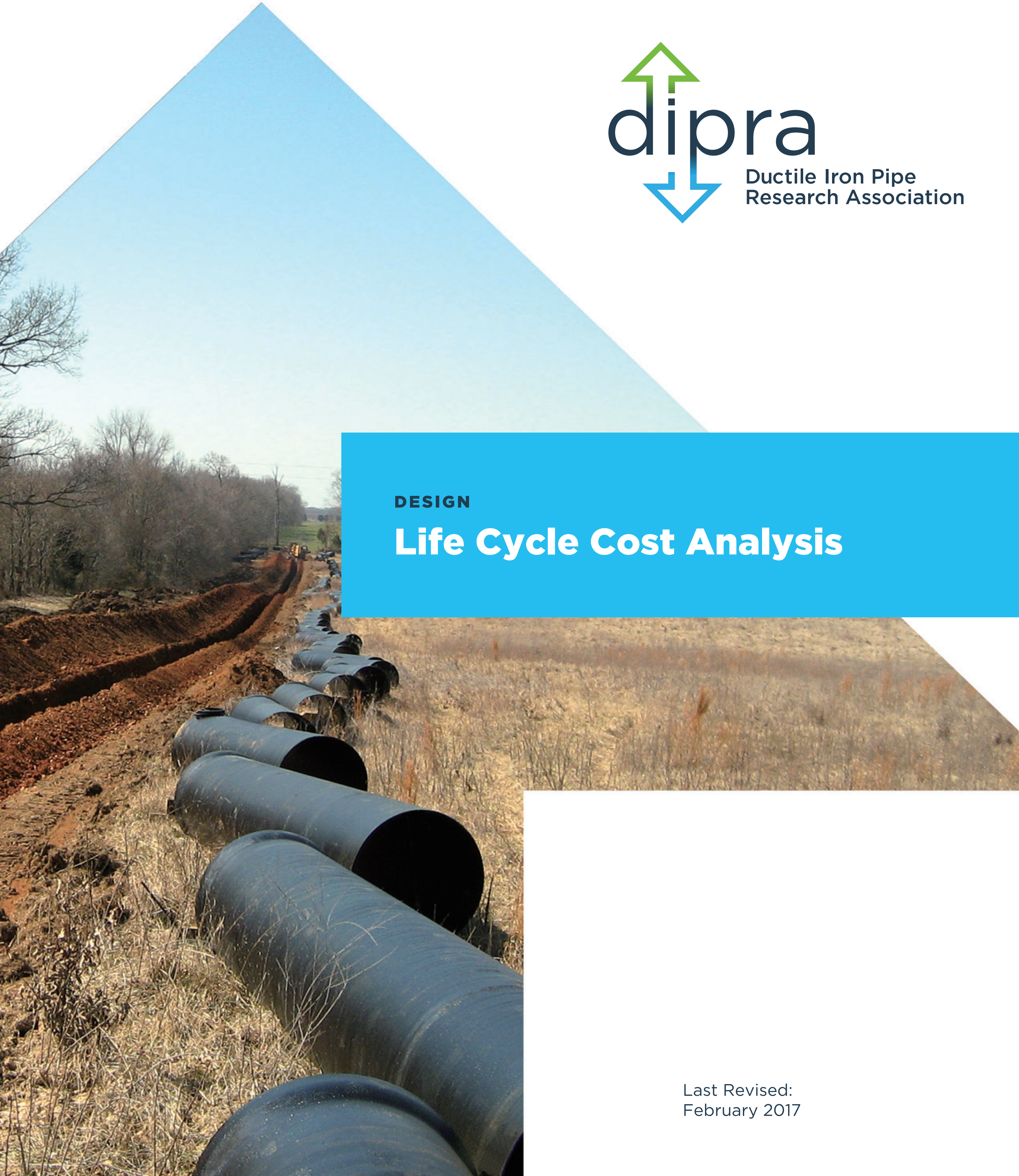
Strength and **Durability** for **LiFe®**

Ductile Iron Pipe Research Association



DESIGN

Life Cycle Cost Analysis

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Every year there are thousands of miles of waterlines installed in the United States through new projects and replacement of existing waterlines. Decisions on which pipe materials to use are based on relative performance and cost, with initial cost being given a preference over relative strength and durability. But this may not be representative of the true value of the alternatives. To accurately compare the value of different pipe materials we must analyze their costs over the entire design life of the pipeline.

