individually with potential distress and their associated severity rated on a scale of 1 (good condition, typically associated with new installations) through 5 (failed condition).

Ratings Descriptions

The new rating descriptions were developed with a focused effort on incorporating more quantitative measures of distress. Our review indicated that previous distress descriptors left significant room for interpretation. In many cases, qualitative adjectives such as "mild" or "significant" were left to the inspector's judgment. The new rating descriptions address this deficiency. The rating descriptions are based on a compilation of the distress descriptions identified in our literature review including industry and manufacturer's literature, design standards, and the collective experience of the research team.

Some distress were an easy fit for providing quantitative measures in their rating criteria. Other distress were more difficult to quantify explicitly and with certainty in terms of their effect on the culvert or storm drain system. In addition, the criteria need to strike a balance between measurable quantities without adding unnecessary complication or detailed measurements that would increase the effort required for routine inspections. Culvert and storm drain inspection must be conducted rapidly, owing largely to a lack of funding support and vast number of systems in a typical inventory. For distress whose nature did not lend themselves to explicit measurements, we have added more detailed assessment criteria to distinguish severity (along with photographs in the catalog). For example, dents in corrugated metal pipe, which are difficult to assess consistently, use qualifiers such as size and whether or not the damage punctures the wall. Other qualifiers are used to measure severity such as exposed rebar versus no exposed rebar or presence of rusting or staining. Splits in plastic pipe are distinguished in their severity by differentiators such as "No water infiltration through splits", "Minor water infiltration but no soil infiltration", and "Evidence of soil infiltration". In addition to traditional width measurements, cracks in concrete are distinguished according to vertical offset, water infiltration, and/or a noted increase in crack size from the previous inspection.

Careful consideration was also given to distress indicators that cannot cause a failed rating. Failed ratings were only used for distress that can cause component or structural failure. For example, channel protection rip rap may be displaced, missing, or degraded such that it is no longer functional but the condition state of missing rip rap does not constitute failure of the culvert. This condition may lead severe bank erosion, or undermining of the structure, however these components are rated separately. Channel protection can only receive a maximum rating of 4 (critical). A rating of 5 for Channel Protection reads "Cannot cause failed condition. Failure will occur in embankment, structure barrel, or end treatment." Other examples of distress indicators that cannot cause a failed rating include surface damage in concrete and metal barrels, spalling, delamination and patches in concrete barrels and footings, efflorescence and staining, and mortar condition in masonry barrels.

The research team relied primarily on existing criteria and terminology and adapted it to culvert and storm drain inspection. Ratings descriptions are a product of consensus terminology from existing references, i.e., pavement ratings are largely from pavement condition guides, embankment and channel ratings are based information from FHWA Hydraulics Engineering Circulars, etc. This avoids creating new definitions and criteria while allowing for inspection data to be used for a variety of purposes. For example, in Approach Roadway, Pavement: Sags and humps in the pavement, which may indicate deflection, differential settlement, or loss of backfill around the pipe, are rated according to low, medium, and high severity: Low severity is defined as 1/8 in. to 2 in. depth over 10 ft of roadway length; Medium severity is 2 in. to 4 in. depth; and High severity is defined as over 4 in. depth. This criterion comes from sources such as the Washington DOT *Pavement Surface Condition Rating Manual*. While not developed specifically for sags over culverts or storm drains, the criteria are suitable for use here and add cross-disciplinary functionality to the data collected. Pavement distress that is not a potential indicator of culvert or storm drain distress was considered extraneous and is not included. This approach was taken throughout our Phase 4 work.

The work produced during this phase is included in the manual as Section 4. Additional information on the rating system is provided in Chapter 3 of this report.

Phase 5 – Prepare the Culvert and Storm Drain System Inspection Manual and Final Deliverables

Phase 5 included assembling the final manual and draft final report, along with developing implementation strategies for the manual.

CHAPTER 3 - INSPECTION MANUAL

This section summarizes new or updated content to the manual.

