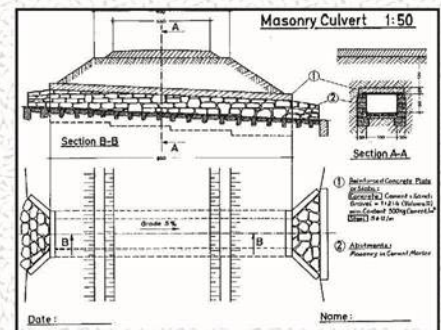


Culvert Management Case Studies:

Vermont, Oregon, Ohio and Los Angeles County



U.S. Department
of Transportation
**Federal Highway
Administration**

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

ABSTRACT

Transportation agencies are responsible for the operation and maintenance of hydraulic control structures including culverts, drop systems, and storm drains. It is difficult for transportation agencies to develop accurate and effective performance measures, budgets, and maintenance plans for culverts because there is a lack of information on the condition and even the location of many of the structures they manage. In this 2013 set of interviews and case studies by the Federal Highway Administration (FHWA), three states (Ohio, Oregon, and Vermont) and one county (Los Angeles) describe how transportation agencies are tackling these challenges and increasing the resilience of their culvert systems. Through the development of effective culvert management systems and policies, they are developing operational protocols and establishing capital improvement budgets that address risks associated with hydraulic control structure failures. Generally, the culvert management systems they have developed are available for other public agencies to use and adapt. The culvert management case studies herein illustrate a path for other departments of transportation and transportation agencies to manage assets more efficiently, reduce risk, and improve public safety.

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EXECUTIVE SUMMARY

State departments of transportation (DOTs) usually know when a highway was built or pavement was last replaced, but they often have considerably less information about the culverts beneath transportation infrastructure. DOTs have sophisticated, dedicated management systems to help prioritize and maximize investments in bridges and pavements. In contrast, culvert locations are not always marked or even known, making them more difficult to manage. State DOTs commonly rely on maintenance staff to observe and report culvert problems before they become urgent, especially if they lack more formal management systems; for example, maintenance forces watch for small dips in the pavement as they drive. When transportation agencies know culvert locations and conditions and can identify and execute repairs before too much damage has occurred, they can greatly extend culvert lifespans. This report shares information from three state DOTs and one county about how DOTs are inventorying culverts and managing their data to extend culvert life and reduce costs and risk.

Section 1203 of the transportation reauthorization act, Moving Ahead for Progress in the 21st Century (MAP-21), encourages state DOTs to extend their asset management efforts beyond pavement and bridges to ancillary structures in the right-of-way through the use of risk-based asset management plans. DOTs are interested in culvert rehabilitation strategies that maximize system performance and reduce risk, whether from eroding conditions or increasing precipitation.

This round of case studies on culvert management at the Ohio DOT, Oregon DOT, Vermont Agency of Transportation (VTrans), and the Los Angeles County Department of Public Works (LA County DPW) extends the series that FHWA started with Alabama DOT, Maryland State Highway Administration (SHA), Minnesota DOT, and Shelby County, Alabama, in 2007. State and county transportation managers tell how they have elevated the priority of culvert management at their agencies and extended culvert maintenance and management systems. Their stories chart a path for other transportation agencies to reduce risk, preserve assets, and improve public safety. The planning sections of these case studies note whether states are seeing impacts to their infrastructure from changing precipitation and climate and what, if any, action they plan to take for the future.

Findings

The number of culverts managed by the agencies interviewed ranged widely from fewer than 10,000 in LA County to close to 100,000 in Ohio. DOTs frequently divided management of small culverts from larger ones already tracked by Bridge Sections. All of the transportation agencies interviewed already used or were switching to electronic tracking mechanisms and databases, though the agencies were reluctant to characterize these as decision support systems.

While deterioration analyses for culverts remain a future goal in all of the systems reviewed, agencies interviewed were finding ways to connect their maintenance and asset management data for culverts. VTrans was connecting culvert management systems with its maintenance management system (MMS) and then linking them with pavement and bridge management systems for infrastructure prioritization. Ohio DOT had begun to develop deterioration models

and was also looking at how to link data from its Structure Management System (SMS) to maintenance and its Equipment, Inventory, and Materials System (EIMS). The LA County DPW already had data on maintenance of each culvert in the agency's MMS and figured that project costs for specific replacement projects or culvert linings could be captured, along with work orders, for better linkage of system value, life cycle costs of culverts, and the cost-effectiveness and benefits of preventive action.

Both Ohio DOT and LA DPW have fully populated culvert inventories and a degree of annual inspection for risk minimization. LA County had already concluded that annual inspection and simultaneous annual maintenance of all culverts is well worth the effort in terms of both asset preservation and risk reduction. Ohio DOT found that the best preservation maintenance and risk management activity is field inspection, required annually of all at-risk culverts; Ohio DOT said that routine field inspection catches a majority of problems before they become emergencies.

Multiple state DOTs said culvert maps and location knowledge alone improved culvert maintenance. The efforts to map culverts increased general maintenance staff knowledge of their locations and conditions. As a result, maintenance staff members are more inclined to realize, check, and address threats earlier, prolonging culvert service life. Generally, all states with culvert management programs are trying to stay ahead of resurfacing projects to prevent open cut of new pavement after resurfacing and to leverage larger capital projects whenever possible.

Some states invested more in culvert inventory training than others. The longest trainings took two weeks and included safety training and more testing to ensure that raters were scoring culvert conditions the same way. Ohio DOT emphasized completion of a statewide inventory of all culverts in a couple of years and conducted the shortest training for locaters and condition raters, noting that risks of unreliability would be reduced along with failure risks as lower scoring (at-risk) culverts were reviewed annually. Districts had the incentive to keep culverts at higher condition levels in order to avoid the annual monitoring that would otherwise be required.

Best Practices and Recommendations

The following potential best practices for launching and institutionalizing a culvert inventory and cost-effective culvert management system were uncovered through this research:

- **High-level management awareness of culvert risks** can help get statewide programs off the ground and gain the attention of regional or district leadership. DOTs that launched programs successfully leveraged opportunities including disasters.
- **Financial incentives for complete culvert inventories.** Ohio DOT pooled all spending on culverts across its bridge, pavement, and maintenance budgets. Starting in fiscal year (FY) 2015, Ohio DOT will allocate those funds to districts according to the culverts in the statewide inventory, which will provide all districts with a solid incentive to complete their inventories.
- **To reduce risk, the number of levels in the system, the amount of training, or accuracy of the technology may not matter as much as just getting a system in place. Start a culvert management system and the data will improve with time.** The DOTs

interviewed were using systems with as few as three categories or levels of culvert condition (or deterioration) and as many as nine, in line with the National Bridge Inventory. Once culverts are located and in a system, with condition assessed in some capacity, the agency is better situated to reduce risk, manage culvert life cycles, and leverage other capital investments in the area such as pavement overlays.

- **Reduce data collection to what will be used.** Internal groups and stakeholders can identify large lists of potential data to be collected; however, the agency should make sure it knows how the data will be used and how often it may be used. Oregon DOT evaluated whether information collection was sustainable over time. Ohio DOT produced a monthly culvert management overview.
- **Some states planned to train Bridge staff** so they could evaluate shorter span culverts as well as the larger ones that already fall under their purview. VTrans planned to train staff on its management system for shorter culverts so the staff could help update the culvert system for all sizes.
- **User-friendly inventory and inspection tools (tablets) help implementation.** Some state DOTs, notably South Carolina, have elected to use iPads for affordable and easy data entry and basic global positioning system (GPS) location. Some interviewed states are considering tablets and said that inspectors enjoyed the all-in-one ease of contacting other staff and downloading related information. More urban or densely populated states often have better cellular service coverage, which enables the use of tablets to establish culvert locations.
- **Visualize! User friendliness extends to the data management system as well,** with simple visualizations winning the most praise. In Ohio, use of the culvert management system with ArcMap and the ELLIS project management system **showed the user where potential transportation improvements were in relation to culvert needs** to leverage investments in each to the maximum extent possible.

The case studies that follow examine how agencies are managing their culvert systems to derive maximum benefit from limited funds.

LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS CULVERT MANAGEMENT

The LA County Department of Public Works (DPW) maintains a smaller number of culverts and storm drains than many state DOTs. Nevertheless, LA County DPW's annual inspection of all culverts, proactive maintenance, and integrated collection of maintenance information provides a model for other transportation and public works agencies. During the annual inspections of all culverts, LA County DPW maintenance staff clean and make minor repairs as necessary. As part of the inspection, staff also photo document the cleaned condition of each culvert entrance. GPS equipment on the cameras stores location information.

LA County DPW has accomplished this notable level of accountability and proactive prevention of culvert failures with a relatively "low tech" approach. As of 2013, staff members documented the condition of inlets, outlets, pipes, and any associated structures on paper and with electronic photos instead of collecting field data electronically. The county anticipates utilizing more mobile electronic devices for data collection in the future.

The LA County DPW Road Maintenance Division and the Design Division Bridge Preventative Maintenance Program are responsible for culvert management under the unified direction of the county's deputy director of public works.

LA County's Culvert and Storm Drain Management System (CMS) is managed from a central office and from the county's four road maintenance district offices. Other storm drains within the county's unincorporated areas are maintained by the Los Angeles County Flood Control District.

Since maintenance staff members are so involved in condition documentation and management, LA County's deputy director of public works considers all county road maintenance staff to be part of the culvert management system. LA County's 5,072 culverts require the attention of 40 maintenance staff members. This includes about 15 percent of the time of 4 engineers and 20 percent of the time of five bridge inspectors. Culvert management is fully integrated with maintenance management and is part of a unified asset management system.

Inventory and Inspection

LA County DPW's annual inspection of all culverts (85 percent of which are steel) is a visual inspection. If the length of the pipe cannot be seen from either end, inspectors shine a light through it to determine whether there is any obstruction. If damage or obstruction is suspected, staff run water through the pipe to test for obstruction or use a closed circuit television camera to assess the condition of the pipe. Maintenance staff members give culverts and storm drains

LA County's Deputy Director of Public Works thinks the maintenance staff's "annual inspection and cleaning has probably been the most beneficial practice for our culverts." The inspections and annual maintenance have helped prevent failures and reduced the county's liability, especially considering that loss of single access in mountainous areas can expose residents to particular risk during the fire season.

descriptive condition ratings such as “good,” “in need of repair,” “blocked,” “eroded,” or “collapsed.” As the culvert system ages, LA County DPW management would like to videotape the system routinely to better assess its condition. This work would likely occur on a contract basis. Once all of the culverts are mapped in geographic information systems (GIS), the department plans to geographically divide the culverts into 10 areas and have the culverts in one area per year videotaped.

LA County DPW maintenance staff schedule inspections between storm seasons. Natural disasters and other maintenance work sometimes impact the scheduling of culvert inspection and repair work since maintenance responsibilities extend to all facilities, not just culverts.

LA County DPW did not have a written culvert management procedure, but it did conduct both formal staff training and on-the-job orientation. Larger bridge culverts were inspected per the American Association of State Highway and Transportation Officials (AASHTO) 2008 First Edition of the Bridge Manual for Condition Evaluation, related FHWA reports, and the Caltrans Element Level Inspection Manual. Bridge culvert condition states are updated in Pontis Bridge Software, including sufficiency rating, culvert rating, and other NBIS ratings.

County DPW staff members were trained to use the county’s Maximo asset management database. Bridge inspectors also took the National Highway Institute’s two-week Safety Inspection of In-Service Bridges course among others. Bridge inspectors attended the Caltrans Area Bridge Maintenance Engineers monthly meeting and received continuing education there as well, some pertaining to bridge-size culverts. In general, county road maintenance personnel were not trained in confined space entry, but if necessary, they could request assistance from other DPW personnel who were trained.

