Wastewater Management
Repairing Collection Systems for Free

Abstract
Wastewater collection systems are traditionally sound assets for many utilities. Once engineered and tested, gravity collection systems rarely need attention and often become a forgotten asset. With utilities looking to trim operational costs and improvements in technology, gravity and transmission systems are becoming the focal point for low budget repairs yielding high impact on financial stability. Over time, the shifting of soils, encroachment of roots, and cracking of gravity pipes can create cavernous openings for groundwater and rainwater to pour into the wastewater treatment plants.

While aging pipes are the typical culprits, it is important to do a collection system and pump station analysis to confirm the most problematic zones of the utility service area. The biggest offenders become the target areas to achieve the most financial gains. This paper will discuss effective steps in identifying and targeting problematic areas. From pumping data to flow and smoke testing, each tactic will be highlighted to provide examples for utilities to follow.

Once identified, correcting the problems is imperative to returning the system integrity and capacity to original conditions. Lining existing piping provides opportunity to restore pipe integrity while utilizing the existing structure. Various products and applications are marketed within the industry however, the appropriate applications of each product must be carefully selected. The paper will present the top systems used in the wastewater market with detail on their application steps, highlights for common applications with detailed engineering assessment of one efficient, and effective applications for each.

Briefly, the cost analyses will be shown for each system to provide a starting point for utilities considering gravity sewer and transmission main lining and hardening of collection systems. Further, the paper will note the multiple areas where I&I results in cost savings to be realized across the wastewater collection and treatment utility.

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Introduction
Typical of most communities, the private and public sewer infrastructure incurs defects over time that allows undesirable contributions from rainwater and groundwater. These unwanted contributions are commonly referred to as inflow and infiltration (I&I). I&I contributions to a Utility’s wastewater collection system during the high rainfall season create significant additional water flow that consumes available capacity at the Utility’s wastewater treatment or reclamation facility. More importantly, inflow contributions from large rainfall events can stress the capacity of a Utilities’ infrastructure for a short period of time. Additionally, the unwanted I&I contributions result in increased discharge to the effluent disposal sources and incur increased annual operating expenses.

Historically, to reduce operating costs and increase available capacity in the collection, transmission and treatment systems, many Utilities have performed I&I reduction efforts such as manhole inspections, closed circuit television (CCTV) inspections and some have further instituted corrective actions. While trying to accomplish these corrective efforts with in-house staff, manpower, other priorities and equipment limitations tend to restrict the output of these efforts. When this occurs, it is imperative that Utilities renew their focus as I&I indirectly affects the financial stability of suffering utilities. To renew the focus on I&I, the initial efforts need to include a detailed I&I Action Plan of the collaborative effort by the Utility and any outside consultant (if desired) to identify and reduce the Utility’s I&I. The I&I Action Plan should include conducting routine testing and inspections to determine where I&I problems exist and perform maintenance to repair the defects responsible for I&I contributions to the sanitary sewer system.

I&I Action Plan
To many Utilities new to I&I identification and tracking, an Action Plan may seem like a daunting task. While there is a significant amount of work to be done, taking action is the key to solving I&I problems. For example, the following plan has been developed as a guideline for Utilities looking to tackle this capacity drain. The I&I Action Plan should be comprised of the following components at a minimum:

Field Target Prioritization
Fieldwork Phasing Designation
Fieldwork Implementation
Communication and Public Notification

Field Target Prioritization
Prioritizing field I&I targets consists of identifying, quantifying and prioritizing potential I&I problem areas within the wastewater collection system. The first step is to complete an initial engineering analysis for the Utility to quantify and prioritize I&I target areas. This step includes identification of areas with high I&I volumes and prioritizing each area using wastewater treatment plant (WWTP) historical flow data and lift station run times. The WWTP historical flow analysis estimates inflow and infiltration amounts in the Utility’s wastewater collection system. The lift station run time analysis is performed to
divide the Utility's wastewater collection system into the individual lift station collection areas for prioritization. This breakdown and ranking of the lift station collection systems focuses the Utility's fieldwork in areas to maximize I&I reduction in a systematic manner: starting with lift station areas having the highest estimated I&I flows. The engineering analysis should conclude the following:

**Estimated I&I based on Historical Flows:** The historical flow analysis for the WWTP should estimate an average daily flow for wastewater and I&I when comparing actual flows to rain events.