Organization of Manual

The *Culvert and Storm Drain System Inspection Manual* is organized into five sections with appendices:

- Section 1 – Introduction: This section introduces the topic of culvert and storm drain system inspections, outlines reasons standardized inspection programs are needed, provides the manual objectives, and identifies the intended audience. Section 1 also instructs users on the manual organization and use for inspections.
- Section 2 – Design and Performance Characteristics: This section introduces the general factors that affect structural and functional performance of culvert and storm drain barrels, the structural shapes and materials, the various culvert and storm drain system components, and pipe coatings and linings. Section 2 provides common system characteristics and refers to Appendix A for additional details about system component details.
- Section 3 – Inspection Procedure: This section covers inspection frequency, preparation and planning inspections, types of inspections, the inspection sequence for routine inspections, type of entry, qualifications of the inspector and inspection team, typical equipment and tools for conducting an inspection, quality control and quality assurance practices, and inspection safety.
- Section 4 – Condition Rating System: This section provides quantitative criteria for rating the condition of culvert and storm drain system components. Tables instruct assignment of a condition rating from 1 to 5 using specific criteria obtained by visual inspection or basic measurements.
- Section 5 – Inventory Management: This section presents tools for developing a culvert and storm drain inventory and asset management program with examples of current asset management practices and provides references for further research into this significant topic.
- Appendix A – Structural Shapes and Materials: Appendix A augments Section 4 to illustrate and describe the various culvert and storm drain barrel shapes, their components, and the common materials from which they are made.
- Appendix B – Catalog of Distressed Conditions: The catalog provides inspectors with a visual comparator for assessing the condition of typical culvert and storm drain system component. The catalog is organized to mirror the distress conditions listed in condition rating tables of Section 4.
- Glossary: Terms and definitions of commonly used culvert and storm drain terminology.
- References: References used in the production of this manual.

Design and Performance Characteristics

Section 2 – *Design and Performance Characteristics* introduces the general factors that affect structural and functional performance of culvert and storm drain barrels, the structural shapes and materials, the various culvert and storm drain system components, and pipe coatings and linings. Culverts and storm drains are buried structures whose design and performance are governed by many performance requirements and specific system characteristics. Familiarity with the basic design and performance characteristics is required to understand how the inspection criteria and the data collected relate to the service life of a structure, and more importantly to any need for maintenance and rehabilitative action. This section discusses hydraulics, structural behavior and design, and typical AASHTO and AREMA design loads. This section also discusses performance issues related to the durability of culverts and storm drains, which present the most significant distress modes for in-service culverts and storm drains, and thus provides critical technical information required to conduct effective inspections.

Section 2 is a combination of several sections that were scattered and repetitive throughout the 1986 manual. We have compiled, condensed, and edited these sections, supplementing heavily with new content. Major content updates in from the original manual include the following:

- Content from the 1986 manual has been updated with relevant information for general factors affecting performance of culverts and storm drains.
- Live load descriptions have been updated to include the latest AASHTO *LRFD Bridge Design Specifications* for live loads as well as discussion of other common design loads, such as railway, aircraft, and construction loads.
- This section also contains material descriptions for thermoplastic, including high density polyethylene (HDPE), polypropylene (PP), and polyvinyl chloride (PVC), and thermoset, including fiber reinforced plastic (FRP) pipe materials, construction, and installation requirements.
- Aquatic organism passage (AOP) information is added. AOP refers to the ability of fish or other water-inhabiting organisms to safely traverse through a location or structure, whether upstream or downstream, for feeding, rearing, migrating, spawning, etc. Several states currently require special permitting to address AOP requirements for culverts, as assessment for specific local species requires a detailed site evaluation. Section 2 includes a discussion of AOP to introduce the topic, describe common design methods, and discuss the importance of identifying culverts that require AOP plans for inspection. AOP plans can be highly variable in scope and requirements and will depend on the aquatic species, site conditions, and current practice. Because of this, inspection of AOP is beyond the scope of the manual and not explicitly covered. Instead the inspector is made aware of the issue and alerted that additional inspection requirements may be necessary to evaluate AOP and associated design features.
- Storm drains are also absent from the 1986 manual. Storm drains and culverts share many of the same features with respect to the barrel, and a focus of the manual will be to rate the barrel and appurtenant components. Section 2 also includes a description of the storm drain system and common features of typical systems.

