

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION



**DRAINAGE HANDBOOK
OPTIONAL PIPE MATERIALS**

**OFFICE OF DESIGN, DRAINAGE SECTION AUGUST 2014
TALLAHASSEE, FLORIDA**

Table of Contents

Chapter 1 - Purpose	3
1.1 Distribution	3
1.2 Revisions	3
Chapter 2 - Design Service Life	4
2.1 Drainage Manual, Table 6-1	4
Chapter 3 - Durability	7
3.1 Project Corrosion Evaluation.....	7
3.2 Special Cases (Jack and Bore Casings, Ductile Iron Pipe, any Ferrous Metals)	15
Chapter 4 - Project Structural Evaluation	17
Chapter 5 - Documentation	20
Chapter 6 - Specifying Optional Pipe Materials in the Contract Plans.....	21
Appendix A – Example Project.....	23
Example Project.....	24
Side Drains under Driveways	24
Side Drains under Intersecting Streets.....	27
Storm Drain	28
Cross Drain	29
Gutter Drain	29
French Drain	29
Appendix B – Corrosion Tables and Charts	30

Chapter 1 - Purpose

Optional culvert materials must be considered for all culverts. Culverts that are extended shall match the existing culvert material to avoid misleading future maintenance assumptions on the type of buried pipe material. However, if the existing culvert fails a corrosion evaluation when the length of time of service is factored in or shows signs of deterioration, the existing culvert should be replaced or rehabilitated (e.g. lined). After the initial hydraulic design, culvert materials shown in Table 6-1 of the Drainage Manual must be evaluated as potential options. The evaluation must consider functionally equivalent performance in durability and structural capacity. This handbook is intended to be a reference for designers of FDOT projects, and to provide guidelines for the evaluation of optional pipe materials.

The guidance and values provided in this handbook are suggested or preferred approaches and values, not requirements nor standards. The values provided in the Drainage Manual are the minimum standards. In cases of discrepancy, the Drainage Manual standards shall apply. As the Drainage Manual states about the standards contained in it, situations exist where the guidance provided in this handbook will not apply. The inappropriate use of and adherence to the guidelines contained herein does not exempt the engineer from the professional responsibility of developing an appropriate design.

1.1 Distribution

This handbook is available for downloading from the Drainage Internet site.

1.2 Revisions

Any comments or suggestions concerning this handbook may be made by e-mailing the [State Hydraulics Engineer](#).

Chapter 2 - Design Service Life

The DSL is the minimum number of years that a pipe is required to perform for a particular application in the design of a project. For most applications, a 100-year DSL is required. Specific DSL's for a particular highway type and culvert function are shown in Table 6-1 of the Drainage Manual. Refer to the example project in the Appendix for further guidance on choosing appropriate DSL.

Although Table 6-1 of the Drainage Manual provides comprehensive policy on the selection of Design Service Life, practical considerations will sometimes override the Manual material. For instance, gutter drains are listed as a 25-year DSL application, but if a gutter drain, or any other pipe, is to be located beneath a structural wall, a 100-year service life is appropriate due to the difficulty of replacing that pipe in the future.

Changing the diameter may change the Estimated Service Life of concrete and metal pipe. This occurs due to the change in wall thickness of concrete and resulting change in the cover over the reinforcing wire, and thicker gage metal for larger diameter metal pipes.

2.1 Drainage Manual, Table 6-1

Table 6-1 from the Drainage Manual is included on the next page for easy reference by users of this handbook. Users should refer to the Drainage Manual for the latest version:

TABLE 6-1 CULVERT MATERIAL APPLICATIONS AND DESIGN SERVICE LIFE

Application		Storm Drain		Cross Drain		Side Drain ⁴	Gutter Drain	Vertical Drain ¹⁰	French Drain		
		Minor	Major	Minor	Major	All	All	All	Replacement will Impact the Roadway ⁵		Other
Design Service Life →		50	100	50	100	25	25 ⁶	100	50	100	50
Culvert Material		An * indicates suitable for further evaluation.									
P I P E	Corrugated Aluminum Pipe CAP	*	*	*	*	*	*		*	*	*
	Corrugated Steel Pipe CSP	*	*	*	*	*	*		*	*	*
	Corrugated Aluminized Steel Pipe CASP	*	*	*	*	*	*		*	*	*
	Spiral Rib Aluminum Pipe SRAP	*	*	*	*	*	*		*	*	*
	Spiral Rib Steel Pipe SRSP	*	*	*	*	*	*		*	*	*
	Spiral Rib Aluminized Steel Pipe SRASP	*	*	*	*	*	*		*	*	*
	Steel Reinforced Concrete Pipe RCP	*	*	*	*	*	*		*	*	*
	Non-reinforced Concrete Pipe NRCP	*	*	*	*	*	*		*	*	*
	Polyethylene Pipe – Class I HDPE-I	*		*		*			*		*
	Polyethylene Pipe – Class II ⁸ HDPE-II	*	*	*	*	*	*		*		*
	Polypropylene Pipe PP	*	*	*	*	*	*		*	*	*
	Polyvinyl-Chloride Pipe ⁷ PVC	*	F949	*	F949	*		F949	*	F949	*
	Fiberglass Pipe							*			
S T R P L	Structural Plate Aluminum Pipe SPAP	*	*	*	*	*					
	Structural Plate Alum. Pipe-Arc SPAPA	*	*	*	*	*					
	Structural Plate Steel Pipe SPSP	*	*	*	*	*					
	Structural Plate Steel Pipe-Arch SPSPA	*	*	*	*	*					
B O X	Aluminum Box Culvert	*	*	*	*	*					
	Concrete Box Culvert CBC	*	*	*	*	*					
	Steel Box Culvert	*	*	*	*	*					

Table notes are on the following page

Notes for Table 6-1

1. A minor facility is permanent construction such as minor collectors, local streets and highways, and driveways, provided culvert cover is less than 10 feet. Additionally, this category may be called for at the discretion of the District Drainage Engineer where pipe replacement is expected within 50 years or where future replacement of the pipe is not expected to impact traffic or require extraordinary measures such as sheet piling.
2. A major facility is any permanent construction of urban and suburban typical sections and limited access facilities. Urban facilities include any typical section with a fixed roadside traffic barrier such as curb or barrier wall. Additionally, rural typical sections with greater than 1600 AADT are also included in this category.
3. Temporary construction normally requires a much shorter design service life than permanent does. However, temporary measures that will be incorporated as permanent facilities should be treated as permanent construction with regard to design service life determination.
4. Although culverts under intersecting streets (crossroads) function as side drains for the project under consideration, these culverts are cross drains and shall be designed using appropriate cross drain criteria, not the shorter sidedrain service life criteria. Index 273 shall be used for end treatment..
5. Replacing this pipe would require removal and replacement of the project's pavement or curb.
6. Gutter Drains under retaining walls should use a 100 year DSL.
7. F949 PVC service life is 100 years. Other PVC pipe has a 50 year service life. PVC pipe should not be used in direct sunlight unless it meets the requirements of Section 948-1.1.
8. Class II HDPE pipe may not be used in the Florida Keys.
9. Any pipes under permanent structures such as retaining walls, MSE walls, buildings, etc. shall use a 100 year DSL.
10. Resilient connections required for all vertical pipes.

Chapter 3 - Durability

The requirements for DSL may vary between projects as well as within a project, depending on the highway functional classification and the application of the culvert.

The projected service life, hereafter referred to as the Estimated Service Life (ESL), of a culvert is the duration of service time after which significant deterioration is predicted to occur. At this point, major rehabilitation, lining or replacement should be considered. For a material to be included in the design of a project, its Estimated Service Life must meet or exceed the required Design Service Life.

For metal pipe, the time of first perforation (complete penetration) is the service life end point. For concrete culvert, the service life ends when the culvert has experienced a corrosion related crack in the concrete. The Estimated Service Life of a specific culvert material is determined from an evaluation of the corrosiveness, based on the environmental conditions of both the soil and water, at the intended culvert site.

For plastic pipe (PVC and HDPE), the service life is independent of the environmental conditions. The service life ends when any crack appears in the pipe. Plastic pipes sometimes crack from initial field loadings, but can also crack through a creep / rupture mechanism called slow crack growth. The Estimated Service Life of plastic pipes is determined by the State Drainage Office rather than by site-specific corrosion analysis.

3.1 Project Corrosion Evaluation

There are several types of corrosion that may occur with metal pipes or culverts containing steel reinforcement. Some types of corrosion are more severe and must be addressed in the design stage of a project. Therefore, environmental data must be collected when designing a culvert system for a specific site. Corrosion rates of culverts containing metal are governed primarily by the four environmental parameters listed and discussed below; these site-specific environmental parameters are used to predict the rate of corrosion and the resultant estimated service life at the site or region of interest:

- pH
- Resistivity
- Chlorides Concentration
- Sulfates Concentration

pH – The measure of alkalinity or acidity

A neutral environment has a pH of 7. When a culvert is placed in an environment in which the pH is too low (≤ 5.0) or too high (≥ 9.0), the protective layers of the culvert (concrete, galvanizing, aluminizing, etc.) can weaken, leaving the metal vulnerable to early corrosion. For example, any organic material from vegetation which is decomposing will lower the pH of the soil and clayey soils, organic soils or chloride bearing soils would tend to generate low resistivity values.

Resistivity – A measure of the electrical resistance of soils and waters. Resistivity is the inverse of conductivity. Highly conductive media tend to promote corrosion

Corrosion is an electrochemical process. For corrosion to occur, charged ions must migrate through the soil or water from a corroding area (anode) to a non-corroding area (cathode). Soils with relatively high resistivity values (> 3000 Ohm-cm) impede the migration of these ions, which slows corrosion. Environments with low resistivity values (< 1000 Ohm-cm) provide an easy path for ions to migrate from anode to cathode, which in turn accelerates corrosion.

Chloride Concentration – A measure of the number of chloride ions present

Chloride ions react with and break down a protective layer on the surface of the metal which otherwise protects against corrosion. When the chloride concentration is too high (> 2000 ppm) the protective layer breaks down quickly, leaving the metal vulnerable to corrosion. In addition, high chloride concentrations result in low resistivity values that allow easy electrical paths for ion migration and accelerated corrosion. Salt or brackish water will be high in chloride concentrations.

