CHAPTER 3 – CULVERT DECISION-MAKING TOOL

SUMMARY OF DECISION-MAKING TOOL

The purpose of this decision-making tool is to provide Federal Lands Highway personnel with project-level decision-making guidance for post-assessment actions to be taken for existing roadway culverts. The procedure assists the user in making follow-up recommendations to the culvert assessments, which might include repair, replacement, and Level 1 and 2 activities. Guidance is also provided to users to assist with repair or replacement technique selection, following the assessor's preliminary recommendations. The decision-making tools include a set of flowcharts, presented in the following Culvert Action Flowcharts section and in attached Appendix D, that outlines the possible actions for the various culvert types. The process flow for the decision-making process is described in the FLH Culvert Decision-Making Process Map, shown in the following Figure 18 and in Appendix D.

The decision-making procedure begins after the termination of the culvert assessment procedure, with a rating having been assigned. The procedure then steps through a number of qualifiers intended to guide the user toward the appropriate action path, the options of which are no further action or a recommendation of Level 1 maintenance, Level 2 in-depth investigation, replacement, or repair.

For replacement and repair recommendations, the user is provided a series of action flowcharts for the various culvert materials and site conditions that further develops the best technique to use. A repair liner selection comparison matrix is included, which provides rough cost information, capabilities and limitations for each commonly-used liner option. The tool also includes matrices for considering and comparing culvert man-entry repairs and replacement techniques, as well as culvert-related construction activity options based on the FLH bid history database. Appendix C of this procedure presents photographic guide to culvert rehabilitation, which illustrates some of the more common techniques discussed.

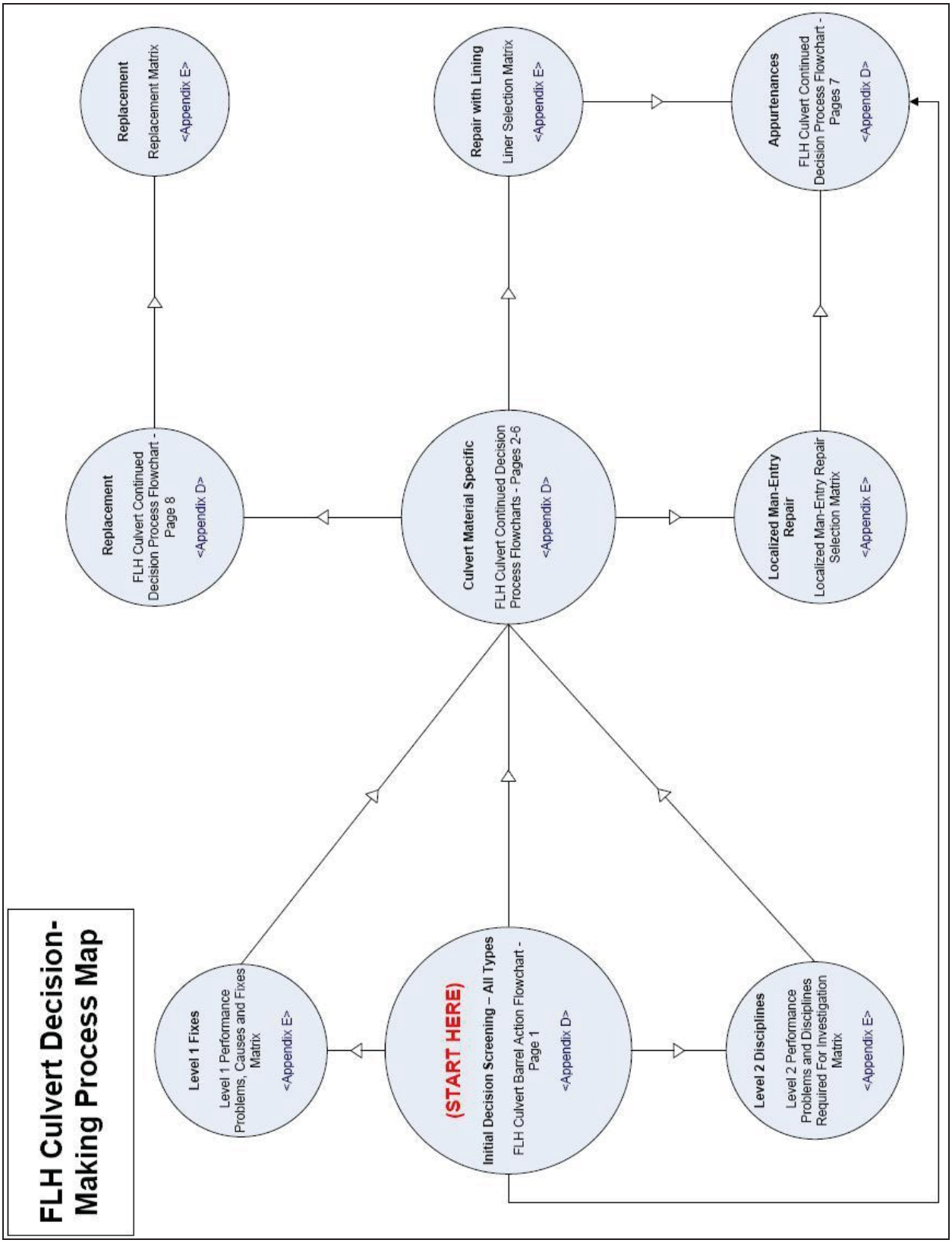

Figure 18. Flowchart. FLH Culvert Decision-Making Process Map.

CULVERT ACTION FLOWCHARTS

The Culvert Action Flowchart set, including Pages 1 through 8, are presented in Appendix D at the end of this manual. The following section steps through the various flowcharts in the set to demonstrate the decision-making methodology employed.

DECISION-MAKING METHODOLOGY USING ACTION FLOWCHARTS

The following is an explanation and example of the decision-making methodology employed in the Culvert Action Flowcharts and Matrices. Decision points, process boxes and terminators are referred to within the following text by name using quotation marks.

Page 1 – All Types Flowchart

To execute the culvert decision-making procedure using the action flowcharts, the user begins on the first page of the set, "FLH Culvert Barrel Action Flowchart – Page 1 All Types". The Page 1 flowchart addresses site conditions and other general factors that are common to all culvert types. Below is a step-by-step description of each flow path possible on this first action flowchart, shown in Figure 19 below and presented in Appendix D. The user starts at the left-most process box titled "Initial Field Assessment of Culvert Complete".