**Lift Station Area Prioritization based on Run Time Analyses:** Gravity collection areas within the Utility's wastewater service area can be prioritized by lift station run times that revealed a high correlation with rainfall events and/or the lift station having a daily run time above 10 hours.

Once the analysis is complete, each lift station collection areas in the Utility's wastewater service area can be categorized into four target priority levels:

**Priority 1 Target Areas:** Lift stations with a run time above 10 hours per day and significant correlation with rainfall events.

**Priority 2 Target Areas:** Lift stations with a run time between 7 and 10 hours per day and some correlation to rainfall events.

**Priority 3 Target Areas:** Lift stations with a run time between 3 and 7 hours per day and any correlation with rainfall events.

**Priority 4 Target Areas:** Lift stations with a run time less than 3 hours per day and no correlation with rain fall events.

**Fieldwork Phasing**

To maximize effectiveness of the I&I Action Plan, it is recommended for Utilities to phase the fieldwork focusing initially on higher priority areas. Also, to better estimate the type of I&I defects and repair needs/costs, it is recommended that the Utility complete a Pilot Test Area in one of the high priority areas. The information gained from the Pilot Test Area will be used to focus fieldwork efforts on identifying and correcting the most common and highest I&I contributing defects. The gravity collection areas for lift stations categorized as Priority 1 are recommended for the pilot testing. These areas should be strongly correlated to significant rainfall events. If possible, select a target area that doesn’t have other contributing areas connected to their collection system.

Following completion of the Pilot Test Area, the Utility will have a feel for the level of effort and impact the fieldwork will have for the remaining collection area. Of course, once the Pilot Test Areas are complete, fieldwork for the remaining Priority 1 and 2 Target Areas should be planned and performed. Once completed, the historical flow analysis can be updated to gauge the effectiveness of the I&I Program and re-prioritize target areas. The following fieldwork phasing is a recommended approach for a Utility's I&I Action Plan:
Perform Pilot Test Area Fieldwork (Select one or two Lift Station areas)
Update Fieldwork Method and Cost Estimate (Based on Pilot Test Area Fieldwork)
Perform Remaining Priority 1 and Priority 2 Fieldwork
Update I&I Flow Estimate and Re-Prioritize Target Areas

A significant portion of the I&I in the many Utility’s collection systems comes from the first two priority levels. With some quick engineering estimates, the total length of pipe for the Priority 1 and 2 levels can be approximated. Therefore, the I&I Action Plan capital costs can be estimated for the duration of the I&I Action Plan. Further identification tests such as smoke testing, CCTV, and flow testing, as well as repairs of visually identified defects can help to further refine the estimated costs of the I&I Action Plan. Once the costs are established and considered in the Utility’s budget, an estimated schedule for the fieldwork phasing of the I&I Action Plan can be completed and engaged.

Fieldwork Implementation
The fieldwork implementation includes identifying defects and repairing them. I&I flow estimation following defect repairs will measure the success of the fieldwork to ensure that I&I contributions are being reduced. To address the immediate needs of the I&I in the Utility’s wastewater collection system, it is recommended for the Utility to focus efforts towards the inflow as that typically has the most return on the investment. Inflow defects are typically easier to locate and less costly to repair than infiltration. Therefore, the defect identification and defect repair can be performed in the sequence similar to the following:

Smoke Testing: The Utility or an outside service (trained in smoke testing) should smoke test the pilot area and priority areas to identify defects where rain is accessing the collection system, as well as connections to the storm water system.
Repair Smoke Test Identified Defects: The smoke testing identified defects should be identified, reported on field logs, and repaired by the appropriate Utility, Consultant or Contractor staff.
Closed Circuit Television (CCTV) Review: If the Utility has the ability to CCTV, or can hire a Contractor to CCTV as much of the Priority 1 and 2 areas, it is recommended to do so during the field investigation. Further review of the CCTV outputs is valuable to help identify and prioritize gravity main rehabilitation.
Flow Testing: The Utility, Consultant or a Contractor should perform flow tests for areas that have previously been smoke tested and no smoke is visible at the ground surface level, but the lift station run times still have a correlation with rainfall events or are above the 10 hour daily allowance. At specifically identified manholes, flow measurements are recommended to see if there is an increase in flow through the manhole due to a rainfall event. By following upstream gravity mains with increased flow, the area of concern can be narrowed down and further testing can then be implemented.
Additional Targeted Closed Circuit Television (CCTV) Inspections: The Utility should conduct targeted CCTV tests for locations not previously CCTV’ed and targeted by flow test results or with suspect pipe materials. CCTV tests should be conducted in areas where increased flow had been measured, during significant rainfall events, and
followed back to an isolated part of the collection system. The results of the CCTV test will allow the Utility to identify and develop a specific solution for the issue causing the I&I flow.

**Repair Flow Testing and CCTV Identified Defects:** The flow testing and CCTV identified defects should be identified, logged and repaired by the appropriate entity.

**Communication and Public Notification**
A Communication and Public Notification Plan is critical to the public implementation of these types of activities. The Public Notification Plan should be developed to inform all Utility departments and customers of scheduling, instructions and potential impacts of the I&I Action Plan. It is recommended that a contact list be developed and carried by I&I fieldwork personnel that include a contact telephone numbers and e-mail addresses to be used for daily routine field work, as well as emergency situations. The Communication and Public Notification Plan should also include providing customers with public notifications for field work, especially smoke testing to prevent any unwarranted emergency calls. Public Notifications are typically scheduled according to respective field work phasing and implementation.

Examples of traditional public notifications methods used are listed below:
- Websites
- Utility newsletters
- Door hangers
- Street signs
- Mailers
- Bill Stuffers
- Reverse 911

Additionally, communication between emergency dispatch, schools, hospitals, fire departments, police, and special needs communities shall be included as well so that the emergency response personnel are aware of the activities and potential concerns from utility customers.

**Options for Repair and Replacement**
The options of collection system repairs fall within two major categories: lining and replacement. There are several avenues and products to complete either lining or replacements so the following sections will focus on a couple of the commonly used materials and others can be substituted as necessary.

**Lining:**
Lining is the addition of a composite material that is coated to the inside surface of a pipe creating a fully or semi-structural liner. The liner can restore structural integrity preventing leaks and reduce pipe roughness by creating a smooth jointless interior. This method involves taking the existing pipe out of service and actively bypassing or trucking out sewage during the maintenance extent. Full installation of the liner and return of the pipe to service is estimated to take 1 to 2 weeks depending on the size and length of pipe. Additional lining options include swagelining which elongates high
density polyethylene (HDPE) pipe using tension and dyes to reduce the outside diameter of the pipe. Once the pipe is pulled through the existing pipe, the tension is released and the pipe is allowed to expand back to its original diameter. For the purposes of this analysis, the composite material will be the focus of the comparison.

**Construction Process:**
- Inspection (As-built review and TV inspection)
- Clean/remove all corrosion & tuberculation and inspect the pipe prior to lining [(20-150)LF/day]
- Set up approved maintenance of traffic (MOT) and/or lane closures
- Dewatering and by-pass pumping
- Point repair to remove any obstructions prior to pipe renovation
- Preparation, installation, and curing of liner
- Liner terminations
- Final inspection

Some advantages and disadvantages for lining include:

**Advantages**
- 50+ year lifespan
- No need to abandon existing pipe
- Provides corrosion resistance
- Leak free joints
- Potentially lower installation cost

**Disadvantages**
- High cost to bypass for 1 to 2 weeks
- Limitations of installation (discussed below)
- High risk

While lining is a desirable rehabilitation method that can increase the life of the pipe there are limitations to the installation process.