Section 2 is intended as a primer for new inspectors or inspectors that are looking for a review of design and performance related topics. Appendix A provides a more basic discussion of culverts and storm drains for the new inspector or as a reference for the experienced inspector.

Inspection Procedure

Section 3 describes the inspection procedures. Several changes have been made to the approach to culvert and storm drain inspections. Significant changes include the following new content:

- Tools: Standard tools and equipment are presented along with their application in inspection. Standard tools are grouped into six categories: tools and equipment for access, cleaning, inspection and measurement, visual aid, documentation of condition, and miscellaneous tools and equipment. Specialized equipment has also been added to introduce existing nondestructive technologies available to inspectors.
- Remote Inspection: Remote inspection equipment has been added to this section. Internal inspection of the pipe barrel that cannot be performed via person-entry can often be accomplished using remote inspection equipment, such as remote controlled vehicles equipped with CCTV or

high resolution video cameras, lasers, sonar inspection, remote field eddy current, and optical sensing. Remote inspection is typically used for storm drains that have limited access or for culverts that are too small for person-entry or are difficult or dangerous to enter, e.g., sonar inspection for the lower half of pipes with active high-water flow.

- Frequency: Explicit recommendations for frequency of inspection are included, based on risk and consequence of failure, and consensus practical experience inspecting large asset inventories.
- Inspection Types: The manual defines four types of inspections, which vary in scope and purpose, based on the NBIS program for bridges. These are the Initial (Inventory) Inspection, Routine Inspections, Special Inspections, and Damage Inspections.
- Also introduced is a recommended framework for an inspection team, with defined roles and qualifications to help support quality and consistency in an asset management program. These recommendations will allow agency planning for training and budgeting qualified staff for inspections.

These updates are discussed below.

Frequency of Inspection

Our literature review revealed a wide disparity in the state of practice with respect to state DOTs approach for frequency of inspection for culvert and storm drain systems. Highway culverts larger than 20 ft are categorized as bridges and are therefore required to be inspected every 2 years under the NBIS program. However, culverts under 20 ft span (diameter for round pipe) do not have federal inspection requirements, and state practices range from frequent regular inspection to no formal inspection program at all. Culvert and storm drain structures should be inspected on a regular schedule, based on importance criteria, to ensure public safety and to allow agencies to plan for maintenance and rehabilitation. The manual provides recommended minimum inspection frequency but also provides a technical basis for agencies to vary frequency of inspection for characteristics such as size, culvert condition or age, or other measures of importance. Table 1, from Section 4 of the manual, provides a recommended minimum frequency for routine inspection of culverts and storm drain systems, based on the culvert size, *S* (diameter or span). Note that this is the frequency for routine inspection, condition assessment, and condition rating of the culvert or storm drain system and is not the frequency for routine maintenance. Some culvert and storm drain systems will require more frequent visits than is listed in the table below for maintenance actions such as clearance of debris or sediment accumulation.

Table 1 – Inspection Frequency (Routine Inspections)

Barrel Size (S)	Inspection Frequency (Ratings ≤ 2)	Inspection Frequency (Ratings ≥ 3)
New Installation (S > 1 ft)	Inspect annually for the first 2 years after construction.	N/A
S ≤ 1 ft	No routine inspection required. Inspect during roadway maintenance activities.	No routine inspection required. Inspect during roadway maintenance activities.
1 ft < S ≤ 4 ft	Every 10 years or prior to routine roadway maintenance activities, whichever is less.	At least every 5 years and with routine roadway maintenance activities.
4 ft < S ≤ 10 ft	Every 5 years or prior to routine roadway maintenance activities, whichever is less.	At least every 2 years and with routine roadway maintenance activities.
S > 10 ft	Every 2 years	At least every 2 years and with routine roadway maintenance activities.