Sulfate Concentration – A measure of the number of sulfate ions present

Sulfate can cause concrete components to deteriorate. If the sulfate concentration is high (> 5000 ppm), concrete is vulnerable to accelerated deterioration. Sulfate ion concentrations rarely exceed 1500 ppm in Florida, therefore the threat sulfate ions pose is not as considerable as that of chloride ions.

Instances of high pH values are extremely rare. Observed pH values in virtually all soils and waters in Florida are less than 10, which are of no concern.

Elevated chloride values are typically only seen in or near coastal areas. High sulfates can be seen anywhere, but are more prevalent in coastal areas.

Valuable information can be obtained from a field review. A prediction of the actual service life of a culvert material at a particular site can be determined by the performance of a similar culvert material in the same or similar environmental condition. Premature failure of a similar culvert material warrants additional site specific testing. In addition, a discrepancy between the field review and results of field testing justifies the need for further investigation, especially since soil conditions may vary throughout the year. Request the complete soils report to verify site specific test data. If this does not eliminate or satisfy the discrepancy, a second set of field tests may be requested in order to verify data. Ultimately, conclusive field performance should be weighted more heavily than predicted service life when field performance and predicted service life disagree.

As an example, the environmental data furnished indicates that the environmental conditions along the project are not aggressive. However, upon visiting the site, the engineer notices that, at a specific site, the existing culvert is highly deteriorated. By reviewing the complete report or performing additional testing, the engineer can verify that at this particular site highly corrosive soils are present. Ultimately, if the engineer cannot resolve the discrepancy between environmental test data and observed field performance, prudence suggests that the historical performance of a particular pipe material should outweigh the theoretical analysis of corrosion parameter test data.

Because of the varying complexity of projects and soil conditions, it is difficult to establish a rigid format for conducting subsurface investigations. As stated in the Department's Soils and Foundation Handbook, "A subsurface investigation should be performed at the site of all new structure and roadway construction, and at widening, extensions, and rehabilitation locations as directed by the District Geotechnical Engineer or project scope". Typically, environmental corrosion tests, as discussed above, are performed on soil and water at structure locations, on structural backfill material and on subsurface materials along drainage alignments. All information resulting from the geotechnical survey is available in the geotechnical report. Contained within the report is a "Roadway Soils Survey" sheet which identifies a range of values of all tests performed. An example of a Roadway Soils Survey Sheet is shown on page 11.

Because these are a range of values, the designer may encounter a situation where the data provided on the Roadway Soil Survey Sheet does not match actual field conditions. The designer should request a copy of the complete geotechnical report, then locate and identify the test results for the particular site. If the test data provided within the report does not correlate with the actual field conditions, request additional testing at the site in question.

Analysis of the test data should take into consideration the most corrosive values of the native soils. Seasonal variations in the flow and water table can affect test data values. Surrounding land use should also be considered when reviewing the test data. For example, a golf course, dairy, farming operation, coal burning power plant and cement plant can all be sources of corrosive media.

Test values are seasonally affected by such factors as rainfall, flooding, drought and decaying vegetation. Whenever possible, environmental tests should be taken during periods when no unusual weather conditions exist.

With site specific project environmental test data available, the engineer should not use the most corrosive individual site data for the entire project or extract the most aggressive individual parameter results from the testing data to create a "worst case" project-wide condition. Such over conservatism is unwarranted and unrealistic.

If deep pipe installations are foreseen early in the design, the hydraulics engineer should coordinate with the geotechnical engineer in targeting soil sampling with the expected pipe depth.

NOTICE: THE OFFICIAL RECORD OF THIS SHEET IS THE ELECTRONIC FILE SIGNED AND SEALED UNDER RULE 61G5-23.003, F.A.C.

STATE OF FLORIDA
DEPARTMENT OF TRANSPORTATION
MATERIALS AND RESEARCH

DISTRICT : 3
ROAD NO : S.R. 166
COUNTY : JACKSON

PROJECT NAME :
FINANCIAL PROJECT ID :

DATE OF SURVEY : 2/15/2007-5/1/2007
SURVEY MADE BY : HARTFORD TESTING COMPANY
SUBMITTED BY : LARRY BALLARD, P.E.

CROSS SECTION SOIL SURVEY FOR THE DESIGN OF ROADS
SURVEY BEGINS STA. : 400+00 SURVEY ENDS STA. : 554+00
REFERENCE: BASELINE SURVEY

STRATUM NO.	ORGANIC CONTENT				SIEVE ANALYSIS RESULTS				ATTERBERG LIMITS (%)	DESCRIPTION	NO. OF TESTS	CORROSION TEST RESULTS			PH		
	NO. OF TESTS	% ORGANIC	MOISTURE CONTENT	NO. OF TESTS	10 MESH	40 MESH	60 MESH	100 MESH				NO. OF TESTS	LIQUID LIMIT	PLASTIC INDEX		ASPHALT GROUP	NO. OF TESTS
1																	
2	4	87-98	71-93	59-82	44-55	3-10			N.P.	ROCK BASE, ASPHALTIC CONCRETE							
3	7	3-4	6-20	94-100	86-94	65-71	34-45	15-21	N.P.	SUBGRADE, GRAY & TAN SAND W/TRACE SILT, LIMEROCK & SHELL	7	3400-4300	40-60	18-72	6.4-8.3		
4	3	1-2	15-25	64-100	71-93	60-90	53-82	37-45	4	FILL DARK BROWN SAND W/SOME SILT & TRACE LIMEROCK	4	2300-2800	60-120	84-96	8.4-9.9		
5	3			99-100	96-98	75-80	30-34	3	4-4	GRAY AND BROWN SILTY SAND W/TRACE CLAY AND LIMESTONE FRAGMENTS	3	6800-8000	60-120	156-206	7.5-8.2		
6	3	18-40	20-60						11-15	TAN AND LIGHT GRAY SILTY SAND W/SOME CLAY AND TRACE SHELL							
7	3			88-92	73-79	60-69	51-55	3	10-15	MICA, ORGANIC DARK BROWN SILTY SAND W/SOME CLAY							
8	3	16-20	20-38	99-100	97-99	88-97	77-80	10-15	38-53	YELLOW AND GRAY SILTY SAND CLAY	3	20000-35000	120	120	4.6-5.2		
9									N.P.	MICA, BROWN SAND W/SOME ORGANIC AND TRACE SHELL							
										NATURAL LIMESTONE							

EMBAKMENT AND SUBGRADE MATERIAL
STRATA BOUNDARIES ARE APPROXIMATE MAKE FINAL CHECK AFTER GRADING
SW - WATER TABLE ENCOUNTERED
GNE - GROUND WATER NOT ENCOUNTERED

The material from Stratum Number 1 is Rock Base under Asphaltic Concrete.
The material from Stratum Number 2 appears satisfactory for use in the embankment when utilized in accordance with Index 505.
The material from Stratum Number 3 appears satisfactory for use in the embankment when utilized in accordance with Index 505. However, this material is likely to retain excess moisture and may be difficult to dry and compact. It should be used in the embankment above the water level existing at the time of construction. This material may not be used in the subgrade portion of the roadbed due to its organic content.
The materials from Stratum Numbers 4 and 5 are plastic materials and shall be removed in accordance with Index 500. They may be placed above the existing water level at the time of construction, to within 4 feet of the proposed base. They should be placed uniformly in the lower portion of the embankment for some distance along the project rather than full depths for short distances.
The material from Stratum Numbers 6 and 8 is ORGANIC/A-8 material and shall be removed in accordance with Index 500, except where noted in the cross sections.
The material from Stratum Number 7 is Highly Plastic material and shall be removed in accordance with Index 500. It may be used within the project limits as indicated in Index 505 only when excavated within the project limits and is not to be used when obtained from outside the project limits.
The material from Stratum Number 9 is the Natural Limestone Formation. Special tools and equipment may be required to excavate and/or dewater this material.

EXHIBIT SS-1
Date: 1/11/08

DATE	DESCRIPTION	REVISED DATE	DESCRIPTION
STATE OF FLORIDA		DEPARTMENT OF TRANSPORTATION	
COUNTY		FINANCIAL PROJECT ID	
JACKSON		123456-1-52-01	
ROAD NO.		166	
ROADWAY SOILS SURVEY			
SHEET NO.		87/25	

Use of the Culvert Service Life Estimator Program (CSLE) is required in determining types of culvert material which have Expected Service Life that meet or exceed the required DSL. When the DSL, pipe size, pH, resistivity, chlorides, and sulfates are input, the program provides a listing of those materials which meet the DSL. Use of the program also furnishes the designer with an excellent form of documentation.

An example of the CSLE input data and printout follows:

DSL: This application is to be a storm drain system which is located on a major urban facility and functions as an "urban principle arterial road." Thus, the appropriate DSL for this application is 100 years.

The following data was furnished and a field review gave no indication that these values were suspect:

Ph: 7.6

Resistivity: 2610

Chlorides: 2390

Sulfates: 1120

Diameter (Pipe Size): 42" - because this is a storm drain system an n-value of 0.012 was used.

Figure 2 illustrates materials the designer would use in performing the structural analysis.

