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Pipe Culvert Durability

INTERIM REPORT

MARCH 1988

Utah Department of Transportation

RESEARCH STUDY

PIPE CULVERT DURABILITY

INTERIM REPORT

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MARCH 1988

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This interim report reflects the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Utah Department of Transportation.

SUMMARY

Overall objectives of this study were to (1) Evaluate the performance of the original fifty-eight pipe culverts that were used to establish the current procedure for pipe selection (in light of the additional years since the last rating), (2) Determine the service life of these pipe culverts and the appropriateness of the original life span prediction, (3) Rate additional sample culverts and (4) Recommend modifications to the pipe selection procedure.

The original pipes were evaluated and their life expectancy was projected compared to the original predictions. In general, the resulting correlation between life expectancy at different ages was good. Seventy additional pipes were selected randomly to span all pipe classes, materials and many of the protective coatings in use. The combined data were used to develop performance projections for concrete, aluminum and galvanized pipe. Actual field ratings were used against results from linear projections that would have been made at the time of installation. The results of this comparison resulted in a good correlation and indicated that pipes are lasting somewhat longer than the projected life.

Selected harsh environment sites, where different combinations of aluminum, steel and concrete pipes were installed, provided comparative durability under a specific combination of environmental conditions. These sites provided information on effectiveness of pipe materials and coatings under accelerated conditions which would not normally be present.

The effect of soluble salts was found to be overrated as a criterion for predicting culvert life. Six samples actually performed better than expected for installations in high soluble salt areas. The pH of an area was found to have a very definite affect on the predicted life of culverts. Four samples indicated that a higher pH shortens culvert life when other variables (which should ameliorate the high pH condition and lengthen expected life) are present. No direct conclusions were determined for soil resistivity as the third factor in projecting culvert service life.

The findings indicate that UDOT should probably give greater consideration to concrete pipe in the selection of those culverts which would be expected to remain in service over extended time periods.

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Background

The timing of this study allows for greater depth and scope, coming more than a decade after the initial pipe durability study was completed. That study, titled, PIPE CORROSION AND PROTECTIVE COATINGS, set Utah's criteria for pipe selection; the present study evaluates the UDOT's method of pipe selection and examines the pipes that were used to set these criteria. Since completion of the prior study, a number of new products have entered a competitive market with claims of increased durability.

Objectives

- Evaluate the performance of the fifty-eight pipes used to establish the current procedure of pipe selection.
- Determine if these pipes are still in service, and
- Observe if they are lasting as predicted.
- Rate additional pipes randomly according to a standard evaluation.
- Make recommendations on weaknesses and strengths of different materials, pipes, and coatings available.

Study Method

The Challenge - Old Criteria:

Groundwork for this study was set by reviewing previous research in an attempt to locate and justly evaluate the same culverts used to establish Utah's culvert selection method. Bob Welch, author of the initial pipe durability study, selected 58 culverts around the state. Their locations are described in Appendix 1 on a list and accompanying map showing soluble salts. Roger Stewart, who assisted in the previous study, helped locate the pipes and evaluate them. The same form (sample

in Appendix 2) and rating scale were used in both studies. They concur with the FHWA method of culvert inspection. Ratings are somewhat subjective; therefore, evaluating is a learned procedure. The evaluator needs to be logical and free from prejudgment and bias.

Soil and water data were taken to compare with data taken fourteen years ago to determine if environmental severity has changed. The comparisons are displayed in Appendix 3.

VISUAL INSPECTION RATINGS

	CORRUGATED METAL PIPE		REINFORCED CONCRETE PIPE
10	New condition.	10	New condition.
9	New condition -- some dents and/or deflection.	9	New condition, uneven alignment.
8	Light occasional rust; or light loss of coating or galvanizing; or minor deflection or seam buckling.	8	Minor cracks; and/or uneven alignment.
7	Light general rust; or light loss of coating or galvanizing; or minor deflection or seam buckling.	7	Minor abrasion; or minor cracks; or uneven alignment.
6	Moderate occasional rust; or moderate loss of coating or galvanizing; or moderate deflection or seam buckling.	6	-----
5	Moderate general rust; or moderate loss of coating or galvanizing; or moderate deflection or seam buckling.	5	Moderate abrasion; or cracks; or wide joints; or uneven alignment.
4	Minor perforation; or major rust; or major loss of coating or galvanizing.	4	-----
3	Major perforation; or major rust; or major deflection or seam buckling.	3	Major abrasion; or major cracks; or wide joints; or uneven alignment.
2	Extreme deterioration.	2	-----
1	Totally destroyed.	1	Totally destroyed.

Photos on the following pages display the range of visual inspection ratings.

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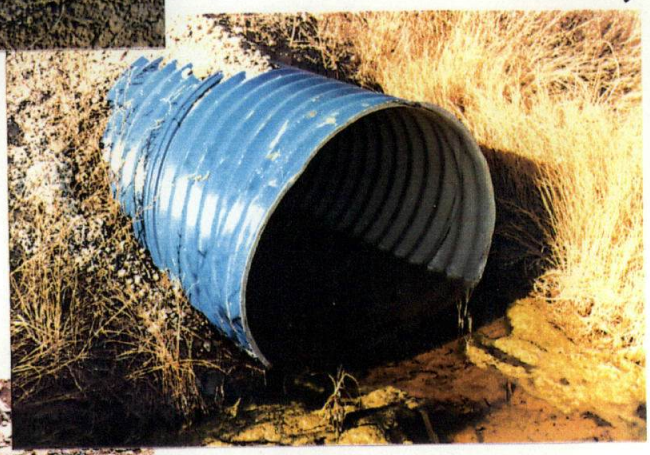

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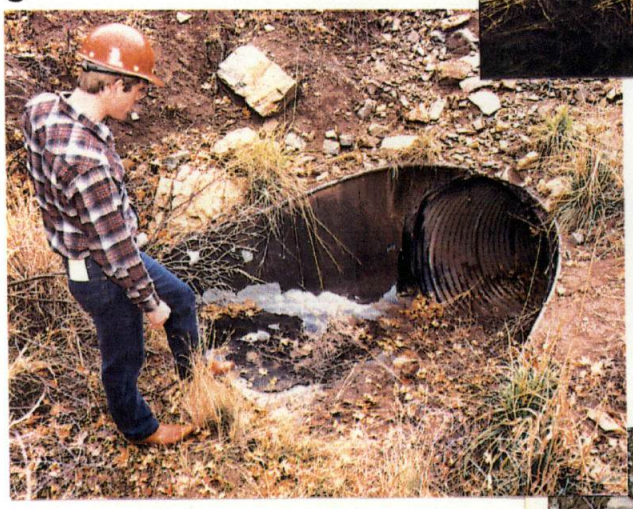

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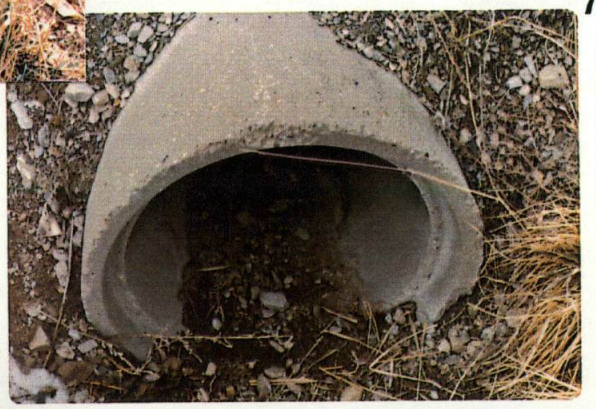

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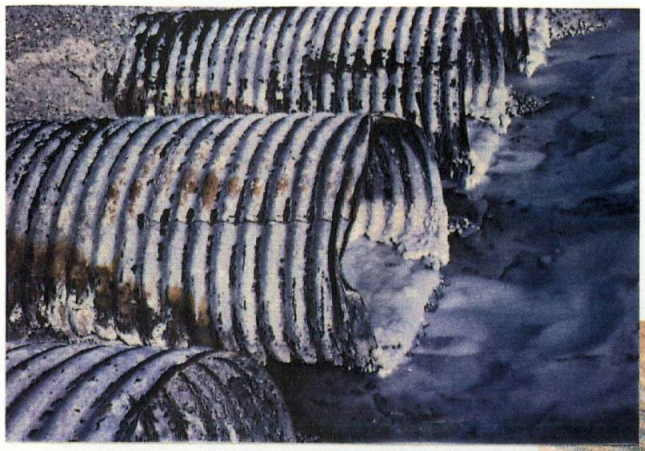
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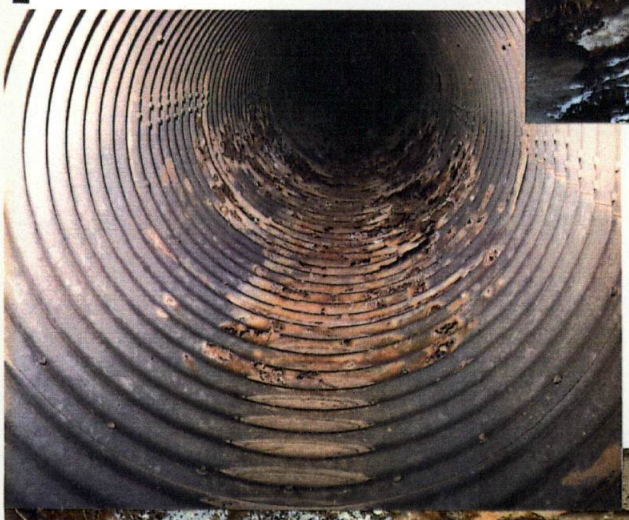