Developing a schedule for inspection frequency should carefully weigh the risk and consequences of failure and the impact of deferred maintenance versus the cost of regular routine inspection condition assessment, and data management. Factors to consider in the risk and consequence of failure include:

- Size: The diameter or span and rise of a culvert or storm drain barrel should be considered when determining inspection frequency. Culverts whose size and geometry are essentially short-span bridges should be inspected on a frequency similar to bridges as the consequence of failure is also similar. Large structures under shallow fill also carry higher consequence of failure to the traveling public when compared with small structures under high fill cover. Some small diameter culverts whose consequence of failure is relatively low may not need frequent routine inspection as agency protocol dictates that these structures are replaced rather than repaired, and the consequence of failure is reduced approximately proportional to the reduced span..
- Condition Rating: The inspection frequency should increase as the culvert shows signs of deterioration. At the onset of deterioration, the rate at which the structure degrades may increase. The frequency of routine inspections may be too infrequent to capture the point at which degradation progresses to a level that maintenance or repairs could prevent failure. When a component receives a “poor” condition rating, an agency-level decision should be made to determine if the defined frequency for routine inspections will be adequate to ensure a consistent minimum level of safety if no action is taken to rectify the component distress, such as rehabilitation. Table 3.3-1 provides guidance on increased frequency of the inspections as the condition degrades and the associated rating number increases.
- Structure Age: The age of the buried pipe should influence inspection frequency. New culverts should be inspected immediately after construction and, for more important systems (based on span > 1 ft or other criteria), should be inspected annually for the first 2 years after they are placed in service. Structural problems with culverts are typically related to poor installation and distress indicators will often appear within the first 2 years after installation, as the system is subject to loading and weather cycles.

  Culverts and storm drains often deteriorate at an accelerated rate as the structure ages. Older structures therefore may require more frequent inspection than newer structures to prevent increased risk of failure. Older structures may also be designed to older codes with lower design vehicular loads (live loads). Lastly, older structures may have cyclic load induced distress (i.e., fatigue) from years of passing traffic loads, freeze/thaw cycles, etc.
- ADT: Average daily traffic should also be considered in assigning inspection frequency. Culverts and storm drains under roads with higher average daily traffic or unusually large trucking loads have greater consequence of failure (increased importance) and may warrant more frequent inspection intervals.
- Environmental Conditions: Structures in environments which are corrosive towards the material may require more frequent inspection. For example, buried metal pipes with poorly performing coatings or linings in acidic soil or water may deteriorate at a more rapid rate requiring more frequent inspection. Corrosion and abrasion often work together to produce a greater rate of deterioration than either would individually. Hence, abrasive conditions may also warrant more frequent inspections. As discussed in this manual, the abrasiveness of a waterway affects all barrel material types and can be determined using the FHWA guidelines.
- Special Function: Special functions, such as AOP, may have additional guidelines that require its own frequency of inspection. Consideration should be given to the special function importance to coordinate inspection schedules that ensure required functional performance is met.

Types of Inspections

Section 3 defines a four-tiered approach to culvert and storm drain system inspections. These include initial (inventory), routine, special, and damage inspections. These inspection types are based on the NBIS program for bridge structures. Phase 3 work by the research team concluded that culvert and storm drain system inspections should be conducted with a tiered approach to lead to more-efficient inspections and improved economics of resource management. The scope and purpose of each type of inspection is discussed below.

Initial (Inventory) Inspection

The initial system inspection, or inventory inspection, is the first inspection of the culvert or storm drain as it is commissioned, and typically occurs after the completion of roadway construction. Initial inspections should also be conducted after any major rehabilitation work to the structure. If an inventory record does not exist for a structure, an initial inspection may be conducted as part of the first routine inspection.