Some of these limitations include:
- If the pipe is hydraulically undersized replacement provides an opportunity to increase capacity.
- Deformed or deteriorated pipe will need to be replaced.
- Inability to cost effectively bypass line (Additional cost required to bypass for pipe inspection and liner installation)
- Pressure class limitations for non-gravity pipes (50 psi is approaching upper limits. 100 psi might be able to be obtained)
- Liner cannot be installed through bends greater than or equal to 45°.
- Maximum lengths equate to approximately 1,500 feet for 6-inch; 1,000 feet for 12-inch to 30-inch.
- Maximum cleaning length extends approximately 1,000 feet.
- Requires CCTV inspection prior to liner design.
It is also important to note while considering lining, lines are not inspected (via camera) prior to design may present a risk that the condition of the pipe is not suitable for lining. Therefore, once the majority of the setup and lining prep would be wasted in the event the pipe is unrepairable via lining.

**Replacement:**
Replacement can be achieved in a number of methods depending on the depth of pipe, pipe size, accessibility, etc. One of these methods includes open trench excavation, removal and replacement. Other methods includes horizontal directional drilling (HDD) or pipe bursting with either HDPE or fused PVC. Traditional methods of open trench excavation are fairly common and easily understood by most Utilities. For the purpose of this paper, this replacement section will focus on pipe bursting as it may not be as familiar of a replacement method for gravity collection systems. Pipe bursting is a trenchless method of installing underground pipe along the same horizontal and vertical plane as the existing pipe. It is composed of a hydraulic jacking mechanism that expands and cuts the existing pipe while pulling a replacement pipe in its same path. For this evaluation, consideration was given to installing a new HDPE pipe that would replace the existing gravity pipe.

**Construction Process:**
Excavating a receiving and entrance pits (depends upon existing pipe depth and new bending radius)
Layout of new pipe and roller systems
Pipe is pulled into place behind the bursting head

Some advantages and disadvantages for HDPE replacement via HDD include:

**Advantages**
- Completely New Pipe
- 50+ Year Lifespan
- Leak-Free Joints
- More Durable than PVC
- Does Not Corrode or Tuberculate
- Provides an Opportunity to Easily Increase Capacity if Desired
- Quicker Installation Time

**Disadvantages**
- Slightly Higher Cost
- Requires Bypass Pumping
- Requires an Experienced Contractor

**Cost Analysis**

**I&I Fieldwork Labor/Cost Estimation**
I&I fieldwork consists of smoke testing, flow monitoring and CCTV. Engineering services are typically used to determine where to focus I&I fieldwork in order to get the most return on the investment. Each of the field activities are quick and cost effective in identifying repairs that need to be completed. If the fieldwork activities are completed in
the order as described in “Field Implementation”, the results from each of the field activities will help in determining where and which field activity should be completed next. Determining which field activity to complete next can be based on the type of I&I that the system is experiencing. Which is a key point, because the type of I&I a system is experiencing, determines which field activities should be completed, as well as how each activity is completed. For example, during smoke testing where no smoke is making it to the surface, then the gravity system is most likely experiencing infiltration. Therefore, long term flow monitoring is advised rather than spot testing the collection system during a rain event. Below is Table 1 that shows unit price ranges for each of those field activities to be performed.

<table>
<thead>
<tr>
<th>Engineering and Field Activities</th>
<th>Contracted Unit Cost ($/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Analysis</td>
<td>$0.01 to $0.05</td>
</tr>
<tr>
<td>Smoke Testing</td>
<td>$0.25 to $0.55</td>
</tr>
<tr>
<td>Flow Testing</td>
<td>$0.2 to $0.40</td>
</tr>
<tr>
<td>CCTV Testing</td>
<td>$1.00 to $4.50</td>
</tr>
</tbody>
</table>

These costs can be extrapolated based on the system size that is experiencing I&I to determine the level of effort and capital costs needed for inspection and problem identification.

