

State of New Jersey  
Department of Transportation  
Division of Research and Development

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CORROSION OF CORRUGATED METAL PIPE

Final Report

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## ABSTRACT

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A study of the factors influencing the corrosion of corrugated metal pipe is reported.

The main thrust of the voluminous literature reviewed is that the influence of the environmental variables prevailing at a particular site on pipe corrosion is a complex, and to a large extent, unsettled question. A statistically-based design procedure, involving both structural considerations and a corrosion metal loss allowance, is recommended for use in New Jersey.

The corrosive nature of New Jersey waters and our maintenance field experience are discussed.

Installed pipe costs are compared for aluminum, steel, and reinforced concrete. A bibliography of corrosion studies and an example of the recommended culvert service life design procedure are presented.

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## I. Objective

This report presents the results of an investigation of corrosion rates and corrosion design procedures for corrugated metal (steel) pipe. The principal objective of the work was to determine the possibility of predicting New Jersey pipe corrosion rates by coupling criteria developed by other agencies with information on the corrosive nature of the waters in our State. Successful development of such corrosion guidelines would promote the solution of an existing New Jersey problem in consistently providing adequate metal pipe service life.

## II. Introduction

The New Jersey Department of Transportation has in the past permitted metal (steel) culverts to be substituted for reinforced concrete pipe at the discretion of the contractor. Loss of some of these alternate metal installations due to corrosion has put an end to this practice. However, corrugated metal culvert pipe is still specified in some areas where certain design considerations preclude the use of reinforced concrete pipe.

Corrosion of a highway drainage structure is the result of an electro-chemical reaction between the structure and its soil-water environment. Depending on the extent of metal loss, the drainage element may suffer leakage, structural weakness, or collapse.

All corrugated metal pipe ultimately will be rendered in-serviceable thru the process of corrosion. As will be described, the Department's maintenance experience indicates that the rate at which such corrosion proceeds varies considerably from place-to-place within the State. Consequently, the desired goal of a long service life for metal culverts is not always achieved, with many installations in certain of our more highly corrosive waters having to be replaced only a few years after construction.

It is generally accepted that the rate of metal loss due to corrosion is the predominant factor governing the useful life of corrugated metal pipe. Unfortunately, determining the specific influence of the many environmental variables prevailing at a particular construction site on corrosion rate is a complex and to a large extent, unsettled question. The more important parameters reported as influencing the corrosion service life expectancy of metal pipes are the pH of the carried water\*, its dissolved oxygen content, velocity of flow, temperature, and content of dissolved metallic and nonmetallic ions (e.g., copper, iron, mercury, chlorides, carbonates); as well as the electrical resistivity\*\* of the soil surrounding the pipe.

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\*Recall that in this system of relative acidity/alkalinity, a value of 7 is considered neutral, with lesser pH values indicating acidity and greater values indicating alkalinity. A one unit pH change is indicative of a difference of 10 times in relative acidity. Thus, water with a pH of 6 is ten times more acid than a neutral water, while a pH of 10 is 1,000 times more alkaline than a neutral value.

\*\*The flow of the minute electrical currents involved in the electrochemical process of corrosion is governed by Ohm's law ( $E = IR$ ). Metal loss increases with current flow ( $I$ ). Thus, for a given corrosion potential ( $E$ ), a pipe surrounded by a soil having low resistivity ( $R$ ) will deteriorate at a relative high rate.

In the particular case of steel pipe, Uhlig<sup>1</sup> states that the content of dissolved oxygen in the conveyed water will be the predominant factor controlling corrosion in the usual pH range of natural streams (i.e., a pH of 4 to 10). Any variation in the composition of the steel or its heat treatment will have no bearing on corrosion rate, with the progress of deterioration depending solely on dissolved oxygen content, water temperature and velocity. Thus, for given values of these three parameters, exposure of any of the various types of iron or steel pipe to fresh or seawater would result in the same observed rate of corrosion.

In view of the high acidity indicated for some New Jersey waters, it is important to note that in such waters, the corrosion of steel will be markedly accelerated at a rate depending on the particular prevailing pH level. More specifically, as shown in Figure 1A, exposure of steel to a pH condition of about 4 or less will result in an aggressive chemical attack accompanied by the liberation of hydrogen gas.