The purpose of an initial inspection is to verify the as-built structure meets the design as provided in stamped construction drawings and is safe for service. The initial inspection also records the necessary data for the culvert or storm drain system to become a part of the inventory and any data relevant to the initial structural or component condition that is necessary for the agency asset management system. This inspection data provides a baseline for comparison to future inspections.

Routine Inspection

Routine inspections are conducted on a defined frequency and consist of the visual and nondestructive condition assessment in accordance with the condition rating system described in the manual. Changes to inventory items identified during this inspection, or during the pre-inspection planning and data collection, should also be recorded.

The purpose of the routine inspection is to confirm the inventory data and to document condition information about the structure, including its performance and how the system components are aging. Routine inspections seek to identify changes in condition since the initial inspection and any previously recorded inspections. This data is used to identify conditions that warrant further action such as maintenance activities, special inspections, repairs, or changes to the frequency of future routine inspections.

Special Inspection

Special inspections are conducted outside of the routine inspection, and are used to monitor a particular distress condition or to conduct an in-depth review by a qualified inspector, typically an Engineer. Special inspections include close-up inspections of one or more members above or below the water surface to identify any distress not readily detectable during routine inspections.

Special inspections by a qualified inspector are triggered by a critical or failed rating that is identified during a routine inspection, and are needed in order to determine corrective action. If the qualified Inspector performing a special inspection is not a Professional Engineer, the inspector must be instructed regarding the nature of the identified distress and its relationship to structural or functional performance. Guidelines and procedures for inspection must also be provided. Results of the special inspection must be reviewed by a Professional Engineer in a timely manner.

Special inspections may also be conducted at more frequent intervals in order to track rates of deterioration or structural distress that may be nearing a critical stage sooner than would be captured under the routine inspection schedule. Other types of special inspections may include monitoring of new structural materials, types of structures, or system details being evaluated on a trial or research basis.

Damage Inspection

A damage inspection is an unscheduled, event-driven inspection. These may be conducted to assess damage after flooding, fires, appearance of roadway sinkholes, or traffic accidents. Damage inspections should be conducted by a qualified inspector.

The purpose of a damage inspection is to document structural or functional damage caused by environmental events or human actions. Damage inspection may be used to determine if emergency restrictions or closures are required for traffic safety. Resulting actions may range from preventive maintenance to preserve the life of the structure from more rapid deterioration to critical repairs that must be undertaken immediately to restore service and/or address public safety issues.

Inspection Team and Qualifications

There are no specific federal guidelines for qualifications of culvert and storm drain inspectors. National Bridge Inspection Standards (NBIS) describe the minimum qualifications for three levels of bridge inspection personnel: the Program Manager, the Team Leader, and the Inspector. These levels are directly applicable to personnel responsible for the inspection of culverts and storm drain systems and have been incorporated into the manual, with appropriate modification, as follows:

- The Program Manager is responsible for managing the agency culvert and storm drain inspection program. This individual provides supervision of the inspection teams and can provide guidance or assistance to the inspection teams when technical problems are encountered. The Program Manager should be a registered Professional Engineer with minimum 10 years bridge or culvert inspection experience. The Program Manager is responsible for inspection quality assurance.
- The Team Leader or Inspector is in charge of the culvert or storm drain inspection team and is responsible for the onsite inspection supervision. The Team Leader should have 5 years of experience or be a registered Professional Engineer with 2 years bridge or culvert inspection experience. For personnel safety and ease of inspection, including measuring, and documenting, inspection teams should be composed of at least two people, including the Team Leader and Assistant Inspectors. The Team Leader is the Inspector of Record (IOR). All references to the term "Inspector" are intended to indicate the Team Leader. The Team Leader or Inspector is responsible for inspection quality control and should sign the inspection report prepared under their direction.
- Assistant Inspectors working under Team Leaders should complete agency culvert inspection training and be thoroughly familiar with the provisions in the manual. Assistant Inspectors assist the Team Leader in day-to-day inspections.
- For the purpose of the manual, the term "Inspection Team" will be used to indicate a team comprised of two or more personnel, including the Inspector and Assistant Inspectors.