2

1

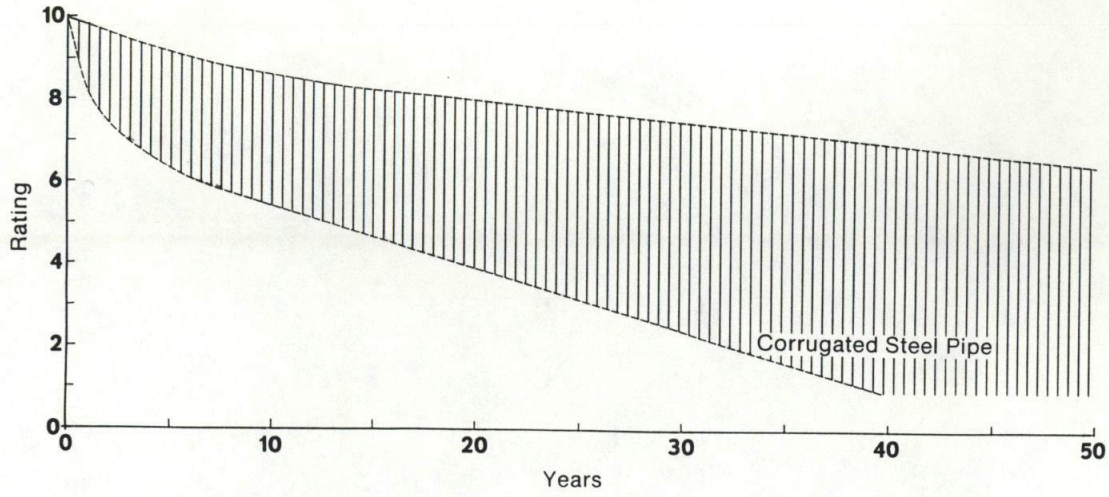
New Selections

Random pipe culverts were selected for evaluation that span all pipe classes, all pipe materials and many coatings used in Utah. Seventy new pipes were evaluated which were combined with the other fifty-eight pipes to form a significant data base. Current ratings vs. age were used as data points to form performance projections shown on the Anticipated Life Span charts. These charts show the ranges (maximum and minimum) for which Concrete, Aluminum and Galvanized steel pipe are expected to last in Utah. The pipe inspected embraced all the pipe classes A-F and covered many of the new products currently being used. Pipes of all ages were considered so as to obtain a large and complete data base. Culvert pipe was separated into six classes (A through F). Steel was the predominant material in classes A through E; aluminum was found in classes B and E; portland cement concrete was in class F only.

FORMER PIPE CLASS	PIPE MATERIAL
A	Plain Corrugated Steel
B	Bituminous Coated Corrugated Steel
	Aluminum Alloy
	Galvalume
	Pitch-Resin Adhesive Coated Corrugated Steel (coated on exterior side only)
C	Asbestos Bonded Bituminous Coated Corrugated Steel
	Pitch-Resin Adhesive Coated Corrugated Steel (coated on both sides)
D	Plain Corrugated Steel Structural Plate
E	Bituminous Coated Corrugated Steel Structural Plate
	Aluminum Alloy Structural Plate
F	Portland Cement Concrete Type II Cement (SO_4 0.5 percent)
	Portland Cement Concrete Type V Cement (SO_4 0.5 percent)

The current pipe classification is shown in Appendix 6.

ANTICIPATED LIFE SPAN



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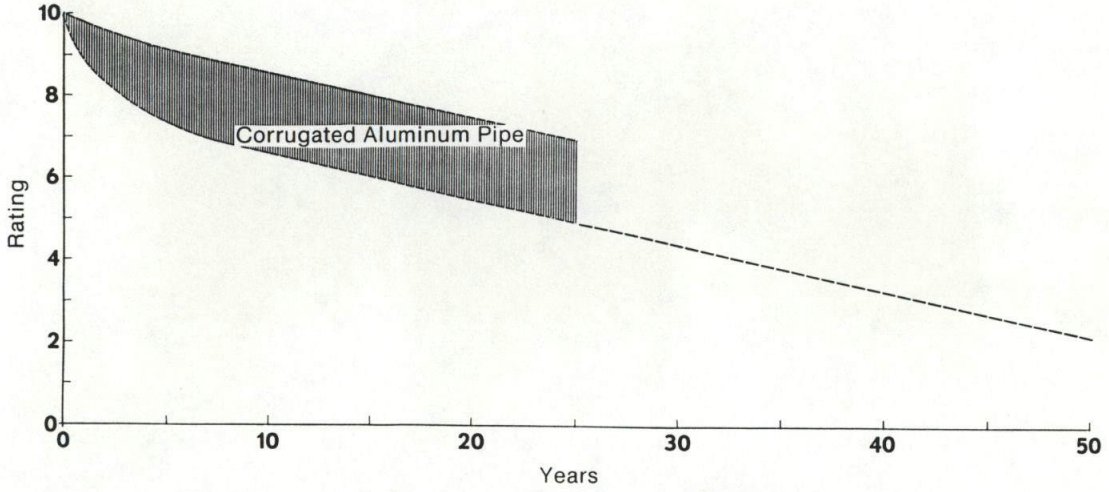

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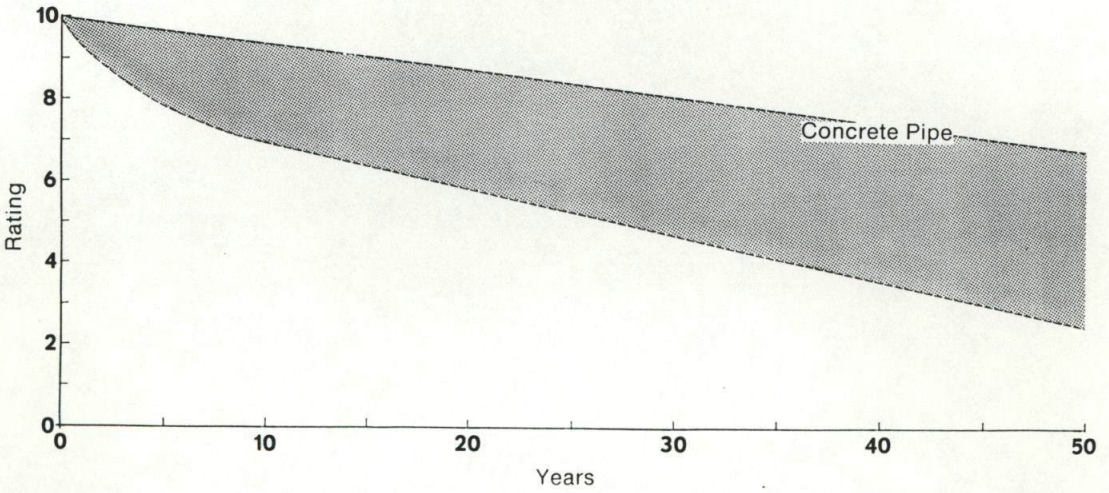
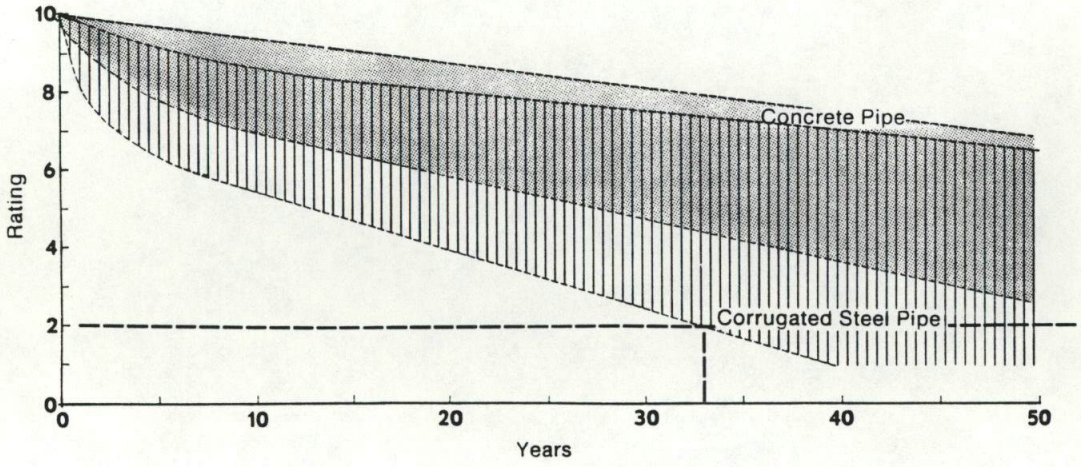


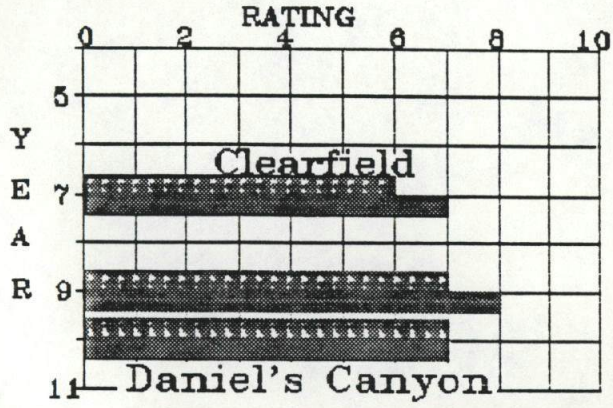
Based upon the observed condition of more than 100 pipe culverts -- and using a rating value of 2 as replacement criterion -- corrugated steel pipe (as shown in the combined graph below) should have a life expectancy of at least 33 years. This, as stated, is conditioned upon proper selection for the environmental conditions, correct installation and proper maintenance. Under similar circumstances, it can be seen (also from the graph) that the minimum expected life for concrete pipe would be more than 50 years. Aluminum pipe was not included in this combined graph because there were, in the study, none which reached an age where the rating approached a value of 2.

