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Economics of Corrosion Protection

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Cost of Corrosion

- NACE IMPACT Study 2016
 - Estimated global cost of corrosion using available studies
 - \$2.5 trillion per year
 - 3.4% of global GDP
 - 15%-35% cost savings possible using available corrosion control practices
- Recommend adoption of corrosion management system



<http://impact.nace.org/economic-impact.aspx>



Coatings Maintenance and Cost

- Maintenance options:
 - Spot repairs
 - Full recoat or reline (lifecycle end)
 - Add cathodic protection as a secondary protection mechanism
 - Effort (and cost) increase for each maintenance step after initial coating
- Cost is increasing
 - Structures inaccessible
 - Need to stay in service
 - Regulations



Cost of Not Maintaining Coatings

- Corrosion and metal loss
 - May lead to weld repairs or section replacements
 - May require significant design work
 - Time intensive in field
 - Quickly exceeds many \$100k's
- Structures are critical resources
- Replacement may be "cost prohibitive"



Research Efforts

- Goal is to keep costs low by improving timing of coatings maintenance
 - Maximize coating lifecycle (service life)
 - Maintain before metal loss
- Studies to discuss:
 - Cathodic protection payback period
 - Econometric analysis to better understand corrosion cost trends and predict future costs



Cathodic Protection (CP) Break-Even Analysis

- CP extends coating service life; may delay recoating until ~20% deterioration^{2, 3}
- Research: break-even analysis to estimate payback period
Inputs: install costs, maintenance, etc.
Output: *when* added life pays for CP
- Results: CP system cost-effective after 15–30% extended life
 - Impressed current (ICCP) has economies of scale, i.e., payback period decreases as surface area increases
 - Galvanic anode (GACP) economical for smaller surface areas



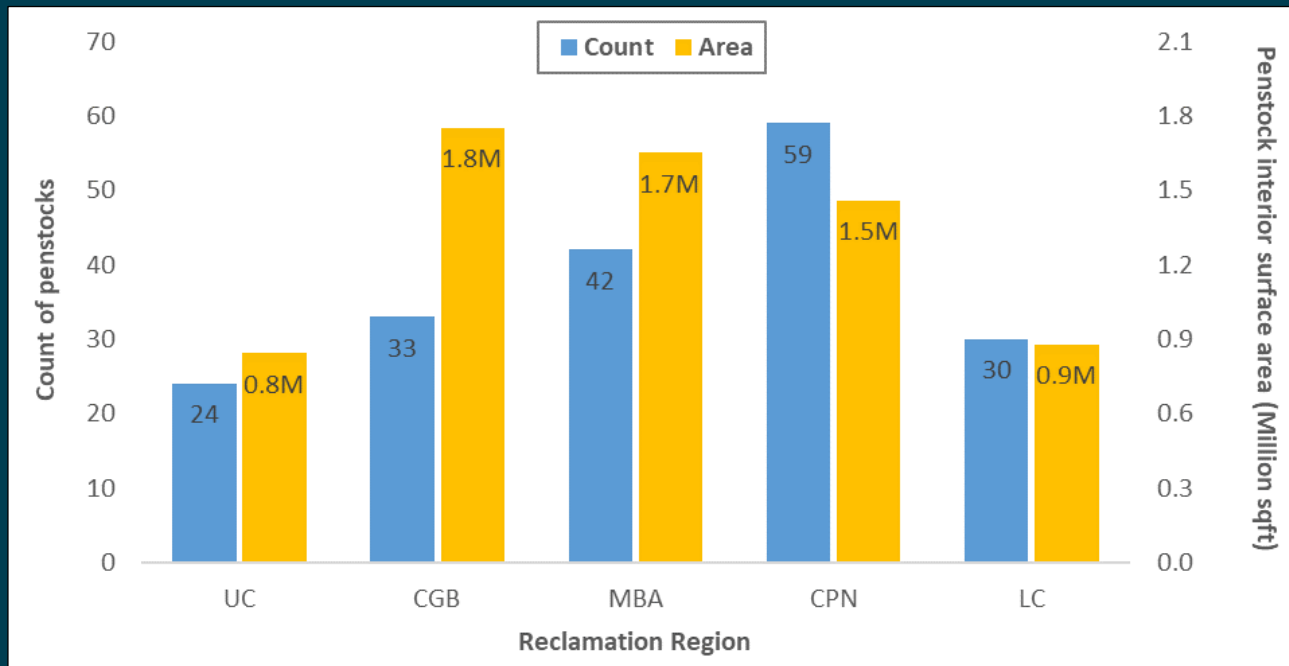
²D. Kroon and J. Rog, Opflow 37, 11 (2011): p. 16