Training should be provided by owner or inspection agency and should include a formal educational seminar based on the manual and on-the-job experience gained working under a qualified individual. Training should include the following topics:

- Understanding of failure modes, critical inspection points, and the condition rating system described in the manual.
- Basic familiarity and understanding of culvert and storm drain function and hydraulic aspects of culvert functionality.

- Basic familiarity and understanding of culvert and storm drain design and soil-structure interaction for rigid and flexible pipe.
- Ability to read and interpret plans, construction documents, and inspection reports.
- Complete knowledge of ratings tables and distress indicators.
- Working knowledge of inspection tools, their use, application, and limitations in collecting data needed for ratings table use.
- Knowledge of safety requirements for site access around the motoring public and the use of safety equipment.
- Familiarity with requirements to ensure the quality, completeness, and consistency of the work produced by the Inspection Team.

Inspection of culverts and storm drains may require physically strenuous activity. The Inspection Team must be capable of working under physically demanding conditions, including cramped spaces, rugged terrain, steep embankments, and in and around water. In addition, the Inspection Team will often be traversing this terrain carrying tools and equipment adding difficulty to their work. Physical limitations that prevent an individual from carrying out these tasks safely should preclude inclusion in an Inspection Team.

Certain skills are needed to adequately prepare for, conduct, and document a culvert inspection. To prepare for an inspection the Inspector must be able to read and interpret plans, construction documents, and previous inspection reports. The Inspector should have a working knowledge of the use and application of the standard tools and equipment listed herein as well as agency technology tools used to collect and document inspection data. All inspectors should be trained as competent personnel for site safety.

Rating System

Section 4 – *Condition Rating System*, provides a guide that will enable a qualified inspector to assess common types of culvert or storm drain system distress, and recognize the severity and significance of distress. This guide is summarized in tables with quantitative measurements to allow assignment of a rating. The chapter concentrates on the most common types of culvert barrel materials, including plastic, corrugated metal, concrete, masonry, steel (solid wall), and timber. Additional information is provided on approach roadways, waterways, footings, and end treatments.

The condition rating system is based on a 5 number scale. A rating of 1 (Good) indicates a like-new component, with little or no deterioration that is structurally sound and functionally adequate. Ratings numbers increase with worsening condition up to a rating of 5 (Failed), indicating failure of a component that directly affects the structure capacity the roadway or the functional capacity to carry the waterway. Similar systems are in use by many agencies for bridge and culvert condition. Condition ratings are based on a comparison of the existing condition with the as-designed condition. Use of the rating system should follow these guidelines:

- The Inspector should select the poorest rating which best describes the component condition. If a condition has more than one criterion for evaluation, the criterion with the poorest rating should be used to select the condition rating. For example, a flexible culvert may receive a low rating for local poor shape, even if all other factors rate as good along the culvert length. In this example, the local distress can cause complete system failure.

- The criteria described for each numerical rating should be considered as general condition, pervasive and representative of the structure as a whole, unless otherwise specified as pertaining to localized distress. The inspection report will provide the defect location for tracking purposes.
- Significant changes in condition since the last inspection should be carefully evaluated even if the structure is still in good or fair condition. In other words, consideration should be given for changes to the rate of deterioration and any associated recommendation to modify inspection frequency.
- The Inspector must be trained to have the necessary skill and judgment for assigning the appropriate numerical rating. The numerical ratings are correlated to the action indicated in the following table:

Table 2 – Rating Scale and Associated Action

RATING SCALE AND ASSOCIATED ACTION					
	1	2	3	4	5
	GOOD	FAIR	POOR	CRITICAL	FAILED
CONDITION	Like new, with little or no deterioration, structurally sound and functionally adequate.	Some deterioration, but structurally sound and functionally adequate.	Significant deterioration and/or functional inadequacy, requiring maintenance or repair.	Very poor conditions that indicate possible imminent failure which could threaten public safety.	Failed or non-functional condition.
ACTION INDICATED	No action is recommended. Note in inspection report only.	No immediate action is recommended, but more frequent inspection may be warranted. Maintenance personnel should be informed.	Team Leader (Inspector) evaluates need for corrective action and makes recommendation in inspection report.	Corrective action is required and urgent. Engineering evaluation is required to specify appropriate repair.	Emergency action is required to address public safety hazard. Roadway closure is typical.

After careful consideration, the research team and oversight panel opted to eliminate the overall single culvert or storm drain system rating. Other rating systems, in an attempt to provide an overall condition rating, used a single number to represent the condition of the entire system and tried to address this by augmentation with some type of importance modifier to emphasize the importance of the component that was most in distress. The 1986 manual does not provide explicit guidance on assigning an overall rating, but rather states “the inspector should consider each component and its possible effect on the structure”. Developing an overall rating can be cumbersome as distress indicators carry different importance with respect to structural materials, culvert size, specific location around the circumference, cross-sectional shape, fill cover, geographical location, environmental requirements, etc. In addition, an overall factor can risk diluting the importance of low ratings if one specific area rates poorly while all others are satisfactory.

A modern culvert and storm drain system inventory management process includes a computerized database that provide a searchable means of statistically analyzing the ratings collected. Agencies and engineers will need to understand where the culverts and storm drains are distressed on a component basis in order schedule maintenance, initiate further inspection, or conduct engineering analysis.

We determined that use of component level ratings is more practical to the managers and engineers who will need to understand the exact nature of the distress in order to take appropriate action. For example, a culvert that receives a poor condition rating due to blocked waterway will be treated differently from a scheduling and engineering perspective than for a culvert that has a highly deflected barrel. Rarely is an entire culvert or storm drain system in poor condition. Typically, there are only specific components that warrant attention. If any component rates low, then it will flag action; therefore, there is no need to provide a single number to represent the entire system.

Condition Assessment Catalog

Appendix B of the manual contains the Catalog of Distressed Condition. The catalog includes photographs from actual culvert and storm drain inspections that depict distress and distress indicators, as listed in the ratings tables. The catalog serves as a visual reference to supplement the description of the condition ratings in Section 4. The catalog should be referenced for both familiar and unfamiliar subject matter to ensure assignment of consistent ratings. As an example, the following Table provides ratings for concrete barrels, e.g. the buried pipe section. The concrete barrels are assessed for cracking, spalling / slabbing / delamination / patches, and deterioration. Joints, alignment, end treatments, and other components are rated in additional Tables in the manual.