Database and Management Systems

The DPW inventories and tracks maintenance on all structures (including culverts and storm drains) using its MMS. All of the county’s non-bridge culverts and other assets are tracked and managed in Maximo, a system the county has used for asset management for more than 16 years. The DPW has kept data on bridge culverts in Pontis Bridge Software for consistency with Caltrans and FHWA. Upcoming versions of Pontis are expected to be able to predict future deterioration of bridge culverts. To date, LA County DPW has lacked deterioration projections for culverts, so this type of decision support has not been available. To conduct project and maintenance planning, LA County DPW uses both ArcGIS and Maximo.

LA County DPW’s Maximo system did not store hydraulic design or watershed information, but, unique among FHWA’s 2013 case studies, it had been tracking maintenance work history and describing repair or replacement strategy and improvement projects. The department said that it was not used as a decision support system for projecting future conditions or for funds allocation, but data within the system were used by staff in their discussions on asset needs. Since Maximo was used for all of the department’s assets, the department did not feel able to move to another system with more extensive deterioration or remaining service life models that could proactively explore different maintenance strategies.

LA County DPW is in the process of developing a GIS map of all its drains and culverts. That data will be incorporated into an integrated multi-agency GIS-based storm drain network map to provide information about all Flood Control District drains in LA County. Previously, LA County used Google Earth to update GPS coordinates for bridge culverts. A series of “zoom-in” views are shown on the next pages.

LA County DPW also has a financial management system that tracks expenditures on culvert management. The department’s financial management system links to its MMS with routine updates of labor and material costs. Financial information is updated at the program level (inspection and cleaning for all culverts). In the future, LA County DPW thinks that costs for specific replacement projects or culvert linings could be captured, along with work orders, for better linkage of life cycle costs, action benefits and cost-effectiveness, and system value.

For LA County, the main point is that critical maintenance and culvert cleaning are being completed on an annual basis and that all culverts are inspected annually. This high-level accomplishment, with inspection and maintenance performed in one trip, serves the county’s purposes and budget capacity.

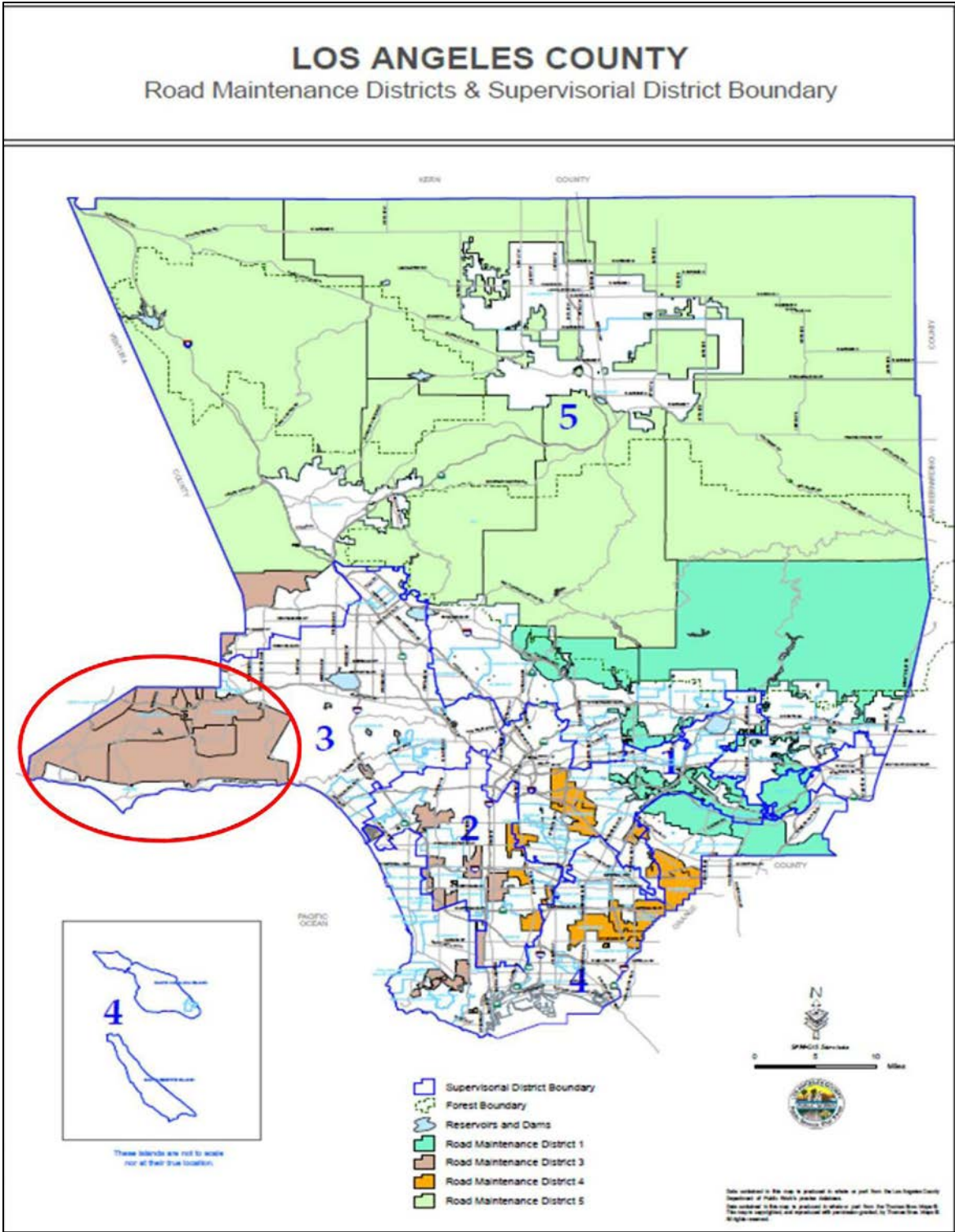


Figure 1: Los Angeles County Road Maintenance Districts & Supervisorial District Boundary Map can be scaled down to look at culverts.

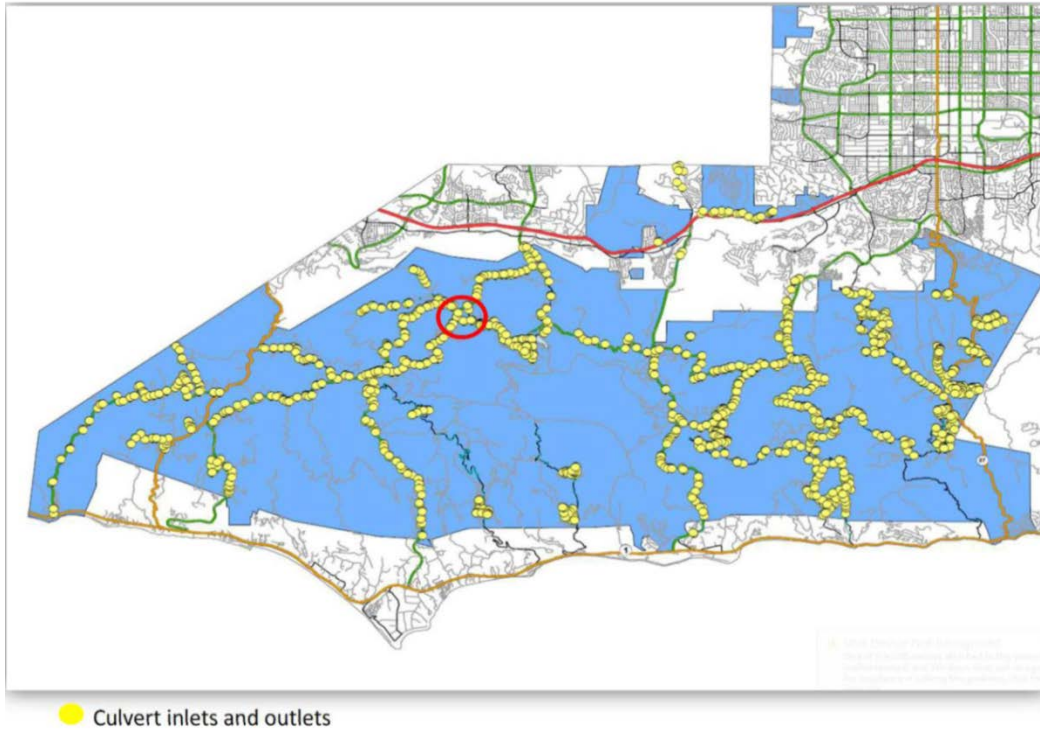
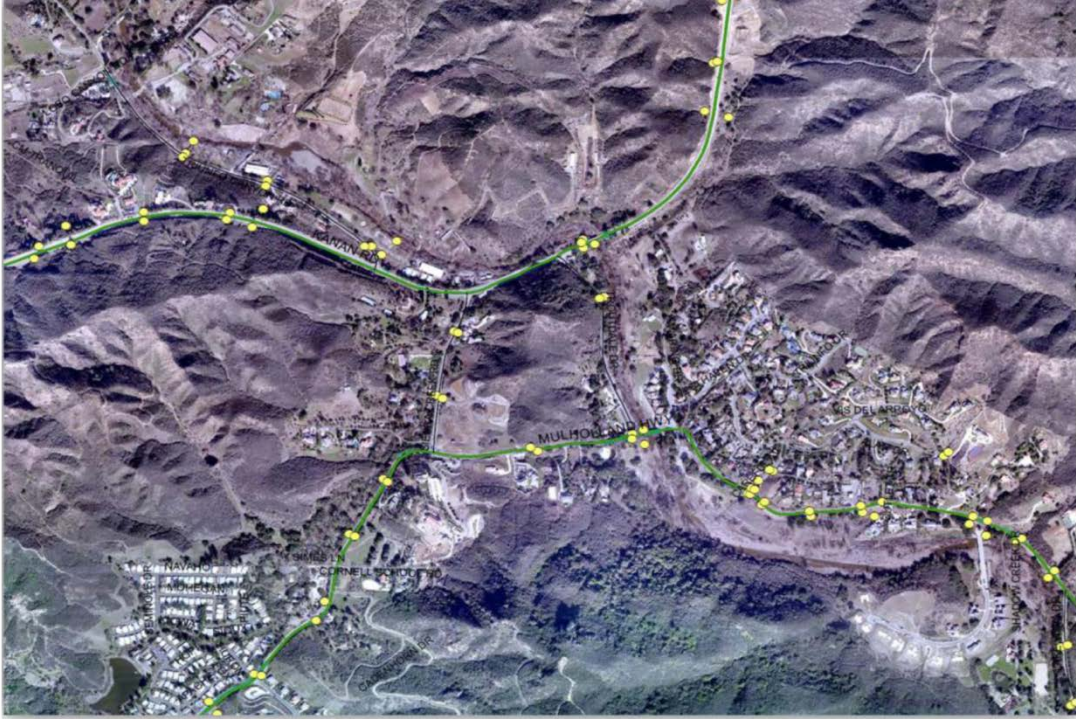


Figure 2: Zoom-in View of Culvert Inlets and Outlets – Los Angeles County.



● Culvert inlets and outlets

Figure 3: Aerial - Further Zoom-In of Los Angeles County Culvert Inlets and Outlets.