**Pipeline Repair/Replacement Cost Analysis**

To provide some further details for consideration between complete I&I pipe repair and replacement options, a cost comparison is warranted. For the purposes of simplicity, two pipe sizes will be considered for lining or replacement and the associated costs will be compared for each pipe size. Since the general standard minimum size for gravity collection pipe is 8-inch, we'll consider an 8-inch pipe and a slightly larger 12-inch pipe for the Utilities that have larger collection system areas. First we must identify the costs associated with each alternative to validate the cost analysis. Each option is identified below for clarity:

**Lining:** The costs associated with lining include bypassing, cleaning, inspection/CCTV, lining material, and installation. Bypassing costs can be estimated using a quantity of flow through the pipe to calculate the number of trucks to transport or an alternate bypass pump and piping system. Since the traditional gravity pipe can be isolated at both ends and typical pipe lengths are less than 500 feet between manholes, bypass pumping typically offers the most cost effective method of bypassing during lining operations and will be utilized for this cost analysis. Note: Bypass pumping is only needed for mains that experience heavy flow at all hours of the day. Typically bypassing can be eliminated or minimized by selecting the low flow periods for repair.

**Replacement via Pipe Bursting:** The costs associated with pipe bursting replacement include excavation of entry and exit pits (depending on pipe depth and new pipe
bending radius), pipe material, replacement of modified manholes from installation, as well as other general construction installation costs.

Below are assumptions made on a general basis for each pipe size analyzed:

**Example Pipe 1 – 8-inch gravity pipe:** For the demonstration of this cost estimate, it is assumed that providing access to the pipe, cleaning and inspection/CCTV can be completed in 4 hours and then another 4 hours to install the liner, let it cure, and reopen the wastewater flow to the pipe. Therefore the pipe must be bypassed for a total of 8 hours. See Tables 2 and 3 for detailed cost estimate.

**Table 2. 8-Inch Gravity Pipe Lining Cost Estimate**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Unit Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-inch Lining</td>
<td>1,000</td>
<td>feet</td>
<td>$35</td>
<td>$35,000</td>
</tr>
<tr>
<td>Bypassing (8 Hours)</td>
<td>1</td>
<td>each</td>
<td>$1,200</td>
<td>$1,200</td>
</tr>
<tr>
<td>Cleaning and CCTV/Inspection</td>
<td>1,000</td>
<td>feet</td>
<td>$15</td>
<td>$15,000</td>
</tr>
<tr>
<td><strong>Total Cost per 1,000 feet:</strong></td>
<td></td>
<td></td>
<td></td>
<td>$51,200</td>
</tr>
</tbody>
</table>

**Table 3. 8-Inch Gravity Pipe Pipe-Bursting Cost Estimate**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Unit Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation with 8-inch Pipe</td>
<td>1,000</td>
<td>feet</td>
<td>$55</td>
<td>$55,000</td>
</tr>
<tr>
<td>General Excavation/Rehab</td>
<td>1</td>
<td>each</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Bypassing (8 Hours)</td>
<td>1</td>
<td>each</td>
<td>$1,200</td>
<td>$1,200</td>
</tr>
<tr>
<td><strong>Total Cost per 1,000 feet:</strong></td>
<td></td>
<td></td>
<td></td>
<td>$57,200</td>
</tr>
</tbody>
</table>

**Example Pipe 2 – 12-inch gravity pipe:** For the demonstration of this cost estimate, it is assumed that providing access to the pipe, cleaning and inspection/CCTV can be completed in 4 hours and then another 6 hours to install the liner, let it cure, and reopen the wastewater flow to the pipe. Therefore the pipe must be bypassed for a total of 10 hours. See Tables 4 and 5 for detailed cost estimate.

**Table 4. 12-Inch Gravity Pipe Lining Cost Estimate**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Unit Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-inch Lining</td>
<td>1,000</td>
<td>feet</td>
<td>$65</td>
<td>$65,000</td>
</tr>
<tr>
<td>Bypassing (10 Hours)</td>
<td>1</td>
<td>each</td>
<td>$1,600</td>
<td>$1,600</td>
</tr>
<tr>
<td>Cleaning and CCTV/Inspection</td>
<td>1,000</td>
<td>feet</td>
<td>$15</td>
<td>$15,000</td>
</tr>
<tr>
<td><strong>Total Cost per 1,000 feet:</strong></td>
<td></td>
<td></td>
<td></td>
<td>$81,600</td>
</tr>
</tbody>
</table>
Table 5. 12-Inch Gravity Pipe Pipe-Bursting Cost Estimate