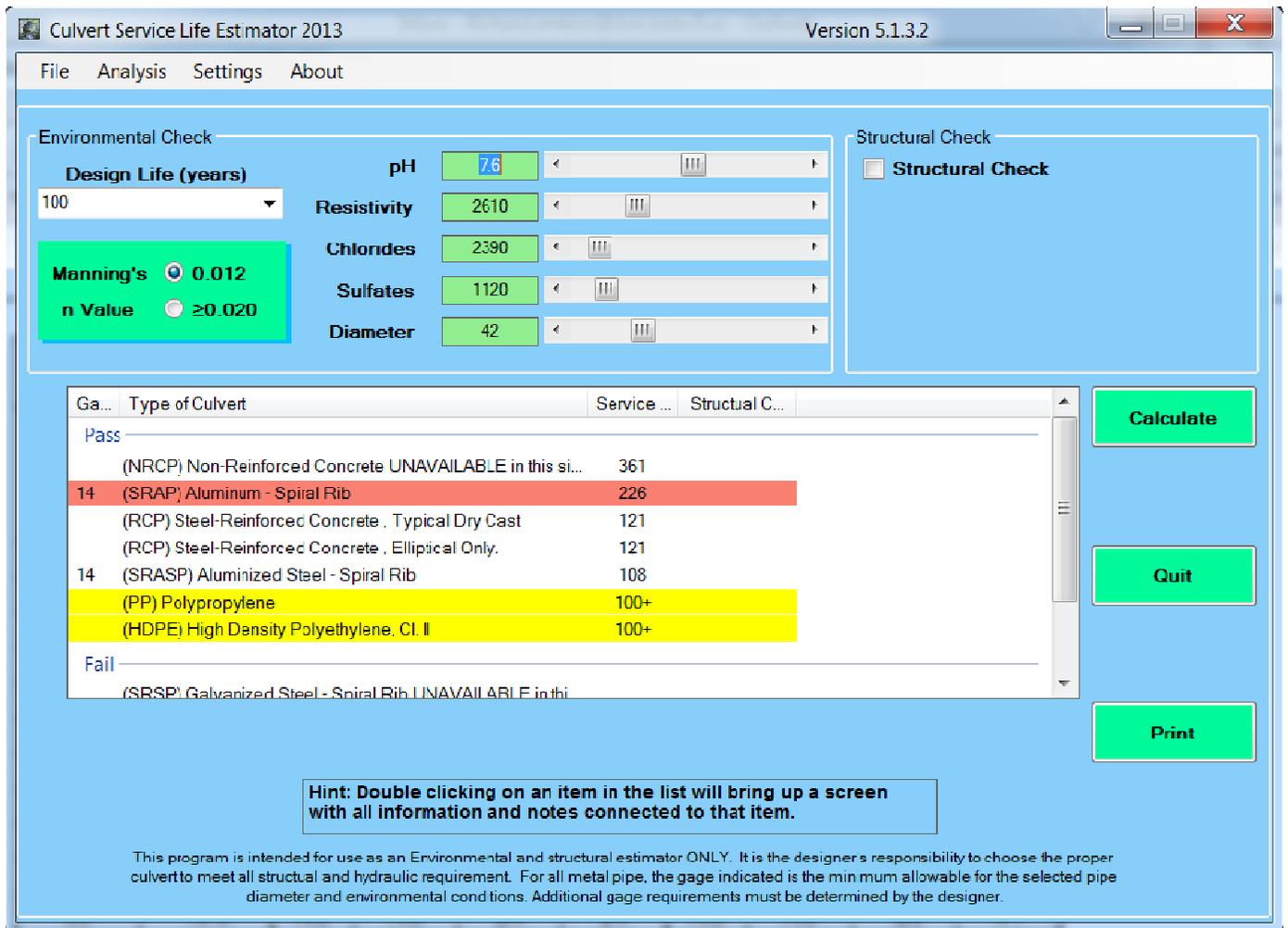


Figure 2

No additional consideration should be given to one material over another having less service life if all meet the minimum required. In looking at the printout, culverts made from concrete, aluminum, aluminized steel, polypropylene, high density polyethylene class II and F949 PVC all meet the 100 year DSL. By changing the DSL to 50 years as shown in Figure 3, galvanized steel is now allowable and the required thickness is reduced for the aluminized steel option. Figure 4 illustrates that changing the pipe size can also increase or decrease the expected service life of concrete pipe.