Prioritization and Risk Assessment

The LA County DPW Design Division and Road Maintenance Districts collaborate to identify the best preservation, maintenance, and rehabilitation solutions. Maintenance districts perform the initial prioritization of culvert improvements based on risk minimization, placing higher priority on those culverts located on routes with no alternative route if the culvert failed and the road became impassible. Districts use Excel, Maximo, and Pontis Bridge Software to help prioritize culvert remediation actions that should be taken next to minimize risk or maximize future protection.

To enhance network level and programmatic analysis, LA County DPW is working toward better identifying and prioritizing its deficiencies through GIS mapping and routine condition assessment of all culverts. The county's combined multi-agency GIS-based storm drain network map will help the agencies identify weak links in the network, whether inside or outside of the systems each agency manages. As previously described, the county has primarily minimized risk by inspecting and cleaning its culverts annually and making subsequent minor repairs. This process has reduced the need for emergency repairs or prioritizations of maintenance activities. It also has extended culvert life cycle and culverts to be replaced within the county's allocated budget.

If, in the course of their annual inspection, field staff discover a culvert or drain is damaged, then county maintenance staff make repairs or replace the drain or culvert depending on the condition, with assistance from the Design Division. Field staff members handle routine maintenance. Maintenance district engineering makes repair or replacement recommendations, and the deputy director decides whether to proceed with repair or replacement projects beyond routine maintenance. Managers receive annual inspection reports for culverts and biennial inspection reports for bridge culverts. Each maintenance district develops its own informal plan for improvement.

The drivers for culvert improvements are diverse. Outside of transportation/capacity and renewal projects, condition assessment, and in some instances natural disasters like fires, major storms, or landslides, drive culvert improvement actions and upgrades. As road construction projects are programmed or developed, planning and design staff members solicit input from maintenance districts regarding which culverts need to be repaired/replaced and could be incorporated into road and bridge improvement projects. The county reported that culvert improvements were sometimes delayed because of regulatory permit and right-of-way issues.

Planning and Funding

Life cycle costs are of high concern to senior management at LA County and to designers who are managed under the same deputy director of public works as maintenance forces. County management reports to the Commission and provides agency accountability if and when culvert washouts occur. To manage life cycle costs at the project scoping level, the county compares the cost of a culvert replacement/improvement project and its resultant reduced maintenance cost with minor concrete repair and ongoing additional maintenance costs. The county also weighs the cost to manage risk and the community benefit in both scenarios. These factors are

considered at the conceptual level; detailed analyses of actual costs other than the construction cost are not prepared.

On average, LA County DPW's budget for culvert and storm drain maintenance is \$5 million annually, of which 65 percent is spent on preservation (inspection and cleaning); 15 percent on maintenance (repair); 10 percent on rehabilitation (lining and reconstruction); and 10 percent on complete removal and replacement of the existing culvert or drain. Drain lining and major drain replacement are generally performed under contract by third parties.

If a deficiency is discovered during the course of an annual culvert inspection and a maintenance crew cannot make a minor repair to address the issue at the time, the county generally proposes and completes a culvert lining or replacement project within a year. This approach has enabled the county to avoid a repair backlog on its small culverts. Meanwhile, the county recommends remedial repairs for approximately 30 percent of bridge culverts yearly.

Unlike some other areas of the country, Los Angeles has not had to cope with increasing storm flows. With respect to extreme weather or climate change vulnerability and risk assessment, LA County has tracked projected rainfall across the county based on climate change and hydraulic capacity analysis from new data; however, rainfall amounts do not appear to be increasing overall, and the county has not been experiencing culvert failures when major storms come through, except when other infrastructure and property damage occurs.

LA County has not undertaken an assessment of climate change vulnerability and risk; nor is the county measuring or comparing performance of its culverts in record storm events. With no forecast increase in rainfall, LA County is planning no adjustments to hydraulic design criteria or plans, programs, or standards. The DPW collects rainfall data, and road maintenance personnel conduct drive-by inspections of culverts and drains during and after significant storms.

Summary

LA County's culvert management program is unique not only in its annual inspection of all culverts in the county system, but also in the agency's annual maintenance of all culverts in the system. While annual drain cleaning and inspection is resource intensive and state DOTs have decided they cannot afford this level of maintenance, LA County thinks the benefit gained has been well worth it. The DPW is reducing washout risks and extending culvert lifespans, and the county has no backlog of small culvert repairs.

Best Practices

- Culvert and maintenance management integrated in a unified asset management system.
- Annual inspection of all culverts and photo documentation of cleaned culverts and culvert condition. Inspection and maintenance occurs and minimizes backlog.
- Use of GPS equipment on digital cameras to capture culvert location.
- Conducting inspections before the storm season or between storm seasons to prevent culvert failures during the storm season.

- Ability of maintenance and asset management system to track maintenance activities, store facility inventory information, analyze staffing needs, and provide cost analysis.
- Financial management system linked with the MMS to track expenditures on culvert management and information updated at the program level.
- Use of Excel, Maximo, and Pontis Bridge Software to help prioritize culvert remediation actions that should be taken next to minimize risk or maximize future protection. Use of GIS to identify and prioritize deficiencies and identify weak links in the network.
- Prioritization for culverts located on routes with no alternative route if the culvert failed and the road became impassible.
- Planning for culvert repair/replacement occurs when road construction and improvement projects are programmed or developed.
- Conceptual comparison of costs at the project scoping level.

OHIO DEPARTMENT OF TRANSPORTATION CULVERT MANAGEMENT CASE STUDY

Ohio DOT developed the concept for a Statewide Culvert Management System for conduits with spans less than 10 feet after a collapse in Cleveland on Interstate I-480 in 2001. (See Figure 4, below). A district staff member noticed a small dip in the pavement, which turned out to be an indication of a large void resulting from a culvert collapse beneath the interstate. Only the concrete pavement above the void supported the traveling public. The emergency repair closed lanes on the interstate, which caused traffic delays and made the evening news. Ohio DOT used the close call and negative publicity to launch an effort to create a Statewide Culvert Management Program.

Initially, Ohio DOT headquarters created an optional rating system and database that districts could use. This effort spurred little action, but in 2011, the new chief engineer created an Office of Hydraulic Engineering (OHE). According to the OHE staff members, the chief engineer was one of the best advocates of the culvert program because of his background in hydraulics and his understanding of the risks culvert failures can present. The OHE was responsible for administering and implementing the statewide culvert program and database from a technical program perspective, while the DOT districts were responsible for collecting field data. As of July 2013, Ohio DOT had a nearly complete inventory of the state's culverts and a sizeable percentage of the state's larger storm drains. More than 79,000 features that were less than 10 feet in diameter were in the inventory, the results of which are shown in Figure 5.

Ohio DOT established an incentive for all ODOT districts to complete inventories of their culverts by creating dedicated funding to repair or replace deficient culverts, starting in FY 2015. Ohio DOT will fund each district based on the conditional needs of culverts and storm sewers within their districts, thus helping incentivize district attention to culverts, data collection, and management.



**Figure 4: Culvert Collapse on I-480 in Cleveland in 2001.
(Ohio DOT)**

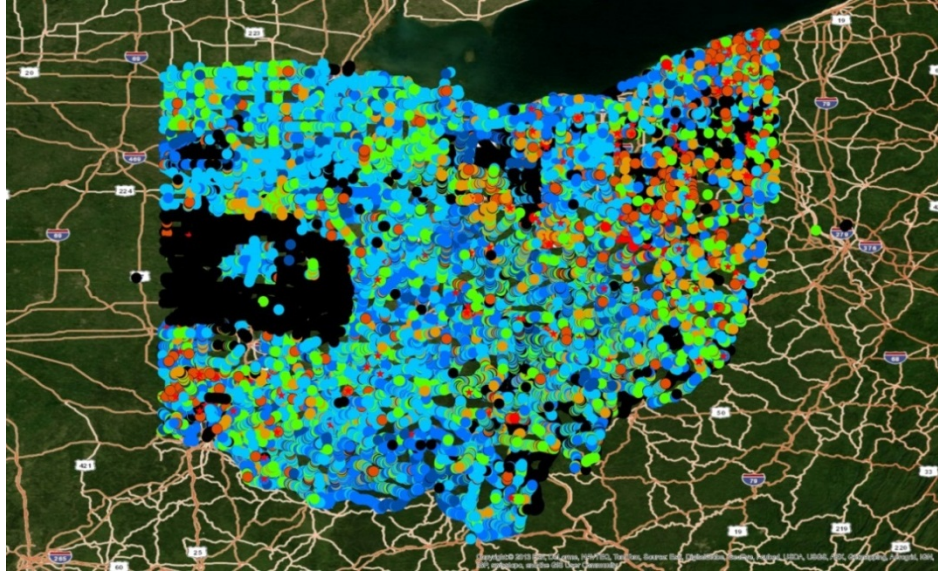


Figure 5: Ohio DOT Culvert Management System Inspection Results – location points are color-coded to represent the General Appraisal Rating. Black indicates that no inspection was performed.

Inventory and Inspection

Ohio DOT district employees collect culvert inventory and inspection data with hand-held Trimble GeoExplorers. Ohio DOT’s mobile software syncs existing data from a central database to the mobile device, which can then be modified in the field and re-synced to the database upon return to the office. The custom software presents separate inventory and inspection screens that match the methodology outlined in the state’s Culvert Management Manual. Drop-down boxes facilitate easy data entry.

Ohio DOT opted to continue and adapt the 0-9 rating system from the NBIS so it could more easily be used in conjunction with the 9-level mandatory inspection that occurs for bridges and culverts with spans greater than 10 feet. In Ohio DOT’s 9-level system, a culvert condition rating of four or less indicates that maintenance or replacement (and annual tracking until this occurred) is required.

Ohio DOT’s OHE staff members have been rigorous about regulating the culvert inventory information to be collected. OHE urged staff to get the most needed information, “the 5,000-foot level,” and assume that the data they could collect would improve over time.

ODOT does not currently have the ability to store pictures in the database, but some districts take photographs and they have their own storage methods. This deficiency will be addressed with a new database and Culvert Management System that will begin development in summer of 2014. A new mobile device, the Juniper Systems, Archer 2 units will be utilized to collect inventory and/or inspection data in the field with both the current mobile software and the upcoming Culvert Management System. The device will be able to take pictures for direct placement within the new Culvert Management System.

As of July 2013, Ohio had more than 79,000 hydraulic features in its inventory of culverts and storm sewers (spans between 12 inches and less than 10 feet). The diverse culvert system includes 44 percent concrete, 26 percent metal, 12 percent plastic, 10 percent clay, and 6 percent cast iron pipes, in addition to smaller percentages of brick, stone, timber, and other materials. More than 85 percent of Ohio DOT's culverts were under less than 8 feet of cover, though some culverts lie beneath 100 feet or more of fill. Around one-third of the culvert inventory has been inspected and rated in the last four years.

Ohio DOT's inspection training is shorter than in other states. Ohio DOT's culvert management engineer in the OHE offers a one-day training class of six hours. The class reviews the inventory process and spends most of the time reviewing how to perform an inspection. Instructors discuss the 0-9 rating scale and focus on applications in concrete and metal. The OHE also offers field data collection software training to districts as requested. The training follows the manual, which has been updated biennially.

OHE started spot-checking for inter-rater reliability/duplicability in 2013. In the same year, Ohio DOT began performing quality assurance inspections for all districts by checking the inspections and ratings of five randomly selected culverts in 50 percent of the districts. This cycle will be ongoing, with the completion of the first cycle in two years unless a change in the frequency is later warranted. The OHE noted that ratings by the most experienced staff tended to be the same, and agency policy was for raters to provide ratings within one level of each other.