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Unit Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation with 12-inch Pipe</td>
<td>1,000</td>
<td>feet</td>
<td>$80</td>
<td>$80,000</td>
</tr>
<tr>
<td>General Excavation/Rehab</td>
<td>1</td>
<td>each</td>
<td>$1,800</td>
<td>$1,800</td>
</tr>
<tr>
<td>Bypassing (10 Hours)</td>
<td>1</td>
<td>each</td>
<td>$1,600</td>
<td>$1,600</td>
</tr>
</tbody>
</table>

Total Cost per 1,000 feet: $83,400

Table 6 below shows an estimated cost savings that is associated with the different cost references described above. With unit costs for treated water per 1,000 gallons, which includes treatment and disposal, a kWh price for pump/transfer station runtimes, it is possible to calculate the total savings per year for reduction in I&I contributions. While 100% I&I reduction is the goal of any I&I program, realistically 50% reduction is more reasonable and considered a major victory in any collection system.

Table 6. Estimated Average Treatment Savings

<table>
<thead>
<tr>
<th>Percent of I&amp;I Reduction</th>
<th>100%</th>
<th>75%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per treated 1000 gallon</td>
<td>$0.75</td>
<td>$0.75</td>
<td>$0.75</td>
</tr>
<tr>
<td>Total I&amp;I Flow (gpd)</td>
<td>1,000,000</td>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Eliminated I&amp;I Flow (gpd)</td>
<td>1,000,000</td>
<td>750,000</td>
<td>500,000</td>
</tr>
<tr>
<td>Treatment Savings per Year</td>
<td>$273,750</td>
<td>$205,313</td>
<td>$136,875</td>
</tr>
<tr>
<td>Pumping Saving Per Year</td>
<td>$36,000</td>
<td>$27,000</td>
<td>$13,500</td>
</tr>
<tr>
<td>Total Saving Per Year</td>
<td>$309,750</td>
<td>$232,313</td>
<td>$150,375</td>
</tr>
</tbody>
</table>

Understanding the prices associated in Table 6 above is important for determining a payback period for repair and replacement projects associated with reducing I&I. Knowing how much I&I in a collection system is costing a utility, makes it possible to calculate and determine how much money is available for those repair and replacements in the system.

Each collection system is different and therefore to really understand and verify the pricing for a specific collection system, a pilot area should be completed in each system. This allows for better understanding of the collection system, for example determining the type of I&I and which field activities are required. It also allows for percentage of I&I reduction to be established. However, as shown in Table 6 above, lining operations that reduce I&I by 1,000 or more can add up quickly for activity that is looking to stretch the most return out of their investment. Very quickly, the cost savings can account for a significant amount of I&I repair.

Conclusions/Recommendations
When considering the impacts of I&I within a wastewater collection system, the cost impacts reach far beyond treating of those waters by wastewater treatment plant. Increases in pumping, transmission within the collection system, additional wear and
treatment processing power, chemical consumption, and pumping; and effluent disposal pumping and transmission become quite costly when we consider the extensive I&I additions to wastewater treatment plants. For Utilities that are aware of I&I being present within the collection system, an evaluation is warranted to quantify the impact on the Utility both physically and financially.

For those utilities that are reaching capacity limitations, perhaps an I&I Action Plan can facilitate a deferred expansion of collection and treatment infrastructure. In either case, I&I is prevalent in most gravity collection systems and can be a significant drain on the financial stability of a wastewater Utility.

In general, lining and pipe bursting are both practical methods for repairing or replacing, respectively, existing gravity mains that are experiencing significant I&I contribution. Both methods have distinguishable advantages and disadvantages. Lining has an added risk due to the unknown condition of the pipe until it is inspected and requires longer durations of bypassing flow. Although the cost of materials and installation for lining is less than pipe bursting there are other costs associated with lining which include CCTV inspection and bypassing which need to be considered. Therefore each application for repair/replacement must be considered using the total costs for replacement and weighing in on the benefits/drawbacks for each method being considered.

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