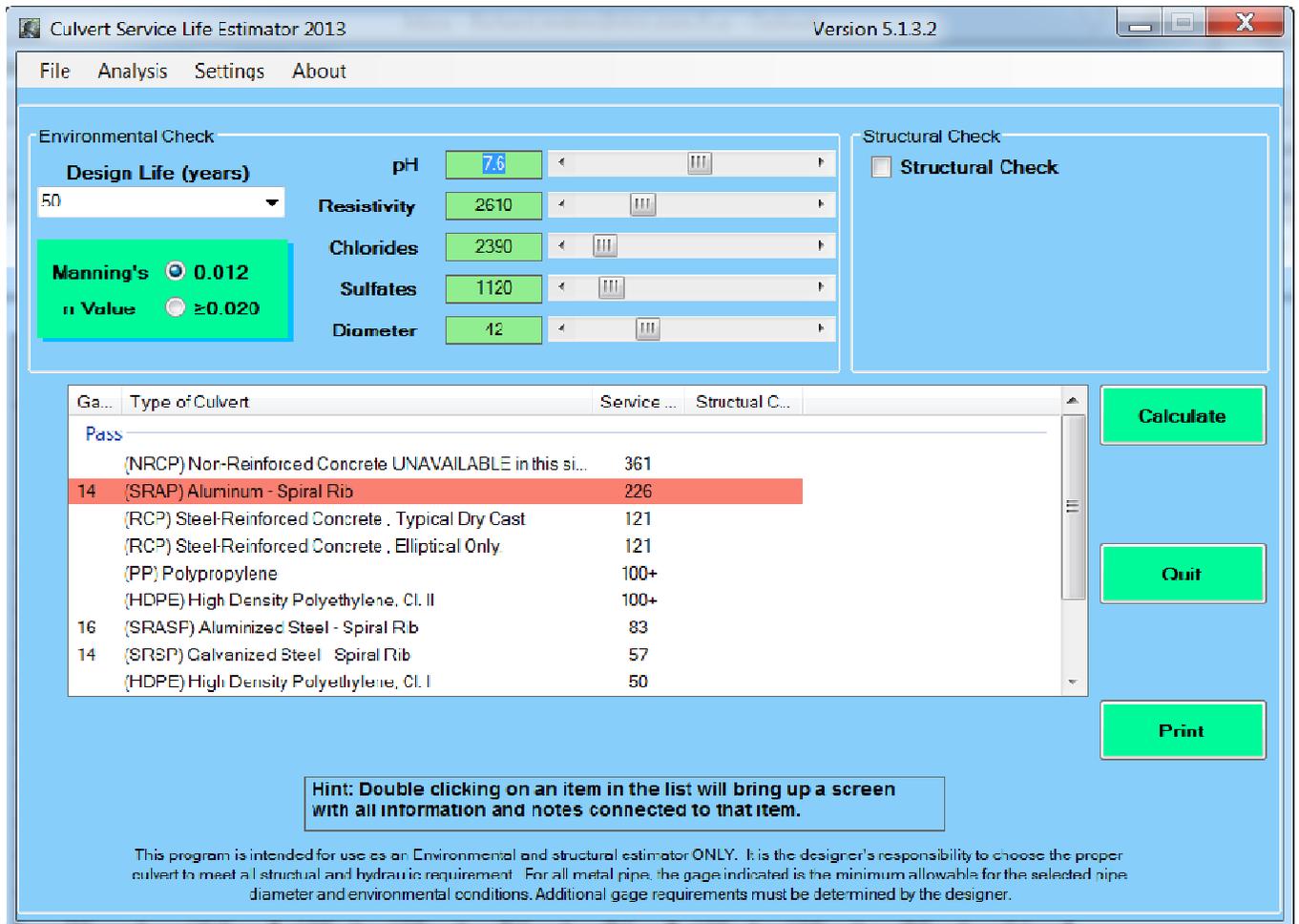


Figure 3

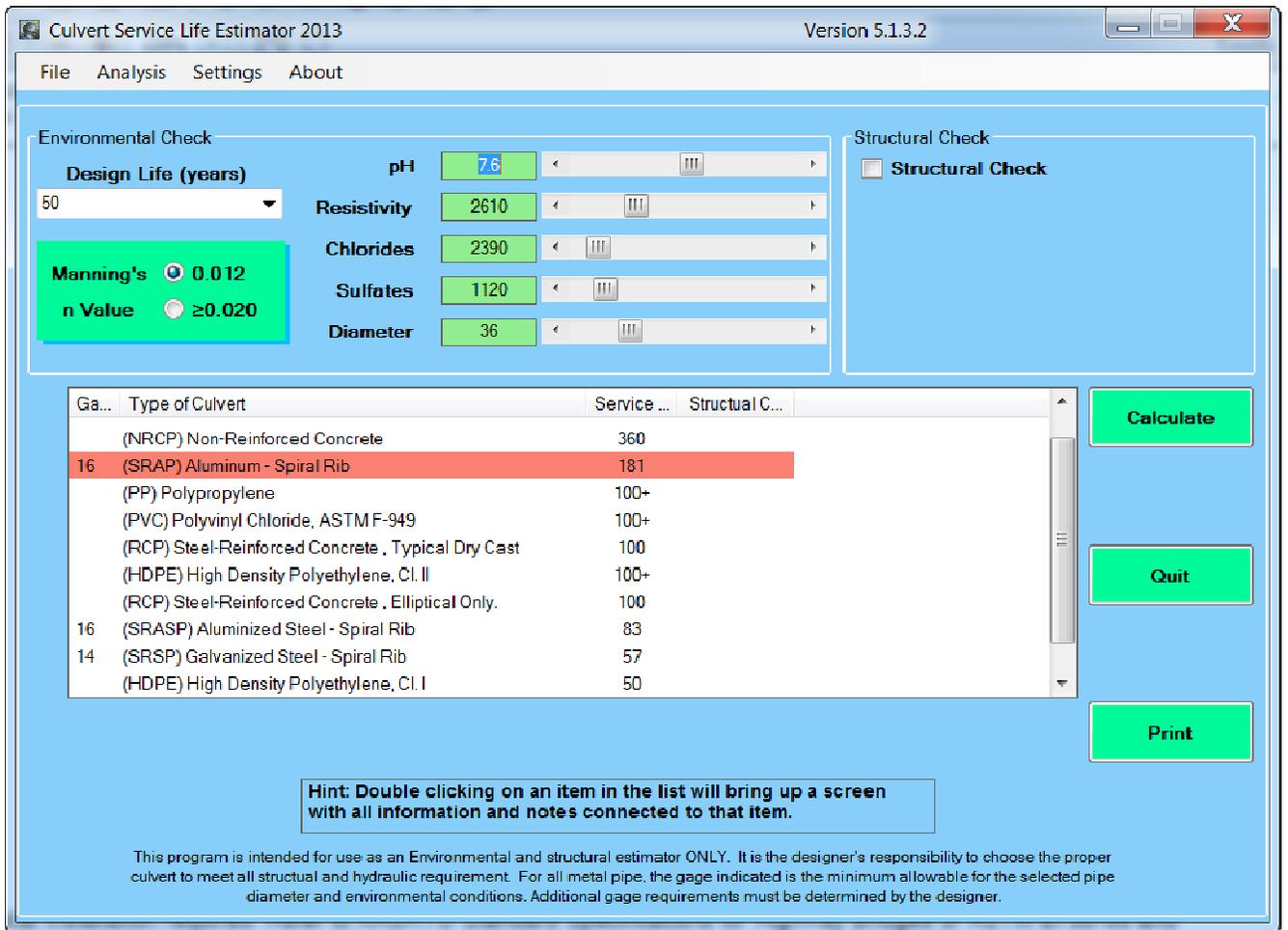


Figure 4

3.2 Special Cases (Jack and Bore Casings, Ductile Iron Pipe, any Ferrous Metals)

When a culvert is to be installed by jack and boring instead of open cutting, the designer should evaluate using the jacked and bored casing as the conveyance pipe. Use of the casing for this purpose has been allowed, however, this was not the original intent for its use. Jack and bore installation is usually specified on high AADT roadways or under railroads, both of which are applications where open cutting often causes significant impacts on users. Thus, this example will assume the typical 100 year DSL for jack and bore installations. The following steps should be used to determine the casing requirements.

1. Run the Service Life Estimator Program or use the figures or tables in Appendix B with site specific environmental parameters. If the casing or pipe will be exposed to water (surface or ground) for extended periods of time the environmental parameters of the water should be compared with that of the soil and those testing results that produce the shortest service life for the galvanized steel option should be used.
2. To be conservative, deduct 10 years from the Estimated Service Life of the galvanized steel option generated by the program.
3. Determine the pitting rate by dividing the wall thickness of the galvanized steel option estimated by the program by the estimated service life determined (ESL - 10 years) in Step 2. From FDOT Drainage Manual Appendix E, identify the wall thickness of the gage pipe called out on the output.

$$\text{Pitting Rate} = \frac{\text{Gage Thickness}}{\text{ESL (years)}} = \frac{0.\text{xxx inches}}{\text{year}}$$

Knowing the Pitting Rate, the Required Wall Thickness can be determined by multiplying the Design Service Life for the application by the Pitting Rate.

Required Wall Thickness = Pitting Rate x (DSL)

Using the galvanized steel option shown on Figure 3:

Estimated Service Life for Galvanized Steel Culvert = 57 years.

Deduct 10 years from this: 57 yrs. - 10 yrs. = 47 yrs.

14 gage = 0.079 inches (thickness of 14 gage galvanized steel culvert per FDOT Drainage Manual Appendix E)

Therefore the Pitting Rate = $0.079 / 47 = 0.00168$ inches/year

Required Wall Thickness = 100 years (Design Service Life) x 0.00168 (Pitting Rate)
= 0.1681 inches

In summary, the use of a steel casing with a wall thickness of at least 0.1681 inches would be required. A note such as: "For corrosion purposes, steel casing must have a minimum wall thickness of 0.1681 inches" should be included in the plans.

The required wall thickness is for corrosion purposes only. Greater wall thicknesses are typically required for the structural loadings associated with the jacking of the casing.

In the event that the designer elects to use the casing as the conveyance pipe, additional consideration must be given to joint integrity and impact to the roadway if a joint failure was to occur. For instance, when welding is used to join a jacked pipe, the weld might not be around the full circumference of the pipe. If that welded pipe however was to now carry stormwater as the conveyance pipe, the weld must be fully around the pipe circumference to prevent leakage and sand infiltration.

When using the casing alone is not allowed, a note disallowing this practice should be placed in the plans to communicate to the Contractor that a VECP (Value Engineering Change Proposal) eliminating the interior pipe will not be approved.

Chapter 4 - Project Structural Evaluation

After performing the corrosion analysis, the next step in determining the allowable optional material is to determine the structural adequacy of these materials. This analysis is done using FDOT Drainage Manual Appendix E. The information provided in the FDOT Drainage Manual Appendix E was developed based on criteria found in AASHTO LRFD Bridge Design Specifications, Section 12.

For each of the allowed options from the corrosion analysis, verify that the depth of backfill over the pipe is between the minimum and maximum fill heights on FDOT Drainage Manual Appendix E. If the cover height is outside the limits, the following options are available as discussed below:

1. The flow line of the pipe could possibly be adjusted if other design criteria are not violated.
2. The gage of metal pipe or the class of concrete pipe may be increased. The engineer should verify that the specified thicker gage is available for the corrugation specified.
3. The material may be eliminated as an option for the job.

The Plans Preparation Manual requires that the acceptable type or types of pipe materials have to be called out in the plans. Required class of concrete or gage and corrugation for metal pipe are established using the FDOT Drainage Manual Appendix E.

The example below, using the data shown on Figure 2, illustrates general guidelines for using FDOT Drainage Manual Appendix E on cover requirements.

Project Conditions: Storm Drain application, 42 inch pipe, DSL 100 years, minimum height of cover 7 feet, maximum height of cover 25 feet, and corrosion parameters listed in Figure 2.

The allowable materials to be checked (from Fig. 2, the Culvert Service Life Estimator) are as follows:

- 14 gage aluminized steel,
- 14 gage aluminum,
- F949 PVC, PP and HDPE Class II
- Concrete (RCP and NRCP) All concrete pipes have the same cover requirements and will therefore be addressed as “concrete pipe” for this example.

The structural analysis to determine allowable pipe materials is shown below:

- A. Check minimum fill heights, using FDOT Drainage Manual Appendix E. All materials meet the minimum fill height limitations.
- B. Check the maximum fill height for Concrete Pipe, using FDOT Drainage Manual Appendix E. According to Appendix E, concrete pipe must be Class IV or greater.
- C. Check the maximum fill height for steel pipe. Use the table “Steel - Round Pipe - Spiral Rib” This table applies to both galvanized steel pipe and aluminized steel pipe.

Referring to the same table, 14 gage 42 inch aluminized steel pipe is acceptable because the height of fill does not exceed the maximum fill height allowed by FDOT Drainage Manual Appendix E.

- D. Check the height of fill against the maximum height allowed for the size/gage combination for aluminum pipe using the table “Aluminum Round Pipe Spiral Rib”. In checking the table we find that 42 inch, 16 gage pipe is not available. Thus, the thinnest allowable wall is 14 gage and restrictions are placed on the use of this size and gage combination. To use this size and gage combination, special installation requirements set forth in AASHTO Standard Specifications for Highway Bridges or ASTM B788 as well as the manufacturer’s installation recommendations must be detailed in the plans. In addition, before using this size and gage combination, approval must be given by the State Hydraulics Engineer.

In lieu of the requirements referenced above for aluminum pipe, the designer may use a lower gage (greater wall thickness) pipe to eliminate the requirement for a design review. For documentation purposes, a note can be added to the printout sheet which

states: In lieu of design review, use 42 inch 12 gauge.

In the example shown above, if there was a concern for minimum cover, the designer would not only consider elliptical concrete pipe but also evaluate the use of the metal pipe arch options

It should be noted that the fill heights shown in the FDOT Drainage Manual Appendix E are calculated using a very conservative approach. In those cases where the designer encounters very high or very shallow fill heights we encourage the designers to use methods set forth in AASHTO LRFD Bridge Design Specifications, Section 12.

Chapter 5 - Documentation

Justification for allowing or eliminating a pipe material is required. Documentation requirements can be found in Chapter 6 of the Drainage Manual. Requirements include the required Design Service Life for the application, environmental data, and the results of the structural evaluation. An excellent form of corrosion analysis documentation is provided in the printout from the Culvert Service Life Estimator Program.

The environmental parameters for the specific site, the Estimated Service Life, and the materials that fail to meet or exceed the Design Service Life are documented on the printout. Also, additional comments may be added for documentation purposes. An example would be; "Not allowed per FDOT Drainage Manual Appendix E ".

Chapter 6 - Specifying Optional Pipe Materials in the Contract Plans

For cross drains, storm drains, french drains, and gutter drains, optional pipe materials are to be shown in the plans as illustrated in the Plans Preparation Manual. The Optional Pipe Tabulation Sheet includes the size, class of concrete, gage and corrugation and type of metal, and type of plastic pipe are to be included in this tabulation.

For specifying optional side drains on a project, two approaches are available:

1. Specify only the pipe sizes in the plans - if all materials meet the environmental and structural requirements the designer need only specify the pipe size in the plans. When only the size is specified in the plans, the contractor has the option to use any material allowed by specification meeting the minimum class or gage contained in the specifications. If a material is not allowed on a side drain application(s), the plans should include a note disallowing the use of that specific material. If this option is chosen, then pipes having n-values greater than 0.012 will be allowed. Thus, if a designer wishes to use only n-value 0.012 pipes, option 2, below, must be utilized.
2. Specify allowable side drain pipe materials on the optional pipe plan sheet - in such cases, the Contractor is restricted to the plan sheet options. This plans preparation approach is commonly used when shallow roadside ditches or larger side drain sizes create low pipe cover clearances, eliminating pipes with higher cover requirements.

When elliptical or pipe arch pipe are the allowed options, the designer should call out the specified size, class, gage, and corrugations in the plans with payment to be made using the equivalent round size.

When round pipes meet the required clearances, elliptical and arch pipes should not be listed as options since they are generally more expensive than their round equivalents. For example, if round concrete and arch metal pipe qualify due to low clearance requirements, elliptical RCP should not be listed as an option since it will likely be more expensive than round concrete pipe.