Ohio DOT's culvert management program depends on the leadership of a single full-time engineer within the Hydraulics Section of the OHE, who ensures the statewide culvert management system is operational and provides training and technical assistance to districts and consultants. Ohio DOT has conducted some cross-training within OHE and the districts to extend staff coverage; OHE management is also actively involved in the program to provide some program security in case of staff succession. Consultants supplement internal staff inventory efforts. Since districts were responsible for completing the inventory of all of their culverts in the 2012-2013 year, several made use of consultants that were hired via a central office task order.

Database and Management Systems

Ohio DOT's culvert database allows linking and display of culvert data in conjunction with other data sources within the department. Ohio DOT's database containing project information (ELLIS) can be mapped and overlaid onto ArcMap, a geographic information system that contains a layer with culvert information. The culvert database is designed to store watershed and hydraulic design information as well as condition assessments of culverts and storm drains. Ohio DOT did not have the ability to store pictures in the culvert management database at the time of the interviews, but some districts took photographs and stored them according to their own methods. As of 2014, Ohio DOT is consulting with AgileAssets to develop a new Culvert Management Program for Ohio DOT. This new system will store pictures, videos, or any other

“The best preservation maintenance activity and risk management activity is field inspection. Routine field inspection will catch a majority of the problems before they become emergencies.”

*Jeff Syar, P.E., Ohio DOT
Hydraulics Manager*

document. Photos will include upstream and downstream images, which will assist environmental assessments into the future. Other raster images such as plan sheets, sketches, or notes will be able to be associated with each culvert within the new Culvert Management System as well. Features, such as documentation of maintenance activities and new data fields for repair or replacement strategy, will be included. Counties and other local jurisdictions will have access to the Culvert Management Program when it comes online.

Ohio DOT OHE staff and management were in the position of having “everything they want in their system. It’s a matter of being able to filter and present it.” OHE continues to add functionality, such as identifying the percentage of culverts being lined instead of replaced. Though Ohio DOT does not track specific maintenance activities, if culvert modifications such as relining or field paving are performed, Ohio DOT adds the year modified and the material used. Ohio DOT is close to being able to estimate the costs and benefits of a culvert management system to show the returns on man hours spent inspecting, and the DOT recognizes the benefit of preventing or avoiding an emergency project. As Ohio DOT staff said, “A good system enables repair and rehabilitation instead of replacement.”

Prioritization and Risk Management

OHE believes that field inspection is the best preservation maintenance and risk management activity. “Routine field inspection will catch a majority of the problems before they become emergency problems. Emergency problems are more costly and they can be minimized through routine field inspection,” said an Ohio DOT OHE staff member.

Prioritization started in the initial inventory; most districts started with the interstates and worked their way down the list of priorities or risks as they understood them. Many of the districts organized their inventories to try to stay ahead of the resurfacing projects, to prevent open cut of new pavement after resurfacing or to ensure culverts requiring attention were addressed in upcoming projects.

Ohio DOT also utilizes a risk-based assessment cycle to help prioritize among its culverts and drains spanning less than 10 feet. Ohio DOT’s data collection effort includes small storm sewers, but culverts are a higher priority due to their constant stream flow and abrasive conditions, which make scour a concern. Ohio DOT inspects culverts with spans from 12 inches to less than 120 inches and storm drain systems with spans from 36 inches to less than 120 inches. Storm sewer with spans from 12 inches to less than 36 inches may be collected at the discretion of the district Office. Conduits with general assessment ratings of four or less require annual inspection. The frequency of conduits above the general assessment rating of four is shown in Table 1.

Table 1: Ohio DOT Culvert Sizes and Risk-Based Inspection Frequencies

Culvert Size	Cycle/Inspection Frequency
1 to 4 feet	Every 10 years or prior to routine roadway maintenance activities, such as resurfacing, whichever is less. These spans pose less of a threat to the traveling public if they deteriorate.
4 to less than 10 feet	Inspect all culverts with a span greater than 48 inches but less than 120 inches every 5 years.

Risk-based review is also built into follow-up requirements. In addition to annual inspection, conduits with a condition rating of four or below, regardless of span size, entail review due to their higher risk of failure. This obligation for review and re-inspection also functions as an incentive for the district to address the culvert and eliminate what could otherwise be an annual extra job. Conduits receiving scores of three and less require immediate action. To avoid emergencies and annual inspection tasks, many districts track culverts rated five as well.

Management has remained very involved in Ohio DOT’s program. The OHE made screenshots of the Excel sheet monthly for management review, prioritization, and decision support. Higher levels are also privy to the information, so all who need it can get to live data.

With the completion of inventory and inspection and increasing system maturity, some districts develop management plans for culverts, an ultimate goal. Inspection ratings in combination with planned projects drive culvert maintenance action/improvements. The highway management administrator in each district uses the culvert data matrix to help allocate funds. Sometimes the district highway management administrator contacts the OHE for an expert opinion, but the Central Office has no plans for a further decision support system or matrix.

“We want them to think about this,” said OHE. “Sometimes the districts go for the ‘Cadillac’ fix for the additional security. If you have culverts that are bad and culverts that are good beneath a road, do you take advantage of the scale and the fact that it is a paving project? Likely, yes.

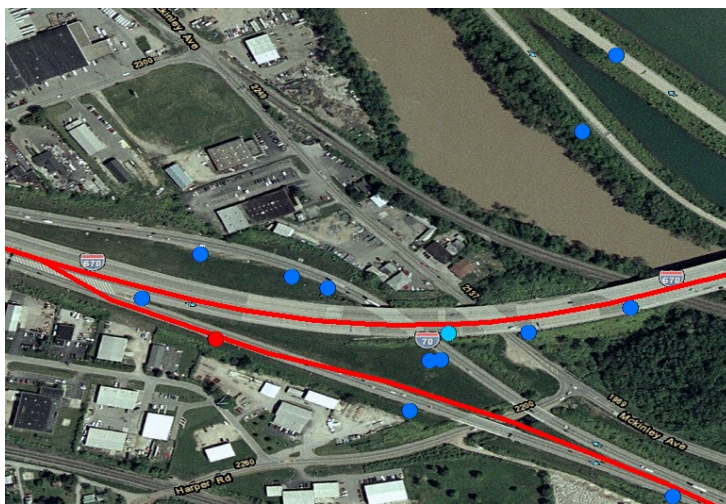


Figure 6: District 6 Culverts (blue dots) with FY 2013 Ellis Layer representing Mill and Fill Project (red line)

Some culverts may be rated a four for several years though, as long as the district is keeping an eye on them at least annually. districts don’t want to have to look at it annually though, so that is another carrot.”

District forces inspect culverts in advance of resurfacing projects so that culvert replacement needs can be included in project scopes of work (as shown in Figure 5). If geometric issues prompt the need to buy right-of-way, the time and expense involved can preclude fixing the culvert(s) that way, since resurfacing projects typically do not include such

additional work. Use of the culvert management system with ArcMap and the ELLIS project management system tells the user what projects are coming up and where and when they will be funded and designed.

OHE stressed that culverts are durable and have a 50-70-year service life, and the agency is working at extending those all the time. With this inspection program, Ohio DOT staff said that if they catch a corrugated pipe culvert soon enough, they can do small paving and avoid replacement or lining that is more expensive. They hope to get to an economical point and do the cheaper maintenance earlier, to reduce costs. They are trying to catch invert deterioration earlier.

At Ohio DOT, the life cycle cost of the culvert material is not a big consideration in deciding how to rehabilitate or replace culverts. Conduit durability data is somewhat suspect as durability is “based on data collected in the ‘70s and guidance created in the ‘80s,” said OHE, and new research, material, and protective coatings are available now. Ohio DOT has active research that is re-evaluating conduit durability. Ohio DOT reported that some culverts were lasting longer than expected when site-specific abrasiveness and pH were not issues.

Planning and Funding

To give more attention and incentive to culvert maintenance, Ohio DOT created a dedicated pool of funding beginning in FY 2014. OHE estimated that Ohio DOT districts were spending a combined \$18 million annually on culvert rehabilitation and replacement when expenditures from pavement, bridge, and maintenance programs were combined. In FY 2014, Ohio DOT distributed funds for culverts from a pool of \$20 million based on the number of lane miles each district managed. Beginning in FY 2015, Ohio DOT distributed the culvert funding based on the number of culverts and condition ratings found in each district. This creates a strong incentive for districts to complete culvert inventories in order to get their share of the pool of funds.

Ohio DOT rehabilitates and extends the life of culverts whenever possible. Ohio DOT internal maintenance forces were restricted to a maximum dollar amount of \$50,000 of work per culvert through the Ohio Revised Code (ORC) until July of 2013 when the ORC was revised. The ORC now specifies a maximum cross sectional area of 52 square feet versus a dollar amount limit. This gives ODOT internal maintenance forces increased ability to make repairs.

The state relies on contract maintenance task orders for invert paving and concrete re-lining, and the DOT has found efficiencies with grouping culvert replacement and rehabilitation projects. MAP-21 allows spending contract work on maintenance items, and Ohio DOT’s agreement with FHWA lists bridge and culvert-related expenditure codes among transportation investment program projects in ELLIS.

Ohio DOT attributed the culvert failures the agency had experienced to lack of maintenance in the past, rather than the stresses of increasing storm intensities or frequencies. Ohio DOT derived new intensity-duration-frequency (IDF) curves after downloading and mapping recent National Oceanic Atmospheric Administration (NOAA) Atlas 14 rainfall data in a GIS format. Ohio DOT developed rainfall regions for the state using contours from the 10-year frequency, 60-minute duration precipitation data, which produced areas that roughly matched the existing regions used by the department.

OHE found that the intensities for the more frequent events were slightly higher and that the intensities for the less frequent events were slightly lower. The new IDF curves will be implemented in July 2014. Alterations may be made to designs using the more frequent events (lower frequency); however, this would only pertain to smaller events and what is designed using the rational equation. Ohio DOT anticipates changing the design of inlets over the next year and adopting the Hydrologic Engineering Circular (HEC-22) Urban Drainage Manual and software to design inlet spacing.

Summary

Ohio DOT learned a number of lessons during the development of its culvert program. OHE particularly valued the attention of senior leadership and the consolidated funding for culverts, which incentivized completion of the state's culvert inventory. Ohio DOT also noted that dedicated staff members at the Central Office and the districts were involved in promoting and administering the program, and districts shared specialized staff such as those with roving inspection cameras. Most of all, OHE valued its completed inventory and inspection program that operates, so that if the department catches a corrugated pipe culvert soon enough, they can do invert paving and avoid replacement or more expensive repair solutions. Ohio DOT said its existing culvert management system is helping to "get to an economical point and to do the cheaper maintenance earlier. This helps reduce our costs, to find them early."

Information regarding Ohio DOT's Culvert Management Manual and Culvert Management Training is available at: www.dot.state.oh.us/ and SEARCH: "Culvert Management Training" or "Culvert Management Manual." Google Keyhole Mark-up Language (KML) files, enabling viewing in Google Earth and Google Maps, are created for every district on a weekly basis and placed on an ftp site for consultants' use for the Culvert Inventory/Inspection Task Order.

Best Practices

- Focused, one-day training on the 0-9 culvert rating system.
- Completed inventory of culverts. Districts incentivized to complete inventory and provided with central task orders to tap consultants for help doing so.
- Dedicated funding to repair or replace identified, deficient culverts starting in FY 2015.
- Full-time hydraulics engineer devoted to the culvert management program.
- Viewability of culvert database in relationship to DOT investment program, helping visualize opportunities to leverage projects, funds, and staff time.
- Proactive inventory, inspection, and maintenance of all culverts statewide.