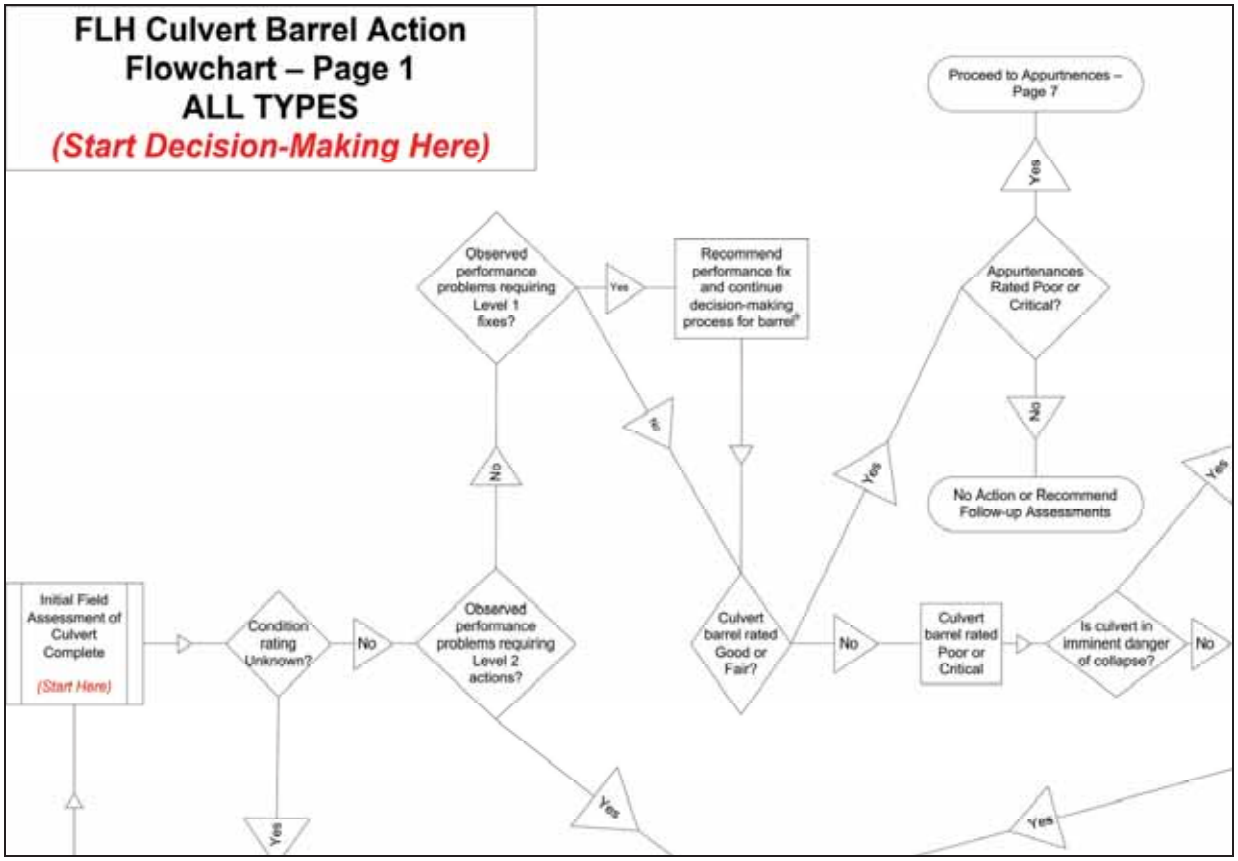

Figure 19. Flowchart. Starting portion of FLH Culvert Barrel Action Flowchart – Page 1 ALL TYPES.

The user is first queried if the culvert was rated Unknown. If the response is Yes, then that pathway is followed to the next query, whether simple maintenance will allow access. As an example, in the case of significant debris accumulation preventing access to the culvert, the user would respond Yes and continue to the process box 'Request Maintenance, then Re-assess', after which he/she would reattempt the assessment after the maintenance was completed and access achieved.

On the next attempt at assessment, the answer to the condition rating qualifier will be No and the user will continue down that path rather than around the maintenance loop. If simple maintenance will not allow access, the user answers No and is directed to the 'Special access equipment or personnel needed' terminator. Special access might typically include divers, rope access techniques, or a remotely operated vehicle (ROV).

A negative response to the 'Condition rating Unknown' prompt leads the user to the 'Observed performance problems requiring Level 2 actions' qualifier, which relates to the section of the assessment form entitled "Culvert & Channel Performance Indicators Leading to Level 2 Actions". If any of the Level 2 indicators on the assessment form are checked as present, the user responds Yes and moves on to the Level 2 investigation directive. Figure 20 below depicts this portion of the Page 1 flowchart.

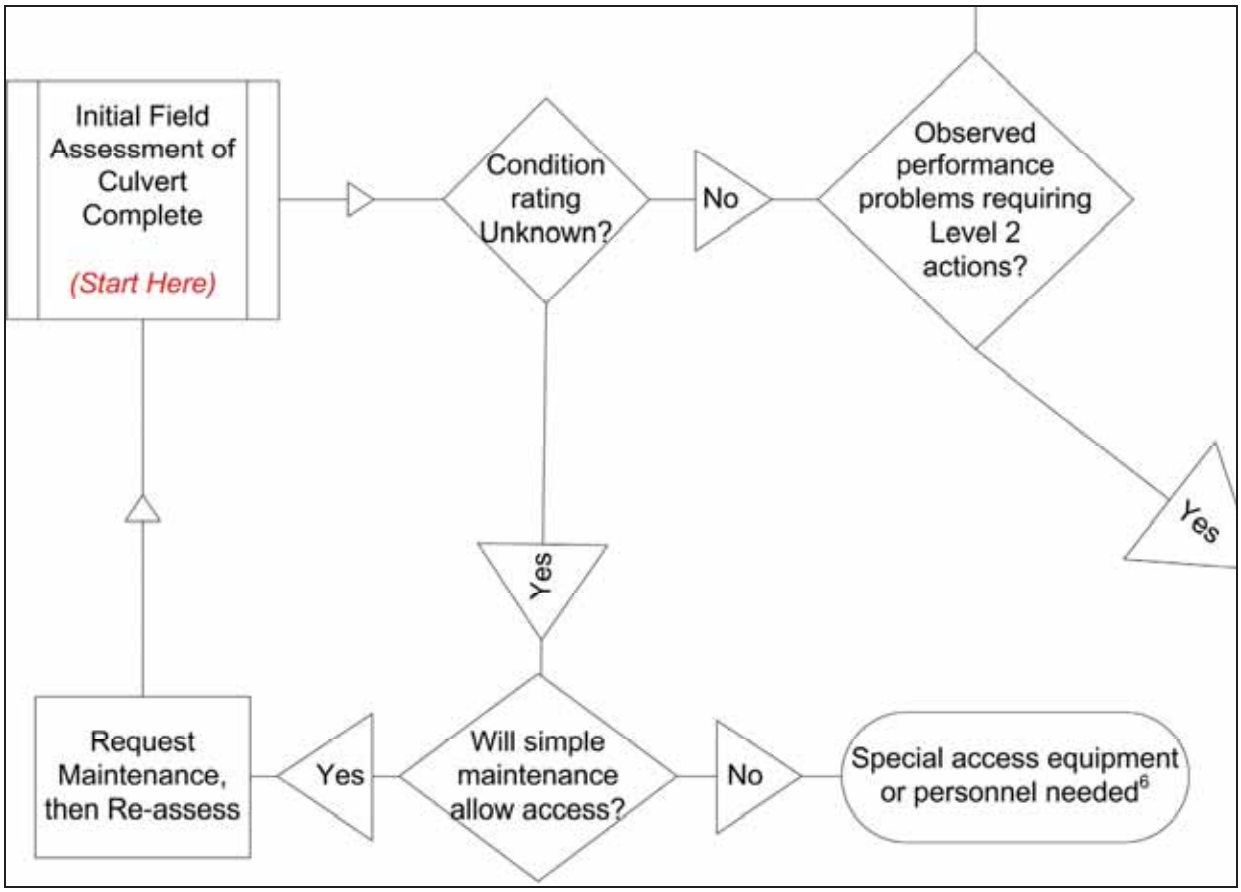

Figure 20. Flowchart. Maintenance loop at start of Culvert Barrel Action Flowchart – Page 1 ALL TYPES.

If there are no observed performance problems requiring Level 2 actions, the user is then queried whether there are observed performance problems requiring Level 1 fixes. If there are Level 1 triggers present, as indicated on the assessment form, the user progresses to the process box 'Recommend performance fix and continue decision-making process for barrel'. The Level 1 triggers are explained in more detail in the previous Table 1, as well as in the Level 1 Performance Problems – Causes and Fixes matrix in Appendix E. In the event that a Leve1 action recommendation has been made, or there are no Level 1 triggers, the user then moves on to the prompt 'Culvert barrel rated Good or Fair?'

Answering No to the 'Culvert barrel rated Good or Fair' query indicates the culvert barrel was rated Poor or Critical, which carries the user further into the flowchart with the assumption that there are significant problems to be addressed. If the answer is Yes, the culvert barrel is rated Good or Fair, then the next query is whether the 'Appurtenances were Rated poor or Critical'. If Yes again, the user is directed to proceed to the flowchart "Page 7 – Appurtenances". A negative answer indicates both the barrel and appurtenances are in Good or Fair condition with no further action or follow-up recommendations necessary, as shown in Figure 21 below.