In order to accurately compare the true costs associated with different pipe materials over a desired design life, The University of Michigan developed a Life Cycle Cost Analysis model that considers the costs associated with the production, installation, operation and maintenance, and service lives of two of the most commonly used pipe materials, Ductile Iron Pipe and PVC pipe. As part of their work, the University of Michigan (UM) evaluated published literature to conclude that PVC should be evaluated with a design life of 50 years, whereas Ductile Iron Pipe could be expected to serve 100 years or more. This led UM researchers to observe that "there is an emerging need for a comprehensive life cycle analysis of major pipe materials under varying conditions of operation and actual service life scenarios".

Methodology

The Life Cycle Cost Analysis determines the total cost of a pipeline by considering all of the phases a pipeline experiences over a 100 year design life. These include production, installation, operation and maintenance, and end of life, recognizing that a pipe material's service life may not meet the project's desired design life. Costs to the environment during each phase of the pipeline's life cycle are considered, as well.

One of the first steps that The University of Michigan undertook was to determine the service life of each pipe material. To accomplish this, they conducted an extensive literature review on the reported service lives of Ductile Iron Pipe and PVC pipe. Their review found a consensus for service life, 100 years for Ductile Iron Pipe and 50 years for PVC pipe.

Production Phase

The production phase involves the costs for raw material extraction, pipe production and pipe transportation, which is represented in the unit cost of the pipe. The University of Michigan used compiled averages of pipe materials costs obtained from pipe suppliers. Environmental impacts associated with the energy used to manufacture pipe materials were obtained from published literature on embodied energy.[1]

Installation Phase

The installation phase involves the operational costs of the necessary equipment as well as the cost of any bedding material required for installation of each pipe material. To determine the proper installation procedure of the pipe materials, The University of Michigan used the relevant AWWA standards, as well as industry and manufacturer reference materials. The costs associated with the installation of pipe materials were obtained from the RSMeans estimating database as shown below. It was assumed that the cost of transportation of the pipe materials to the project site was between 5 to 7 percent of the total pipe material cost.

Item	Unit	Rate
Mobilization of Equipment	Ea.	$641.89
Excavation	BCY	$2.11
Bedding Placement	LCY	$32.27
Bedding Compaction	S.Y	$0.62
Structural Backfill	ECY	$0.78
Final Compaction	ECY	$0.27
Demobilization of Equipment	Ea.	$641.89

Operation and Maintenance Phase

The operation and maintenance phase involves the costs associated with pumping as well as performing repairs and regular maintenance activities over the 100 year design life. To calculate relative pumping costs, the Hazen-Williams equation was used based on industry recommendations for C factor and the actual inside diameters of the pipe materials. This calculation gave results for head loss (H_L) for each material. The resulting head losses were then used to calculate the costs to pump a given flow of water through the alternative pipelines. The relevant calculations are listed below.

$$H_L = 1000\left[\frac{V}{0.115\,C\,(d)^{0.63}}\right]^{1.852}$$

Where:
H_L = Head loss (ft./1,000 ft.)
V = Velocity of flow (fps)

$$V = \frac{Q}{2.448\,d^2}$$

C = Flow coefficient (C factor)
d = Actual inside diameter (in.)
Where:
Q = Flow (gpm)
V = Velocity (fps)
d = Actual inside diameter (in.)

$$PC = 1.65\,H_L Q \frac{a}{E}$$

Where:
PC = Pumping cost ($/yr. based on 24-hr. per day pump operation/1,000 ft.)
H_L = Head loss (ft./1,000 ft.)
Q = Flow (gpm)
a = Unit cost of electricity ($/kWh)
E = Total efficiency of pump system (%/100)

As shown on the previous page the actual inside diameter of the pipe is the determining factor in calculating the head loss and pumping cost. Ductile Iron Pipe has a larger than nominal inside diameter, which results in a lower head loss and lower pumping cost than other pipe materials. The table below shows the larger inside diameter of Ductile Iron Pipe compared to other common pipe materials.