OREGON DEPARTMENT OF TRANSPORTATION CULVERT MANAGEMENT CASE STUDY

For decades, Oregon DOT (ODOT) has been committed to extending the state's asset management data system to culverts and other small assets. Oregon started collecting location and type information for culverts down to 36 inches in span in the mid-1980s by taking information from existing paper plans. The Bridge program also has a long history of gathering information on larger culverts, including those down to spans of 6 feet. In the last decade, ODOT started locating culverts 12 inches and larger in span and assessing conditions of culverts on state-identified priority routes under ODOT's Geo-Environmental Section.

ODOT's Asset Management Steering Committee has acknowledged culverts as a priority asset warranting additional effort. While major culvert failures have not been a driving factor for instigating ODOT's culvert management program, staff members statewide have been aware of the poor and critical condition of many culverts. As one staff member said, "The agency understands culverts are a problem, but they've never had a 'school bus in a hole' or been able to say exactly how big a problem it is."

Historically, some ODOT District Maintenance managers used varied methods for keeping district-specific information on culverts in each district. The state still lacked data to support strategic prioritization, especially on a larger scale and for larger allocations for culvert repair.

Inventory and Inspection

In 2002, ODOT initiated a project to develop a data management system to track, document, and supply information concerning stormwater facilities and culverts. Leveraging FHWA's existing inspection criteria for cross-culverts, ODOT headquarters developed inspection criteria and a condition rating system for each type of facility. ODOT also wanted to estimate the time and effort required to collect and enter data on all culverts, pipes, and stormwater facilities within the entire ODOT system based on pilot data collection.

In 2006, ODOT selected a pilot set of routes to inventory a suite of assets and district maintenance staff collected the culvert data. ODOT included this in the agency's Asset Management Integration (AMI) effort. ODOT's first pilot inventory sampled highways with a variety of different terrains and with enough points and information to conduct a statistically valid analysis. ODOT Information Technology staff then developed the Drainage Facility Management System with contractor assistance. With this data, ODOT examined general benefits and costs for three possible levels of culvert inventory as shown in Table 2.

Table 2: General Benefits and Costs for Three Levels of Culvert Inventory at Oregon DOT

Benefits	Definition	Level 1	Level 2	Level 3
Location	Culvert location along the state highway system.	X	X	X
Magnitude of problem	The condition of culverts along the highway system.	X	X	X
General culvert condition	Good, fair, and poor rating system.	X	X	X
Detailed condition rating	Detailed culvert and site condition assessment and ratings.		X	X
Project scoping & cost estimate	Ability to use information for project scoping and cost estimates.		X	X
Risk	Severity of problem at each location.		X	X
Life cycle costs	The overall cost of a selected repair or replacement alternative over the life span of the facility.			X
Risk benefit analysis	The comparison of the risk of a situation to its related benefits.			X
Complete photo record				X
	Estimated total cost in \$ without inflation (in millions)	\$3.83	\$4.03	\$ 5.04

ODOT also considered the consequences of “moving too slowly” in inventorying culverts, including increased repair costs due to rising inflation and overhead and higher risk that problem culverts would remain undiscovered and delay funding requests and repairs. The risks of moving too fast were also considered, including not having business processes in place, quality control of field work and higher probability of re-doing work, training challenges, and taking time from other priority initiatives. This analysis was unique among the DOTs interviewed for this study.

In 2007, ODOT implemented the agency’s CMS Work Plan, a framework for improved management of state highway culverts. ODOT hired a consultant to help collect data statewide during the following two years on routes of greatest concern to the Maintenance and Technical Center. Freight routes and those supported by key bridges rounded out the list of high priorities.

By 2010, ODOT refined its Condition Assessment Protocols after input from a variety of sources, including ODOT Research staff, FHWA’s CMS, Utah DOT, Caltrans, and ODOT’s Maintenance and Hydraulics Engineering staff. This refinement resulted in a suite of information that included 45 site fields, 27 condition fields, and 13 photographs per culvert. ODOT documented the protocol and the workflow process to improve efficiency and quality of data in a 2010 field handbook. In 2011, ODOT’s consideration of the data collection effort evolved; ODOT tried collecting and using multiple versions of the culvert condition assessment dataset and ultimately chose a smaller number of fields than was originally attempted. Staff noted the “delicate balance between collecting enough data to provide useful information and the time and resources necessary to collect, manage, and maintain the data.” Just five photographs were

standard in the final protocol. The management system the agency developed still had the ability to capture additional fields, but they were neither required nor regularly collected.



Fig. 7: Field Examples of Culvert Conditions from Oregon DOT's Culvert Assessment Guide

The Engineering and Asset Management Unit provided direct supervision and oversight of the day-to-day operations of culvert data collection and data management, in addition to its general responsibility for asset management of unstable slopes, material sources, walls, and stormwater features. A cross-disciplinary Statewide Culvert Asset Management (SCAM) group provided support and included staff from Maintenance, Asset Management, Engineering, Geometrics, GIS, and Transportation Data. The SCAM provided direction and coordination among stakeholders statewide as well as review of significant scope and budget modification requests. This leadership group made the difficult decision to collect a smaller amount of data in the 1R inventory as part of its effort to get to a sustainable level of information collection and management, especially as the agency continued to reduce staff.

ODOT's Asset Management staff cautioned that they experienced 30-40 percent data deterioration (inaccuracy due to change in asset condition over time) over five years for traffic barriers. The agency experienced 20-30 percent data deterioration for other assets over similar periods of time, which sparked conclusions that more comprehensive, expensive inventories lose their value quickly.

The SCAM reported to the Maintenance Leadership Team and compiled lessons learned. ODOT learned that crew members must have a minimum skill set, be motivated, and be dedicated to the effort for an extended period of time. After several attempts using staff with little training produced data that could not be loaded into the management system, ODOT concluded that appropriate training of field staff was essential.

ODOT estimated the total number of culverts in the state based on the average number of culverts per mile (4.5 culverts) in the inventoried areas, multiplied by the total number of highway miles in Oregon: 8,045. Based on this, Oregon DOT expects the agency owns 35,000-36,000 culverts. ODOT has no plans for a full inventory because the agency lacks sustainable resources to perform regular inspections of culverts 12-72 inches in span and is "too busy chasing the 'critical' and 'poor' culverts." As of 2013-14, the Culvert Inventory Project had a dedicated team of inventory crews assigned to collect data statewide across 1,700

priority miles. This project contributed to the state's IR inventory on priority corridors and segments scheduled for transportation improvements. The process evaluated and rated culverts and six other assets as "Fair/Better, Needs Inspection, or Needs Urgent Attention." ODOT called this "triage-type information" a basic culvert assessment (BCA). ODOT has since determined the safety of the field crews working along the Interstate Highways was of higher priority and have discontinued the use of the BCA on these routes. The data set needed for culvert condition assessment (ACA) is now collected during the initial site visit, eliminating the second site visit required on culverts rated as "Needs Inspection" or "Needs Urgent Attention" using the BCA methodology.

Thus far, ODOT's culvert inventory indicates about one-third of the culverts are in critical (13 percent) or poor (20 percent) condition. Another one-third or more are in fair condition (36 percent) and another one-third are in good condition (31 percent). After the BCA, ODOT evaluates which sites warrant additional investigation to complete the Advanced Condition Assessment and further data collection.

ODOT developed a two-day training class on Culvert Inventory and Condition Assessment procedures and two days of training on GPS equipment and data post processing, following a week of safety training. Based on earlier pilots, ODOT had discovered that approximately three person-hours of work were required to collect the basic level of information about each culvert. After one month's training and practice, a two-person field crew was able to inventory 100-125 culverts per month. The program estimated time needed for the culverts to be inventoried and trained 17-18 internal transfers and new hires, in addition to interested District Maintenance staff. Bridge inspectors rated larger culverts using NBIS methods and Pontis Bridge Software, and ODOT planned to train Bridge staff on the system for shorter culverts so they could help update the overall culvert system. ODOT also trained staff interested in collecting culvert information but who were not part of the inventory project over the priority routes. Training on the use of the Drainage Facility Management System is also under development.

Database and Management Systems

Oregon DOT's Drainage Facility Management System (DFMS) is an Oracle-based database with a Cold Fusion user interface. It is managed from ODOT's central Technical Services/Geo-Environmental Section/Engineering & Asset Management Unit. The DFMS allowed districts and regions to update data. Furthermore, it is integrated with ODOT's agency-wide asset management system, TransInfo, an evolving system ODOT has used for almost 10 years. FileNet is used to store the project plans, and TransInfo captures pipe outfall and stormwater control facility information from project plans.

In developing the data fields, ODOT looked at the data fields in its statewide databases and district spreadsheets as well as in FHWA's CMS. ODOT reviewed its existing Hydraulics Inspection Form and the Oregon Fish & Wildlife fish passage culvert inventory. Staff laid out the data items for each source in adjacent spreadsheet columns to identify a complete set of unique data fields and overarching categories to evaluate the options. Photos and a history of condition assessments will be new features stored online. ODOT also decided to present different user interfaces based on user needs (e.g., maintenance vs. fish passage) to encourage regular updating

of information in the database. ODOT still lacks a process to record maintenance fixes and design fixes in the asset system, but this issue may be tackled in the future.

Prioritization and Risk Assessment

The information in the DFMS is used by Oregon’s Transportation Commission in funds allocation decisions and justifications. The DFMS is also used in financial reporting, project development and design by maintenance and by other staff. After Statewide Transportation Improvement Program (STIP) funding allocations are set, a committee of headquarters and region representatives evaluates the list of culverts in need of repair or replacement and selects individual culvert projects, since the STIP has placeholders for “Culvert Repairs.”

ODOT says there is no overall management plan for culverts and that each transportation capacity project is required to scope culverts within project limits for facilities in need of repair or replacement due to structural conditions or fish passage needs. When the culvert inventory on priority routes is complete and available, ODOT staff plan to include more culvert work in the STIP as stand-alone projects or as additions to planned transportation improvements. ODOT did not plan to add functionality to the DFMS to perform deterioration analysis, but the agency is in the process of identifying how it can roll up its ratings to identify what infrastructure is in “critical” or “poor” condition overall and which culverts should be addressed when.

Another driving factor in culvert prioritization is the need to address and improve fish passage barriers. ODOT often looks for opportunities to create projects, especially where infrastructure would otherwise not be addressed for some time and ODOT could partner with other programs or agencies and leverage funds. Fish passage requirements can work against addressing culvert needs and leveraging funding. Due to permit and aquatic organism passage (AOP) requirements, the common wisdom at ODOT has been “don’t touch it unless it’s falling apart;” however, waiting until failures occur can entail other inefficiencies, such as cutting into new pavement, in addition to increasing risks to the traveling public.

Outside of planned transportation/capacity and renewal projects, emergency failures drive maintenance action/improvements. ODOT estimates it has a backlog of culvert and storm drain works in the \$750 million range. When inventory data are available, ODOT anticipates it will be able to tie engineering decision-making at the project scoping level to the program level, which will help optimize budgets as well as allocations among culvert and storm drain preservation, rehabilitation, and replacement projects.

Planning & Funding

ODOT staff members have performed considerable cost estimation for ODOT leadership. After pilot inventories of culverts, ODOT estimated that it would cost \$2.4 million to complete inventory and condition assessment of culverts just on the state’s priority highway routes. Staff also estimated the cost per culvert repair or replacement over the course of its service life at about \$126,000 per culvert (based on one-time culvert funding of \$17.5 million to repair/replace 140 culverts). Total service life needs for the entire culvert system came to a total of \$4.4 billion for all the culverts across a 50-year design life. If the need for repairs occurred evenly, staff estimated that annual replacement and repair costs would come to \$88 million per year. If 25

percent of culverts were in need of repair or replacement in short order, then potential immediate need could exceed \$1 billion, according to ODOT staff estimates. This estimate compares to current funding of \$2.7 million per year for ODOT's large culvert program and \$4.1 million per year for fish passage improvements.