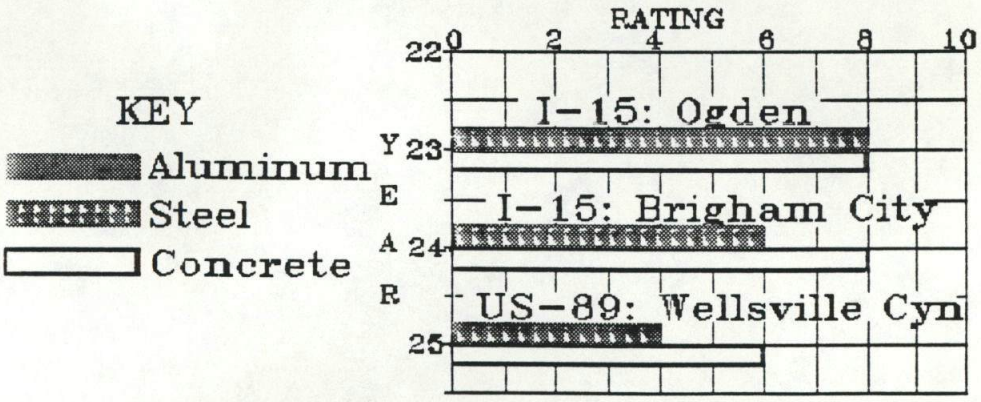
ANTICIPATED LIFE SPAN

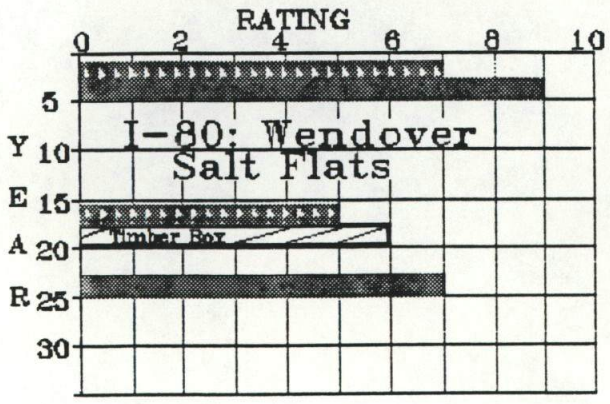


The most valuable data collected were comparisons of material where environment is constant and different materials of the same age are used. Such performance sites are shown in bar graphs on the following page (Rating vs. Year). Advantages of concrete performance over steel can be seen at Brigham City and Wellsville Canyon (after many years of service). Aluminum seems to be enduring at least as well or better than steel in Daniels Canyon and at Clearfield on the Interstate. However, steel has fulfilled its design life in these cases.

The Salt Flats provide a unique testing ground. Although it is believed that soluble salts are most harsh in marine conditions at approximately 6% -- and the Salt Flats are more nearly 10% -- pipes corrode rapidly in this area. The bar graphs show that aluminum excels over all other materials in such environments. Asbestos Bonded CMP also

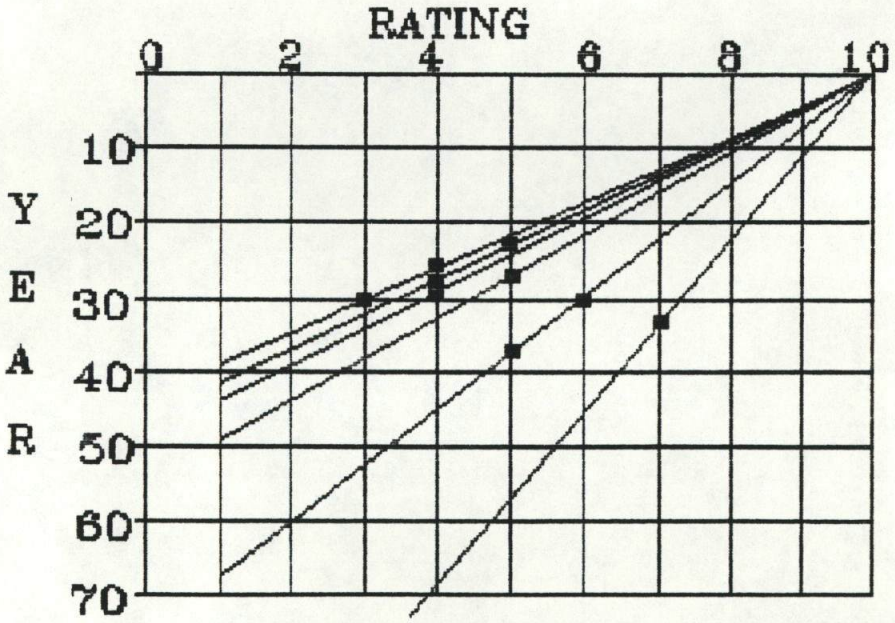






serves well. Recent installations of Polymeric coated CMP indicate that the coating serves poorly. After less than five years much of the coatings are not effective. A specially treated timber box, although expensive, is very unique and proves to be virtually permanent in such an environment.

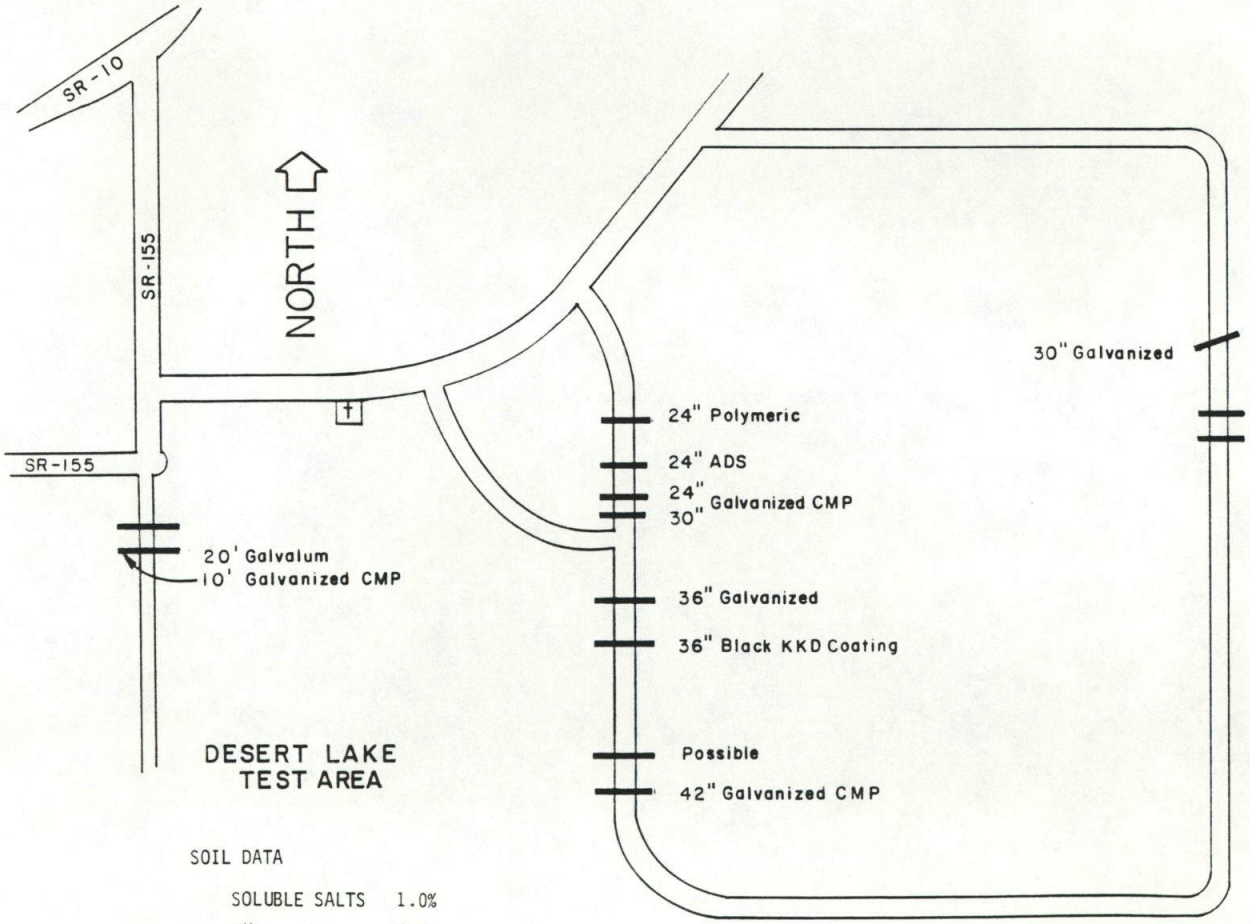
Another way of looking at the implications of the bar graphs is to plot the points on a graph and extend them linearly to failure (a rating of 1). The graph, below, shows that failure may be expected anywhere from 39 to more than 70 years for the comparative samples in the bar graphs, recognizing that linear projections are probably very approximate.



Due to funding problems, the amount of soil data taken in this study was limited. The environmental information taken in conjunction with prior data from the earlier report identifies the affect of existing

soil, water and environmental conditions on pipe performance for each class of pipe. Are pipes in known pH soluble salts, and soil resistivity values lasting as expected?

Desert Lake Waterfowl Management Area, as the name implies, is a wet, harsh area on culverts. It is located in Emery County where, historically, pipe failed rapidly. Soil data are shown on the map. These represent accelerated test conditions; however, they must be recognized as representing only one set of environmental parameters. Many test pipes have been set up in this area. Their age and soil data is known and many products are still being observed. Although other valuable data is not available, it is forthcoming. New experimental sections can be placed there without disrupting roads.