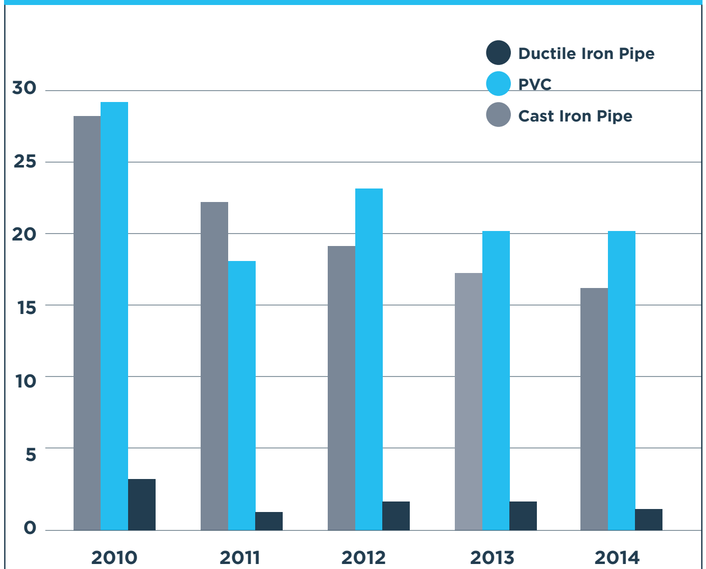
TABLE 1
Comparison of Actual Inside Diameters (in.) of Piping Materials for Water Transmission and Distribution Systems

Nominal Size (inches)	Ductile Iron Pipe[1]	CCP[2]	STEEL[3]	PVC[4]	HDPE[5]
6	6.28	–	6.00	6.09	5.57
8	8.43	–	8.00	7.98	7.31
10	10.46	–	10.00	9.79	8.96
12	12.52	–	12.00	11.65	10.66
14	14.55	–	14.00	13.50	12.35
16	16.61	16.00	16.00	15.35	14.05
18	18.69	18.00	18.00	17.20	15.74
20	20.75	20.00	20.00	19.06	17.44
24	24.95	24.00	24.00	22.76	20.83
30	31.07	30.00	30.00	28.77	25.83
36	37.29	36.00	36.00	34.43	32.29
42	43.43	42.00	42.00	40.73	38.41
48	49.63	48.00	48.00	46.49	44.47
54	56.29	54.00	54.00	–	51.34
60	60.28	60.00	60.00	–	–
64	64.30	–	–	–	–

(1) From AWWA C150, Table 5, using the nominal wall thickness of the lowest available pressure class with Standard C104 cement-mortar lining.
(2) From AWWA C301 - IDs are based on nominal sizes for pre-stressed concrete cylinder pipe.
(3) From manufacturers' information - IDs are based on nominal sizes for routine manufacture of steel pipe.
(4) Cast Iron equivalent outside diameters. Sizes 6"-12" from AWWA C900, and sizes 14"-48" from AWWA C905, using average ODs and minimum wall thickness plus 1/2 wall tolerance. DR 18 for sizes 6"-24", DR 21 for sizes 30"-36", and DR 25 for sizes 42"- 48".
(5) From AWWA C906 using average Ductile Iron Pipe equivalent outside diameters and average wall thickness. DR 11 for sizes 6"-30", DR 13.5 for 36", DR 15.5 for 42", DR 17 for 48", and DR 21 for 54".

To determine the costs and frequency of repair activities, The University of Michigan obtained standard failure rates from industry sources and literature. The graph below shows the average frequency repairs for different pipe materials between 2010 and 2014.

Frequency in Repairs



• Frequency and average cost information collected from utility sources
• The cost of individual repair and maintenance is obtained from literature (RSMeans 2015, Haas 2012)

End of Life Phase

Once a pipe reaches the end of its service life, it can either be exhumed for future uses, such as recycling or disposal, or it can be abandoned in place. The University of Michigan found that the recovery costs, both monetary and environmental, result in pipes typically being abandoned in place at the end of their service lives. Although an iron pipeline, at the end of its service life, can be recycled to make new pipe, the salvage value is outweighed by the costs associated with recovery. As a result, the salvage value is assumed to be zero for all pipe materials.