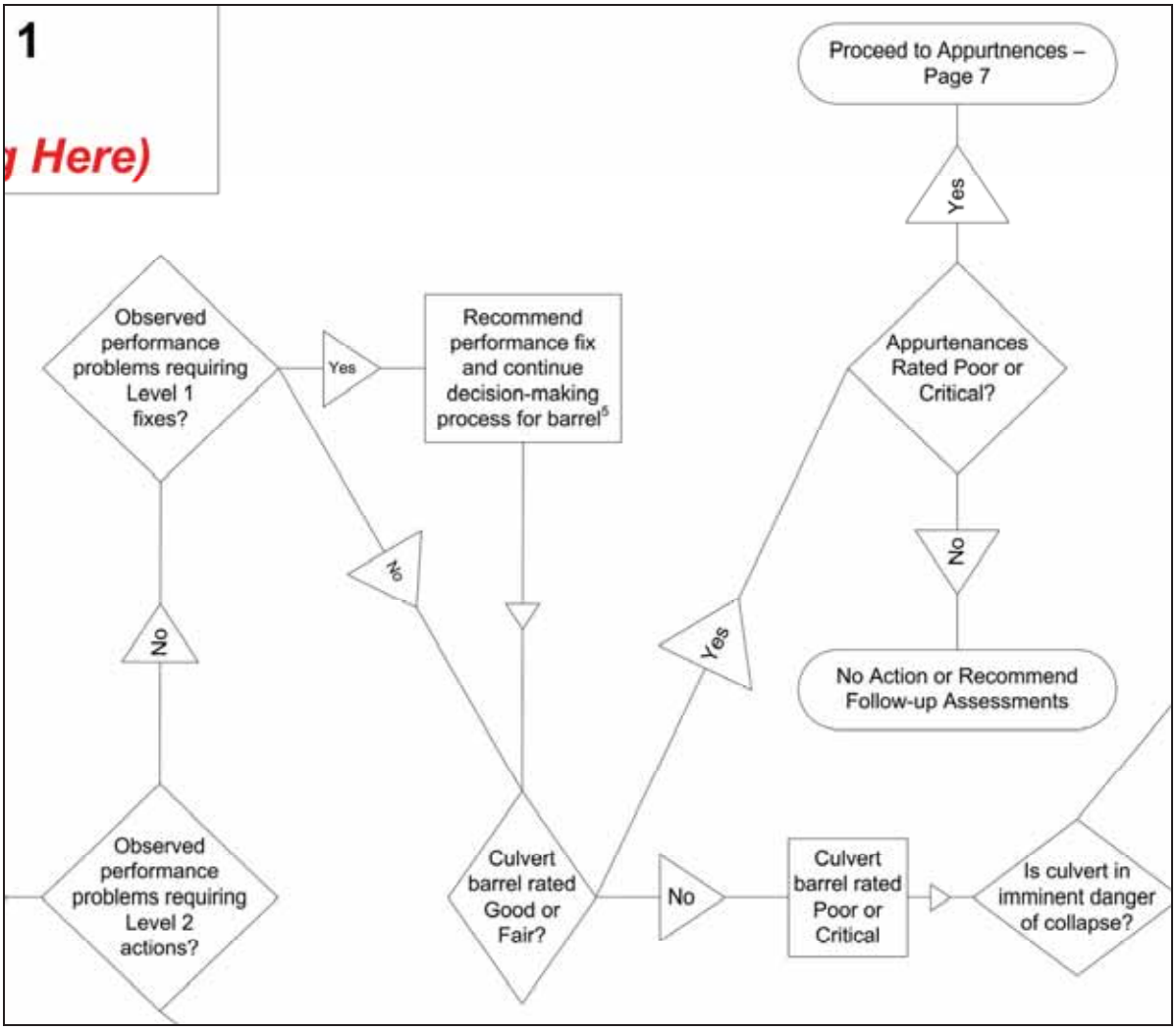

Figure 21. Flowchart. Level 1 fixes, Good and Fair barrel ratings and appurtenances in Page 1 flowchart.

If the culvert barrel is rated Poor or Critical, the next question the user encounters is whether the culvert is in immediate danger of collapse. If there is danger of collapse, temporary structural bracing and road closures recommendations should be considered. If the culvert is not in imminent danger of collapse, or it is and measures have been considered, then the next query is whether the culvert has an open bottom, has been designated as fish passage, aquatic organism passage (AOP) or historic structure. Any positive answer to this query diverts the user to the Level 2 investigation terminator. Note that the fish passage, AOP and historic qualifiers should be designated by environmental and cultural resource specialists. This may be the case for the following qualifier for special environmental permitting issues as well, which provides the user an additional opportunity to recommend a Level 2 investigation of this contingency.

If the culvert is not significant from a fish passage, AOP, cultural, historic or environmental permitting perspective, then it goes to the first major junction in the repair versus replacement pathways, whether the 'Pipe Rise (diameter) less than or equal to 36 inches'. If the pipe rise is less than or equal to 36 inches, it is a "small" pipe and should be further considered for possible replacement if deemed cost-effective, as shown in Figure 22 below.

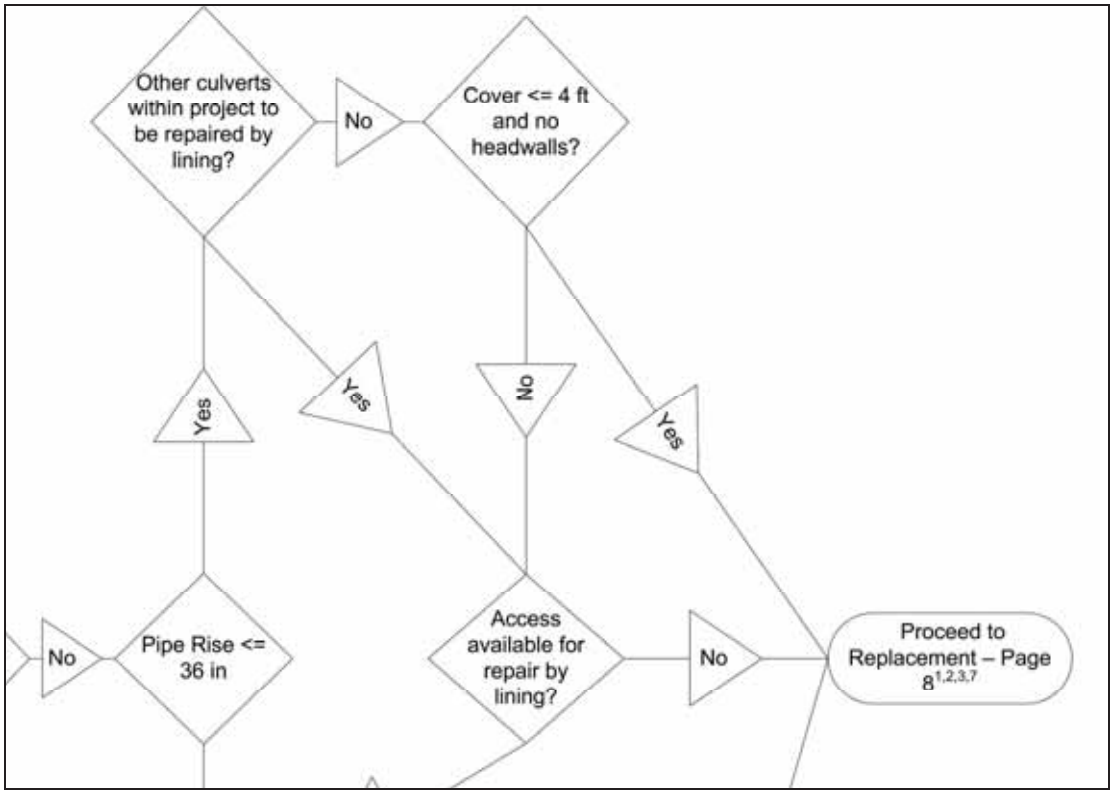

Figure 22. Flowchart. Treatment of small, shallow pipes in Page 1 – ALL TYPES flowchart.

If the pipe 'Cover is less than or equal to 4 feet, it is a "shallow" pipe. If the small, shallow pipe also has no headwalls, it is assumed to be most cost-effective to address it with open-trench replacement. In this case, the user is directed to 'Proceed to Replacement – Page 8'. Note that if this replacement terminator is reached, the user must also check the "Appurtenances – Page 7" flowchart, and also consider if other adjacent culverts are to be addressed with in-situ repairs, as described in the related footnotes. If cover is deeper than 4 feet, the user is prompted if there is 'Access available for repair by lining?' at the culvert ends.

Access for lining repair refers to available right of way, means of ingress/egress, and work space for the lining equipment, machinery and crew at the ends of the culvert. Responding No directs the user to the 'Proceed to Replacement – Page 8' terminator. The recommendation to replace culverts less than 36 inches in rise, under 4 feet of less of cover, with no headwall and favorable traffic conditions is based on limited cost analysis and trench safety guidelines. Specific project conditions, such as the use of trenchless techniques on nearby culverts or availability of cost-effective lining technology, may counter this recommendation.