⁶³W. von Baekmann, et. al., Handbook of Cathodic Corrosion Protection, 1997



Econometric Analysis

- Reclamation has 188 steel penstocks with 6.6 million sqft interior surface area
- Total replacement is nearly \$0.5 Billion at \$50 per sqft (typical)
- As of 2021, about 120 penstock had yet to be relined and had avg lining age of about 63 years (near replacement age)



Variable	Average	Min	Max
Total cost (\$1,000's)	1,245	44	8,765
Average cost (\$ per sqft)	85	19	382
Quantity (sqft)	26,019	114	471,804
Existing Lining Type*			
Coal Tar Enamel	0.88	0	1
Cement Mortar	0.04	0	1
Polyurethane	0.03	0	1
Vinyl	0.04	0	1
Epoxy	0.04	0	1
New Lining Type*			
Polyurethane	0.08	0	1
Vinyl	0.03	0	1
Epoxy	0.90	0	1
Pipe Diameter (ft)	14.8	4	39.3
Pipe Slope (degrees)	17.9	0	41.9
Pipe Length (ft)	1,207	85	12,515
Robotic	0.51	0	1
Time (year)	2017	1999	2020
Reclamation Region			
Upper Colorado Basin	0.04	0	1
Lower Colorado Basin	0.19	0	1
Columbia-Pacific Northwest	0.62	0	1
California Great Basin	0.03	0	1
Missouri Basin/Arkansas-	0.12	0	1
Rio Grande-Texas Gulf			
Reclamation	0.88	0	1

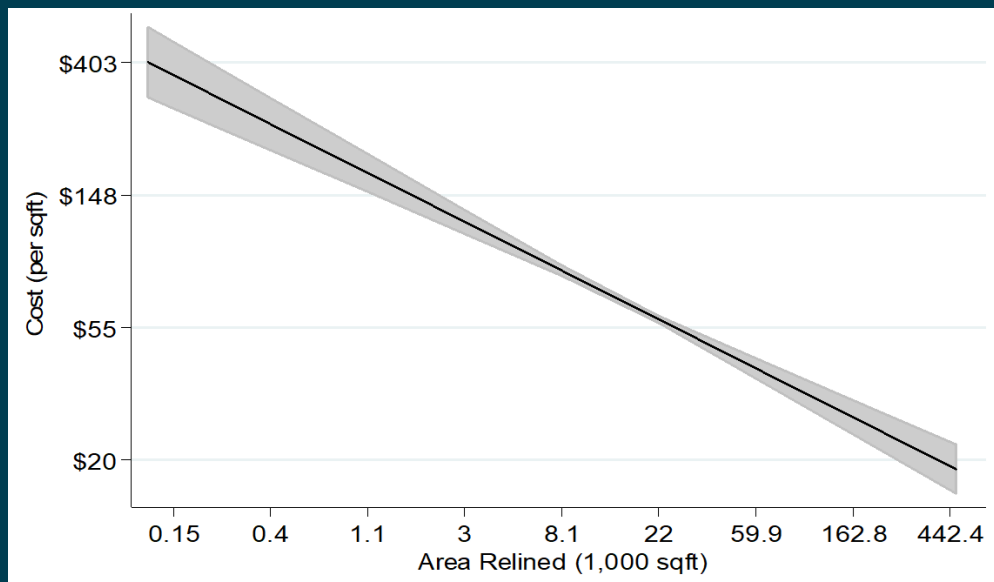
Data Statistics

- Evaluated 73 relining jobs with pipe diameters larger than 42" (3.5 ft)
- All costs indexed to 2020\$
- Contract award costs only; does not include:
 - Modifications
 - Non-contract costs



Final Model

- Modeled for cost per sqft (shown) and total relining cost
- Cost per sqft decreases as area relined increases (economies of scale)