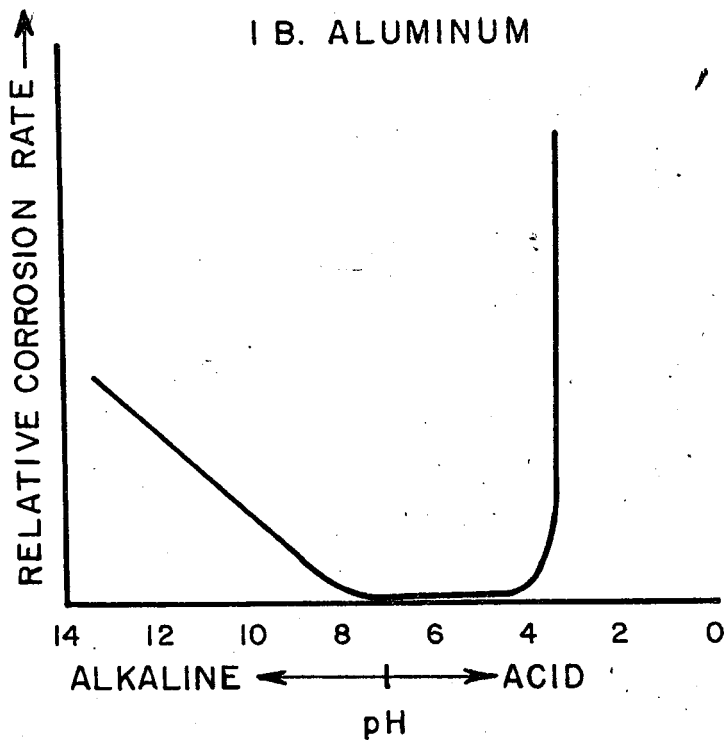
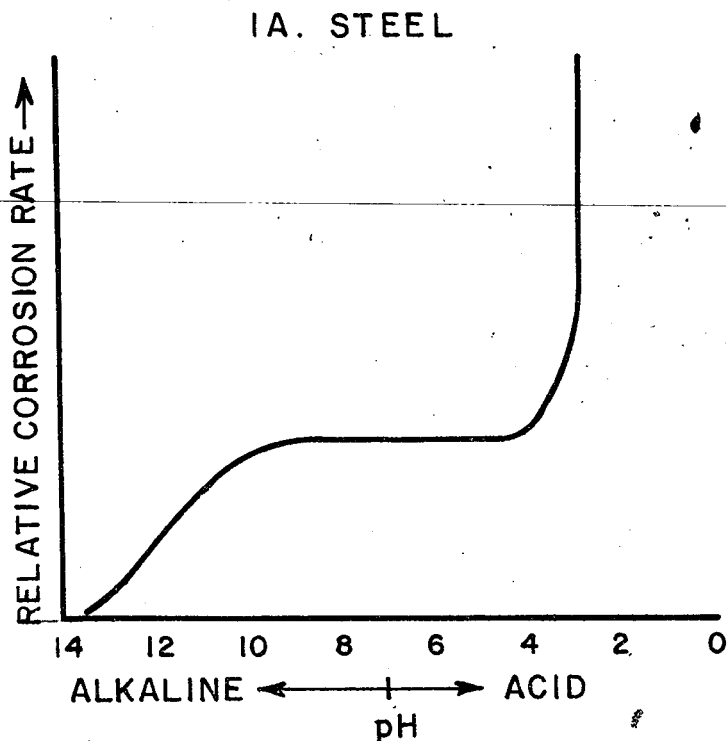
Aluminum culverts are being used more frequently in an effort to reduce the costs incurred in the required repair or replacement of corroded steel culverts. At the present time, however, relatively limited data is available regarding the service life of aluminum-based

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<sup>1</sup>Uhlig, H. H. Corrosion and Corrosion Control, John Wiley and Sons Inc.; New York (1971)

FIGURE 1

RELATIVE INFLUENCE OF pH ON THE CORROSION OF STEEL AND ALUMINUM<sup>1</sup>  
(after Uhlig, 1971)



culvert pipe. Initial field examination by other states<sup>2,3</sup> have indicated little corrosion except in the presence of abrasive or chemical flow. For example, if copper or iron is present in the flowing water, these metal ions successively lead to staining, pitting, and general involvement of the pipe. Further, unlike steel pipe, aluminum deteriorates rapidly in highly alkaline\* as well as highly acid environments (Figure 1B).

One of the best ways of determining metal loss rates is to examine existing culverts in the stream where a new culvert is to be installed. Since this is obviously not always possible, other highway agencies have developed a variety of empirical methods for estimating culvert service life. Such methods generally involve a prediction of service life from water quality data using general relationships derived from historical performance data. Certain of these methods clearly have limited applicability beyond the geographic location for which they were formulated. However, others are founded on a sufficiently broad range of performance experiences as to be of particular value in dealing with New Jersey conditions. The remainder of this report will concern itself primarily with describing the development and use of the latter service life expectancy criteria.

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<sup>2</sup>Berg, V. E. "Culvert Performance Evaluation" Washington State Highway Commission, Department of Highways, Olympia, Washington (April 1965)

<sup>3</sup>Haviland, J. E.; Bellair, P. J.; Morrell, V. D.; "Durability of Corrugated Metal Culverts" New York Department of Transportation Research Report 66-5 (November 1967)

\*A familiar example of the effect of high alkalinity on aluminum is the inclusion of hydrogen gas bubbles in fresh concrete conveyed with aluminum chutes, and thus the universal prohibition of such metal in concrete handling equipment.

### III. Review of Corrosion Studies

Accurately predicting corrosion rates is a difficult task because of the many factors contributing to such distress. Consequently, many states\* have at some time conducted studies of the service life of corrugated metal pipes subjected to their particular conditions.