When specifying pipe options on the Optional Pipe Tabulation Sheet, pipes may be called out individually, by storm drain system, by station to station, or any combination of these groupings. Additionally, optional pipes may be identified as a group and then certain pipes within the group accepted and assigned a different list of optional materials. The Plans Preparation Manual shows examples of these approaches. The focus of using groups rather than evaluating and listing each pipe is to provide a fair, competitive pipe supply market with a reasonable level of effort on the part of the

designer. In general, if the designer needs more than one Optional Pipe Tabulation Sheet on a project, he has gone into too much detail in specifying pipe options and should consider employing more groups of pipes rather than listing pipe by pipe allowable materials.

In some low clearance situations, a single concrete pipe may be allowed but a metal arch culvert may not satisfy minimum cover. In such cases, a multiple, smaller metal pipe may have the required hydraulic capacity and minimum cover. For example, consider the case where a 60", $n = 0.012$ cross drain, is required for hydraulic capacity but metal pipe, even in arch shape, does not provide the required minimum clearance in FDOT Drainage Manual Appendix E. In such a case, double 48" metal pipes should be checked for hydraulic capacity and, if hydraulically acceptable, the minimum clearance and physical fit within the channel should be verified. Multiple barrel culverts are more susceptible to debris clogging and are likely to be generally more costly, especially considering the additional headwall costs. Typically, double pipes are not used for storm drains due to the required size and cost of the adjacent drainage structures. Occasionally, broad, shallow creeks crossing roadways will require triple or quadruple cross drain pipes in parallel to make efficient use of the pipe cross section or due to pipe clearance requirements.

For design/build projects, an optional materials analysis is still required and either an optional materials tabulation sheet included in the construction plans or the pipe material which is to be installed should be documented somewhere in the plans.

Appendix A – Example Project

Example Project

The project consists of the widening and resurfacing of a state road in northern Leon County, Florida. This particular section of roadway contains both rural and urban sections. The project design includes the following:

- Side drain replacement
- Cross drain replacement and extensions to existing culverts
- Storm drain (new design)
- French drain (new design)
- Gutter drain (new design)

For this example, each application will be addressed and will include a determination of the design service life, commonly asked questions and proposed solutions to those questions.

Side Drains under Driveways

For this example, we will assume that the soils data provided was fairly consistent throughout the project, therefore the data from the boring having the most stringent values was used in the environmental analysis. Pipe sizes range from 18 inches to 30 inches in diameter. Although actual calculations determined that in certain locations a 12 inch pipe would satisfy the hydraulics, the Drainage Manual recommends a minimum size of 18 inches.

Referring to Table 6-1 on page 5, we located the Side Drain column. From the table we see that all highway facilities require a 25 year design service life. Use the Culvert Service Life Estimator program to determine the materials allowed from the environmental standpoint. At this particular location an 18 inch pipe is needed. See Figure 5, below, for results. From the print out we find that the following materials meet the environmental criteria established to meet the 25 year Design Service Life: 16 gage Aluminum, 16 gage aluminized steel, 16 gage galvanized steel, concrete, polypropylene, polyethylene and PVC pipe.

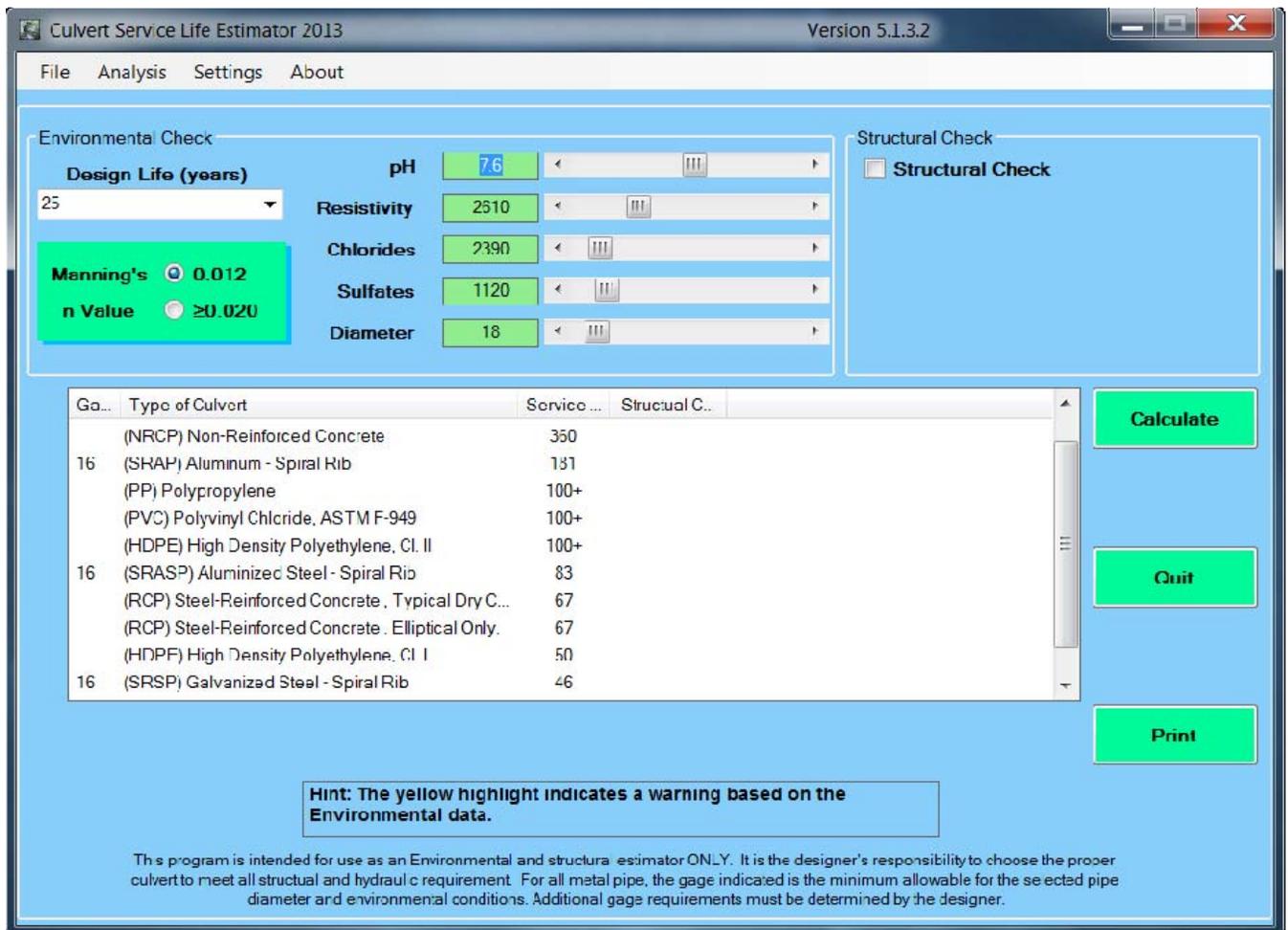


Figure 5

The next step in our selection process is to check the structural capacity of the pipe materials allowed. Using FDOT Drainage Manual Appendix E we can check for the minimum and maximum fill height requirements. Throughout the project the minimum amount of fill over the pipe to the bottom of the flexible pavement did not fall below 30 inches, except for two driveways having 10" of cover to the bottom of the flexible pavement. Assume flexible pavement thickness of 3 inches. Also, throughout the project the maximum amount of cover was 4 feet. The following steps were followed to check structural capacity:

- A. Check minimum fill heights, FDOT Drainage Manual Appendix E, "Flexible Pavement". Knowing that the minimum height of cover is not less than 30 inches, each material is checked. All materials meeting the environmental requirements also meet the minimum fill height requirements except for the two shallow driveways. For the two driveways with a clearance of 10", only concrete pipe (RCP, NRCP), with a minimum required cover of 12" to the top of the flexible pavement may be used.
- B. Check the maximum fill height for Concrete Pipe, FDOT Drainage Manual Appendix E, Table "Concrete Pipe - Round". We have a maximum fill height of 4 feet, therefore, according to the table, concrete pipe meeting the requirements of Class I is allowed. NOTE: Section 430 of the standard specifications states that concrete pipe used as side drain must meet the strength requirements of Class I pipe at minimum unless the Class is specifically called out in the plans.
- C. Check the maximum fill height for steel pipe. Use the table "Round Pipe - 2 2/3" x 1/2" Corrugation. This table applies to both galvanized steel pipe and aluminized steel pipe. Each size is checked to assure that the size/gage combination meeting the environmental criteria has an allowed maximum fill height greater than or equal to 4 feet.

In looking at the table to determine the acceptability of galvanized steel pipe we find that the size and gauge combination of, 16 gauge, 18 inch, would be allowed with a fill height up 100 feet or more, therefore, 16 gauge 18 inch galvanized steel pipe is an option. This same process is followed for the aluminized steel pipe. The aluminized steel pipe is also allowed.

- D. Check the height of fill against the maximum height allowed for the size/gage combination for aluminum pipe using the table "Round Pipe – 2 2/3" x 1/2" Corrugation. In checking the table we find that for 18 inch, 16 gauge pipe is allowed with fill heights up 83 feet.
- E. Check the maximum fill height for Polyethylene, Polypropylene and PVC pipe using FDOT Drainage Manual Appendix E. From Appendix E the maximum fill height allowed for Polyethylene (17 ft), Polypropylene (19 ft) and PVC (42 ft) are all greater than 4 ft and therefore are allowed.

All pipe materials shown on the output meet the maximum fill height requirements.

Specification 430, Type of Pipe to Be Used, of the Standard Specifications for Road and Bridge Construction states that the Contractor may use any material referred to in that particular section unless a specific type of pipe is called out in the plans. Note, since all materials allowed for use under the specification meet the environmental and structural requirements the designer may elect to tabulate the sizes required. If we could not have used all of the materials called out in Section 430, we would tabulate in the plans those materials meeting the environmental and structural requirements.

When looking at optional pipe materials we are generally looking at the round pipe options. In those cases where minimum cover restricts the use of round pipe you should look at the elliptical and pipe arch pipes. In low cover situations, if elliptical RCP will not satisfy the minimum allowable cover, then multiple smaller pipes may suffice if the ditch cross section is wide enough. Another option may be calling out a larger round pipe and burying to allow for silting up to the flow line.