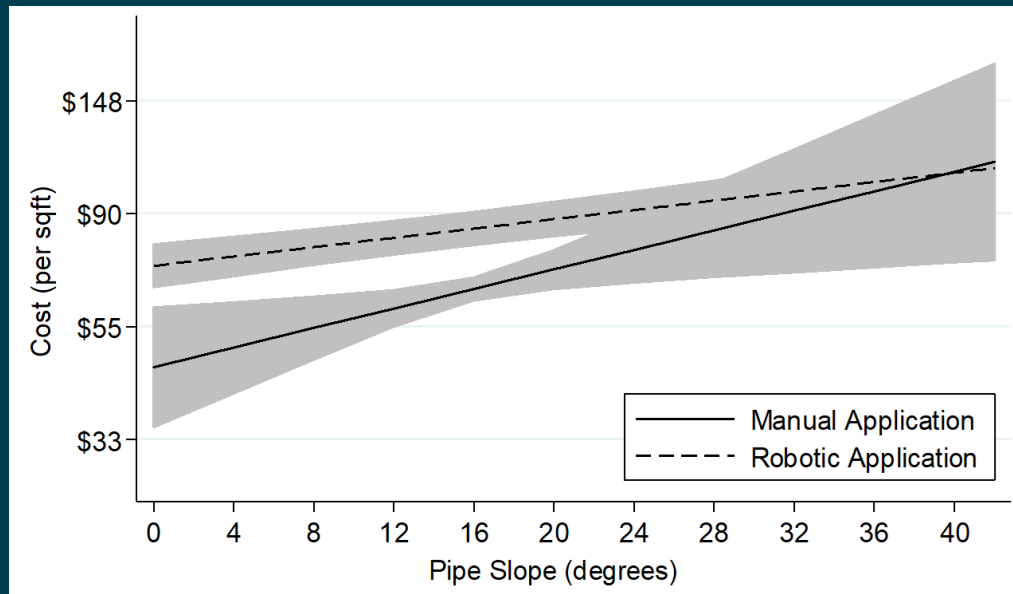
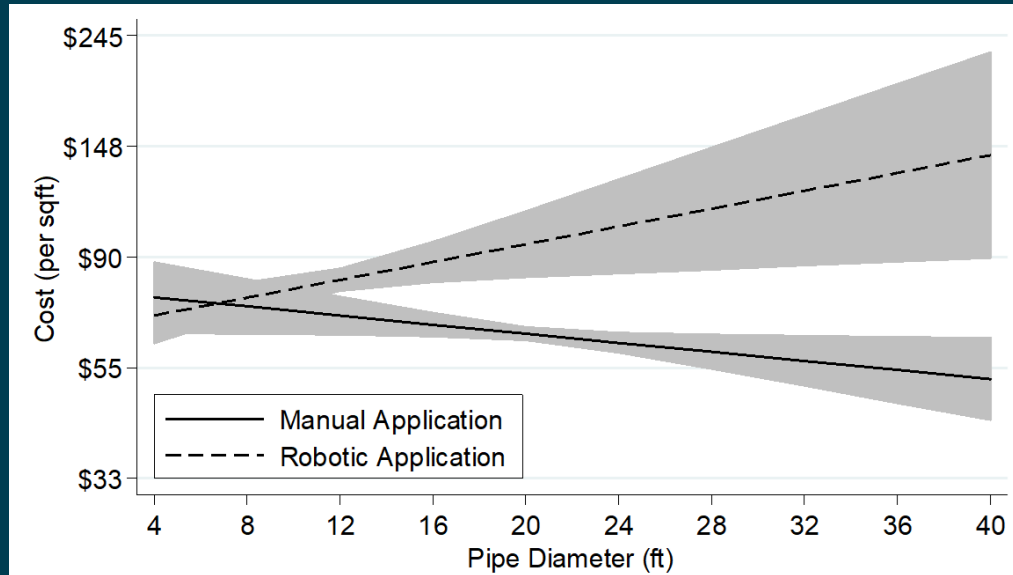
Independent Variable	Final Model
ln(Area Reline)	-0.369*** (0.025)
Reclamation Ownership	0.553*** (0.083)
AW Diameter	-0.010** (0.004)
AW Slope	0.022*** (0.008)
Robotic Application * AW Diameter	0.030*** (0.008)
Robotic Application * AW Slope	-0.011* (0.006)
Region	
California Great Basin	-0.420*** (0.125)
Columbia Pacific-Northwest	-0.915*** (0.088)
Missouri Basin/Arkansas-Rio Grande-Texas Gulf	-0.624*** (0.081)
Upper Colorado	-0.571*** (0.076)
R-squared	0.9199

Lower Colorado shown:
Region coefficient below.
Standard errors shown in
parenthesis.
Statistical Significance: ***1%
Level, **5% Level, *10% Level.
Area Weighted (AW).