For example, the Georgia Highway Department<sup>4</sup> uses a method for the initial selection of culvert material type based on an evaluation of pH, conductance, hardness, dissolved chemicals, and industrial wastes. A relative corrosion rating is determined using a chart weighing each of these parameters. If the resulting rating is less than a given limiting value indicative of low corrosion potential, plain galvanized pipe is used. A high rating results in a design choice between aluminum, bituminous coated steel, or concrete pipe. Since neither the information used in developing the chart nor the data for sites where the chart has been used are available, a meaningful evaluation of the Georgia method is not possible. Further, since all corrugated metal pipe in New Jersey at a minimum is bituminous coated steel, their method would not provide an appropriate design choice in our state.

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\*Apart from studies specifically cited in this report, a historical bibliography of other metal pipe corrosion research is provided for general reference in Appendix I.

<sup>4</sup>Krizek, R. J.; Parmelee, R. A.; Kay, J. N.; and Elnaggar, H. A.; "Structural Analysis and Design of Pipe Culverts" NCHRP Report 116 (1971)

Culverts in California<sup>5</sup> are designed using the graph shown in Figure 2. This design aid estimates the influence of the average water pH and soil resistivity values measured at the intended culvert channel site on the life of the installation. As a check on the validity of this method, California researchers evaluated the degree of correlation between the estimated life and actual service life of metal culverts. Unfortunately, a rather imprecise relationship was found to exist between the pipe life estimated from the chart and field observations of actual culvert condition. Further, the correlation that did exist was based on an evaluation of average differences between predicted and actual service performance, not on the more meaningful basis of how valid individual predicted values were.

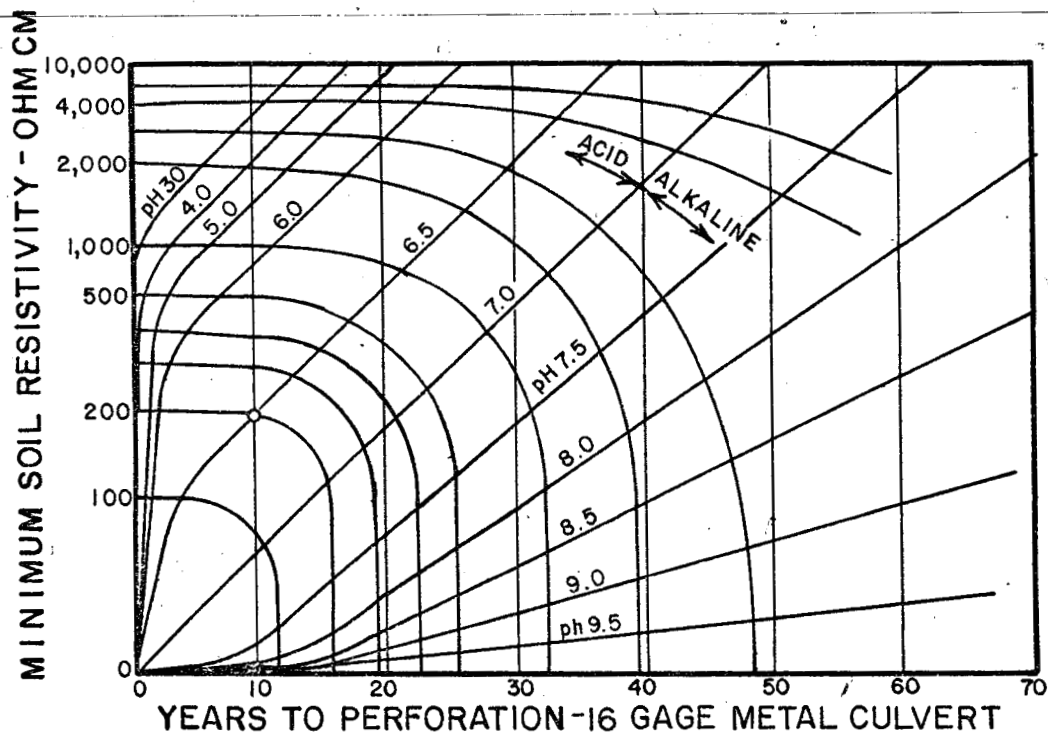
The California work also included an evaluation of culverts that received a protective bituminous coating. California observed that such bituminous coatings provided an average of about six additional years service compared to uncoated galvanized pipe. While this service life difference is significant, the authors caution that an added six years should not be assumed for all pipes. Abrasive flows resulting from high velocities and/or suspended solids can remove coatings in one year or less.

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<sup>5</sup>Beaton, J. L. and Stralfull, R. F.; "Field Test for Estimating Service Life of Corrugated Metal Pipe Culverts" Highway Research Board Proceedings Vol. 41, pp. 255-272 (1962)

FIGURE 2

CHART FOR ESTIMATING METAL  
CULVERT CORROSION RATE (Developed  
By State of California)



**EXAMPLE:** Given, pH=6.5 & Resistivity =200 ohm cm  
Then 16 Gage CMP Perforated in 10 Years.  
For A Culvert Metal Gage Of 12 Multiply  
Years By Factor Below i.e. 1.8 x 10= 18 Years