Responding that the culvert is either greater than 36 inches in rise or has access at the culvert ends for lining repairs will lead the user to the prompt, is the 'Barrel rated Critical?' An affirmative response offers the user another opportunity to end up at the replacement terminator by inquiring if there is 'Extensive Damage to the Embankment?' In most cases, culverts with Critical ratings are accompanied by extensive roadway and embankment damage, requiring replacement. If this is not the case, the user returns to the previous pathway and the question of if there is 'Frequent overtopping known (as indicated by client)?' Answering Yes indicates that the culvert is likely undersized and of insufficient capacity, and the user is directed through the 'Replace with larger size' process box to the terminator 'Proceed to Replacement – Page 8'. If frequent overtopping is not indicated or known to occur, the user is directed through the 'Repair' process box to the terminator 'Continued Decision Process per Type – Pages 2-7', as shown in Figure 23 below.

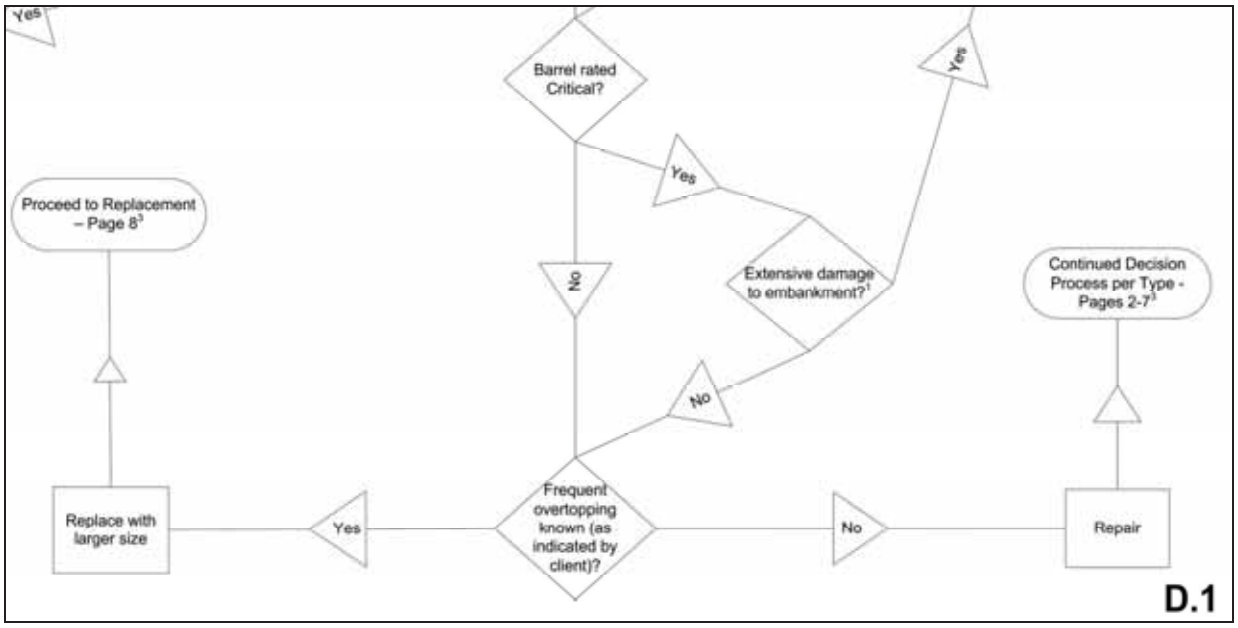

Figure 23. Flowchart. Page 1 Critical barrels, embankment damage and frequent overtopping.

The "Page 1 – All Types" action flowchart ends with the selection of either no action, replacement, repair, or appurtenance terminator. If the Level 2 terminator is reached, the assessment should be continued if possible at the 'Culvert barrel rated Good or Fair' qualifier if all Level 2 triggers have been addressed. If a barrel repair is called for, depending on the type of culvert material - concrete/RCP, Metal/CMP, Plastic, Timber, or Masonry – the user moves on to one of the action flowcharts on Pages 2 through 6 of the set. Page 7 provides guidance for actions related to appurtenances, and page 8 provides a replacement decision flowchart for all types of culverts.

Pages 2 through 6 – (Material Specific) Continued Decision Process Flowcharts

In the case of the Page 1 flowchart calling for possible repairs to a culvert, the user moves on to the Continued Decision Process Flowcharts on Pages 2 through 6, depending on the material type. Each of the material-specific continued process flowcharts begins on the left-hand side at the process box titled "Continued Decision Process Needed (From Page 1) *(Start Here)*". The flowcharts step through the various possible deterioration modes that led to the Poor or Critical barrel rating, specific to the materials type. The possible terminators the user may reach on these flowcharts typically include Replace, Repair with Lining, Localized Man-Entry Repair, and Level 2 Investigation. The following section steps through the Page 2 flowchart for concrete and RCP culverts, as an example of how the material specific flowcharts on Pages 2 through 6 are used.

Page 2 – Continued Decision Process Flowchart for Concrete & RCP

After reaching a Page 1 terminator for a concrete or RCP culvert, the user moves to 'FLH Culvert Action Flowchart – Page 2 Concrete & RCP'. The first prompt in this flowchart is if the 'Cross-section deformation is Poor or Critical', the assumption being that this type of culvert loses most of its structural integrity when deteriorated to this extent. Concrete and RCP culverts with Poor of Critical cross section deformations immediately go to a replacement terminator and proceed to the Page 8 replacement flowchart.

If the cross-section deformation is not Poor or Critical, the user is queried if 'Cracking is Poor or Critical?' If cracking is Critical, then the replacement terminator is again reached, the assumption being that the pipe has lost most of its structural capacity and the condition is not repairable. If the cracking is only Poor, than the alternate path leads to the qualifier is the 'Rise less than or equal to 48 inches?' This question stems from the understanding that man-entry repairs should only be considered for pipes greater than 48 inches in size. This means that barrel repairs for smaller pipes would require a lining technique and if lining is not feasible, require replacement. If the size is greater than 48 inches, the next question is whether there is 'Access available for Repair by Lining?' If so, the user proceeds to the 'Repair with Lining and proceed to liner type selection matrix' terminator and this is his/her preliminary recommendation to complete the procedure. If there is not access for a liner repair, the recommendation and path for a small pipe with Poor cracking becomes replacement, as shown in the following Figure 24.

If the rise of the concrete or RCP pipe is greater than 48 inches, the user is queried if 'Most of the culvert is affected by Poor/Critical conditions?', the assumption being that spot repairs on 50 percent or more of a pipe is not cost efficient when compared to lining or replacement. If this is the case, the user is queried about access to the pipe ends for lining repairs, and if not sufficient, replacement should be recommended. In the case where less than half of the pipe is affected by Poor or Critical conditions, the path leads to a 'Localized Man-Entry Repair' terminator and recommendation.