Example

The University of Michigan did a case study analysis of 8-inch and 24-inch Ductile Iron Pipe and PVC pipe using their assessment tool. This case study reports the total life cycle cost of ownership for each size and pipe material. The table below outlines the key assumptions that were used in the assessment tool to conduct the analysis.

Main Parameters

Description	Units	Inputs
Location of the job site	N/A	Michigan
Total length of pipe	Feet	1,000
Nominal diameter of the pipe	Inches	8 and 24
Project life span	Years	100
Service life (Ductile Iron Pipe/PVC)	Years	100/50

Financial Inputs

Description	Inputs	
Initial pipe costs 8” diameter	Ductile Iron Pipe	$12.91
	PVC	$6.33
Initial pipe costs 24” diameter	Ductile Iron Pipe	$51.40
	PVC	$61.90
Discount rate	2.0%	
Inflation rate	1.9%	
Cost of electricity	$0.06/kWh	

Design Inputs

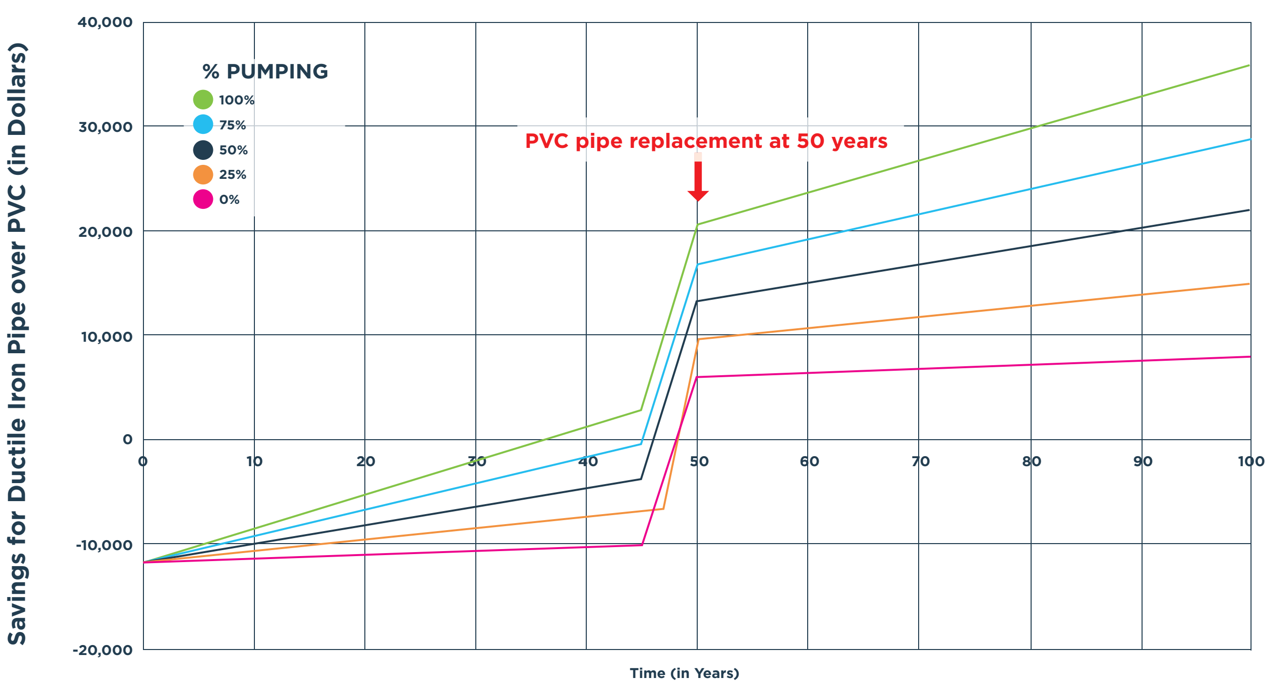
Description	Inputs	
Ductile Iron Pipe	Pressure Class 350 (8”) - pressure rated at 450 psi	
	Pressure Class 200 (24”) - pressure rated at 300 psi	
PVC	DR 18 (8” and 24”) - pressure rated at 235 psi	
Hazen-Williams Factor (C)	Ductile Iron Pipe	140
	PVC	150
Actual internal diameter – 8” pipe	Ductile Iron Pipe	8.43”
	PVC	8.04”
Actual internal diameter – 24” pipe	Ductile Iron Pipe	24.95”
	PVC	22.93”
Efficiency of pump system (E)	70%	
Q (Flow rate)	1000 gpm (8”)	
	6000 gpm (24”)	
% of pumping	Varies	