Methods of Analysis

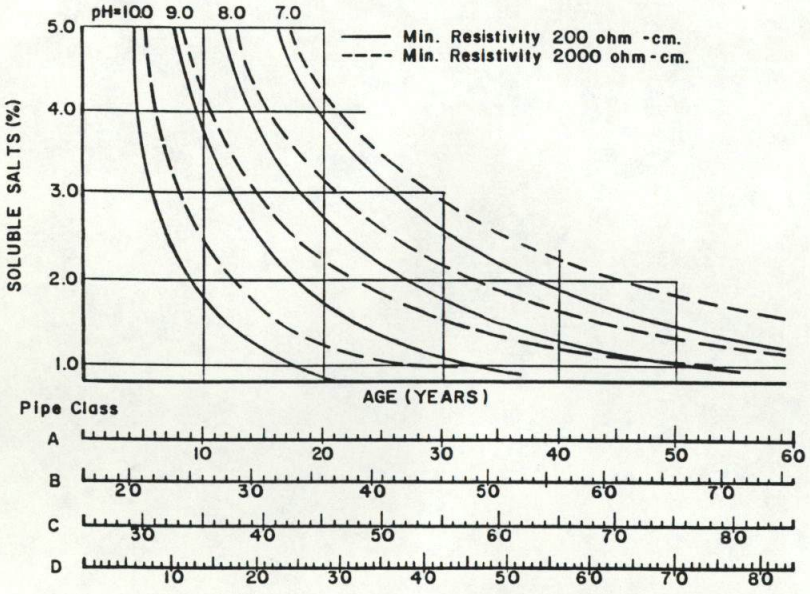
Can the life of a pipe be accurately predicted? Short range predictions in harsh environments have been successful but longer life predictions have fallen short in terms of accuracy. The UDOT Implementation Package: PIPE SELECTION FOR CORROSION RESISTANCE (UDOT-IMP-76-1) outlines a method suggested by Bob Welch in 1974. Therein it predicts that life-span of each class of culvert is based on pH, soluble salts and soil resistivity.

Actual field ratings aid in accurately projecting culvert life. Time reveals the accuracy of prediction methods. Linear projections are shown in the Rating vs. Year graph. These linear projections were compared with predictions which would have been made at the time of installation. The results are tabulated in Appendix 4 and show close correlation.

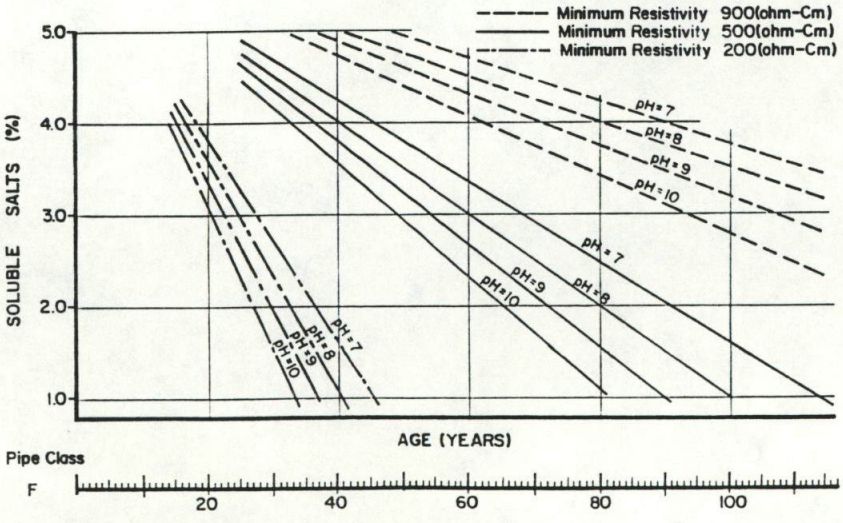
Pipes are actually lasting 1.76 years longer (on the average) than predicted by using the method cited in UDOT-IMP-76-1. A conservative criterion serves better where safety and expense are concerned. The standard deviation is 27.2 years which shows the difficulty of accurately predicting culvert life.

Cumberson would be a proper word to describe culvert performance prediction. Projection is better if many years of experience are available. The charts provided for Corrugated Steel Pipe and Concrete Pipe (extracted from UDOT-IMP-76-1) show material life but are not site specific. The experience and judgement of each District Materials Engineer serves well to complement this procedure.

Corrugated Steel Pipe



Concrete Pipe



Other factors hamper expectations of culvert longevity. Frequent large storms erode inlets and outlets, change alignment and even wash out some culverts. Strong currents carry heavy bedloads which mechanically chip away at pipes. Abrasion removes protective coatings and deforms softer material. Chemicals produced by man such as fertilizers, insecticides, etc., damage pipes. Each of these factors need to be measured accurately to predict culvert life.

On the average, soluble salts in Utah fall between 0.8% and 2.0%; pH is approximately 8.0; and soil resistivity between 500 to 1500 ohm-cm. In this range on the UDOT-IMP-76-1 charts, a great deal of extrapolation is needed to determine culvert life. If a whole number for pH is not used, extrapolation three ways is necessary and a prediction can vary 10-20 years. It is only safe to say a typical culvert (using former classifications) may last --

Class A	-	30+ years
Class B	-	45+ years
Class C	-	55+ years
Class D	-	45+ years
Class E	-	60+ years
Class F	-	120+ years

These results can be affected by other factors as stated above.

Further analysis is enlightening: soluble salts appear to be overrated as a criterion in predicting culvert life. Samples 13, 15, 30, 39, 40, 41, Appendix 4 all performed better than expected for high soluble salt areas.

The pH in an area definitely affects life as predicted. Sample 47, 49 (Appendix 4), and 22, 31 show that a higher pH shortens life when other factors should be conducive to a longer life. Sample 6 shows that a pH of 8.5 shortened the life of the culvert by 36 years. And, as shown in the preceding curves, the higher pH ranges tend to have a significantly greater impact on steel pipe than on concrete. Manufacturer recommendations for aluminum pipe suggest a pH range of 4.5-8.5.

No direct conclusions could be reached concerning soil resistivity. UDOT-IMP-76-1 states that "Minimum soil resistivity is described as the most important single parameter affecting pipe culvert durability." Further research will be conducted in this area.

Storm Sewers

Several large storm sewers of concrete and steel were evaluated. The concrete storm sewers had been in service for eighteen years and little problems were encountered. There were no problems with silting or corrosion as far as could be observed.

Most metal storm sewers observed were also in good condition. No serious silting had occurred and little corrosion was evident after fourteen years of service. A smooth flow metal storm sewer was observed to have several problems. The lining had fallen off in many locations after only a few years of service. Silting-in had occurred possibly due to backing up of water near the outlet or a change in slope. Elliptical shaped areas indicated some vertical deformation. It was not known whether these structure deflections occurred during or after construction of the storm sewer; however, the "Culvert Inspection Manual" FHWA-IP-86-2(5-4.2) states,"... such defects may affect their ability to perform in ring compression and their interaction with the surrounding soil envelope." These deflections also caused coatings to be removed thus exposing the pipe to more rapid corrosion. Misalignment or sags and deflections at joints were also noticed. Because of the difficulty with metal pipe linings, hydraulic characteristics of concrete pipe are generally superior to those of corrugated metal pipe of the same diameter. More study is needed in this area because of the large investment that storm sewers require in replacement.

Coatings

Coatings have been used successfully for many years to protect metal culverts in harsh conditions. Some coatings have served well while others are rendered ineffective after a few years. Galvanizing of pipe

has deterred corrosion for many years. Other coatings have been used in addition to zinc in harsh conditions. Asphalt coats are durable yet hard to handle and adhere poorly. Asbestos bonded asphalt has successfully protected culverts in most of the locations it has been placed.

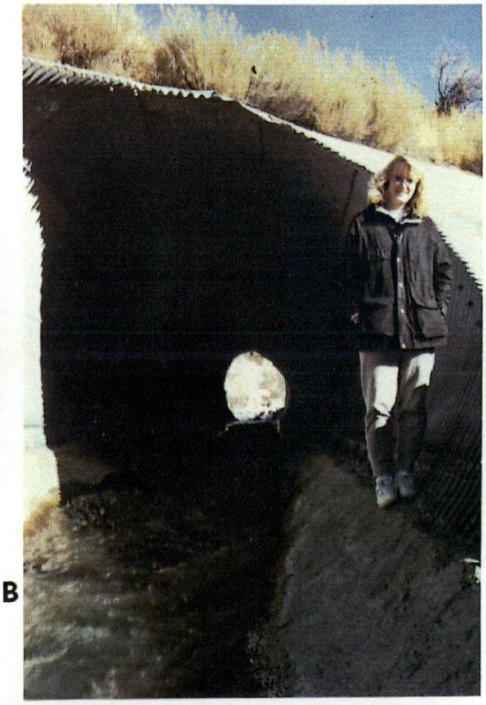
Coatings must be strong enough to handle construction strain, adhere well, and withstand chemical effects. Nexon coatings observed have lasted well. Some of the polymeric coatings have problems with adhesion as observed with several pipes in Emery County. Black Klad coatings at Thistle are heavily abraded after three years of service due to steep slopes and stream bed loads in the area as shown in photo D (following page).

Several other noteworthy items encountered during the study are shown in photos on the following page:

A - Class "B" Nexon coating outside serving well; Invert coating worn.
B - Class "D" Structure Plate, concrete invert heavily abraded.
C,E,F - Outlet failure due to improper design (constriction + elbow).