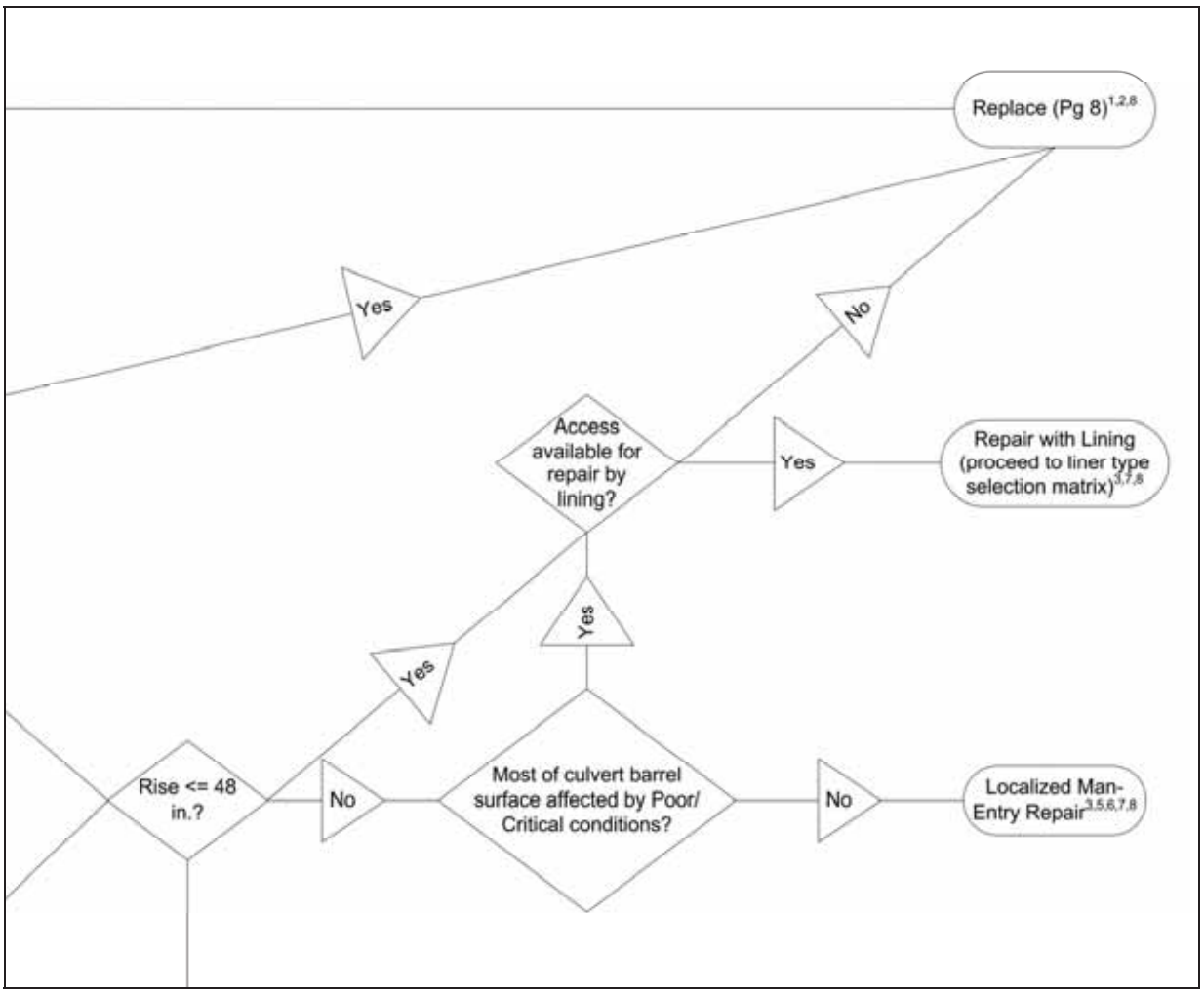

Figure 24. Flowchart. Page 2 terminators for concrete and RCP culverts, except L2 investigation.

Going back to the question of whether 'Cracking is Poor or Critical', a No response leads to a prompt for the next mode of deterioration to consider, is 'Chemical/corrosion Poor or Critical?' If Yes, the user is asked a Level 2 – Condition qualifier, is it an 'Aggressively corrosive environment?'. If it is, as indicated on the assessment form, he/she proceeds to the Level 2 investigation terminator. Note that the user may continue the procedure and evaluate the culvert for the remaining modes of deterioration; however, further efforts towards Level 1 recommendations may not be cost-effective if a more-in-depth Level 2 investigation will ensue. If the corrosion/chemical environment is not aggressive, the user proceeds to the prompt if the pipe 'Rated Critical?', at which point the repair versus replacement procedure duplicates that for cracking as described above.

If there are no Poor or Critical chemical or corrosion problems, the user progresses to the 'Invert deterioration and abrasion is Poor or Critical?' deterioration qualifier, and if Yes, is it in an 'Aggressive abrasion environment?'. If the environment is aggressively abrasive, the Level 2 investigation recommendation is again reached. If the abrasion environment is not aggressive, the user proceeds to the prompt if the 'Rise less than or equal to 48 inches?', at which point the repair versus replacement procedure duplicates that for cracking as described above and shown in the following Figure 25.

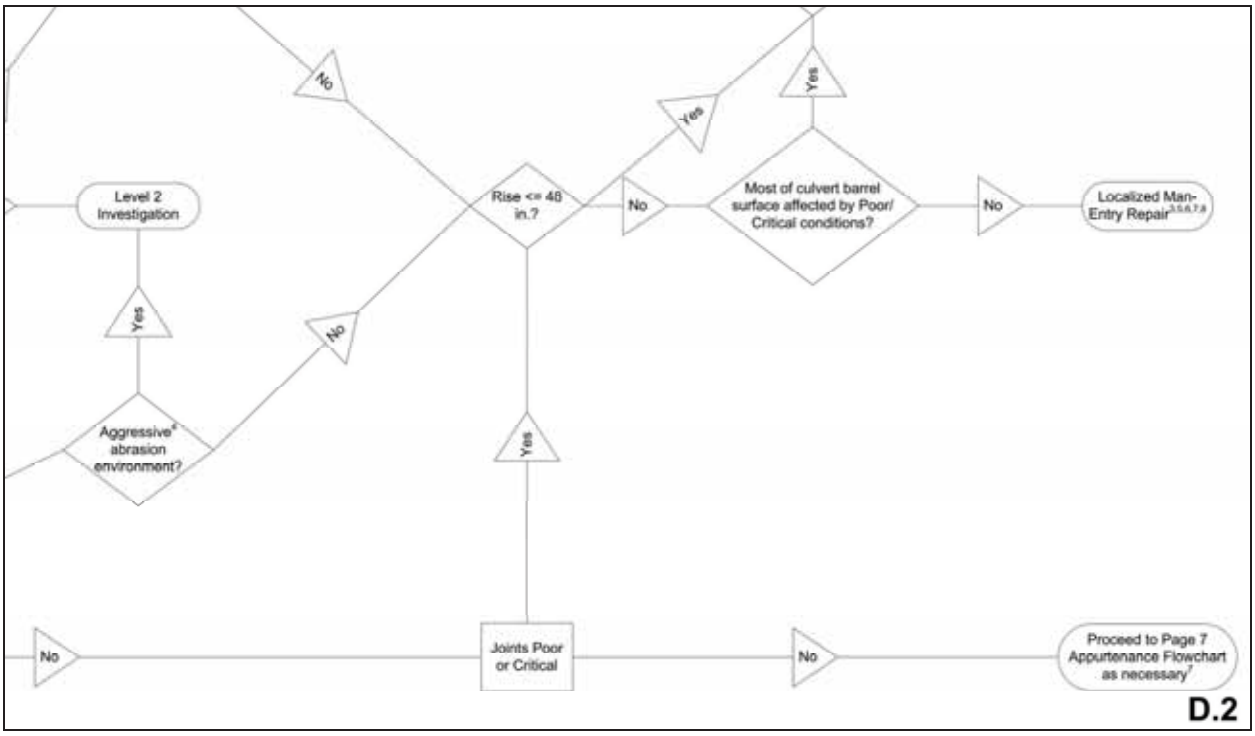

Figure 25. Flowchart. Page 2 treatment of concrete culverts with joint deterioration.

Answering No to the invert deterioration query leaves the user with one remaining mode of deterioration possible, 'Joints Poor or Critical'. If this is the case, the user moves on to the question regarding if the 'Rise is less than or equal to 48 inches?' If the joints were not Poor or Critical, the user is directed to proceed to the appurtenance flowchart as necessary. If the rise is greater than 48 inches, the user proceeds to the prompt is 'Most of the culvert affected by Poor/Critical conditions?'. Another negative response leads the user to the terminator 'Localized Man-Entry Repair' and the end of the procedure. Affirmative answers to either of these two questions regarding rise and coverage will lead the user to the final question is there 'Access for Repair with Lining?', at which point this final path diverges to either the 'Repair with Lining and proceed to liner type selection matrix' or the 'Replace (proceed to Page 8)' terminator. The logic in this region of the flowchart is driven by the concept that joint repair by man-entry is feasible and desirable if the pipe is large enough and the number of joints needing repair is reasonably small; however, if many joints need repair, a liner or replacement may be more cost effective.

Page 7 – Appurtenance Continued Decision Process Flowchart

In the event the culvert barrel is in Good or Fair condition but one or more of the appurtenances is Poor or Critical, the terminator "Proceed to Appurtenances – Page 7" on the top center of the Page 1 flowchart is reached. The user proceeds to the 'FLH Culvert Continued Decision Process Flowchart - Page 7 Appurtenances'. The first qualifier of the appurtenance flowchart is whether the 'Culvert barrel is to be replaced?', in which case the user is directed to the terminator 'Replace appurtenances as needed', as shown in the following Figure 26.