GAGE	14	12	10	8	6	2	0	000
FACTOR	1.3	1.8	2.3	2.8	3.3	4.3	5.0	6.0

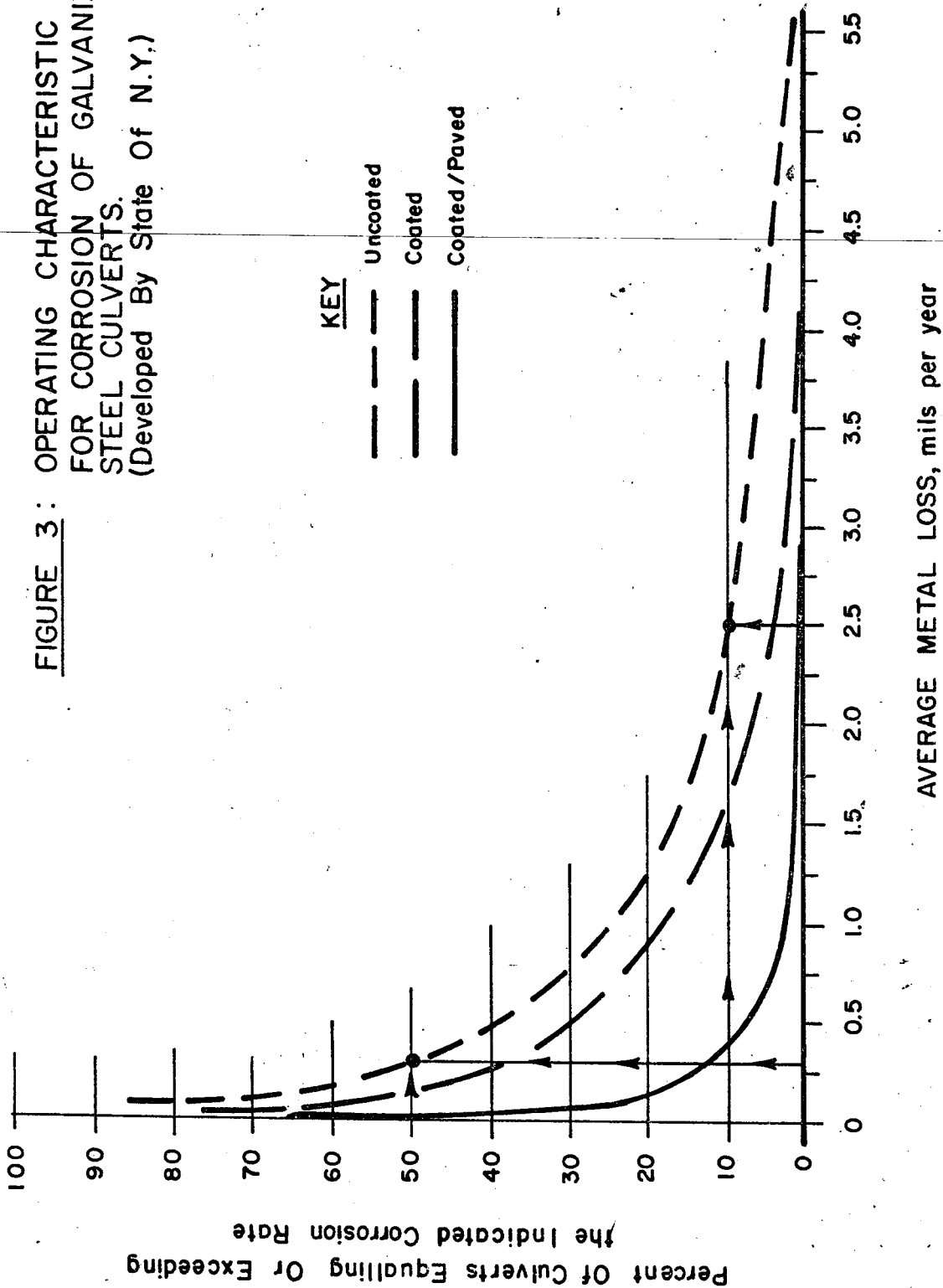
The service life estimation procedures developed from the California study--in spite of their apparent lack of precision--serve as the basis for the design criteria offered in the current National Corrugated Steel Pipe Association publication, "Corrugated Steel Pipe Storm Sewers", and in the ARMCO "Handbook of Steel Drainage and Highway Construction Products". The design procedure described in the latter publication modifies the California approach by considering the influence of various additional factors (slope, soft or normal water, abrasion, invert paving and protective coatings). Structural design and corrosion design for required wall thickness are considered separately. For example, if the wall thickness required to effectively combat corrosion is less than the structural wall thickness required, the structural design controls. On the other hand, if the required corrosion wall thickness is greater than the structural wall thickness, this greater wall thickness or a thinner wall and paved invert is used. This publication states that bituminous coating will provide 6 to 10 years of added life to metal culverts, and makes no mention of the limitations of bituminous coatings under some field conditions (e.g., the rapid loss in abrasive flows noted in the California work).

The state of Washington surveyed more than 500 culvert installations to establish a performance history for the various culvert materials and reviewed their design procedures. Field observations of individual culvert conditions were used to develop projected culvert service lives. Use of the California method on pH and resistivity data collected at the various sites resulted in estimated service lives which displayed no substantial correlation with the projected life based on actual field

data. Further, attempts to relate the pH and resistivity data to actual performance in any of numerous formats also yielded no meaningful relationship. Washington observed great benefit from invert paving, but no increased service life from simple bituminous coating. This latter observation is not in conflict with the cited California work since, while California reported an average of six years added life, they also noted that such coatings yielded no increase in performance in some cases and a marked (20 year) increase in others. In general, however, one can interpret the Washington Study as being an indication of the real lack of precision associated with design service life expectancy predictions made using the California method.