Table 3 – Rating System for Concrete Barrel

CONCRETE BARREL					
	1	2	3	4	5
	GOOD	FAIR	POOR	CRITICAL	FAILED
CRACKING	No measurable crack width greater than hairline (maximum 0.01 in.).	Longitudinal cracks 0.01 in. to 0.05 in. wide (thickness of dime) with spacing of 3.0 ft or more. Some circumferential cracks with no infiltration. Efflorescence but no rust staining emanating from cracks.	Longitudinal cracks between 0.05 in. and 0.1 in. wide, no exposed rebar with spacing 1.0 - 3.0 ft. Water infiltration through circumferential cracks. Efflorescence and/or rust staining emanating from cracks. No cracks with vertical offset. No increase in cracking from previous inspection.	Longitudinal cracks greater than 0.1 in. wide, exposed rebar, significant water infiltration and/or soil migration. Cracks with vertical offset. Large areas of rust staining emanating from cracks.	Collapse (complete or partial) or imminent collapse of culvert barrel.
SLABBING, SPALLING, DELAMINATION, PATCHES	No spalling or slabbing, as indicated by wall visual appearance. No delamination. Patched areas that are sound.	Localized spalls less than 1/2 in. depth and less than 6 in. in diameter. No exposed rebar. No slabbing. Small delaminations indicated by hollow sounds at patches but patch remains stable.	Spalling and/or delaminations larger than 3/4 in. in depth and larger than 6 in. in diameter. No exposed rebar. Some rust staining from spalled areas, structure stable. No slabbing. Patched areas that are delaminated or deteriorating.	Widespread spalling greater than 3/4 in. in depth or delamination with exposed rebar, structure unstable. Slabbing of concrete.	Cannot cause failed rating.
DETERIORATION	No scaling, abrasion, or other surface damage.	Light or moderate scaling (less than 0.25 in. exposed aggregate). Abrasion less than 0.25 in. deep over less than 20% of pipe surface. Localized superficial (less than 0.25 in.) impact damage No rebar exposed. Multiple plugged weep holes.	Moderate to severe scaling (aggregate clearly exposed). Abrasion between 0.25 in. and 0.5 in. deep over more than 30% of pipe surface. Impact damage with exposed rebar.	Extensive surface damage and aggregate pop-out. Includes exposed and/or corroded rebar. Complete invert deterioration and loss of pipe wall section.	Collapse (complete or partial) or imminent collapse of culvert barrel.

The full list of rating tables in the *Culvert and Storm Drain System Inspection Manual* includes:

- Approach Roadway
- Embankment
- Channel Alignment and Protection
- End Treatments and Appurtenant Structures
- Concrete Footings and Invert Slab
- Barrel Alignment
- Plastic Barrel
- Concrete Barrel
- Corrugated Metal Barrel
- Masonry Barrel
- Timber Barrel
- Joints
- Seams (Corrugated Metal Plate)
- Manholes, Catch Basins, and Buried Junctions

CHAPTER 4 - CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

The results of this research produced a complete update and revision to the 1986 FHWA *Culvert Inspection Manual*. The new *Culvert and Storm Drain System Inspection Manual* meets the objectives of NCHRP Project 14-26: Inspection techniques have been updated; the condition rating system has been revised to include new materials and more quantitative measures; inspection reporting has been updated; and the manual includes a Catalog of Distressed Conditions to provide photograph references for distress indicators. The manual also includes discussion on best practices to help agencies manage their culvert inventory.

The *Culvert and Storm Drain System Inspection Manual* will prove to be a useful resource to agencies developing an in-house manual for culvert and storm drain inspection programs.

The research team will be presenting the results of this project to the AASHTO Subcommittee on Bridges and Structures (T-13), the AASHTO Subcommittee on Materials (T-4) members at a meeting to be hosted by the National Academy of Sciences, and at the meeting of the TRB Technical Committee AFF70 Culverts & Hydraulic Structures. We have also identified opportunities for publications through which we will present the manual.

Suggested Future Research

Documents such as inspection manuals benefit greatly from periodical updates to include new research on degradation models, insights into material behavior and performance, and new specialized inspection equipment. While writing the *Culvert and Storm Drain System Inspection Manual*, the research team identified several areas for which there is currently a knowledge gap. The following areas for suggested research:

- Use the results of routine culvert and storm drain inspections to provide insight into deterioration mechanisms and their effect on service life.
- Develop a statistical and cost-based approach to evaluating the frequency of inspection based on risk and consequence of failure.
- Develop standards for conducting remote inspection (ASTM Committee C13 on Concrete Pipe is currently developing a Standard Practice for Inspection and Acceptance of Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe).
- Continue to integrate rehabilitation methods with inspection and update as new methods are developed.
- Add criteria for new barrel materials as they are implemented by DOTs.
- Consider development of software for inventory and inspection tracking. There is currently a need for asset management software that incorporates inspection and maintenance data as input to an inventory management process.

APPENDIX A

CULVERT AND STORM DRAIN SYSTEM INSPECTION MANUAL