A

B



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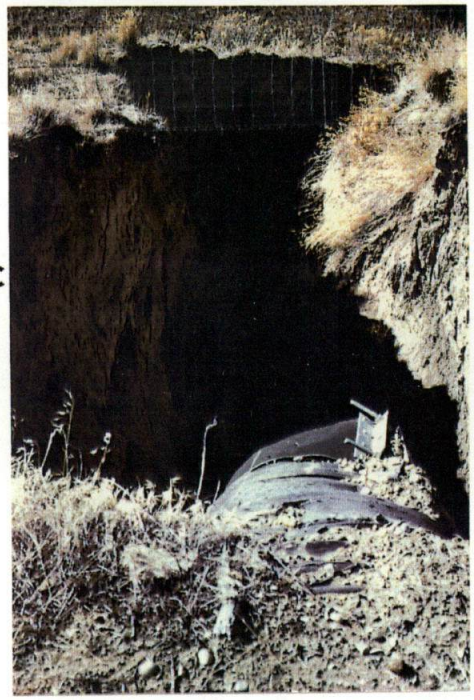

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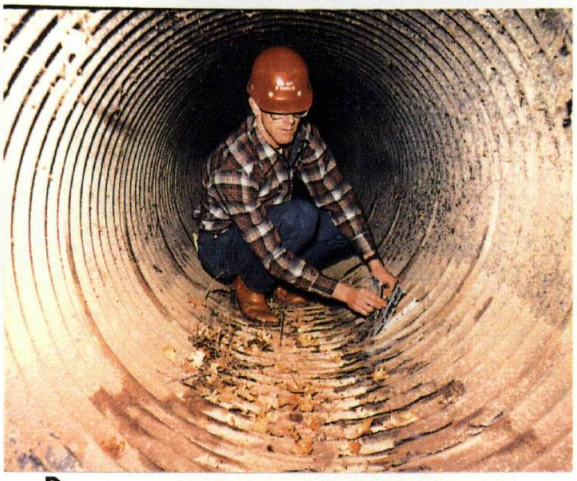


E

F

FINDINGS TO-DATE

There is no evidence yet gained from this study to suggest that the existing UDOT pipe selection procedure -- as outlined in Implementation Package UDOT-IMP-76-1: Pipe Selection for Corrosion Resistance -- is in need of major revision. Some additional study and review of available data will be undertaken in connection with this study to more accurately verify the selection procedure for steel pipes in classes A-C and for steel plates in classes D and E. These items will appear either in another interim report or in the final study report.

Although there is a modest range of price differential in the various classes of steel pipe -- and different ranges for different sizes -- concrete pipe generally runs about 1.3 times the price of a hydraulicly - equivalent corrugated steel pipe. A typical comparison can be seen in 1987 UDOT average bid prices for 24" diameter pipe in the various classes:

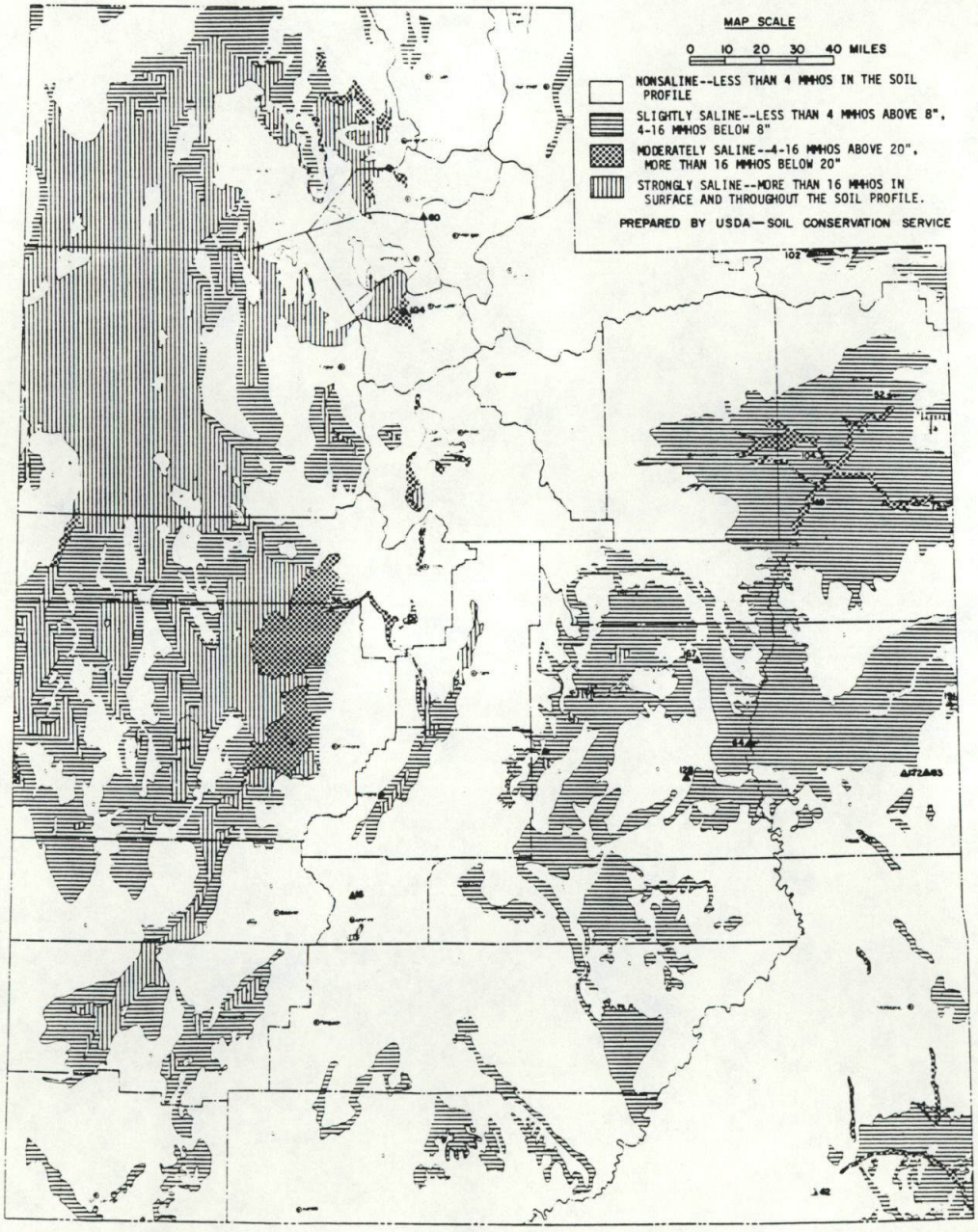
	Steel		Concrete	Aluminum
Class A	B	C	F	B
23.32	30.00	31.89	32.55	52.40

Aluminum pipe cost appears, at first, to be excessive. However, it must be pointed out that there were but 74 linear feet installed in a reasonably remote location, thus accounting for the high unit price. Well over one mile (in sundry locations) of 24" concrete pipe and nearly as much 24" steel pipe was installed in 1987.

Assuming that the life span of a pipe ends when the rating reaches 2, corrugated steel pipe would be expected to last a minimum of 34 years whereas concrete pipe would continue to be serviceable beyond a fifty year horizon. This indicates that, with appropriate selection based on the criteria set forth in UDOT-IMP-76-1, either concrete or steel pipe would perform satisfactorily for a normal highway life span of 30 years. However, for highways which may undergo major rebuilding every 30 years but remain essentially on the same alinement, within the same roadway prism, the greater longevity of concrete pipe would tend to swerve an

economic analysis away from steel. (In harsh soil conditions, the concrete pipe could continue to serve for the rebuilt highway, whereas the steel pipe would need to be replaced.) Appendix 7 contains a brief economic appraisal directed at comparative life-span costs for both steel and concrete culvert pipes.

On the salinity map (below) the high salt soils are, as expected, in the northwest and west-central portions of the state. The Colorado



Salinity Map of Utah

Plateau area shows some salinity, while the populated Wasatch Front and much of southern Utah has little salt content in the soil. This information is valuable as it indicates prime locations for installing culverts made of aluminum, a material which withstands salt better than steel or concrete.

Under normal conditions, life span (visual rating vs. years in place) of the three different pipe materials would be expected to fall within the ranges shown on the Anticipated Life Span graphs (page 6). These ranges do not apply to pipes placed in extreme environments; neither do they apply to pipes improperly installed or maintained. Of note is the wider range shown for corrugated steel pipe. This is a result of lumping all the CSP together (i.e., Types A thru E). Corrugated aluminum stops at 25 years because of the dearth of data for longer term installations. (Only 2 of the 128 samples were outside the ranges shown and it is believed that other factors -- i.e., improper installation, unusually harsh chemical environment -- contributed to these two early failures.)

Environmentally, severity has not changed over the past 14 years; neither the pH, nor soluble salts changed significantly. The soil resistivity decreased 660 ohm-cm on the average. This might account for slight accelerated deterioration of culverts in some locations. The standard deviation was 940 ohm-cm, which shows a wide variation in findings. The pH increased 0.2 and soluble salts decreased 0.56%. There were noticeable changes in some areas, but overall soil conditions remained stable. Throughout the study, old and new soil conditions were both used to evaluate pipe performance. Water conditions vary from season to season, with each storm, and were not used. Most of the pipes were still in service. Several of the culverts in District 4 had failed and others had been extended.

It has been observed that water-tightness in metal pipe occasionally becomes a problem because of the method used in connecting sections of pipe. Where water-tightness is an absolute must, concrete pipe ought to receive priority.

INTERIM RECOMMENDATIONS

No change in the selection procedure outlined in UDOT-IMP-76-1 is suggested. However, an additional set of criteria relating to initial cost vs. longevity would be useful. Without going into an extensive economic analysis, several rules-of-thumb are herewith presented to aid the designer early-on in pipe selection for specific site conditions.

- Specify Aluminum Alloy only where soil is strongly saline (>16 MMHOS); permit its selection elsewhere.

- Specify Concrete (Class F) where pH exceeds 9.0 and allow its use for pH lower than 9.0.

- Permit selection of Steel (Classes A-E) in all other cases, as appropriate, depending on soil conditions and required service life of the roadway prism.

This short-cut approach is not to supersede the recommended selection procedure, but rather to guide the designer through the Location and Preliminary Design phases during which time hydraulic studies, soil tests and preliminary estimates are being undertaken.