ODOT's Culvert Repairs Program identified a minimum of \$45 million in immediate needs, of which \$17 million were fixed and \$27 million remained. The Engineering and Asset Management Unit administers the Large Culvert and "Fix-It" Culvert Programs' funding allocations statewide to address these needs. Further, the state's "Fix It" Program allocated an additional \$6 million per year for culvert repair and replacement projects. Two-thirds of the dedicated funding for culvert projects is required to be used on designated priority routes; the remainder can be more flexibly allocated. ODOT estimated that keeping culverts at the current condition would require \$45-\$58 million per year.

Oregon has 100-200 large culverts that need to be replaced, but the agency has been replacing just 1 or 2 large culverts every 3 to 4 years. A special STIP program is available to repair and replace 6-20-foot culverts inspected and assessed through the bridge program, but this fund has just \$2-3 million per year, allowing just a few culverts to be replaced. Fish passage requirements limit how far the available funding could go, given that the larger culverts are stream crossings and must meet fish passage requirements and be bigger, which can elevate replacement from "in-kind" – about \$1 million – to a \$5 million bridge project.

ODOT highlighted the need for coordination across functional areas and assets in a systems approach to avoid competition between assets on political grounds or "which section or asset group publishes a risk-related report first." ODOT noted the need to think about the whole system and what would be affected by a seismic or extreme weather event.

ODOT has undertaken an assessment of climate change vulnerability and risk and developed an Adaptation Report, using a 50-year planning horizon and has updated the rainfall maps for the state for the second half of the century. ODOT had not made any adjustments to plans, programs, or standards with climate change or increasing precipitation levels or extreme weather events in mind. The agency is not contemplating doing this in the future either, mainly because "fish passage design criteria have required more additional capacity than would be required due to climate change."

ODOT will take a closer look at hazard sites, especially those that are detour routes or where the agency can design for it or provide some additional adaptation flexibility. Average daily traffic is also a consideration, and the level of risk to the travelling public is of primary concern. ODOT will look at 5 to 10 sites for its most recent climate change adaptation project. The agency's Maintenance Dispatch System is the main agency repository recording extreme events and asset condition and performance during and after those events. In January 2012, ODOT used the system to compile specific maintenance problems seen in the storms that month. ODOT tracked problem drainage and rockfall slide areas and other issues and found that state rockfall databases were a good model for risk-based asset tracking; however, ODOT noted that tracking and recording these issues was not consistent among the districts.

Summary

Oregon DOT is notable for its longstanding efforts related to culvert data collection, its estimates of the costs and implications of data collection, and the estimates of culvert repair and replacement needs the state was able to generate for management. ODOT performed a series of pilots and a deep inquiry by Asset Management staff before deciding to collect a reduced set of “triage” data on culverts on priority routes due to lack of funding and declining staff. Oregon has also invested in extensive staff training. In Oregon, fish passage design requirements have required more additional capacity than changing precipitation would require, so the agency is focusing on hazard sites and detour routes.

Best Practices

- Formal analyses of three levels of potential culvert inventory. Benefit and risk analyses of the speed of inventorying culverts.
- Focus of culvert inventory on routes of greatest freight, maintenance, and technical concern.
- Cross-disciplinary SCAM group, including staff from Maintenance, Asset Management, Engineering, Geometrics, GIS, and Transportation Data.
- Dedicated teams of culvert locators and inspectors supported by Maintenance staff.
- DFMS as a tool used in funding decisions.
- Use of web-based GIS geospatial database accessible via laptops in the field.
- Extensive training provided.
- “Whole-system” thinking.
- Assessing climate change vulnerability and risk.

VERMONT AGENCY OF TRANSPORTATION CULVERT MANAGEMENT

Culvert management at the Vermont Agency of Transportation (VTrans) has had multiple drivers and starting points. The state initially started mapping outfalls in urban areas to comply with the agency's National Pollutant Discharge Elimination System (NPDES) permit. Later, VTrans staff thought they might be able to leverage survey grade mapping of culvert inlets and outlets as part of a major fiber optic installation project across the state. VTrans also had three finalized construction projects where sinkholes developed, which required million-dollar replacements of 4-foot pipes soon after construction. These issues drew considerable public attention.

VTrans is unusual among state DOTs in that Vermont has asset management and performance measures written into statute. VTrans assisted the General Assembly, the Joint Fiscal Office, and the Legislative Council in developing the wording of the legislation and the ultimate statute, which require VTrans to:

- Develop an asset management plan and a systematic goal and performance-driven management and decision-making process for operating, maintaining, and upgrading transportation assets cost effectively.
- Include deterioration rates for infrastructure assets and determine the annual funds necessary to fund infrastructure maintenance at the recommended performance level, over the long term.

In 2005 and 2006, the Vermont State Legislature required a quantifiable transportation project prioritization method that assigned a numeric score to projects listed in the annual budget. Later, the federal MAP-21 legislation encouraged management and investment prioritization of assets beyond pavement and bridges. VTrans has responded proactively by inventorying overhead signs, retaining walls, and pedestrian trail bridges in addition to culverts. VTrans extended its culvert mapping after Hurricane Irene and Superstorm Sandy drew attention to drainage infrastructure and flood resilience.

As part of the agency's culvert mapping efforts, VTrans extrapolated the average number of culverts and drop inlet structures per mile on state maintained highways. VTrans estimates there are approximately 60,000 culverts and 40,000 drop inlets on the state system. While VTrans has inventoried interstates and NHS highways, the agency estimates that just 15 percent of the whole culvert system has been located and assessed.

Like many DOTs, VTrans has long been inventorying larger culverts as part of its bridge system and the NBIS; VTrans had been inventorying and tracking culverts and storm drains 6-20 feet in span for more than two decades. More recently, VTrans divided responsibility for culverts between the Structures (and Bridge) Section and the Asset Management Section; the latter oversees data collection for culverts spanning less than 6 feet.

Inventory and Inspection

Every five years, the VTrans Structures Section inspects all bridges and culverts 6-20 feet in length, which the agency calls "short structures." VTrans has 1,265 culverts in this larger size

range, 1,092 of which are buried. Small culverts are handled by Asset Management. VTrans Operations leads the locating effort for the smaller culverts.

VTrans Operations, supported by temporary staff, started locating small culverts less than six feet in span in 2002. This effort is ongoing; VTrans staff stressed that the agency was still in the process of conducting its first-round baseline inventory and assessment and that the number of culverts the state had was unknown. VTrans estimated the state could have as many as 80,000 culverts less than 72 inches in diameter. Of the latter, the Highway Safety and Design, Asset Management Unit had inventoried 14,468 small culverts and 10,468 drop inlet structures across 735 miles of highway investigated as of early 2013.

VTrans' inventory and inspection forces use different rating systems for small and large culverts. The Structures Section does not have a documented culvert management process for rating bridge-size (6-20foot) culverts or short structures beyond what the agency already used with the NBIS; VTrans utilizes a 0-9 NBIS rating system for culverts greater than 6 feet in diameter. For smaller culverts, VTrans developed and uses a 5-level (excellent, good, fair, poor, critical) rating system. VTrans rates the major components – inlet, outlet, and barrel – of each culvert.

Staff and temporary workers assign condition ratings in accordance with descriptions found in the Statewide Small Culvert Inventory (SSCI) field manual. VTrans inspects culverts visually, in combination with a series of structural flags for culverts using “poor” or “critical” descriptors to indicate possible structural or maintenance issues. Variables associated with roadway surface shoulder stability and erosion help identify culvert problems when structural deficiencies are not apparent during the visual inspection process. Sometimes the agency uses smoke to determine if a culvert is open.

Vermont has numerous locations where the drainage structures (the inlet, outlet, or both) are buried. Field crews use the record plan dimensions and metal detectors to attempt to locate pipe ends and drop inlets, but in some locations this has proven unsuccessful. Buried drop inlets and pipes have been found as deep as 3 feet under sediment. When new locations are discovered, culverts are digitized in the office at a scale of 1:2,000 from orthophotography. Dimensions from record plans are included if available. VTrans has mined some data from other efforts, including route survey data from design projects, the pilot program for the SSCI, and the stormwater mapping project in the Municipal Separate Storm Sewer System (MS4) area. This mix of sources allows users access to the best available data and identify sources in the database. For culverts that cannot be reached, VTrans relies heavily on the conditions of culverts in the vicinity, in addition to surface indications of possible problem areas.

Attributes collected in the culvert condition assessment include:

- Inlet treatment condition
- Outlet treatment condition
- Barrel condition
- Pipe joint section separation

- Projecting culvert ends
- Stone pad
- Sediment
- Erosion
- Road surface conditions
- Shoulder sink holes
- Piping

Of all culvert barrels that were able to be assessed for condition, 93 percent were recorded as being in fair or better condition. The majority of VTrans culverts were made of steel (see Figure 4). Reinforced Concrete Pipe culverts were assessed to be in better condition than Corrugated Metal Pipe; 13 percent more concrete culverts were in the good condition rating (Vermont 2010 Condition report, p. 21).

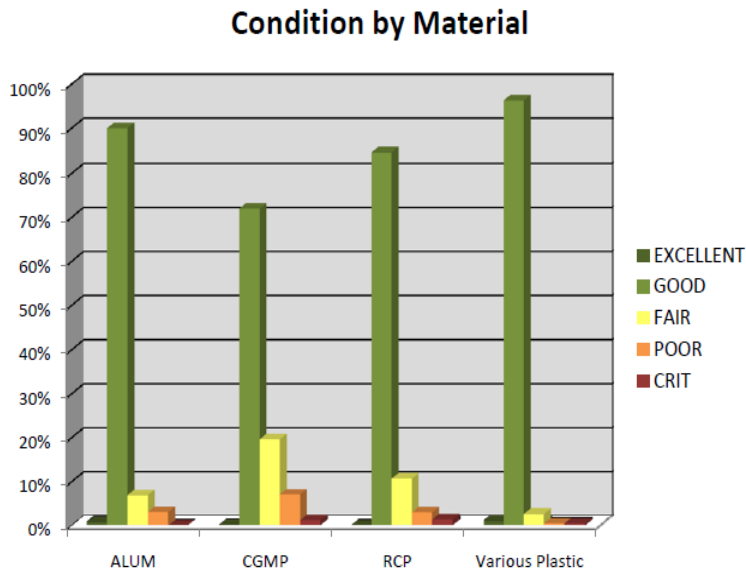


Figure 8: VTrans Culvert Condition by Material (VTrans 2010 Condition Report, p. 21)

The culvert location effort has increased maintenance attention to them, according to VTrans. Once culverts were flagged for action by headquarters Asset Management, district maintenance forces were quick to replace them. For large culverts, VTrans' Bridge staff and the Structures Section flagged those 6-20 feet in span that needed to be addressed and have attempted to program needs into the budget.

In the past, VTrans Operations and Asset Management has used a new group of staff, including interns, to collect data every season. VTrans conducted a week-long in-house training course, followed by one to two weeks of field training to calibrate conditions and understand what is acceptable for sediment accumulation. As VTrans staff noted, "Some of this is describable in a manual, but the condition rating of a 2-foot culvert from the end is a challenge in and of itself. VTrans is more concerned about getting a general culvert condition over a segment of roadway." VTrans would like to move toward a consistent set of in-house inspectors for small culverts, similar to Structures inspection staff, who can build on their experience.