Side Drains under Intersecting Streets

For the sake of this example, let us say that there are approximately 125 side drain locations throughout the project. Of the 125 locations, 25 are located under intersecting streets. Although these have been identified as side drains, they will be designed using cross drain criteria (see note 4 to Table 6-1, located on page 6). Referring to Table 6-1 on page 5 to determine the required Design Service Life and locating the cross drain column, we find that there may be as many as two different design service life requirements.

Of the 25 side drain/cross drain locations in this example problem, let us assume that 10 of the planned culverts would be identified as being located on a minor facility. From Table 6-1, a minor facility is defined as a facility which is permanent construction where design traffic volume is less than 1600 AADT and the maximum cover does not exceed 10 feet. In our example, these roads would be those small feeder roads which tie into the major thoroughfare and would fall under the category requiring a 50 year design service life. Environmental data is the same as that used for the side drain analysis above as documented. Examining Figure 3, Polyethylene, Polypropylene, 14 gage galvanized steel, 16 gage aluminized steel, 14 gage aluminum, NRCP, and RCP meet the environmental criteria required to obtain a 50 year DSL. Note that NRCP and F949 PVC are unavailable above 36" diameter. The next step is to check for structural adequacy. This process is identical to the structural check shown above in the previous section dealing with the other side drains.

The remaining 15 side drain/cross drains fall under the category requiring a 100 year design service life. Referring to Table 6-1 on page 5, a major facility is permanent construction of (1) roads using an urban or suburban typical section, or (2) limited

access facilities, or (3) any roadway where design traffic volume is greater than 1600 AADT. Having determined the required design service life to be 100 years, we are ready to perform the environmental analysis.

Environmental data is the same as that used for the previous side drain analyses. Examining Figure 2, Polyethylene, Polypropylene, 14 gage aluminized steel, 14 gage aluminum, and RCP meet the environmental criteria required to obtain a 100 year DSL. Remember from the previous example that NRCP and F949 PVC are unavailable above 36" diameter. The next step is to check for structural adequacy. This process is identical to the structural check shown above in the previous section dealing with the other side drains.

Storm Drain

Referring to Table 6-1 on page 5 we find that storm drains require either 50 year or 100 year Design Service Life. It should be noted that on a project a combination of the DSL could exist. An example would be where the main storm drain has to be designed to meet the 100 year DSL and the outfall could be designed to meet the 50 year DSL.

When choosing the appropriate DSL, use the same steps as those previously stated. Remember, all storm drains do not require the 100 DSL criteria. Refer to the notes on Table 6-1 for guidance on the selection of DSL.

The 100 year Design Service Life is required on the following example and was determined to be appropriate because the storm drain system is located on a major facility. The following data were produced by the geotechnical survey and the field review did not give any indications that these values were suspect. These values are from the most aggressive test site along the subsection of the project as grouped by the drainage designer.

Ph: 7.6

Resistivity: 2610

Chlorides: 2390

Sulfates: 1120

Diameter (Pipe Size): 42", this size was determined to be needed to handle the flows within this part of the storm drain system. Because this is a storm drain system a one-size (n-0.012) design was used.

Size and materials shown here are those the designer would use in performing the structural analysis.

This data is input into the Culvert Service Life Estimator Program. Figure 2 shows those materials allowed by virtue of their Estimated Service Life (ESL). The designer then performs the structural analysis as previously described.

Cross Drain

Cross drains can require 50 or 100 year DSL's. Refer to Table 6-1. Check the notes to identify which DSL is appropriate for your application. It is possible to have cross drains on the project that require the various DSL's. Determination of environmental data to use and structural analysis are the same as previously described.

When sizing cross drains, only one n-value (usually 0.012 since most cross drains in Florida are outlet controlled) need be considered. However, when the cross drain hydraulics are inlet controlled and metal pipes are environmentally acceptable, the designer should list standard corrugated metal pipes within the allowable options. Standard corrugation metal pipe is often less expensive than spiral rib metal pipe and is available in larger sizes than spiral rib pipe.

When extending cross drains, preference should be given to using the same existing pipe materials. Existing pipe should be replaced or lined if, upon inspection, the pipe displays evidence of corrosion or has structural cracking. When the extension of an existing pipe results in a minor transgression of the structural clearance criteria, the designer should consider providing additional structural support for the pipe extension rather than replacing the entire cross drain. Encasing the extension in flowable fill will typically provide the needed additional support.

Gutter Drain

From Table 6-1 on page 5 we identify a required DSL of 25 years for the gutter drain. The process is the same as that for performing the analysis for the side drain application previously discussed. However, when sizing gutter drain and choosing materials, only materials having an n - value of > 0.012 should be used. If possible, specify pipe of sufficient length to eliminate joints.

French Drain

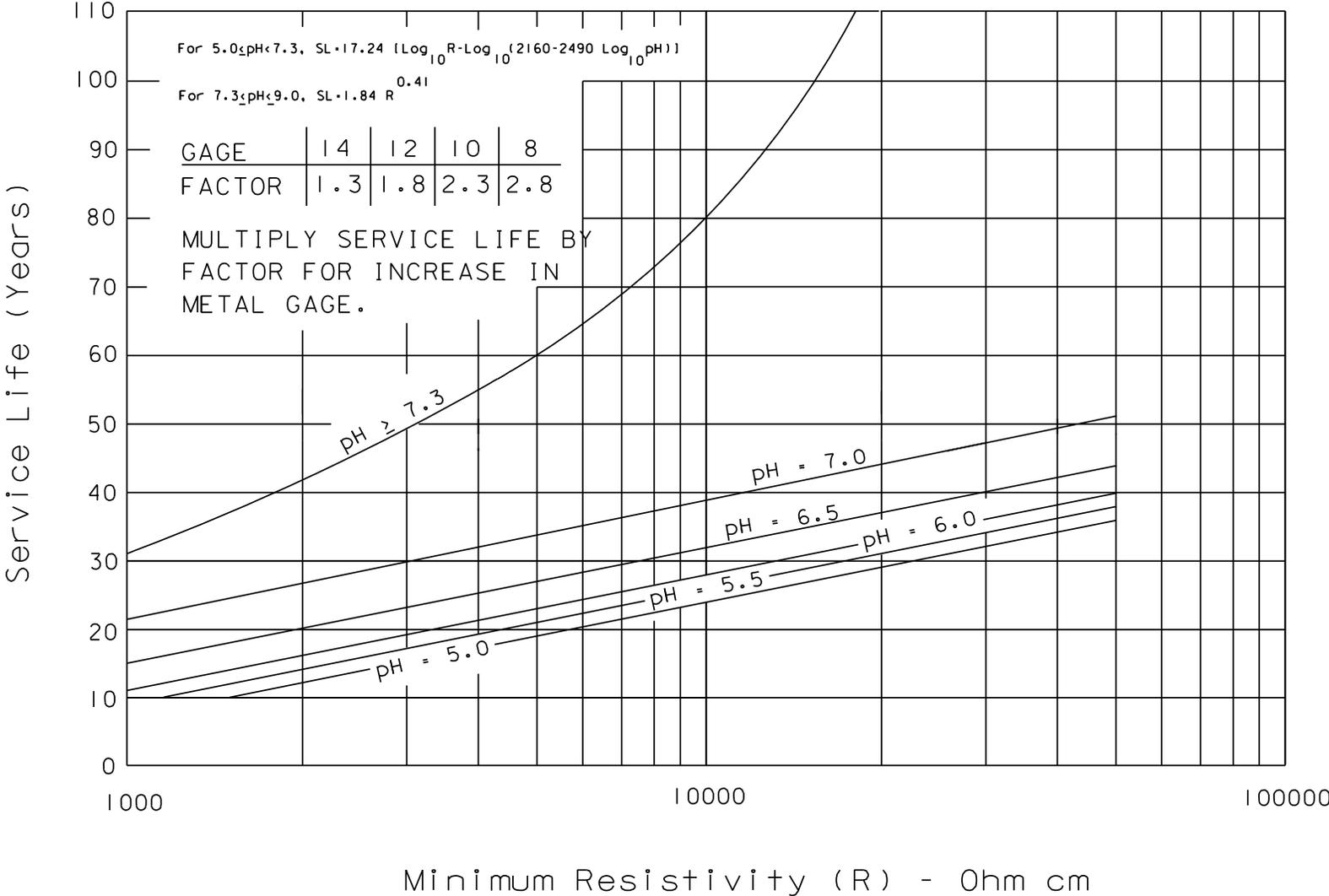
In selecting the DSL appropriate for french drain, the location of the french drain system determines which DSL to use. Consider the case where the french drain is being placed in an urban location along the trunk line located under the sidewalk, parallel and adjacent to the roadway: the french drain is not under the roadway, but replacement of the French drain would require reconstruction of the outside lane due to the depth of cut and angle of repose of the soil. Even though the french drain reconstruction might be performed using sheeting to avoid impacting the roadway, the cost of the sheeting

makes this installation costly enough to elevate the service life to 100 years. A similar situation occurs when a pipe installation is adjacent to buildings: in such cases, sheeting may also be required making the installation or replacement costly and thus earning a 100-year DSL.