Funding constraints dictate that culvert design life may need to be greater than pavement design life. Repeated replacement of culverts in harsh environments is a high-cost item. Examples in Appendix B of UDOT-IMP-76-1, pages 24-27, indicate that, under most circumstances, several different pipe classes would provide satisfactory service. The designer is faced with the choice of limiting the specifications to one or two types -- or -- opening the bidding process to all acceptable types. What usually ensues in the latter case contains both good news and bad news. The good news is that, with more competition, lower prices are bid for all classes of pipe; the bad news is that, almost always, the marginally-acceptable pipe is chosen. Value Engineering principles argue

the point which emphasizes getting adequate (≧ marginal) service for the money spent. Is this proper for culvert pipe selection?

Most of the time, probably yes.

One element in the mix, however, raises some questions: Required Service Life. In any sensitivity analysis, the "guesstimate" of required service life is far and away the item most sensitive to variation. Alkalinity (pH), resistivity (R) and soluble salts (SS) -- the other selection parameters -- are all readily measurable. Not so, the required service life. As pointed out in the preceding section, if a highway remains on an existing alinement through several rebuilding efforts, the required service life might be -- using Value Engineering criteria -- eighty years. There are many such highways in rural Utah which are approaching this longevity. However, if a road is to be widened, or even re-alined minimally, or redesigned for a higher return period (50 year flood instead of 10 year flood), then the required service life may amount to little more than a decade.

The designer should not be saddled with the burden of determining Required Service Life for each individual project (just as the designer is not responsible for the determination of pH, R, SS & SO_4). UDOT's Office of Planning and Programming has the charge to determine future highway needs, along with serviceability of existing facilities. Therefore, an interim recommendation of this study would be that the UDOT's Planning Division, on major projects -- particularly those with extensive drainage requirements, provide the Roadway Design Section with a Required Service Life for drainage structures based upon the best available prognostications for life of the roadway prism (separate from pavement and structure life). This prediction would accompany the (pH, R, SS & SO_4) test results from the district materials laboratory so that the designer would be better armed to implement the selection procedure in UDOT-IMP-76-1.

The Culvert Selection Task Force should make recommendations to the Standards Committee for revised guidelines or policy for pipe selection of both cross drains and storm drains, based on the findings of this report.

APPENDICES

1 - Locations of pipes in initial study and samples with soluble salts

2 - Sample Evaluation Form

3 - Environment Data: 1986 compared to 1974

4 - Projected life of selected samples

5 - Basic data for samples in initial study

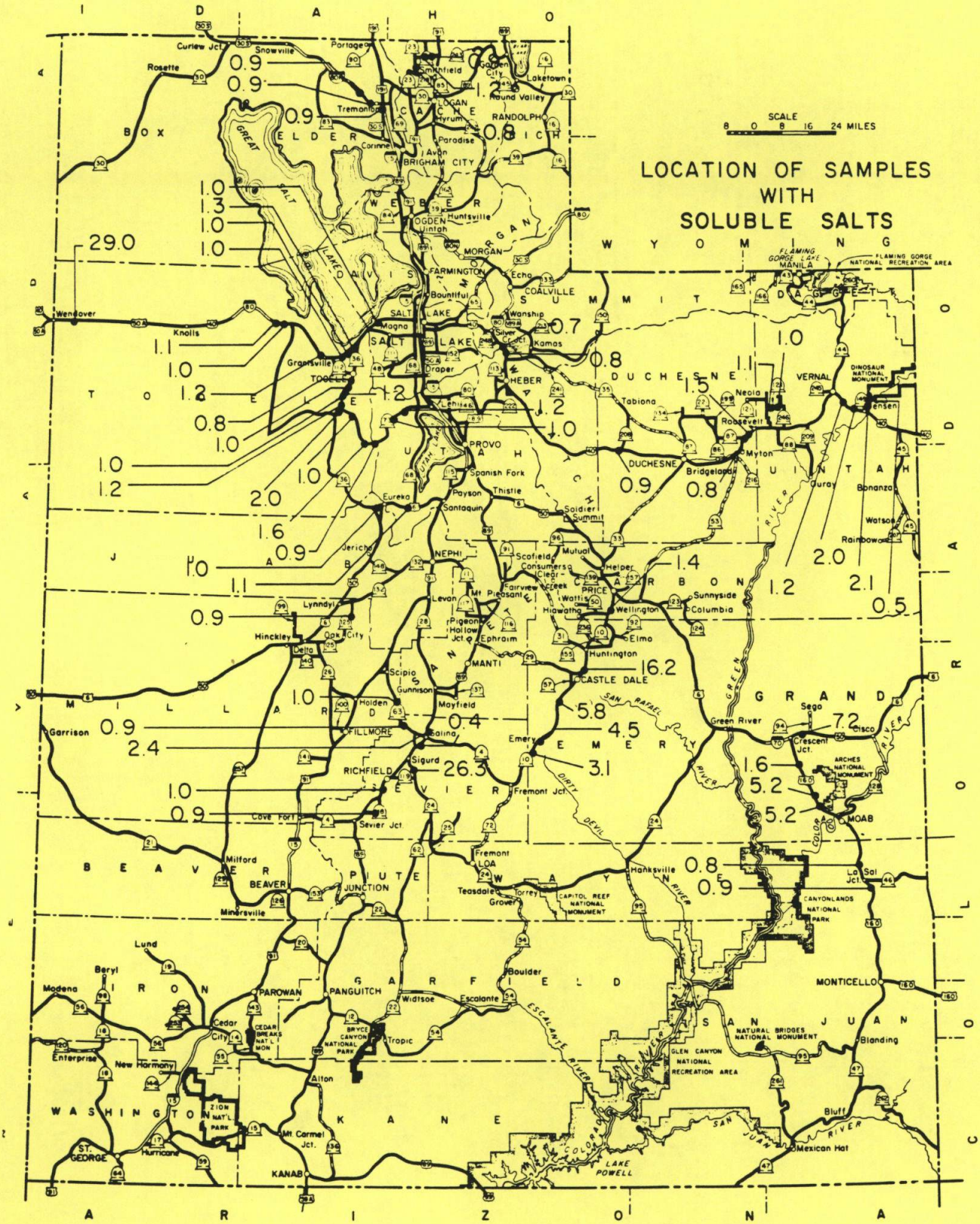
6 - Supplemental Specification Describing the revised (current) UDOT Pipe Classification

7 - Condensed Economic Appraisal

APPENDIX 1

Locations of Pipes in Initial Study
and
Samples with Soluble Salts

No.	Location	
1	Mills Jct. to Grantsville	Concrete Pipe
2	Mills Jct. to Tooele	RCP
3	" " " "	"
4	Grantsville to Tempe Point	CMP
5	" " " "	Spec. Alkali Res. Type-A-CMP
6	" " " "	" " " " " "
7	Tremonton Westerly to Box Elder Co. Line	Struc. Plate Cattle Pass
8	Tooele to Stockton	Concrete
9	" " "	Concrete & CMP
10	Stockton to 9.7 miles South	24" Concrete
11	South edge of Stockton to City Limits	Pipe Arch & Concrete
12	Vernon North - 17 miles	Concrete
13	" " - 9.7 miles	CMP
14	Faust East to Tooele Co. Line	5'-CMP
15	Fairfield to Tooele Co. Line	Struc. Plate Arch
16	" " " " "	Concrete
17	" " Lehi	CMP
18	" " "	Concrete
19	Haus Corner to Dewyville	CMP-Arch
20	Tremonton Westerly	Concrete
21	Kennecott Tailings	Bit. Coated Struct. Plate Arch
22	Newton to Clarkston	CMP
23	Clarkston to Trenton	CMP
24	Jensen to Dinosaur Nat. Monument	(Struct. Steel Plate Arch)
25	" " " " "	(Pipe arch) CMP-Bit. Coated
26	" " Naples	(Bit. Coated CMP)
27	" " "	(" " ")
28	White Rocks Road to LaPoint Jct.	(Struc. Steel Plate Arch)
29	" " " " " "	(CMP)
30	Mitton to Roosevelt	(Special Alkali Res. Type A)
31	" " "	(" " " " ")
32	Fruitland to Tabiona Jct.	CMP
33	Jct. US-40 & 189 North	Cattle Arch
34	" " " " "	Concrete
38	Carbon to Emery County Line North	Bit. Coated CMP
39	1 mile North of Castledale	Bit. Coated Struct. Steel Arch
40	2 miles North of Ferron	Spec. Alkali Res. Type-A-CMP
41	1.6 miles North of Emery	Coated CMP
42	3 miles South of Emery	Concrete Box Culvert
43	2-1/2 miles South of LaSal Jct.	CMP
44	6.7 miles North of LaSal Jct.	CMP
45	1 mile North of Moab Airport	Bit. Coated CMP
46	2 miles North of Moab Airport	" " "
47	3.8 miles South of Crescent Jct.	
48	6.75 miles East of Crescent Jct.	3-types
49	1-3/10 miles So. Richfield Airport	24"x36" CMP Arch
50	1-7/10 miles West Monroe	24" CMP
51	1-3/4 miles East Sigurd	54" Asbestos Bonded Bit. Coated
52	7-2/10 miles South Salina	30"x18" Pipe Arch
53	1-7/10 miles North Salina	24" CMP
54	1/10 mile East Millard Co. Line	24" CMP
55	11-1/10 miles West of Scipio	30" Bit. Coated CMP
56	3 miles South of Leamington	24" CMP
57	3/10 mile East of Eureka Bypass Jct.	6' Struc. Steel Pipe
58	7/10 mile East of Alberta	24" Concrete