Databases and Management Systems

All located culverts have latitude and longitude information, and having a GIS inventory has facilitated the dissemination of culvert information through various means of reporting and mapping and made the information available to maintenance staff, designers, and other agencies. VTrans' databases store culvert and storm drain information, but it does not store hydraulic design or watershed information, plans, or the repair or replacement strategies the agency has devised for culverts when needed.

VTrans stores large culvert/small structure information in an Access database managed by the Structures Section. For the smaller culverts, VTrans stores data in a spatial Structured Query Language (SQL) database, which VTrans is transferring into the agency's Maintenance Activity Tracking System (MATS). SQL is a special-purpose programming language designed for managing data held in a relational database management system. The maintenance activity tracking system to which VTrans is transitioning is not spatial, but the system database does contain coordinate values for the assets. VTrans uses a series of routines to make the MATS data available through GIS and warehouse reporting tables. VTrans anticipates that incorporating small culvert data into the agency's Deighton pavement management system will improve analysis capabilities, aid investment decision-making and help maximize resources.

In addition to integrating asset management into the state's MATS, the MATS/Asset Management Section is developing two ancillary tools for Operations to facilitate GIS linkages:

- **Web mapping site** – A site accessible through an internet browser containing GIS base mapping data and field inventory culvert data as well as available historic district data.
- **Web reports to aid in the selection of culvert data from the GIS database.** The first report allows users to select culverts from a specific district, town, route, and mile marker and returns a basic report table of information on the culverts in that segment. The second report is an inspection report for an individual culvert that shows the full inspection information from the most current inspection.

As the integration moves forward, the process will direct the data flow of the culvert work or inspections of either Maintenance/Asset Management or Structures Section and will feed the dataset to update the master data. Secondary benefits have already been realized:

- Existing MS4 data/inventory of stormwater features within MS4 areas were absorbed and incorporated into the Statewide Small Culvert Inventory to be properly maintained and updated as needed. The Stormwater Compliance Management Program can then access the data.
- Upcoming MS4 areas were incorporated into the Statewide Small Culvert Inventory as well. In anticipation of the Rutland area being designated in the near future as an MS4 area, the standard Small Structure Culvert Inventory collection procedure was appended with the additional needs of the MS4 program. This effort saved the expense of double collection and will ensure agency data integration into the future.
- VTrans has coordinated with paving projects to leverage resources and minimize risks. With the number of issues that came about in recent years on completed pavement projects, the paving section requested information regarding cross culverts. This data was incorporated into plans for several interstate projects and increased what the agency could accomplish with its dollars.

The complexity of the MATS database proved to be more challenging than originally expected, but the group made some fundamental advances that allow for the integration of culverts and pave the way for additional asset integration and mapping of MATS information in the future. VTrans maintenance activities (and MATS codes) lacked specificity to break down the costs of culvert and storm drain works activities. Instead, VTrans tracked staff hours and accomplishments but not the type of maintenance completed. Hours were tracked, but activities were broad, and drainage work could refer to culvert replacement or cleaning ditches. With the small culvert/MATS integration, the agency anticipated the data documentation would have greater detail.

To better enable municipalities to track and maintain their culverts and to facilitate a more comprehensive view, VTrans created the Vermont Online Bridge and Structure Inventory Tool (VOBSIT), which can be used by both VTrans and municipalities to manage their systems and look at interrelationships. VTrans is updating VOBSIT to make it more user friendly for municipalities, which vary widely in terms of their technical abilities and asset management.

Prioritization and Risk Assessment

When asked about prioritization and risk assessment, VTrans staff emphasized they were at the inventory stage and had not gotten to the point where their system provided decision support for repair options or funding allocation. “This is all a definite mind shift for both design and maintenance, and (culvert management) is yet another area where VTrans is asking them to track new data.” VTrans staff stressed they were really just developing the inventory for smaller culverts and maintaining what they had for NBIS for the larger culverts to provide more information for the agency to consider culvert conditions and options anecdotally and to prioritize culvert repair and maintenance needs. Meanwhile, the inventories are building the foundation to monitor culvert deterioration over time.

Maintenance staff members participate in prioritization and risk minimization for small culverts. Without a full inventory and management system for small culverts, rehabilitation and

replacement occur as critical needs arise. The small culvert inventory has yielded a relatively small number of “critical” pipes that are easily replaced by the districts. In undertaking culvert projects, VTrans tries to take advantage of equipment and staff mobilization. Thus, the culvert replacement process can be heavily based on the paving program, with the availability of funds dictating the replacements of smaller culverts. Districts often identify culverts to be replaced when reviewing their paving projects, whether culverts were last replaced in 1960 or just 25 years ago.

For larger culverts, prioritization of a culvert replacement is driven by the level of deterioration seen with eroded inverts or flooding due to beaver dam building. The VTrans Structures Section manager said the agency has not been doing a lot of maintenance on the culvert system. Rather, the Structures Section is trying to use different techniques, such as reinforced inverts and linings to promote life extension. Influences, such as fish passage or hydraulics, have pushed VTrans to replace some culverts. Now, VTrans Structures Section managers say the agency is “sizing culverts so they will not get wiped out in the next flood. Washouts are opportunities to revisit the design process and find out: If we increase it by a certain amount, can we reduce risk and how much more life will that get the agency statistically?”

VTrans wants to get to the point of prioritizing the short structures (large culverts) based on risk. The Structures section would like to extract NBIS data to assess condition and prioritize for their own planning as well as use such information to obtain public input and Regional Planning Commissions’ priorities. VTrans notes that about 75 percent of culverts in Vermont are owned by municipalities, and municipal culverts upstream and downstream can exacerbate aquatic organism passage and flood resilience for VTrans and other roads from a fluvial standpoint. Many culverts with potential AOP issues have not received attention because the culverts and/or the road above were in fine condition. When VTrans has replaced or re-sized culverts, the size has often been driven by AOP and the bankfull-width requirement. VTrans Structures staff notes that 8-foot depth of fill is a threshold with regard to cost and risk; they look at how much fill the structure has on it and how much removal or replacement would impact traffic. Municipalities have limited funds and staff to address culvert needs, risks, and new design standards too.

VTrans’ new drainage manual will have a risk-based approach and bankfull-width standard instead of defined Q50 year standards. The former manual did not include sediment continuity or AOP. VTrans is in the process of assessing vulnerability via GIS analysis, developing a method to determine risk, and then identifying a suite of mitigation options linked to that risk. Pilot projects are testing the method. Since new planning for hydrology and road alignment is often not possible in emergency situations, VTrans is proactively identifying possible critical areas and solutions for culverts. This process requires the availability of most recent and accurate data to conduct the hydraulic analysis.



Figure 9: Culvert washed out by Hurricane Irene. (VTrans photo).

Planning and Funding

VTrans' sections work together to plan, minimize risk, and identify and respond to culvert needs identified through inventory, assessment, and consultative prioritization processes. If culverts are found to need minor maintenance Structures and Asset Management notify Operations, which takes that under advisement and makes its own decisions, including planning and funding.

VTrans Structures Section noted that VTrans may put more money toward culverts if the agency identifies the need to do so.

VTrans' funding for culvert and storm drain preservation, maintenance, rehabilitation, and replacement varies from year to year depending on needs. Large culverts are financially identical to a bridge and subject to fund withdrawal or reprioritization if an emergency occurs elsewhere. No dedicated reserve of money exists for large culverts, and fluvial and AOP demands mean that VTrans' culverts tend to be bigger and more expensive when replaced. Small culvert improvements are funded under many categories as incidental expenses. Those interviewed for this study raised allocation of maintenance funds as an issue for further consideration.

VTrans considers life cycle cost but not systematically or as the primary or only consideration. Mobilization of the contractor is a significant cost. Sometimes VTrans invests in a longer lasting, more expensive structure. Small culverts are easier to include in existing transportation improvement projects than replacements of large culverts.

In programming funds for longer, larger structures, such as bridges, VTrans uses a prioritization system that staff members have been considering modifying for use with large culverts. For existing "long" structure or bridge projects, Rehabilitation and Replacement received the most points to condition (30 percent), followed by 10-15 percent each for Remaining Service Life, Load Capacity and Use, Waterway Adequacy and Scour Susceptibility, Regional Input and Priority, and Asset Benefit Cost Factor. Rankings change from year to year as projects are completed, conditions change, or regional planning commissions' priorities change, but the process has enabled the agency to clear a backlog of projects for long structures in a defined, documented, and efficient manner. However, the preventive maintenance approach VTrans started for bridges six years ago did not extend to culverts.



Figure 10: Hydraulically, geomorphically, and ecologically compatible structure that withstood Hurricane Irene and other flood events. (Readsboro VT 8 Bridge, VTrans photo).

Planning for culverts occurs within the long and short structure programs of the Structures Section. If culvert improvements are part of the Structures or Pavement programs, culvert improvements are programmed as a line item in the STIP, but most of these improvements are for large, major culverts. VTrans anticipates that the culvert inventory and prioritization efforts may ultimately lead to a dedicated funding source in the STIP. Culverts compete against other needs across the state at the same time the agency considers what is needed to produce greater resilience in the face of storms.

Agency director, Rich Tetrault, noted that Hurricane Irene washed out more than 2,000 roadway segments, undermined more than 1,000 culverts, and damaged more than 300 bridges on the combined town and state network. He stressed, “Understanding that our climate is changing and that the frequency and intensity of storm activity will likely be greater during the next 100 years than it was during the last 100, it is prudent that as we rebuild, we also adapt.” VTrans has remained focused on vulnerability with river systems in Vermont and establishing methods for deterring risk to infrastructure from flood inundation and erosion in order to better set agency budget priorities. VTrans is also training staff in incident command center methods.

To address flood resilience needs, VTrans identified sources of data and information the agency needs to understand environmental conditions for transportation infrastructure that are vulnerable to climate change effects. VTrans Operations also began mapping post-storm expenditures in 2011. VTrans has worked with the National Weather Service to analyze more recent hydrological data to determine if trends in the real data could be identified. In addition, the agency has also worked with a climatologist to develop a downscaled climate model. Transportation agencies are concerned with runoff, not precipitation; VTrans believes that the estimated precipitation is not a good proxy for climate change in Vermont. The U.S. Geological Survey (USGS) was also analyzing the data to discern trends. USGS has documented high water marks that might correlate with high water marks in its models.

VTrans has not recorded extreme events and asset condition and performance during and after extreme events, but VTrans monitors bridge scour and emergency response. The post-Irene check of structures was more of an emergency response than a data collection enterprise; nevertheless, discussed and documented information could be part of future records on road sections and culverts. VTrans observed that upgraded bridges and culverts did very well in major storms. Some bridge failures occurred due to scour, but there were no failures of the new culverts built to 1.2 bankfull-width standards.

VTrans is working to identify vulnerabilities with the Vermont Agency of Natural Resources and the Agency of Community Affairs; this helps VTrans better manage its facilities and enables VTrans to better assist municipalities. VTrans is convinced that “the solution is for the rivers to be able to access their floodplains and thus avoid conditions that threaten structures or may be causing erosion problems upstream or downstream of VTrans’ facilities. Being cognizant of river dynamics in planning, design, and maintenance activities, and building and designing structures that are adequately sized to address flood hazards and accommodate river flow and movement” also produces co-benefits. Inundation, AOP, and wildlife passage could all benefit from these shifts, according to VTrans staff, who also said the interagency communication, work, and relationship building of the last 10 years were reaching fruition. Hydro-geomorphological needs are more holistically considered in project planning and design. High-level leadership from both VTrans and the state natural resources agency are fully committed to this new approach to floodplain management and flood resilience.