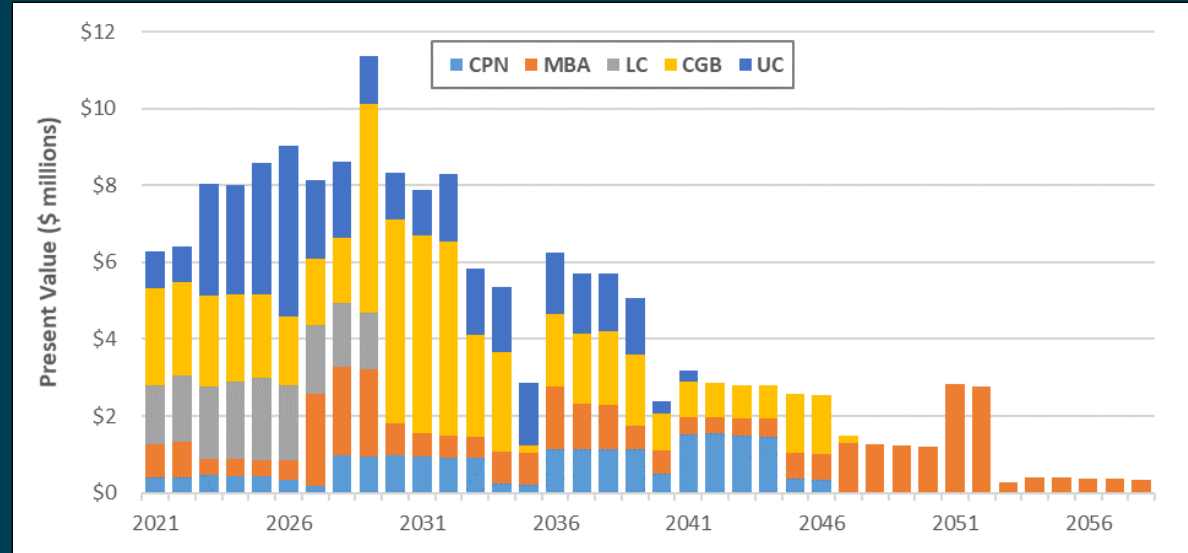
Final Model

- Graphs show robotics cost effect for diameter and slope
- Illustrates interaction variable, e.g., "Robotic Application * AW Slope"
- Future costs may reduce as savings are passed on to Govt.
- Non-contract savings not accounted for (e.g., reduced outage, safety)



Future Spending Prediction

- Applies model to the 121 assumed to need relining soon
- Assumes one relining per year per region



Region	Number of Penstocks	Final Program Year	Avg. area relined per year (sqft)	Present value (\$ millions)	Annualized cost (\$ millions)
California Great Basin	27	2047	64,908	\$58.64	\$3.01
Columbia Pacific-Northwest	26	2046	28,696	\$20.61	\$1.09
Upper Colorado	21	2041	39,101	\$36.67	\$2.27
Lower Colorado	9	2029	15,850	\$16.16	\$2.03
Missouri Basin/ Arkansas-Rio Grande-Texas Gulf	38	2058	36,359	\$35.78	\$1.47
Reclamation, All	121			\$167.86	\$6.89



Cost Forecasting Tool



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Preliminary-Level Predicted Cost for Relining Large Diameter Pipes

Please Enter the Following Information:

Area Being Relined (sqft)

Average Diameter (ft)

Average Slope (degrees)

Reclamation Contract? Yes ☒

Robotics used by contractor? ☒ Yes

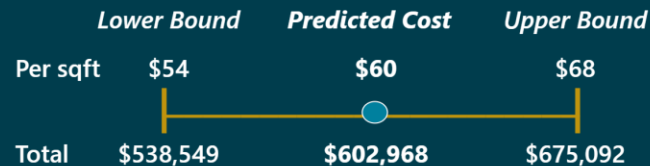
Geographic Region

Predicted cost is derived from regression analysis of award data from past pipe relining contracts. Click "More Information" for analysis details.

The information provided by this tool is intended to be used for planning purposes only and does not capture all the site specific conditions that may have a significant impact on the total costs for a particular project. It is strongly recommended that the user obtains a feasibility-level estimate for a particular project to determine and establish project funding requirements and to request project authorization or construction fund appropriations from Congress.

Predicted Cost and 95% Confidence Interval

(2020 Price Level)



DISCLAIMER: This tool is provided as is, without any representation or warranty of any kind, either express or implied, including without limitation any representations or endorsements regarding the use of or the results of this tool, its appropriateness, accuracy, reliability, or correctness. Any reliance the user places on the information obtained from this tool is strictly at the user's own risk.

Screenshot of app tool user interface (above), weblink: <https://apps.gov.powerapps.us/play/b693bfe3-6ec7-47ed-b5d7-eff742f97b53?tenantId=0693b5ba-4b18-4d7b-9341-f32f400a5494>

Excel tool available to non-DOI users: <https://data.usbr.gov/catalog/4614/item/11466>



Questions? Comments?



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