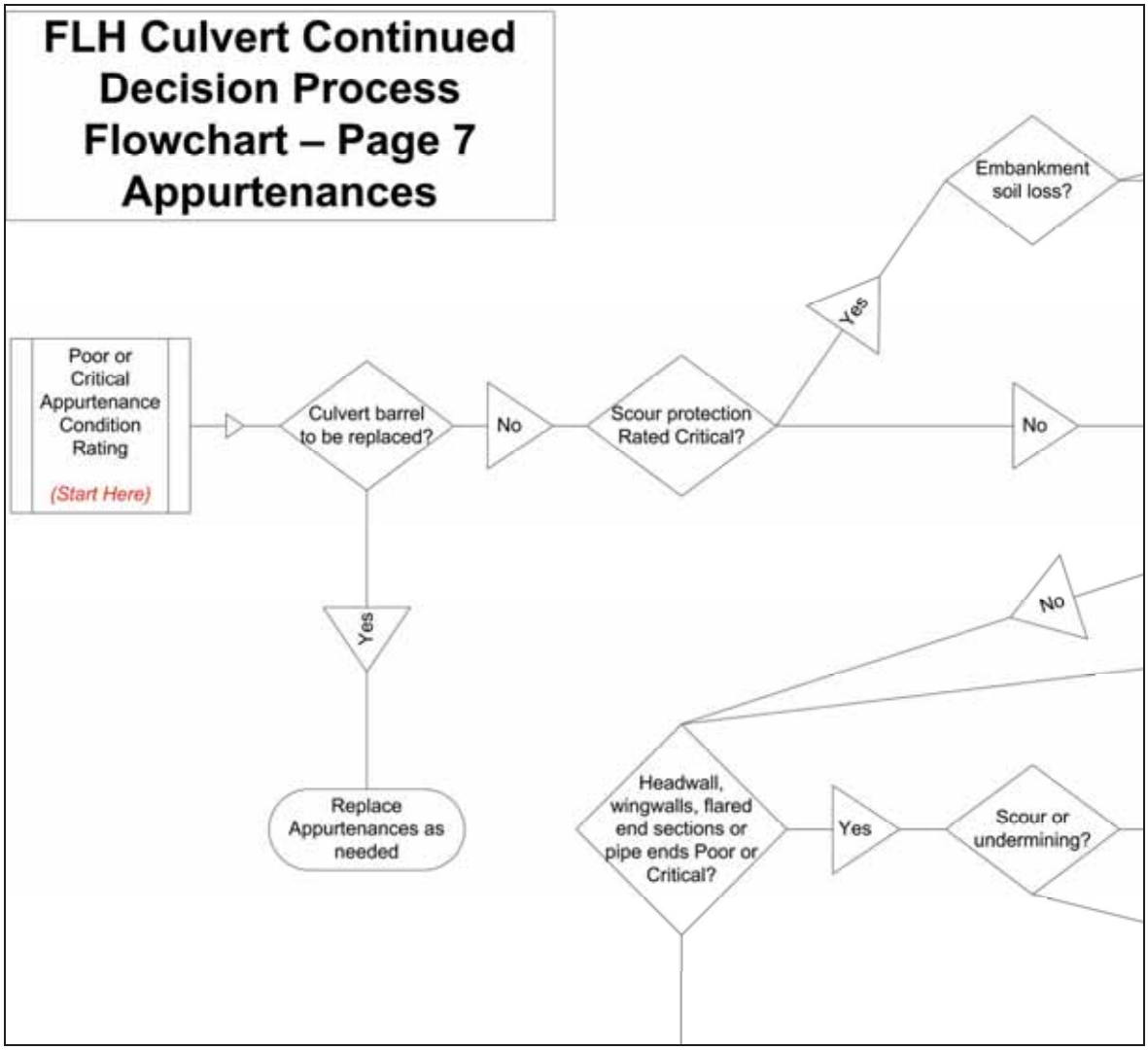

Figure 26. Flowchart. Replacement and scour protection qualifiers for Appurtenances Flowchart.

If the barrel is not to be replaced, the next prompt encountered is the 'Scour protection is rated Critical?', in which case the user is queried whether there is 'Embankment soil loss' or not. If there is embankment soil loss, the user's recommendation is 'Repair soil embankment' and 'Replace Scour Protection System'. If there is no embankment loss, the user moves directly to the 'Replace Scour Protection System' terminator, as shown in the following Figure 27.

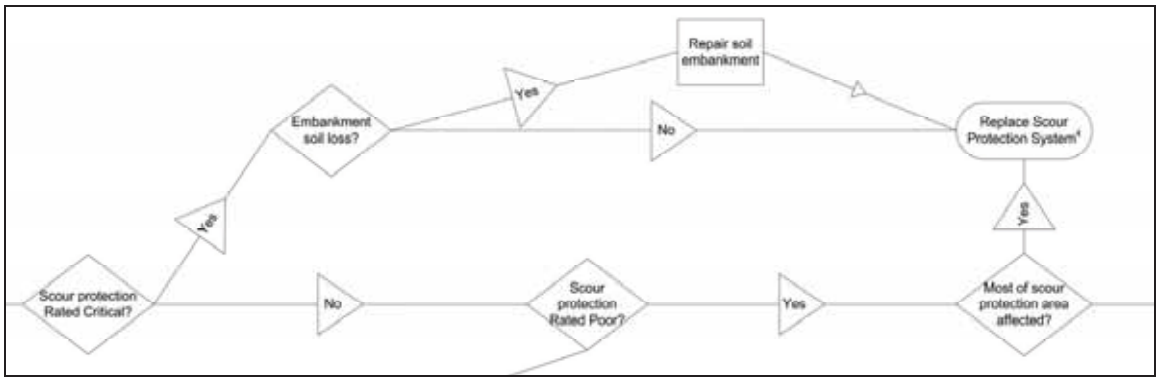

Figure 27. Flowchart. Deteriorated appurtenances with Critical/Poor scour countermeasures.

If the scour countermeasures are not rated Critical, but are Poor, the user is prompted is 'Most of scour protection area affected?' If most of the scour protection area is affected by the deterioration, the user again reaches the 'Replace Scour Protection System' terminator. If the deterioration does not affect most of the scour protection area, the user recommends a 'Local Repair of Scour Protection' and moves on to the next qualifier 'Headwall, wing walls, flared end sections or pipe ends Poor or Critical?'.

If the answer to the 'Headwall, wing walls, flared end sections or pipe ends Poor or Critical?' query is Yes, the next prompt asks whether there is 'Scour or undermining?'. In the instance there is scour or undermining of the appurtenance, the user recommends Repairing backfill' and then answers the prompt 'Appurtenance rotated or displaced?'. If there is rotation or displacement, the user recommends 'Reposition appurtenance to original state if feasible'. After the recommendation is made, or if there was no rotation or displacement of the appurtenance, the user moves on to the query 'Cracking/spalling or section loss led to Poor or Critical rating?', as shown in Figure 28 below.

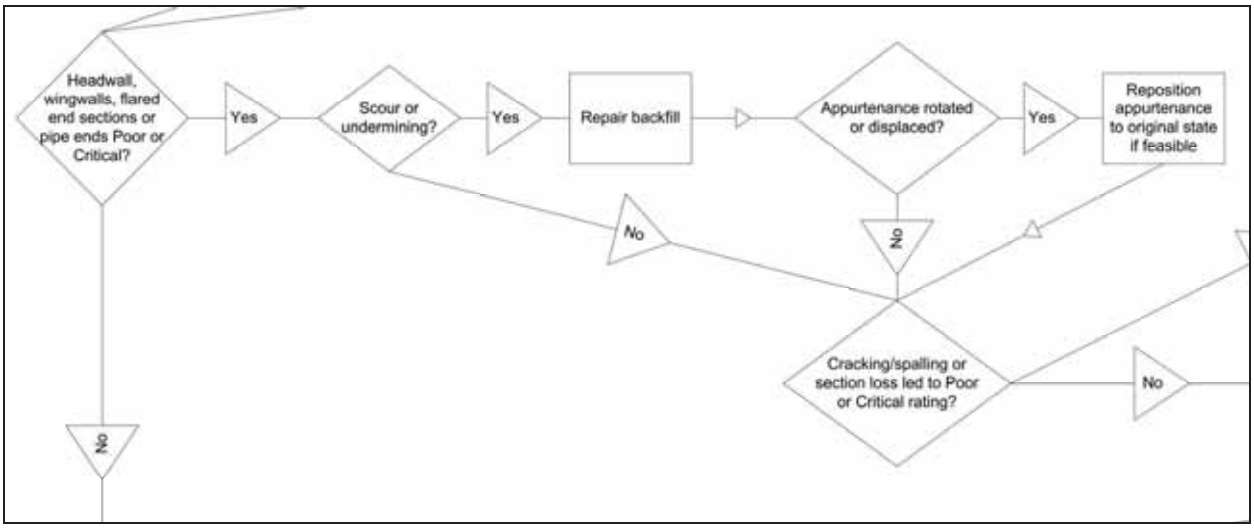

Figure 28. Flowchart. Qualifiers for appurtenances with undermining, rotation, displacement, or cracks/spalls.