The effect of river stability on road stability has been apparent on a corridor level. Agency staff said, “VTrans has a fever in the agency to work better in rivers, understand dynamics, and respect river systems in emergencies and in maintenance. It has been quite surprising for it to move from (that being) a regulatory issue to it being how VTrans is doing business. The districts have experienced the advice of the river engineers and have followed it and have seen in flood

conditions that (these new approaches) protected the roadway. As VTrans has stopped creating those (fluvial) problems, the agency has seen improvements in resilience and longevity of infrastructure.”

Summary

VTrans’ system of small culverts is in relatively good shape from those inventoried on the interstate and NHS, though the backlog of large culvert repairs is increasing. The agency has been improving flood resilience through a revised hydraulic design manual that requires a 1.2 bankfull-width standard and a design strategy that accommodates more of the floodplain in bridge and culvert openings.

VTrans is coordinating with Maine DOT and New Hampshire DOT on integrating asset management into its maintenance tracking. As VTrans integrates the small culvert inventory with the agency’s MATS, it will allow connection between maintenance activities and culvert conditions over time and facilitate incorporation of culvert replacements into transportation improvement and pavement preservation projects. Further integration with the agency’s Deighton Pavement and Bridge Management systems will extend analytical capabilities, help find efficiencies, and leverage other transportation improvements.

Best Practices

- Asset management and performance measures written into statute, requiring a quantifiable project prioritization method assigning a numeric score to projects listed in the annual budget.
- Integration of culverts into the state’s maintenance management system, allowing connection between maintenance activities and culvert conditions over time.
- Implementation of web mapping and web report sites covering culverts.
- Creation of the Vermont Online Bridge and Structure Inventory Tool (VOBSIT), which can be used by both VTrans and municipalities to manage their systems and look at interrelationships.
- Emphasis on river dynamics and floodplain accommodation in culvert, bridge, and road alignment upgrade strategies.
- Revised hydraulic design manual that requires a 1.2 bankfull-width standard.
- Analysis of increasing storm frequencies and flood vulnerabilities.
- Mapping of post-storm expenditures.

CONCLUSION

Good culvert management systems enable repair and rehabilitation instead of replacement. Such systems also help transportation agencies avoid emergencies and fatalities. This report illustrates how four transportation agencies were surveying and managing culverts in order to take cost-effective action to preserve these drainage assets. Many transportation agencies are just beginning to inventory and assess the condition of the culverts they manage, but Ohio DOT and LA County have now completed culvert inventories. Location of culverts has led to more proactive maintenance and increased agency ability to identify, project, and address culvert needs and to extend lifespans and reduce failures.

Inventory and Inspection Best Practices

The four agencies interviewed were moving to in-field electronic data collection with mobile electronic devices; for example, Oregon DOT staff used a web-based GIS geospatial database accessible via laptops in the field in their culvert condition assessments. Agencies also used bridge inspection style 0-9 culvert ratings, 4- or 5-level culvert condition assessment methodologies, and a 3-level triage system that worked well.

In terms of staffing, DOTs found success with dedicated teams of culvert locators and inspectors. Contractor assistance helped districts complete culvert inspections in Ohio. VTrans was shifting from temporary inspectors to training the state's regular bridge inspection staff to add inspection of smaller culverts to their duties and to accumulate the benefit of staff experience. Training new inspectors on the culvert condition assessment methodologies tended to take agencies one to two days, plus on-the-job training. Use of technology and asset management systems required further training, and when safety courses were added, still more training time was necessary.

Oregon DOT conducted extensive pilots and cost estimating ahead of its culvert inventory. Oregon DOT found that three staff hours were needed to collect the basic level of information about each culvert. In the pilot inventories, Oregon DOT also found that about a third of culverts were in "critical" or "poor" condition and two-thirds were in "fair" or "good" condition. This triage enabled Oregon DOT to evaluate which sites warranted additional investigation and an Advanced Condition Assessment. Oregon DOT tried to collect and use multiple versions of the culvert condition assessment dataset and ultimately chose a smaller number of fields than was originally attempted, noting the resources necessary to collect, manage, and maintain data over time.

Both Oregon and Vermont were in the process of completing their first inventories of culverts and locations and associated condition assessments. In one of the most notable best practices found in this study, Ohio DOT successfully incentivized districts to complete culvert inventories by changing how culvert improvement funds were distributed. Ohio created a culvert program of funds to be distributed by the number of culverts managed and their needs. Starting in 2014, completed inventories will be necessary for each district to access maintenance and capital funds for culverts.

LA County's culvert inspection and management program was unique among those interviewed in that the Public Works Maintenance forces inspected, cleaned, and performed minor repairs on culverts in one trip to each culvert site every year. Maintenance forces then photo-documented the results. The county was starting to videotape 10 percent of the county's culvert system every year.

Databases and Management System Best Practices

All the state DOTs interviewed had greatly enhanced their data for culvert investment decision-making and maintenance. Data management systems were evolving to support maintenance decision-making and programming of capital projects.

Particularly noteworthy practices emerged in Ohio and LA County. Ohio developed its own culvert management system and spreadsheet for districts to use in conjunction with the state's project management and GIS systems. Such databases allow viewing of culvert needs in relation to scheduled paving projects and help leverage resources. Ohio DOT was developing deterioration models for culverts and examining how to link data from the Structure Management System to maintenance.

In LA County, culvert and maintenance management were integrated in a unified asset management system, Maximo. The County was mapping all culverts and drains in GIS and integrating this information into a multi-agency GIS-based storm drain network map. LA County's financial management system tracks expenditures on culvert management, which in turn links with the maintenance management system and its routine updates of labor and material costs. LA County's MMS was noteworthy in the extent to which it could track maintenance activities, store facility inventory information, analyze staffing needs, and provide cost analysis. The agency was on the verge of capturing costs for specific replacement projects or culvert linings for better linkage of life cycle costs, action benefits and cost-effectiveness, and system value in the future.

Most of the state DOTs interviewed were still developing processes to record maintenance and design "fixes" in the culvert asset management databases they had under way. Ohio DOT and LA County's systems enabled the agencies to move toward estimating cost effectiveness and the benefits of preventative action. VTrans was integrating a homegrown maintenance activity tracking system with a new asset management system for smaller culverts, which will ultimately be integrated into the agency's Deighton Pavement and Bridge Management system for cross-asset management.

Risk and Prioritization Best Practices

The best risk management and preservation maintenance activity was field inspection. The transportation agencies interviewed found that routine field inspection caught a majority of culvert problems before they became emergencies. Knowledge of culvert locations translated to better culvert maintenance; once maintenance forces were aware of culvert locations or risky conditions, they checked and addressed threats earlier, which prolonged service life and prevented culvert failures.

The agencies interviewed tended to use Excel, their maintenance management or activity tracking systems, any other asset management systems, and Pontis Bridge Software to help prioritize culvert remediation actions that should be taken next to minimize risk or maximize future protection and control costs. As road construction projects were programmed or developed, planning and design staff members solicited input from maintenance districts regarding which culverts needed to be repaired or replaced and could be incorporated into road and bridge improvement projects. The cost of a culvert replacement/ improvement project and its resultant reduced maintenance cost were conceptually compared with minor repair and ongoing additional maintenance costs. Agencies assessed risk and community benefit, again at the conceptual level; detailed analyses of actual costs other than the construction costs were not prepared. A next step and noteworthy practice: LA County DPW is extending the risk assessment to the network level; the county's combined multi-agency, GIS-based storm drain network map will help it and other agencies identify weak links in the network, whether inside or outside of the systems each agency manages.

Oregon DOT was looking at hazards, and both Oregon DOT and VTrans were looking at detour routes in their proactive culvert assessment and prioritization. Counties and states managing roads in mountainous areas (LA County, Oregon, and Vermont) often placed a higher priority on those culverts located on routes with no alternative route if the culvert failed and the road became impassible.

The areas of the United States facing the most intense rainstorms and flooding were represented only by Vermont in this set of case studies. DOTs were aware of climate change and taking steps to prepare for increasing storm intensities where pertinent. Oregon DOT conducted an assessment of climate change vulnerability and risk and developed an Adaptation Report using a 50-year planning horizon and rainfall maps that were updated for the state for the second half of the century. Both Ohio and Vermont have also coordinated with the state climatologist to use the most updated precipitation maps and trends.

DOTs in Vermont, Oregon, and California noted that upsizing requirements for aquatic organism or fish passage usually surpassed other hydrologic needs. DOTs anticipated that as long as they continuously updated the rainfall data in hydraulic design, they would be covered. Upsizing for fish passage notably increased flood resilience of culverts in Vermont and Oregon. There, and in other northern and coastal states, the need to address and improve fish passage barriers could be a driving factor in prioritization of culverts for remediation. Since fish passage requirements can increase the size of the barrel of the culvert that needs to be replaced, the available budget may be taken up by fewer, larger projects. For those upsizing projects that were implemented in Vermont, fish passage design criteria added capacity that contributed resilience in the flood flows of Superstorm Sandy and Hurricane Irene. VTrans was going to a risk-based approach to culvert installation and replacement along with a 1.2 bankfull-width standard instead of defined Q50 standards.

Planning and Funding Best Practices

Enhanced culvert asset management data were helping DOTs develop project prioritization and funding justifications. The goal was to leverage paving projects and also avoid cutting into new pavement to replace a culvert that failed or was about to fail.

Some states allocated special pools of funding for culvert repair and replacement projects, either as one-time or recurring allocations (Oregon DOT's "Fix It" Program) or by combining the funds formerly used for that purpose under all programs (Ohio). Oregon DOT also made estimates of the costs per culvert for repair or replacement over a given culvert's service life, along with total service life needs over the entire system across a 50-year design life and other scenarios.

LA County had the longest running culvert asset maintenance record of the transportation agencies interviewed and could break down how funds were spent under the proactive system. The county's annual budget for culvert and storm drain maintenance spent 65 percent on preservation (inspection and cleaning), 15 percent on maintenance (repair), 10 percent on rehabilitation (lining and reconstruction), and 10 percent on complete removal and replacement of the existing culvert or drain. LA County found that although annual drain cleaning and inspection were resource intensive, the benefit gained from that effort was well worth it; the county was able to minimize the number of drain failures and road washouts with this pre-storm season annual practice.

Due in part to consistent annual maintenance, LA County did not have a repair backlog on its smaller culverts. If a deficiency was discovered during the course of annual culvert inspection and a maintenance crew could not make a minor repair to address the issue, a culvert lining or replacement project was proposed. Those typically were completed within a year. About 30 percent of bridge culverts have some remedial work recommended yearly in LA County.

While DOTs said they did not yet have the data to do life cycle cost analysis for culverts, Ohio DOT was getting close to being able to estimate the costs and benefits of a culvert management system, basing costs on hours spent inspecting. In Vermont and Oregon, the generalized information on conditions that the state was collecting helped prioritize both culvert repair and maintenance needs while building the foundation to monitor culvert deterioration over time.

Through the development of effective hydraulic control structure databases, management systems, and policies, DOTs can develop operational protocols and establish operating budgets that address risks associated with hydraulic control structure failures. This approach reduces risk to transportation infrastructure as well as potential risk to lives and property should culverts or other structures fail. The stories in this set of case studies illustrate a path for other DOTs and transportation agencies to reduce risk, improve public safety, and manage assets for better linkage of life cycle costs and the benefits of preventive action. The state DOTs interviewed were continuing to improve their procedures, inspection and training strategies, and databases. Generally, the culvert management systems they developed were available for other public agencies to use and adapt.

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