A comprehensive culvert corrosion study involving the investigation of a total of nearly 800 coated and uncoated galvanized steel structures installed over a 33 year period has been reported by New York<sup>3</sup>. As a result of this work, New York developed a culvert design method which again involves separate calculation of the respective wall thickness needed for structural and corrosion considerations, and choice of the controlling dimension between the two. The choice of corrosion rate to be used in determining corrosion wall thickness is made using the "operating characteristic" curve shown in Figure 3. This design curve is statistically derived from actual field corrosion rate data and indicates the probability of given corrosion rates being equalled or exceeded in future cases. For example, lines with arrows in Figure 3 indicate that it can be expected that installations of uncoated galvanized steel pipe

**FIGURE 3: OPERATING CHARACTERISTIC CURVE FOR CORROSION OF GALVANIZED STEEL CULVERTS. (Developed By State Of N.Y.)**



will be equally divided between those which corrode at a rate of about 0.34 mils per year or more and installations corroding at a lesser rate, with relatively few (1 in 10) experiencing as much as 2.5 mils per year of metal loss.

In the practice of using the New York design chart, the engineer must decide on what risk he is willing to assume that his design corrosion rate will be exceeded and thus the chances of premature failure. Such a decision obviously will require assessing the relative importance of the proposed installation (e.g., the difficulty and cost of reconstruction). Since the use of New York design chart is subsequently recommended for use in New Jersey, a more complete example of the use of the procedure is presented in Appendix II.

At the request of AASHO, a major effort was initiated in 1968 by Northwestern University to formulate structural analysis and design methods for pipe culverts that would be applicable throughout the United States. This very comprehensive work resulted as NCHRP Report 116<sup>4</sup>. A significant portion of Northwestern's research involved formulation of criteria for dealing with the pipe corrosion problem. After an extremely thorough review of the state-of-the-art, a procedure was adopted to design metal culverts for corrosion losses using the results reported by New York State (i.e., Figure 3) and modified by using pH values and water velocity through the metal culvert. Specifically, when pH values are greater than 4.5, the NCHRP report advises that the New York State method be used to establish the necessary extra metal allowance for corrosion. It is further suggested that aluminum culverts may be used when prevailing pH values are

between 4.5 and 9. Paved inverts are recommended when the flow velocity is expected to be greater than 8 feet per second. In view of the limited performance data available for aluminum culverts, the report recommended the use of the New York curve for bituminous coated galvanized steel to establish conservative estimates of the metal thickness requirements for aluminum culverts. Because of the accelerated corrosion rates of steel and aluminum at pH values less than 4.5 (cf. Figure 1) the NCHRP report urges the use of concrete culverts with waters in this pH range.

#### IV. Corrosion Patterns in New Jersey

##### 1. Prevailing pH Values

Use of any of the various corrosion rate prediction methods described in the preceding section requires a fairly reliable assessment of the pH level of the water that will flow within the pipe.

The maximum, minimum, and mean pH measured at numerous New Jersey stream water quality recording stations<sup>6</sup> are presented in Figure 4. As shown, stream pH values tend to vary with the geological feature of our state. The mountainous areas of northern New Jersey have mean pH values in the range of about 7 to 8, indicating neutral to slight alkalinity. The water of New Jersey's coastal plain (and the southern pinelands in particular) are generally rather acid, with typical mean pH's of about 4.5 to 5.0. An exception to this pattern is the southern perimeter of the Delaware Basin, which displays neutral to alkaline mean pH values.

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<sup>6</sup>Data obtained from "Water Resource Data for New Jersey", Part 2, Water Quality Records, USGS (1971)



In view of the pH guidelines suggested in the literature, some generalities concerning the effect of the relative acidity and alkalinity of our waters on the state's corrosion problem appear warranted. First, it appears that in the acid region of the state, careful attention will be required to determine if any type of metal pipe is appropriate for certain stream crossings. As indicated in Figure 4, a number of locations in the southern and coastal portions of the state have an average pH condition lower than or bordering on the 4.5 lower limit for metal pipe. Further, an even greater number of these locations (e.g., those around the Raritan Bay) have at least short-term pH's that would result in active chemical attack on steel or aluminum pipe.

Secondly, the reverse end of the pH scale will require attention in our alkaline regions to determine if any proposed aluminum installation is feasible. Here again, a number of locations have some periods of flow which exceed the suggested pH limitation (i.e., about 8.5 or 9).

## 2. Maintenance Field Experience

Problems encountered in the northwest portion of the state served by the Department's Region I forces have been with the replacement of metal culvert pipe in secondary roads. These roads were county roads taken over by the state after having been in service for 25 to 30 years.

Corroded metal pipe in Region II (Northeast New Jersey) is reportedly replaced with reinforced concrete pipe whenever possible. In that metropolitan area of the state, the frequently encountered industrial wastes and spilled petroleum products attack the bituminous coating on metal pipe.