Answering affirmative to 'Cracking/spalling or section loss led to Poor or Critical rating?' leads the user to the query is 'Most of appurtenance affected?'. If most of the appurtenance is affected by the deterioration, 'Replace Appurtenance' is recommended. If the deterioration does not affect most of the appurtenance, 'Local Repair of appurtenance' is recommended, and the user continues on to the next mode of deterioration in the flowchart. If there was no cracking, spalling or section loss leading to a Poor of Critical rating, the user would surmise that 'Deformation or crushing led to Poor or Critical rating' and recommend 'Replace Appurtenance', as shown in Figure 29 below.

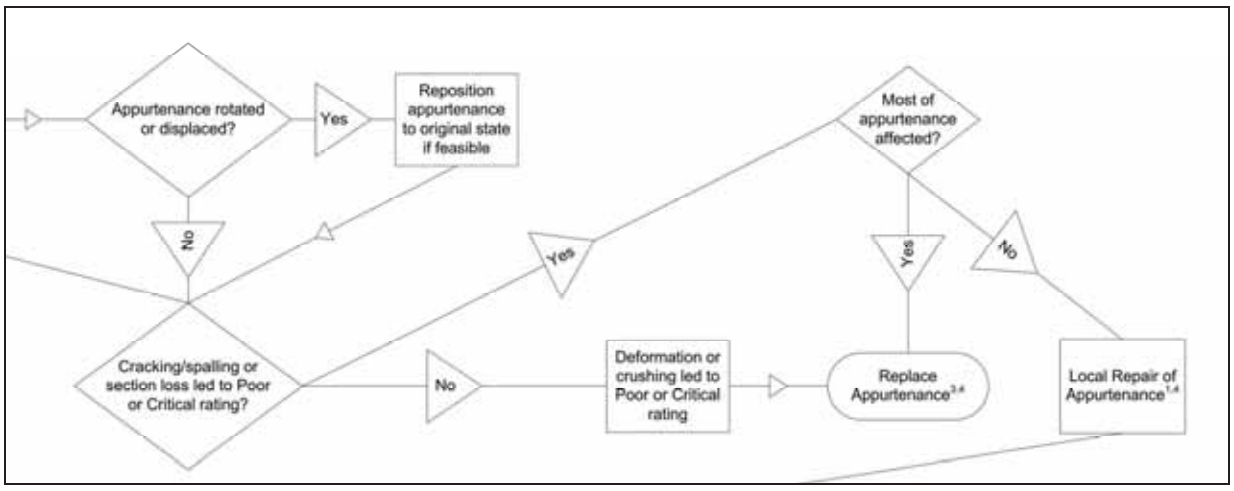

Figure 29. Flowchart. Page 7 qualifiers for repair and replacement of appurtenances.

A negative reply to the qualifier 'Headwall, wing walls, flared end sections or pipe ends Poor or Critical' leads to the final appurtenance deterioration mode 'Apron Poor or Critical', with the assumption at this point in the decision-making process being that it is. The apron condition prompt is also reached from the 'Local Repair of Appurtenance' recommendation discussed above. The user immediately moves to the question is there 'Aggressive Abrasion?'. If there is aggressive abrasion, the recommendation is to conduct a 'Level 2 investigation'. If there is no aggressive abrasion, the user moves on to the query is there 'Scour or undermining?', as shown in the following Figure 30.

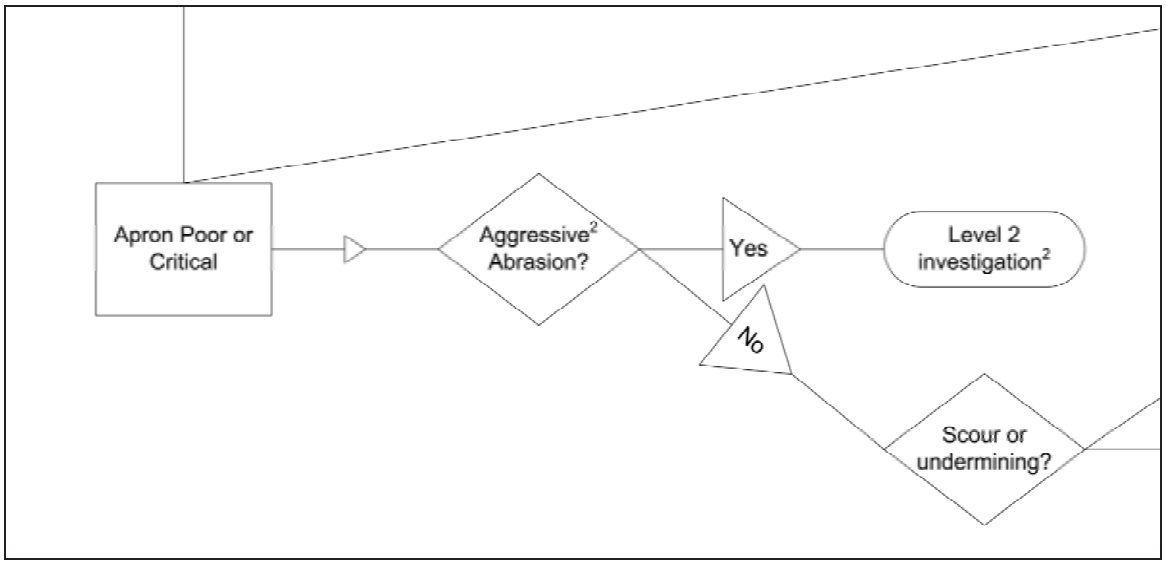

Figure 30. Flowchart. Page 7 qualifiers for Poor/Critical aprons with/without aggressive abrasion.

If scour or undermining of the apron is observed, the user recommends 'Repair subsoil and/or fill voids' and proceeds to the final apron query of whether 'Cracking/spalling or section loss led to Poor or Critical rating?'. If there was no scour or undermining, the user would move directly to this final query. If the answer is Yes, the user is asked if 'Most of the Apron is affected?', in which case the recommendation is to 'Replace Apron'. If most of the apron is not affected, a 'Local Repair of Apron' is recommended. If apron deterioration did not lead to a Poor or Critical rating, the user finishes the Page 7 appurtenances flowchart, as shown in the Figure 31.

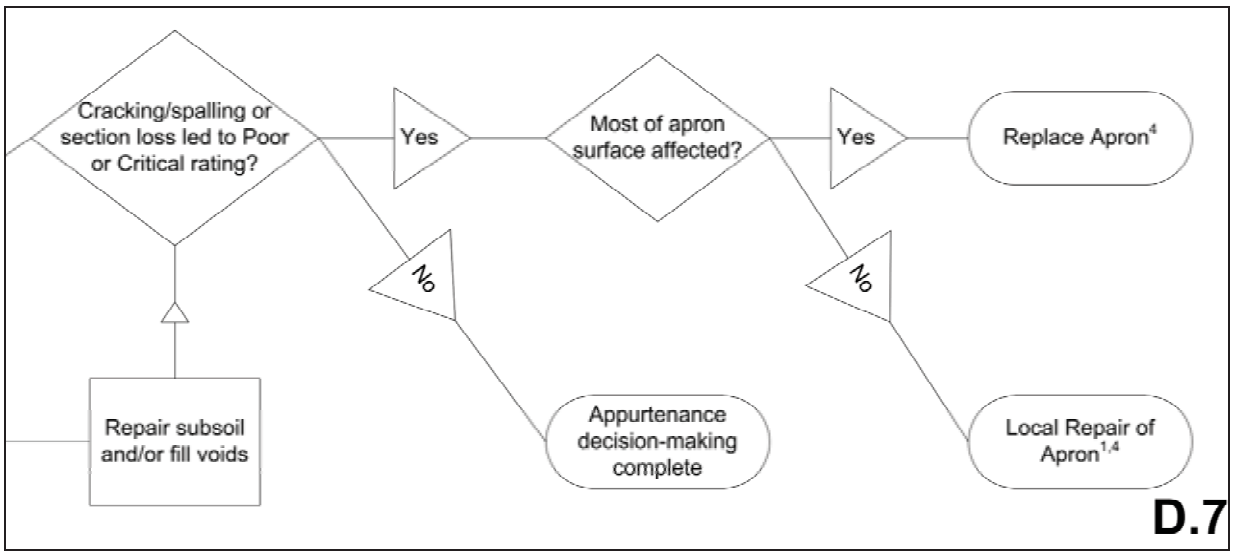

Figure 31. Flowchart. Final Page 7 qualifiers for cracking, spalling and section loss in aprons.