Appendix B – Corrosion Tables and Charts

FIGURE 6-1

Estimated Service Life vs. pH and Resistivity
 for 16 ga. Galvanized Steel



pH	Resistivity												
	1000	1500	2000	3000	4000	5000	7000	10000	15000	20000	30000	40000	≤50000
5.0	7	10	12	15	17	19	21	24	27	29	32	34	36
5.1	7	10	12	15	17	19	21	24	27	29	32	34	36
5.2	8	10	13	16	18	19	22	25	28	30	33	35	37
5.3	8	11	13	16	18	20	22	25	28	30	33	35	37
5.4	8	11	13	16	19	20	23	25	28	31	34	36	37
5.5	9	12	14	17	19	21	23	26	29	31	34	36	38
5.6	9	12	14	17	19	21	24	26	29	32	35	37	38
5.7	10	13	15	18	20	22	24	27	30	32	35	37	39
5.8	10	13	15	18	21	22	25	27	30	32	36	38	39
5.9	11	14	16	19	21	23	25	28	31	33	36	38	40
6.0	11	14	16	20	22	23	26	28	32	34	37	39	41
6.1	12	15	17	20	22	24	26	29	32	34	37	40	41
6.2	13	16	18	21	23	25	27	30	33	35	38	40	42
6.3	13	16	19	22	24	25	28	31	34	36	39	41	43
6.4	14	17	19	22	24	26	29	31	34	36	40	42	43
6.5	15	18	20	23	25	27	30	32	35	37	40	43	44
6.6	16	19	21	24	26	28	31	33	36	38	41	44	45
6.7	17	20	22	25	27	29	32	34	37	39	42	45	46
6.8	18	21	23	26	29	30	33	36	39	41	44	46	48
6.9	20	23	25	28	30	32	34	37	40	42	45	47	49
7.0	22	25	27	30	32	34	36	39	42	44	47	49	51
7.1	24	27	29	32	34	36	39	41	44	46	50	52	53
7.2	28	31	33	36	38	40	42	45	48	50	53	55	57
7.3	34	37	39	42	45	46	49	52	54	57	60	61	64
7.4 - 9.0	34	37	42	49	55	60	69	80	95	107	126	142	155

Estimated Service Life:

$$(SL) = 17.24\{\text{Log}_{10}R - \text{Log}_{10}[2160-2490(\text{Log}_{10}\text{pH})]\}$$

$$(SL) = 1.84 R^{0.41}$$

for $5 \leq \text{pH} \leq 7.3$
for $7.3 \leq \text{pH} \leq 9$

FIGURE 6-2

Estimated Service Life vs. pH and Resistivity
 for 16 ga. Aluminized Steel Type II

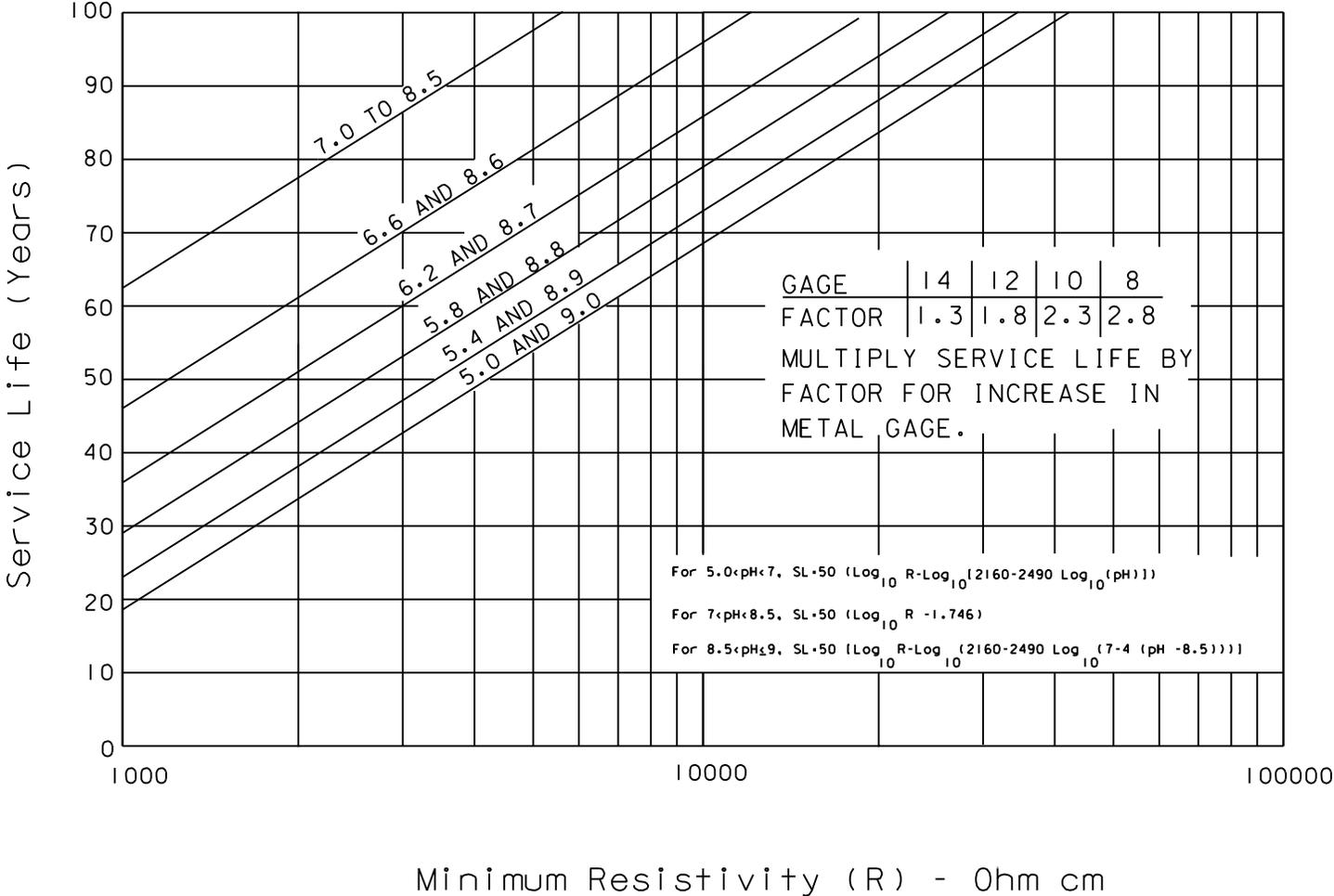


TABLE 6.3
Estimated Service Life vs. pH and Resistivity for 16 ga. ALUMINIZED STEEL Culvert Pipe

pH	Resistivity												
	1000	1500	2000	3000	4000	5000	7000	10000	15000	20000	30000	40000	≤50000
5.0	19	28	34	43	49	54	61	69	78	84	93	99	104
5.1	20	29	35	44	50	55	62	70	79	85	94	100	105
5.2	21	30	36	45	51	56	63	71	80	86	95	101	106
5.3	22	31	37	46	52	57	65	72	81	87	96	102	107
5.4	24	32	39	48	54	59	66	74	82	89	98	104	109
5.5	25	34	40	49	55	60	67	75	84	90	99	105	110
5.6	26	35	41	50	56	61	69	76	85	91	100	106	111
5.7	28	37	43	52	58	63	70	78	87	93	102	108	113
5.8	29	38	44	53	59	64	72	79	88	94	103	109	114
5.9	31	40	46	55	61	66	73	81	90	96	105	111	116
6.0	33	41	48	56	63	68	75	83	91	98	106	113	118
6.1	34	43	50	58	65	69	77	84	93	100	108	115	119
6.2	36	45	51	60	67	71	79	86	95	101	110	116	121
6.3	38	47	54	62	69	73	81	88	97	104	112	119	123
6.4	41	50	56	65	71	76	83	91	100	106	115	121	126
6.5	43	52	58	67	73	78	86	93	102	108	117	123	128
6.6	46	55	61	70	76	81	88	96	105	111	120	126	131
6.7	49	58	64	73	79	84	92	99	108	114	123	129	134
6.8	53	62	68	77	83	88	95	103	112	118	127	133	138
6.9	57	66	72	81	87	92	100	107	116	122	131	137	142
7.0 to 8.5	63	72	78	87	93	98	105	113	122	128	137	143	148
8.6	46	55	61	70	76	81	88	96	105	111	120	126	131
8.7	36	45	51	60	67	71	79	86	95	101	110	116	121
8.8	29	38	44	53	59	64	72	79	88	94	103	109	114
8.9	24	32	39	48	54	59	66	74	82	89	98	104	109
9.0	19	28	34	43	49	54	61	69	78	84	93	99	104

Estimated Service Life

$$(SL) = 50\{\text{Log}_{10}R - \text{Log}_{10}[2160 - 2490(\text{Log}_{10}\text{pH})]\}$$

$$(SL) = 50(\text{Log}_{10}R - 1.746)$$

$$(SL) = 50\{\text{Log}_{10}R - \text{Log}_{10}[2160 - 2490 \text{Log}_{10}[7 - 4(\text{pH} - 8.5)]]\}$$