LOCATION OF SAMPLES
WITH
SOLUBLE SALTS
SCALE
8 0 8 16 24 MILES
IDAHO
WYOMING
COLORADO
UTAH
ARIZONA
Curlew Jct.
Snowville
Rosette
Portage
Tremonton
Corinne
Paradise
Avon
BRIGHAM CITY
Golden City
Fairfield
Lakeview
Round Valley
Laketown
RANDOLPH
Hyrum
Logan
Huntsville
Ogden
Uintah
Morgan
FARMINGTON
Bountiful
Echo
COALVILLE
Wanship
Silver Jct.
Kamas
Wendover
Knolls
Grantsville
Tooele
SALT LAKE
Magna
Draper
Lehi
HEBER
Provo
Spanish Fork
Payson
Thistle
Eureka
Santaquin
Soldier Summit
Jericho
NEPHI
Scofield
Consumers
Mutual
Helper
Clear Creek
Fairview
Mt Pleasant
Watts
Hiawatha
PRICE
Sunnyside
Columbia
Wellington
Lynndyl
Levan
Pigeon Hollow Jct
Ephraim
Elmo
Huntington
Hinckley
Oak City
Delta
MANTI
CASTLE DALE
Scipio
Gunnison
Holden
Mayfield
Sterling
FILLMORE
Garrison
Emery
Green River
Sego
Cisco
Crescent Jct.
Sigurd
RICHFIELD
Fremont Jct
Sevier Jct
Cove Fort
Milford
BEAVER
Minersville
Fremont
Loa
Teasdale
Torrey
Grover
Hanksville
La Sal Jct.
MOAB
Lund
Beryl
Modena
Cedar City
Enterprise
New Harmony
PAROWAN
PANGUITCH
Widtsoe
Escalante
Boulder
Tropic
Alton
Mt Carmel Jct.
ST. GEORGE
Hurricane
KANAB
MONTICELLO
Blanding
Bluff
Mexican Hat
LAKE POWELL
CAPITOL REEF NATIONAL MONUMENT
CANYONLANDS NATIONAL PARK
ARCHES NATIONAL MONUMENT
NATURAL BRIDGES NATIONAL MONUMENT
GLEN CANYON NATIONAL RECREATION AREA
BRYCE CANYON NATIONAL PARK
CEDAR BREAKS NAT'L MON
ZION NAT'L PARK
FLAMING GORGE NATIONAL RECREATION AREA
DINOSAUR NATIONAL MONUMENT
Manila
Vernal
Jensen
Roosevelt
Myton
Tabiona
Neola
DUCHESNE
Bridgeland
Quray
Bonanza
Watson
Rainbow
Great Salt Lake
Utah Lake
Sevier Lake
Green River
Dirty Devil River
San Rafael River
Price River
Colorado River
San Juan River
Escalante River
Hanksville
29.0
1.0
1.3
1.0
1.0
1.1
1.0
1.2
0.8
1.0
1.0
1.2
2.0
1.0
1.6
0.9
1.0
1.1
0.9
1.0
0.7
0.8
1.1
1.5
1.2
1.0
0.9
0.8
1.4
1.2
2.0
2.1
0.5
16.2
5.8
4.5
7.2
1.0
0.4
0.9
2.4
26.3
3.1
1.6
5.2
5.2
1.0
0.9
0.8
0.9

APPENDIX 2

Sample Evaluation Form

TEST SITE EVALUATION FORM

Pipe No. 23-A District 6 Year Placed 1950

Pipe Location: 3.2 Miles West of Myton, Utah on U.S. 40.

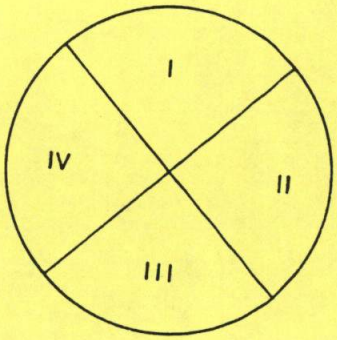
Pipe Description Asbestos Bonded Bituminous Coated Corrugated Steel.

Pipe Coating Asbestos Bonded Bituminous Coated.

Pipe Size. . . . . 36" x Circular

In Place Thickness 86 mills
89 mills
91 mills
87 mills

Design Gauge 16



	Corrosion	Abrasion
I	Soil Side=5%	none
II	Both Sides<2%	none
III	Both Sides=8%	none
IV	Both Sides=5%	none

Remarks: Coating approximately 10-15% intact. Corrosion begining on soil side of pipe. (see pictures). Invert looks good. Discoloration on approximately 40% of exterior side of pipe.

Picture Identification: 23A-Inlet Drainage Basin; 23B-Outlet Drainage Basin; 23C-Pipe Invert at 15ft in.; 23D-Section II Soil Side.

Type Drainage Basin: Semi-Arid Desert flat topography at <2% slopes

Soil _____ Slope of Drainage Basin _____

SOIL	Field	Lab
pH	9.3	9.6
Resistivity	NA	400 ohm-cm.
Soluble Salts	3.4 percent	

WATER	Field	Lab
pH		
Resistivity		
Soluble Salts	(No flowing water)	

APPENDIX 3

Environment Data:
1986 Compared to 1974

Sample	Environment Data 1986 PH	Soluble Salts	Soil Resistivity	Environment Data 1974 PH	Soluble Salts	Soil Resistivity	Environment Data PH	Soluble Salts	Soil Resistivity
6	8.25	.8%	1250	8.5	1.1%	1300	-.25	-.3	-50
16	8.25	.9%	1400	8.1			.15		
22	8.30	.7%	1200	7.7	.8%	1400	.6	-.1	-200
Water	7.85	610 ppm							
24	8.06	2.2%	200	8.4	.5%	3000	-.34	1.7	-2800
Water	8.22	1560 ppm							
31	7.81	3.5%	420	8.4	.8%	1200	-.59	2.7	-780
Water	8.26	240 ppm							
39	7.99	9.2%	570	7.8	16.2%	1400	.19	-7.0	-830
Water	8.10	2300 ppm							
47	8.69	.8%	630	7.5	1.6%	800	1.19	-.8	-170
49	8.19	.8%	760	7.9	1.0	1400	.29	-.2	-640
57	8.39	.5%	1300	7.8	1.0	1100	.59	-.5	200
Water	8.70	730 ppm							
							1.83	-4.50	-5270
							0.20	0.56	-659
							-3	-6	-7
							+6	+2	+1

APPENDIX 4

Projected Life of Selected Samples

Sample	Soil Data 1986 PH	S.S.%	SR	Class	Predicted Life	Rating 1974	Rating 1986	Age	Projected Life	Longer Shorter
6	8.25	.8	1250	C	80+	7/4	3	31	44	-36
16	8.25	.9	1400	CF	80 150+	7	7	34	113	+37
22	8.3	.7	1200	A	55	7	4	26	42	-13
24	8.06	2.2	200	D	35	9	4	28	47	+12
31	7.81	3.5	420	C	42	4/7	4	29	48	+6
39	7.99	9.2	570	E	32	8	5	23	45	+13
47	8.69	.8	630	C	72	7	5	27	54	-18
49	8.19	.8	760	A	58	8	6	30	66	+8
57	8.38	.5	1300	D	80+	7	5	37	74	-6

Sample	Class	Predicted Life	Rating 86	Age	Projected Life		Sample	Class	Predicted Life	Rating 86	Age	Projected Life	
1	F	120	7	31	103	-17	17	A	70	7	38	127	+57
2	F	120+	7	31	103	-17	18	F					
3	F	120+	7	31	103	-17	19	A	70	6	33	83	+13
4	A	45	2	31	39	- 6	20	F					
5	C	60					21	E					
6	C	80+	3/5	31	44	-36	22		55	4	26	42	-13
7	D	78	6	31	78	0	23	A					
8	F	120	6	42	105	-15	24	D	35	4	28	47	+12
9	F	120	4	42	70	-50	25	B	52	3	28	40	-12
10	F	100	8	28	140	+40	26	B	52	4	30	50	-2
11	F+	120+	6	28	70	-50	27	B	75	6	30	75	0
12	F	38	4	35	58	+20	28	D	90	6	31	78	-12
13	A	30	5	35	70	+40	29	A	60	5	31	62	+2
14	D	85	7	18	60	-25	30	C	42	7	29	97	+55
15	D	55	7	34	113	+58	31	C	42	4	29	48	+6
16	F	150	7	34	113	+37	32	A			28		

Sample	Class	Predicted Life	Rating 86	Age	Projected Life		Sample	Class	Predicted Life	Rating 86	Age	Projected Life	
33	D	90	7	28	93	+ 3	49	A	58	6	30	66	+8
34	F	120	7	28	93	-27	50	A	70	5	39	78	+8
35							51	C					
36							52	A					
37							53	A	25	5	16	32	+7
38	B						54	A	75	6	33	82.5	+7
39	E	32	5	23	45		55	B					
40	C	37	6	31	78		56	A					
41	B	27	1	45	50		57	D	80+	5	37	74	-6
42	F	100	5	46	92	- 8	58	F	120+				
43	A												
44	A												
45	B												
46	B												
47	C	72	5	27	54								
48	C												

Mean = 1.76

Standard Dev. = 27.21

APPENDIX 5

Basic Data for Samples in Initial Study

PIPE #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
AGE	19	19	19	19	19	19	19	30	31/51	16	16	23	23	6
P R	7	8	7	3	7/4	7/4	9	7	4/6	7	7/5	3	6	7
S S	1.3	1.1	1.0	1.2	1.0	1.1	.9	.8	1.0	1.2	1.0	1.2	2.0	1.0
pH	8.4	8.1	8.3	8.3	8.1	8.5	8.1	8.0	7.8	7.9	8.2	7.9	7.8	7.9
RES	1200	1200	1600	900	600	1300	700	1200	900	800	1550	325	700	1800
YR. PLCD.	1955	1955	1955	1955	1955	1955	1955	1944	1944	1958	1958	1951	1951	1968
WT. BF.				117.7	125.9	132.5	NA						118.9	165.3
WT. AF.				110.7	121.5	128.0	NA						113.0	160.6
THK. BF.				86.26	80.08	87.98	NA						90.16	109.42
THK. AF.				75.66	77.78	82.46	NA						80.90	107.56
% M L				5.9	3.5	3.4	NA						5.0	2.8