Page 8 – Replacement Flowchart

If a replacement was called for on the Page 1 flowchart, the user proceeds to the 'FLH Culvert Action Flowchart - Page 8 Replacement All Types'. Page 8 can also be reached via references from within the various type-specific Pages 2 through 6. The first qualifier of the replacement flowchart is whether 'Embankment repairs require surface excavation and repair?' If such repairs require excavation and rebuilding of the embankment, then the assumption is that culvert should just be dug up and replaced, thereby leading to the 'Open-trench Replacement' terminator.

If embankment rebuilding is not necessary, then the user is asked if there is 'Access and workspace available at culvert ends for trenchless replacement?' If not, a process follows wherein there is discussion with the client regarding the feasibility and costs of creating access at the culvert ends for trenchless replacement. This process affects and is followed by the question 'Will client allow temporary road or lane closures?' The answer to this question will direct the user to either an open-trench or trenchless replacement terminator. Going back to the access prompt, if there is access for trenchless equipment, then the user is asked if 'Excavation depth is 20 feet or less to the bottom of the pipe?' If the bottom of the pipe is deeper than 20 feet, the user is queried if there are 'Adjacent culverts within project limits are being replaced using a trenchless approach?' If the answer is affirmative, the pathway leads to a terminator and recommendation for trenchless replacement.

In the case where the excavation depth is 20 feet or less, or there are no other culverts being replaced with trenchless methods within the project, the user is directed to the final prompt "Will client allow temporary road or lane closures?" If traffic closures are allowed, the user is directed toward the open-trench recommendation. If closures are not permitted by the client, the remaining replacement option is trenchless replacement. The interview process during the development of the decision-making tool revealed that highway agencies resort to trenchless replacement techniques only in extreme circumstances, because trenchless replacement is typically very expensive. The logic on the Page 8 flowchart therefore reflects an inclination toward open-trench methods when replacement is needed.

If the user answers that either the excavation depth is less than 20 feet, access to culvert ends is insufficient for trenchless replacement, or that there are no other culverts being replaced using trenchless approaches in the project, he/she is directed to a last opportunity qualifier for open-trench replacement. The query is whether the 'Client is will allow temporary road or lane closures?', with an affirmative answer leading to the Open-trench replacement terminator, as shown in Figure 32 below. If the client is not open to closures, then the recommendation is for a trenchless replacement.

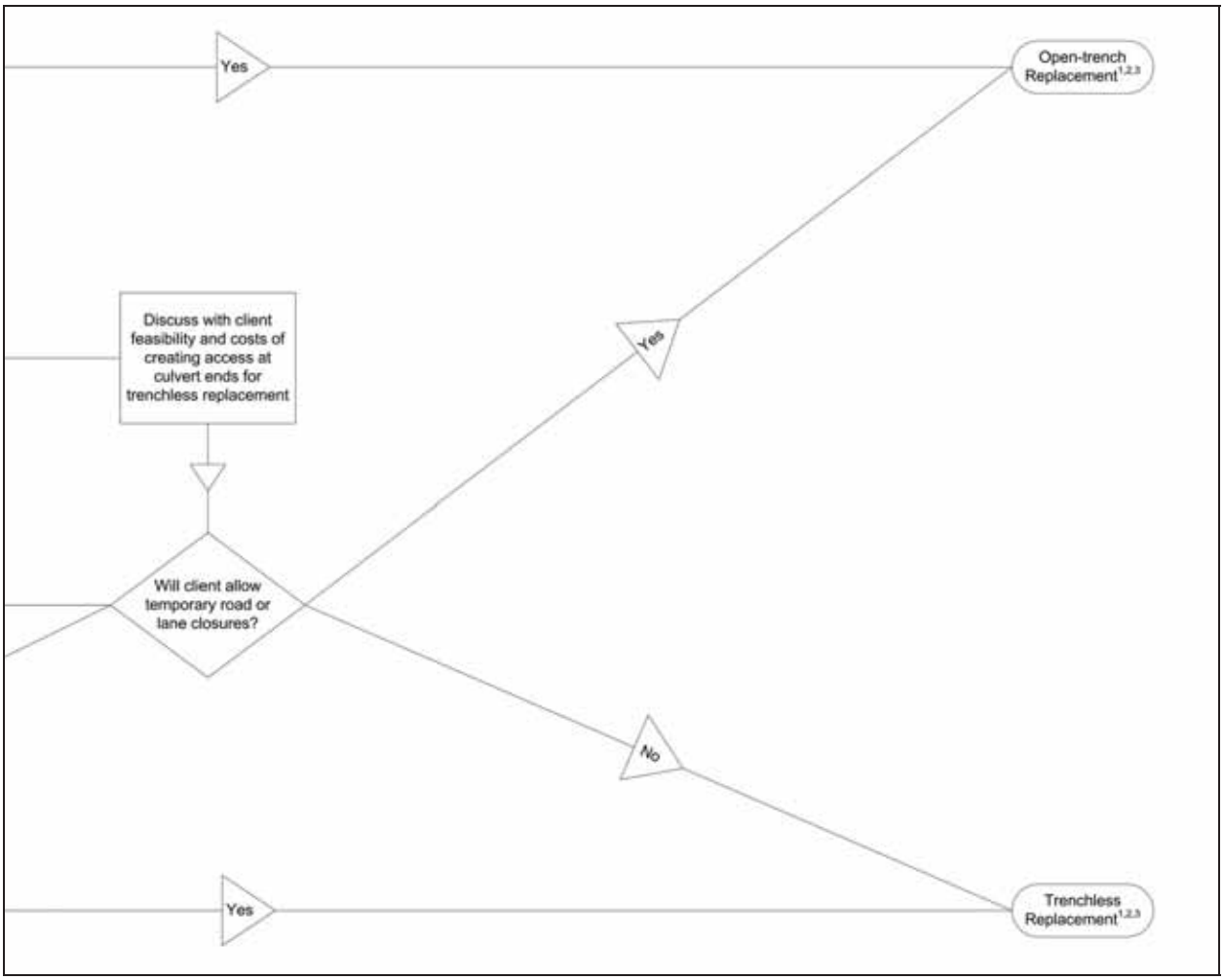

Figure 32. Flowchart. Page 8 qualifiers for no embankment damage, favoring trenchless replacement.

REPAIR LINER SELECTION MATRIX

The one-page culvert Repair Liner Selection Matrix is presented in Appendix E.1 at the end of this manual. This matrix summarizes properties, advantages and disadvantages of some of the liners commonly used in full-length, full-circumference repairs. More options and considerations for liner selection are also presented in the 2005 FLH Culvert Pipe Liner Guide and Specifications, which is listed in the Appendix G – Bibliography of this manual.

LOCALIZED MAN-ENTRY REPAIR MATRIX

The one-page culvert Localized Man-Entry Repair Selection Matrix is presented in Appendix E.2 at the end of this manual. This matrix summarizes properties, advantages and disadvantages of some of the commonly used local repair techniques that require man-entry.

REPLACEMENT MATRIX

The one-page culvert Replacement Matrix is presented in Appendix E.3 at the end of this manual. This matrix summarizes properties, advantages and disadvantages of some of the commonly used open-trench and trenchless replacement techniques.