for $5.0 \leq \text{pH} < 7.0$

for $7.0 \leq \text{pH} \leq 8.5$

for $8.5 < \text{pH} \leq 9.0$

FIGURE 6-3

Estimated Service Life vs. pH and Resistivity for Aluminum

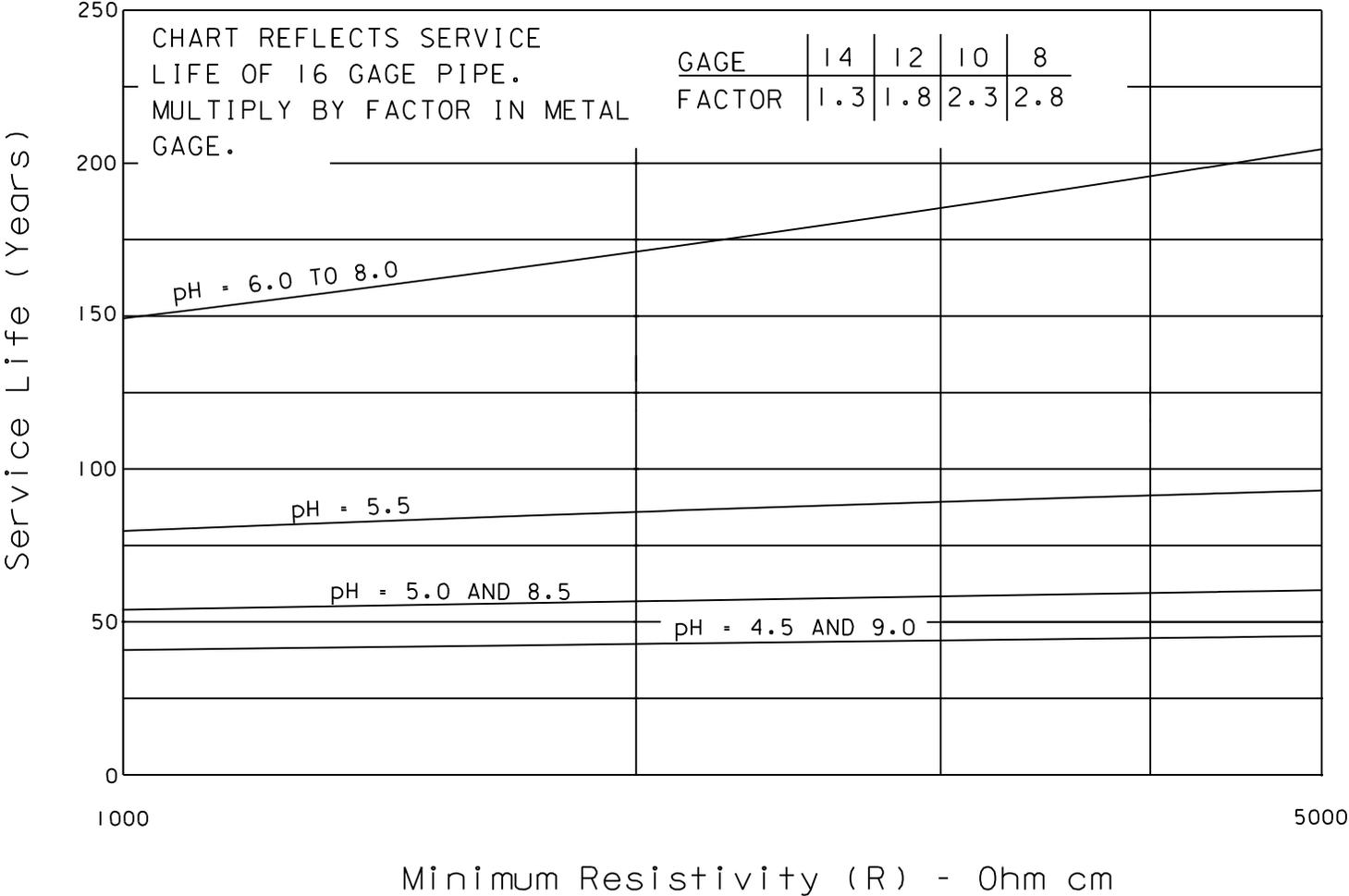


TABLE 6.4
Estimated Service Life vs. pH and Resistivity for 16 ga. ALUMINUM Culvert Pipe

pH	Resistivity															
	≥200	400	600	800	1000	1200	1400	1600	1800	2000	2300	2700	3200	3800	4500	≤5000
4.5 & 9.0	36	39	40	41	41	42	42	42	43	43	43	43	44	44	44	45
4.6 & 8.9	38	41	42	43	43	44	44	45	45	45	45	46	46	47	47	48
4.7 & 8.8	40	43	44	45	46	46	47	47	47	48	48	48	49	49	50	51
4.8 & 8.7	42	45	46	48	48	49	49	50	50	50	51	51	52	52	53	54
4.9 & 8.6	44	48	49	50	51	52	52	53	53	54	54	55	55	56	56	57
5.0 & 8.5	46	50	52	53	54	55	56	56	57	57	58	58	59	59	60	61
5.1	49	53	56	57	58	59	60	60	61	61	62	62	63	64	65	66
5.2 & 8.4	52	57	59	61	62	63	64	65	65	66	67	67	68	69	70	71
5.3	55	61	64	66	67	68	69	70	71	71	72	73	74	75	76	77
5.4 & 8.3	59	66	69	71	73	74	75	76	77	78	79	80	81	82	83	84
5.5	63	71	75	78	80	81	83	84	85	86	87	88	90	91	92	93
5.6 & 8.2	68	78	82	85	88	90	91	93	94	95	97	98	100	102	104	105
5.7	74	85	91	95	98	100	102	104	106	107	109	111	113	116	118	119
5.8 & 8.1	81	95	102	107	110	114	116	119	121	122	125	128	131	134	137	138
5.9	89	107	115	122	127	131	134	138	140	143	146	150	154	158	163	165
≥6.0 & ≤8.0	100	122	133	142	149	154	159	164	168	171	176	182	188	194	200	204

Where:

SL = Years to first perforation

T_p = Thickness of pipe (inches)

R_{pH} = Corrosion rate for pH (inches/year)

R_r = Corrosion rate for resistivity (inches/year)

$$\text{Service Life (SL)} = T_p / (R_{pH} + R_r)$$

FIGURE 6-4

Estimated Service Life vs. pH and Chloride
for 60" Dia. Concrete Culverts, S = 1500

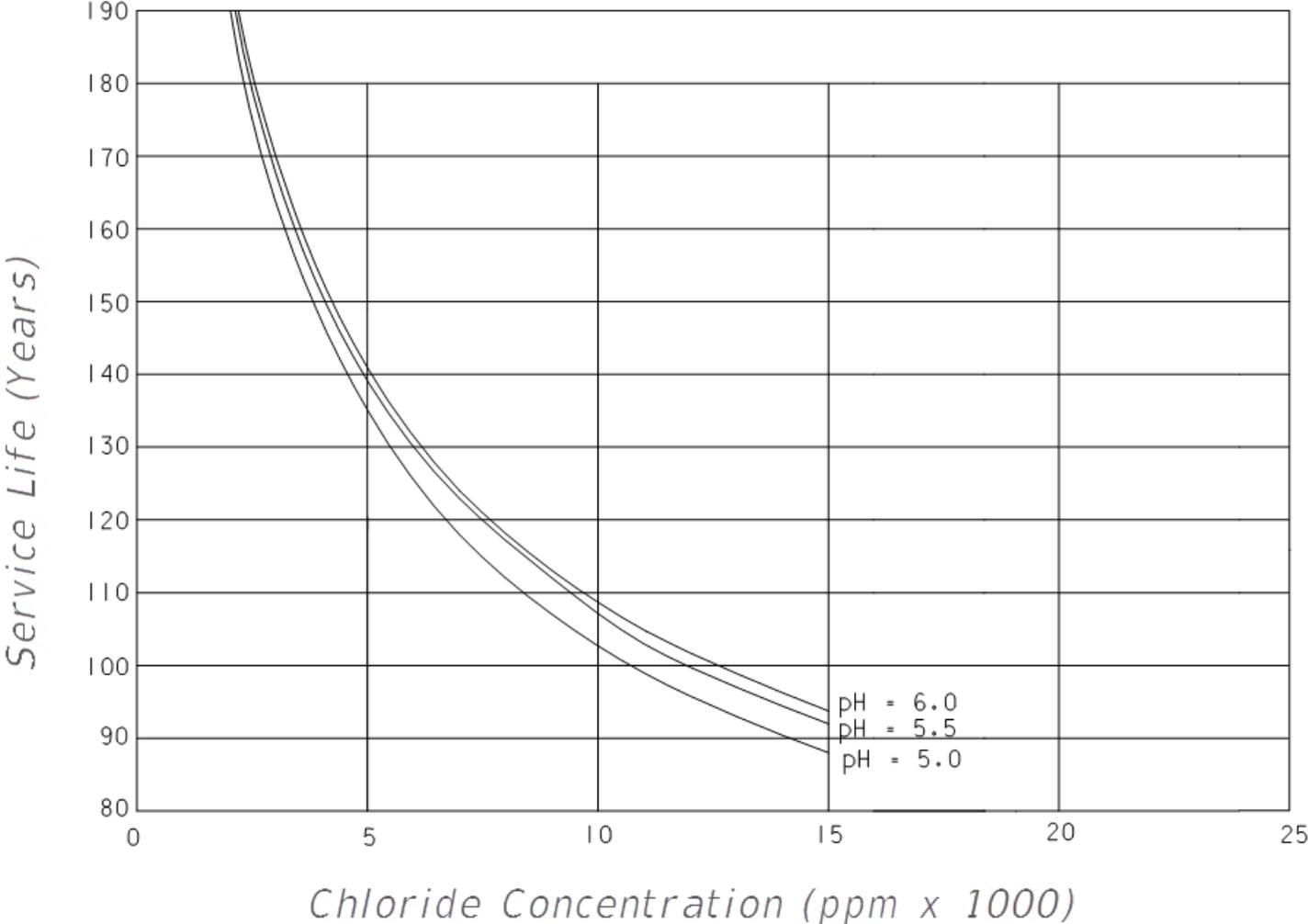


TABLE 6.5

Estimated Service Life vs. pH and Chlorides for 60" Dia. **REINFORCED CONCRETE** Culverts at 1500 ppm Sulfate Concentration

pH	Chlorides											
	15000	13000	11000	9000	7000	5000	3000	2000	1000	750	500	250
5.0	88	93	99	107	118	135	164	192	250	278	324	360
5.1	89	94	101	109	119	136	165	193	251	279	325	360
5.2	90	95	102	110	121	137	167	194	252	281	327	360
5.3	91	96	102	111	122	138	167	195	253	282	327	360
5.4	92	97	103	111	122	139	168	196	253	282	328	360
5.5	92	97	103	112	123	139	168	196	254	282	328	360
5.6	93	98	104	112	123	140	169	196	254	283	329	360
5.7	93	98	104	112	123	140	169	197	254	283	329	360
5.8	93	98	104	113	124	140	169	197	255	283	329	360
5.9	93	98	105	113	124	140	170	197	255	284	330	360
≥6.0	94	99	105	113	124	141	170	197	255	284	330	360

Conversion Factors for Different Size Culverts			
Pipe Dia.	Mult. By	Pipe Dia.	Mult. By
12"	0.36	48"	0.76
18"	0.36	60"	1.00
24"	0.41	72"	1.25
30"	0.48	84"	1.51
36"	0.54	96"	1.77
42"	0.65	108"	2.04

SL Reduction Factors for Sulfates	
Sulfate Content	Subtract from SL
1500	0
3200	5
4900	10
6600	15
8300	20
10000	25

Note: Sulfate derating not applicable
When Type V cement is used.

$$\text{Service Life (SL)} = 1000(1.107^C C^{0.717} D^{1.22} K^{-0.37} W^{0.631}) - 4.22 \times 10^{10} (\text{pH}^{-14.1}) - 2.94 \times 10^{-3} (S) + 4.41$$

Where: C = Sacks of cement per cubic yard D = Steel depth in concrete K = Environmental chloride concentration in ppm
W = Total percentage of water in the mix S = Environmental sulfate content in ppm