Corrosion of steel culvert pipe by seawater is a problem with maintenance forces in Region III (Central New Jersey). Uhlig<sup>1</sup> notes seawater corrodes the steel base metal of a pipe at the rate of about six mils per year and the protective zinc coating at a rate of about 1 mil per year. Thus, about two years of additional life in seawater accrues from the standard two ounce (about 2 mil) galvanized coating. A plain galvanized 16 gauge pipe (say, 18 inches diameter) thus could be expected to last seven years. That is, since corrosion occurs on both sides of a submerged pipe, the zinc coating would be removed in two years and the wall thickness in five years. Actual (hydraulic) failure would of course occur before complete destruction. While New Jersey pipes receive a bituminous coating to inhibit this process, it would appear that such coatings are not always effective, with some New Jersey pipes, such as described above, requiring replacement in on the order of five years.

Region IV (Southern New Jersey) has the problem of corroded steel culverts caused by tidal waters. Rising and falling of the air-water interface caused by tidal action approximately doubles the corrosion rate. Bituminous coverings on these pipes have cracked and many bare spots are evident leaving tidal waters in direct contact with the steel pipe. Another problem encountered by Region IV forces is the cracking of bituminous coatings on the outside and separation of bituminous coating from the inside wall of stored pipe. To avoid possible construction delays the normal practice is to have pipe shipped to the maintenance yard well in advance of the intended time of use. Because of the cracking, only small amounts of bituminous covered pipe can be stored and these amounts are

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further restricted to shapes and sizes which will be quickly used. Culvert pipe with cracked and/or separated bituminous coating is kept until a job can be found which does not require bituminous covered pipe. One solution that has been suggested is to paint the outside of the stored bituminous coated pipe with whitewash to reflect the sunlight which apparently is the causal factor for the cracking and separation of the coating.

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#### V. Cost of Metal Culverts

Designing for culvert service life is basically an economic problem. Consider the situation where a culvert is to be installed in a particular location and is to be maintained forever. It is neither desirable or feasible to expect an agency to spend the larger part or all of its fiscal budget on an expensive first cost structure. Another approach would be a cheaper first cost structure that would have to be replaced an infinite amount of times during the life of the culvert. The latter method would have a deferred high first cost but would have higher continuous maintenance and material replacement costs. Some costs that can be incurred in a future culvert replacement are additional excavation not required for the first structure and costs due to discontinued use of the culvert until it is returned to service.

A summary of typical first costs involved in drainage structures on Department projects is shown in Table 1. The material costs shown were obtained from (three) vendors, while the installed pipe cost is from the most recent list of Department weighted average unit prices.

TABLE 1: Comparative Costs of Various Pipe  
Material Design Alternates

Pipe Size	Reinforced Concrete	Corrugated Metal	
		Coated Steel	Aluminum
15 inch	\$2.75/foot* <b>\$12.15/foot</b> (39,600 feet)	\$2.57/foot \$11.87/foot (4,700 feet)	\$2.27/foot
18 inch	\$3.55/foot \$14.35/foot (20,000 feet)	\$2.99/foot \$14.57/foot (1,800 feet)	\$2.64/foot
24 inch	\$5.80/foot \$16.15/foot (8,000 feet)	\$3.90/foot \$16.00/foot (1,000 feet)	\$4.18/foot
36 inch	\$10.90/foot \$37.27/foot (2,800 feet)	\$9.21/foot \$46.00/foot (72 feet)	\$8.51/foot

\*First price is for material, second is installed cost. Length is total sample on which installed price is based.

The installed cost of comparable sizes of corrugated metal pipe (steel and aluminum) and reinforced concrete pipe are seen to be almost identical. It is assumed here that installation expenses for aluminum pipe are the same as those for bituminous covered steel pipe. Paved inverts would add about thirty (30) percent to the material costs listed for the metal pipes.

The preceding indicates initial first cost should not be a deciding factor when making a decision whether to use corrugated metal culvert pipe or reinforced concrete pipe. Other factors such as maintenance, hydraulic efficiency, ease of construction, and settlement potential of surrounding soil medium should be considered when deciding which material would be best suited for a particular job. It appears in New Jersey that this additional consideration should lead to the selection of reinforced concrete pipe in most instances.

One recommended way of increasing culvert life is to increase wall thickness. AASHO specification M36 allows, in some cases, as many as four different wall thicknesses for the same pipe diameter. Another method which might come to mind--increasing the thickness of the protective (galvanized) coating rather than the base metal--does not appear feasible. That is, conversations with vendors indicate that use of a 4 ounce coating rather than the normal 2 ounce coating is not standard practice with the industry. Another negative factor in this regard is the reported current shortage of zinc.

Typical increases in cost resulting from use of thicker walls to increase culvert pipe service life are shown in Table 2. The cost increase accrues directly from the increase in the amount of metal used. Number 8 gauge is the thickest metal sheet that can be corrugated. All sizes listed are standard sizes for New Jersey metal pipe.