Results

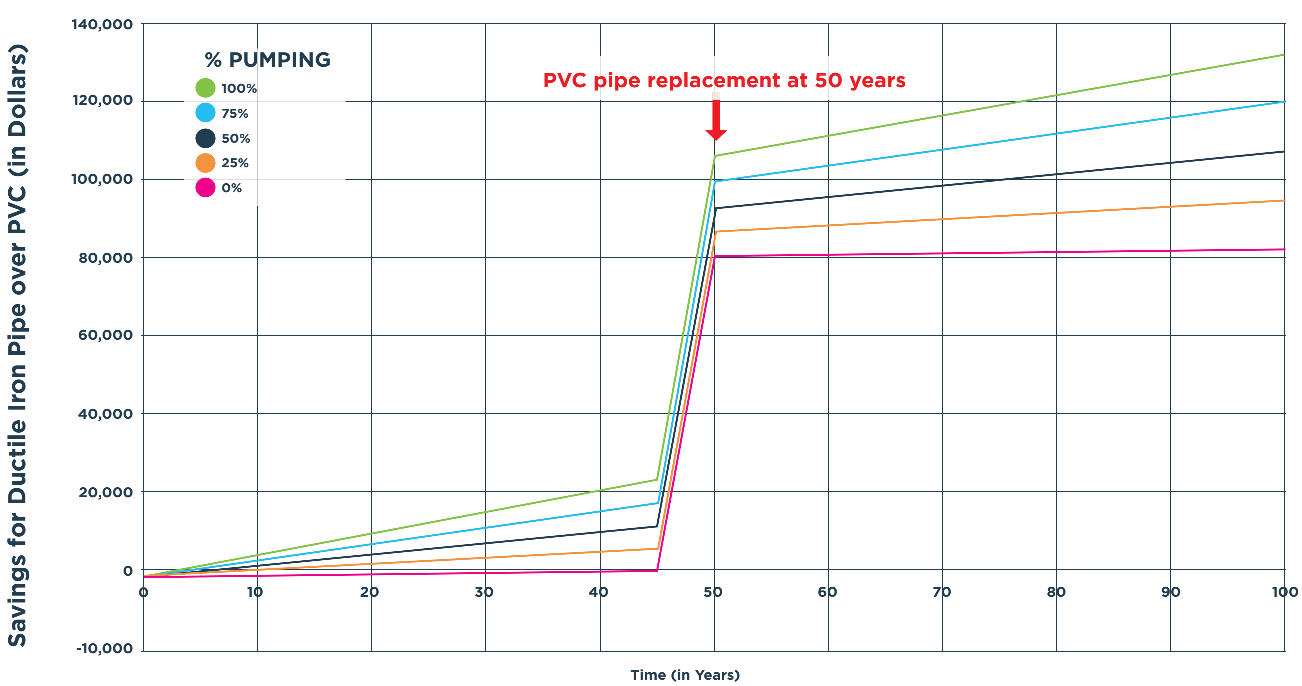
The two graphs below, one for each pipe size, show the savings of Ductile Iron Pipe over PVC throughout the 100 year life cycle. Based on the design parameters entered, the savings shown in the graphs are for a 1,000-foot section of pipe. The results in the graphs are shown on a pumping rate percentage basis ranging from 0% to 100%. A 0% pumping rate represents no pumping in the system while a 100% pumping rate represents pumping 24 hours per day.

Due to the service life of PVC pipe being only 50 years, while a design life cycle of 100 years is analyzed, the PVC pipe must be manufactured and installed twice. In the savings graphs below this is shown by the large increase in savings at the 50 year mark.