PIPE #	15	16	17	18	19	20	21	22	23	24	25	26	27	28
AGE	22	22	26	26	21	19	8	14	18	17	16	18	18	19
P R	8	7	7	8	8	7	8/7	7	3	9	4/4	7/5	6/5	7
S S	1.6	.9	1.0	1.2	.9	.9	1.0	.8	1.2	.5	2.1	2.0	1.2	1.0
pH	8.4	8.1	7.5	8.3	8.2	7.8	7.5	7.7	8.3	8.4	7.3	7.5	8.0	8.0
RES	800	1100	1000	1900	1700	1800	1200	1450	2000	3000	1200	900	1700	1700
YR. PLCD.	1952	1952	1948	1948	1953	1955	1966	1960	1956	1958	1958	1956	1956	1955
WT. BF.	254.9		218.2		119.1		186.6	125.8	113.6	NA	202.0	127.1	172.4	NA
WT. AF.	251.3		215.8		114.4		180.8	120.2	109.2	NA	196.7	122.3	167.3	NA
THK. BF.	169.46		145.22		77.62		113.14	86.38	79.72	NA	130.86	83.86	110.48	NA
THK. AF.	167.60		142.18		74.82		104.16	79.52	74.80	NA	128.60	81.20	105.98	NA
% M L	1.4		1.1		3.9		3.3	4.5	3.9	NA	2.6	3.8	3.0	NA

PIPE #	29	30	31	32	33	34	35 24A	38	39	40	41	42	43	44	45
AGE	19	17	17	16	16	16	16	15	11	19	33	34	13	4	16
P R	6	2/3	4/7	9	9	7	6	7/5	8/8	8/7	2/1	5	9	9	7/2
S S	1.1	1.5	.8	.9	.8	.7	.9	1.4	16.2	5.8	4.5	3.1	.9	.8	5.2
pH	8.0	9.6	8.4	8.2	7.6	7.6	8.1	8.0	7.8	8.1	8.5	8.2	8.2	8.2	7.5
RES	1400	300	1200	1000	1700	1600	2200	800	1400	800	150	800	2200	2800	325
YR. PLCD.	1955	1957	1957	1958	1958	1958	1957	1959	1963	1955	1941	1940	1961	1960	1958
WT. BF.	125.5	104.6	134.2	128.6	NA		206.3	168.4	232.0	127.8	181.0		127.3	NA	125.5
WT. AF.	121.2	101.1	129.9	124.8	NA		202.5	163.5	226.2	123.7	175.2		121.1	NA	119.1
THK. BF.	82.80	78.08	90.18	84.42	NA		140.82	108.12	149.60	83.06	119.68		83.02	NA	83.74
THK. AF.	78.60	76.58	86.28	80.68	NA		138.56	105.88	142.06	81.16	114.94		77.18	NA	76.40
% M L	3.4	3.3	3.2	3.0	NA		1.8	2.9	2.5	3.2	3.2		4.9	NA	5.1

PIPE #	46	47	48	49	50	51	52	53	54	55	56	57	58
AGE	16	15	13/23/25	18	27	11	20	4	21	16	19	25	36
P R	3/2	7	6	8	7	9/8	9	6	8	8/4	8	7	7
S S	5.2	1.6	7.2	1.0	.9	26.3	.4	2.4	.9	1.0	.9	1.0	1.1
pH	7.6	7.5	7.6	7.9	8.0	7.5	7.9	7.8	8.1	8.0	8.2	7.8	8.1
RES	1100	800	800	1400	1500	800	1200	500	1500	1600	1900	1100	950
YR. PLCD.	1958	1959	1951	1956	1947	1963	1954	1970	1953	1958	1955	1949	1938
WT. BF.	100.0	170.5	143.6	133.0	129.6	224.8	122.0	93.4	122.5	175.8	125.0	226.2	
WT. AF.	93.7	165.5	139.2	107.5	125.3	220.5	117.5	89.9	117.1	170.6	120.0	221.0	
THK. BF.	75.54	110.44	113.46	74.76	84.00	104.94	80.90	63.56	81.68	114.08	81.96	148.72	
THK. AF.	66.12	109.58	86.14	70.76	80.82	102.24	76.46	56.16	76.16	110.32	78.20	145.08	
% M L	6.3	2.9	3.1	19.2	3.3	1.9	3.7	3.7	4.4	3.0	4.0	2.3	

APPENDIX 6

Supplemental Specification Describing
the revised (current) UDOT Pipe Classification
(These are not the designations used in the study)

SUPPLEMENTAL SPECIFICATION

SECTION 900 - PIPES - DRAINAGE, STORM SEWER, AND IRRIGATION

GENERAL INTRODUCTION

Categories in Pipe Classes: The "Pipe Class" categories itemized within this section are designated in general according to the type and thickness of coating provided on the pipe wall (both inside and outside) and, in some instances, according to the material or groups of material contained in the pipe wall itself. This variation in coatings and materials is a reflection of the attempt to counter reactive and corrosive properties inherant in the various soils which surround the in-place pipe.

Class A Pipes require no special materials, treatment, or coatings and thus, they are used only in soils which are mostly nonreactive. They include uncoated galvanized steel pipes, plain corrugated aluminum pipes, corrugated polyethylene pipes, and concrete pipes (Type II cement).

Class B Pipes consist of corrugated steel pipes which require special coatings or special wall material and concrete pipes, as they are placed in soils which are both reactive and corrosive. They include bituminous coated steel pipes, pitch resin (polymeric) coated steel pipes, plain aluminum pipes, and concrete pipes (Type II cement).

Class C Pipes consist of corrugated steel pipes which require combinations of material coatings, regular uncoated aluminum pipes, corrugated polyethylene pipes, and concrete pipes requiring special alkali resistant concrete (Type V cement). They are used in soils which are highly reactive and corrosive.

Class D Pipes consist of untreated structural plate pipes which include both steel and plain aluminum alloy. They are used in nonreactive and noncorrosive soils.

Class E Pipes include both asphalt coated structural steel plate pipe and plain aluminum alloy structural plate pipes. They are used in soils which are both reactive and corrosive.

Restrictions on Uses of Various Types of Pipes:

1. Corrugated aluminum pipe culvert, pipe arch culvert, plain aluminum alloy structural plate pipe culvert and pipe arch culvert shall not be used where concrete paved invert is required.

2. Corrugated polyethylene pipes shall be used only in sizes 12" through 24" diameter.

3. Precast nonreinforced concrete pipes shall be used only in sizes 18" through 36" diameter.

APPENDIX 7

Condensed Economic Appraisal
(24" Pipe Comparison)

ECONOMIC APPRAISAL

Steel Class A	Concrete Class F
$23.32/ft.	$32.55/ft.

Interstate

Length = 250'

Steel Cost = 250' x 23.32 = $5,830.00

Concrete Cost = 250' x 32.55 = $8,137.00

Primary

Length = 120'

Steel Cost = 120' x 23.32 = $2,798.00

Concrete Cost = 120' x 32.55 = $3,906.00

Expected Life: Concrete - 45 years Steel - 30 years

(from Anticipated Life Charts)

Therefore, using a 90 year life horizon --

Interstate

Pc = $8,137.50 + $8,137.50 = $16,275

Ps = $5,830 + 5,830 + 5,830 = $17,490

Primary

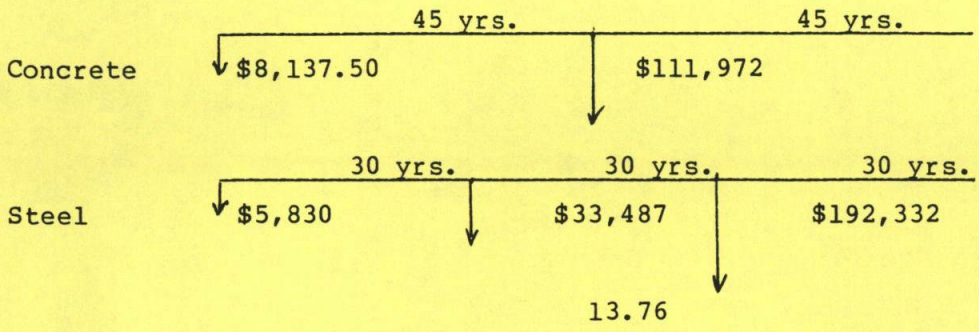
Pc = 2 x ($3,906) = $7,812

Ps = 3 x ($2,798) = $8,395

It should be noted that prices shown show simple installation of pipe. More frequent replacement costs would include demolition of old culvert, traffic disruption, and in-house costs.

INFLATION = 6% (Assume)

Interstate

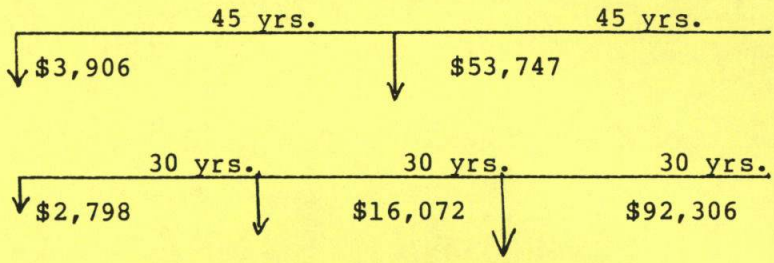


Pc = $8,137.50 + 8,137.50 (F/p 6% 45) = $120,109

5.744 32.99

Ps = $5,830 + 5,830 (F/p 6% 30) + 5,830 (F/p 6% 60) = $231,650

Primary



Pc = 3,906 + 3,906 (13.76) = $57,652

Ps = 2,798 + 2,798 (5.744) + 2,798)32.99) = $111,175

In this method, future costs are summed with present costs. This shows the actual dollars that will be spent but the results exaggerate the difference in replacement.

Method from Engineering Economy by Leland Blank and Anthony Tarquin