TABLE 2: Typical Material Costs for Corrugated Steel  
Pipe of Various Wall Thicknesses

Pipe Size	Gauge	Thickness	Cost (\$/ft)
30 inch Corrugated Metal Sewer Pipe	8	0.1644	\$13.58
	10	0.1345	11.27
	12	0.1046	8.79
	14	0.0747	6.24
24 inch Corrugated Metal Pipe	10	0.1345	\$ 9.36
	12	0.1046	7.29
	14	0.0747	5.35
	16	0.0598	4.48

It is apparent from the preceding that increasing service life by increasing wall thickness (say doubling thickness and life) will entail a directly proportional increase (double) in materials costs. However, the installation costs for both pipes would be essentially the same. It follows then, that since material costs generally vary between 25 and 50 percent of the final in-place cost, a doubling of pipe service life can be achieved with only a 25 to 50 percent increase in first costs to the Department. Increasing wall thickness is thus a very efficient means of increasing pipe service life.

#### VI. Conclusions

Current cost data and relative durability characteristics for various types of drainage pipes indicate that the Department should use reinforced concrete pipe whenever possible. However, in certain situations the demand for physical flexibility of the pipe necessitates that the designer specify use of corrugated metal drainage units. In these instances, a means of accounting for the progressive corrosion deterioration of the pipe must be included in the design process.

A considerably body of literature exists on the subject of metal pipe corrosion. The main thrust of this literature is that determination of the influence of the many environmental variables prevailing at a particular pipe site on corrosion rate is a complex and to a large extent, unsettled question. That is, while certain environmental extremes are well-documented as being hostile to metal pipes, attempts to correlate the more normal range of service conditions to pipe life expectancy have generally resulted in imprecise prediction relationships. In view of the very comprehensive nature of certain of the reported research studies, it seems unlikely that an additional research study by this Department would result in any significant refinements over presently available methods of predicting corrosion rates.

Fortunately, however, the culvert service life criteria developed by a neighboring state--New York--appears to be grounded on data of sufficient scope as to be applicable to New Jersey. This New York design procedure is in fact the fundamental basis of a design criteria indicated as being of general applicability in a comprehensive NCHRP report.

Unlike other methods, which estimate corrosion rates from various combinations of measured values of environmental factors, the New York (and NCHRP) procedures require only one measurement (water pH). The pH value is used simply to determine if a metallic pipe is at all appropriate (i.e., will the base metal undergo acid/alkaline attack). If a metal pipe is deemed an appropriate option, the design

procedure applied is a probabilistic one in which the choice of a design corrosion rate is made from a statistically-derived curve indicating the relative frequency which given corrosion rates are to be expected to occur. Once a design corrosion rate is chosen, the design methodology involves calculation of the respective wall thickness needed for structural and corrosion considerations and choice of the controlling dimension between the two.

One point in connection with the use of the New York-NCHRP design procedure needs some amplification. That is, in the actual practice of using the New York design chart, the engineer must decide on what risk he is willing to assume that his design corrosion rate will be exceeded and thus the chances of premature failure. Such a decision obviously will require assessing the relative importance of the proposed installation (e.g., the difficulty and cost of reconstruction). While no firm guidelines as to appropriate risks are provided in the NCHRP or New York work, criteria from similar (statistically-based) design approaches are available and are believed instructive. That is, in important work (in this case, say, a culvert under a deep fill or a heavily travelled pavement), "confidence levels" of 90 or 95 percent are commonly used. In the case at hand, these confidence levels mean that the risk of a design corrosion rate being exceeded are only 10 and 5 percent, respectively. In more routine work (say a simple driveway pipe or one under shallow earth cover), the 50 percent or 66 percent confidence levels are often employed. It is suggested that confidence levels on these order of magnitude be used in New Jersey.