Ductile Iron Pipe over PVC (8" Diameter)



Ductile Iron Pipe over PVC (24" Diameter)



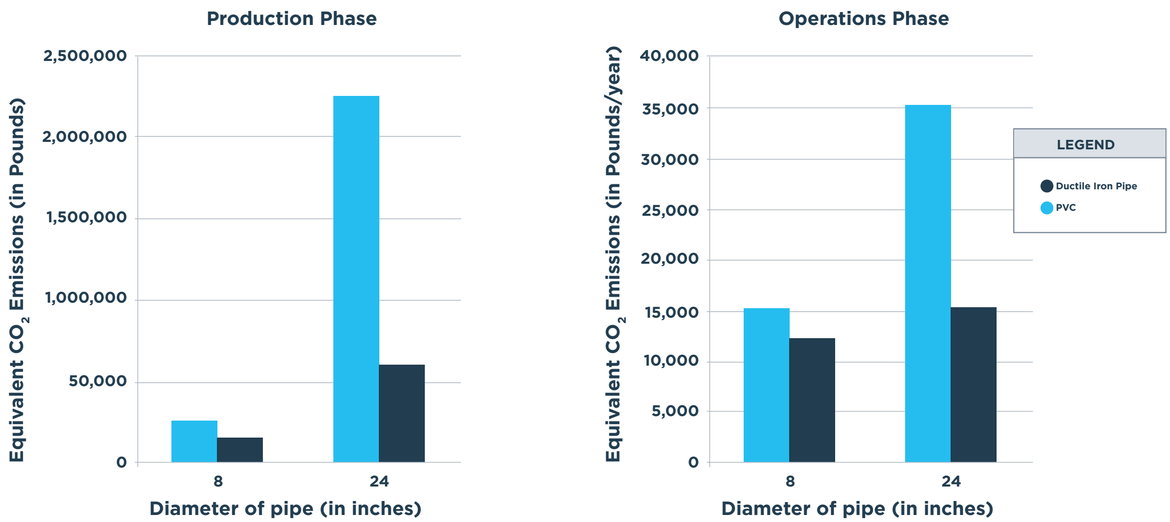
Analysis

The results for the 8-inch pipe show that the life cycle savings for 1,000 feet of Ductile Iron Pipe over PVC ranged from approximately $8,000 at 0% pumping to $36,000 at 100% pumping. Likewise, with the 24-inch pipe the life cycle savings of Ductile Iron Pipe over PVC ranged from approximately $82,000 at 0% pumping to $131,000 at 100% pumping. While these results are for a 1,000-foot pipeline length, new or replacement projects are much longer which would result in much larger savings of Ductile Iron Pipe over PVC.

The University of Michigan determined that the operation and maintenance life cycle phase contributes significantly to the overall life cycle cost of a pipeline. More specifically, pumping costs are a dominating factor over a 100 year life cycle. Ductile Iron Pipe has a significant advantage during pumping due to its typically larger than nominal inside diameter, which reduces head loss and required energy.

Environmental Impact

In evaluating the impact of alternatives on the environment, production values for the energy required to manufacture the two pipe materials was provided from existing literature[1]. Additionally, the costs associated with pumping could be converted to energy consumption as kilowatt-hours. From this, the impact on the environment was evaluated as a function of the emission of CO_2 equivalents. The results showed a greater environmental impact for PVC in both the production and operation phases; the former due to PVC's shorter service life and the latter due to the larger inside diameters for Ductile Iron Pipe.



Total equivalent CO_2 emissions assuming 25% pumping during the operations phase

Conclusion

The University of Michigan developed a Life Cycle Cost Analysis model that allows decision makers to compare the true relative costs of alternative pipe materials. As shown by the example case studies, Ductile Iron Pipe is the most cost effective pipe material over a 100 year design life despite the differences that may exist regarding pipe material costs. Ductile Iron Pipe has significant advantages in service life and in pumping during the operation and maintenance phase due to its larger inside diameter. The result is a lower total cost for Ductile Iron Pipe over its long service life.

The Pipe Material Life Cycle Cost Assessment model created by The University of Michigan is an important and extremely useful tool for utility decision-makers. It allows those professionals to make informed decisions regarding the best pipe material to use by analyzing the total life cycle costs of different pipe materials.

References

1. Ambrose, M., Burn, S., DeSilva, D., and Rahilly, M. "Life cycle analysis of Water Networks." Proc., Plastics Pipe XIV: Plastics Pipes Conferences Association.

For more information contact DIPRA or any of its member companies.

Ductile Iron Pipe Research Association

An association of quality producers dedicated to the highest pipe standards through a program of continuing research and service to water and wastewater professionals.

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