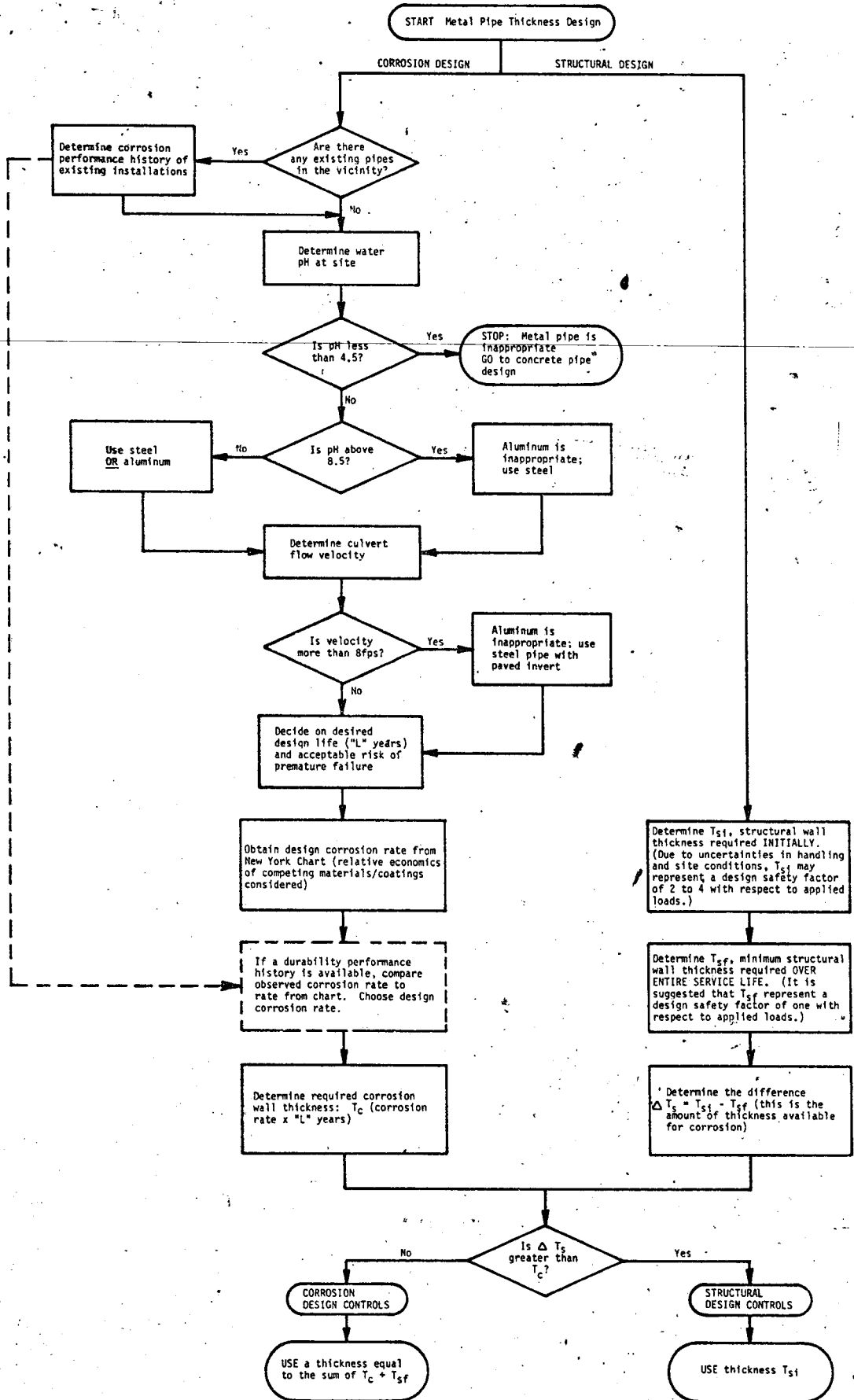
The use of the described criteria will permit New Jersey designers to make informed choices between variously coated or uncoated steel and aluminum pipes. It is worth noting however, that as in any field, new material reportedly providing improved performance continue to be brought on the market. Two new steel culvert products having coatings of supposedly greater durability are U.S. Steel's "Nexon" and Bethlehem's "Galvalume". "Nexon" pipe is coated with both epoxy and coal tar materials, while "Galvalume" is alloyed with zinc and aluminum in about equal proportions. Claims for the latter product, for example, include a 4 to 12 times greater (soil) corrosion resistance than a galvanized coating of equal thickness. It obviously behooves the Department to keep abreast of developments for these new materials to see if they offer any performance economies in our state.

#### VII. Recommendations

1. It is recommended that the Department adopt a corrugated metal pipe thickness design procedure modeled after that presented in NCHRP #116. A flow chart illustrating the steps involved in the recommended design procedure has been developed and is presented in Figure 5.

2. In view of the very comprehensive nature of certain of the reported research studies, it seems unlikely that an additional research study by this Department would result in any significant refinements over the presently available methods of predicting corrosion rates. The

**FIGURE 5**  
**FLOW CHART ILLUSTRATING**  
**RECOMMENDED METAL PIPE DESIGN**  
**PROCEDURE FOR NEW JERSEY**



complexity of the problem of corrosion, together with the low probability of accounting for all the involved factors properly, indicates that the recommended statistical method of estimating corrosion rates is the most practical way of correlating all these factors. The extension of the Department's research efforts beyond that documented in this report is considered unnecessary and, therefore, is not recommended.

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APPENDIX IIExample of Steel Pipe Service Life Design Using the New York State Method

A 48 inch diameter culvert pipe 60 feet under a main highway requires an 8 gauge corrugated culvert to satisfy structural requirements and a final thickness of 0.050 inch after 50 years to provide a minimum safety factor of 1.0, pH value is 8.0.

1. ~~Class of highway and 50 year culvert life suggests that a~~ low risk of failure can be tolerated. An appropriate probability value of 5 percent is chosen.

2. Select the corresponding rates of metal loss from Figure 3 and compute the total metal loss.

- a. uncoated -  $0.004 \text{ inch per year} \times 50 \text{ years} = 0.200 \text{ inch}$
- b. coated -  $0.0023 \text{ inch per year} \times 50 \text{ years} = 0.115 \text{ inch}$
- c. coated/paved -  $0.0007 \text{ inch per year} \times 50 \text{ years} = 0.035 \text{ inch}$

If the uncoated steel culvert is used, it must be a minimum of 1/4 inch thick to have a service life of 50 years. A pipe with a thinner wall may be used, such as a number 8 gauge, but it must be bituminous coated. An ideal but economically unrealistic choice would be a paved, bituminous coated pipe which would serve for an estimated 235 years. The final selection of which culvert is used depends on the economic considerations for all of culverts included in the construction contract.