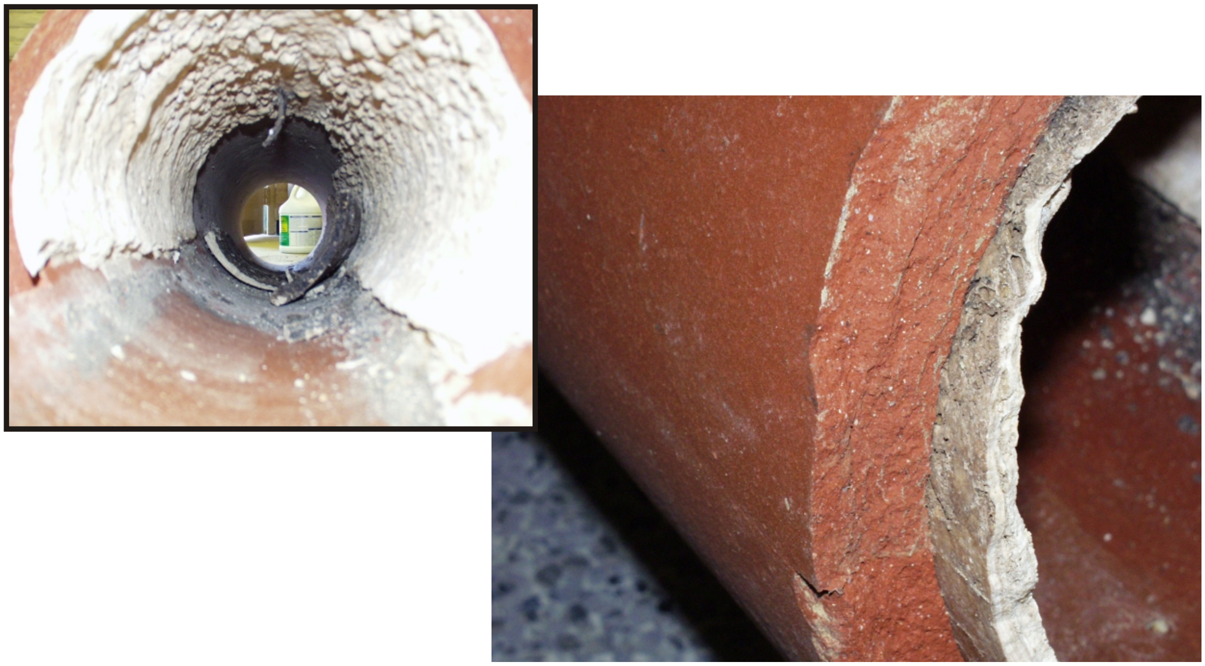
EVALUATION OF SCALE FORMATION IN COLLECTION SYSTEM



Prepared for

LEUCADIA WASTEWATER DISTRICT

LEUCADIA
WASTEWATER
DISTRICT

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Executive Summary

PBS&J has evaluated the scale formation in the Luciernaga area of the Leucadia Wastwater District (District) service area. Based on the findings, we have developed a recommended course of action to safely and effectively remove the scale and to help ensure the problem does not redevelop in the future. This report presents an explanation of why the scale is forming, the best way to remove it, the estimated cost of removing it, and recommendations for long-term maintenance to prevent the scale problem from reoccurring.

The scale is forming because of the infiltration of groundwater into the sewers. The groundwater is high in total dissolved solids and calcium. The infiltrated groundwater evaporates off the interior of the pipe and reacts with the sewer gases to form a calcium carbonate (calcite) scale in the non-wetted portions of the sewer pipe. The high groundwater condition has developed over the past 30 years. Landscape irrigation combined with natural springs in the area has resulted in local high groundwater conditions that cause enough hydrostatic pressure on the pipe to cause infiltration and the resulting scaling problems.

Replacement, rehabilitation, and cleaning of the affected sewers were evaluated. Replacement and rehabilitation could eliminate the infiltration problems and prevent future scaling problems, but the cost is much higher than cleaning the lines. A cleaning program can be implemented to effectively remove the scale with a follow on preventative maintenance program developed to monitor and remove scale before it poses a serious threat to the District. A comparison of the costs between replacement, rehabilitation, and cleaning are presented below.

Replacement	$6,435,000	$143 per LF
Rehabilitation	$3,276,000	$73 per LF
Cleaning (Plug, Fill & Flush)	$572,715	$13 per LF

The recommended cleaning method is to plug and fill individual reaches of the sewer with a mixture of hydrochloric acid and citric acid. The acid will dissolve the scale. The spent acid solution can be diluted or neutralized in the pipe and safely discharged downstream through the collection system for ultimate disposal at the Encina WPCP. High pressure flushing after the acid cleaning will be a final step to dislodge any remnants of the scale left in the pipe.

The following additional activities are also recommended to further quantify the scale issue and to gather information for better planning and scheduling the cleaning activities.

- A field test to both confirm the effectiveness and refine the cleaning method on a full-scale basis.
- Local flow monitoring program to determine the wastewater flow rates and diurnal variations in the wastewater flow.
- A video inspection program before and after the acid cleaning to assess the condition of the sewers and to evaluate effectiveness of the cleaning.
- A public outreach program to notify the public of the proposed activities.

Section 1
Background and Objective

1.1 Background

Two sewage spills occurred in the NE section of the District in late 2002. The second and most serious of these caused sewage to backup into six residences, completely inundating one residence. Investigation of the spills by the District staff revealed a significant scale layer had formed in the upper non-wetted portions of the specific sewer pipe. It was determined that large pieces of the scale had fallen out of the crown of the sewer causing the two blockages. Video inspection of the sewers by the District staff, showed the scale to be widespread throughout the project area. There is a concern that future blockages and property damage will occur if the scale is not mitigated. The District authorized this project to evaluate the scale problem and to develop possible solutions.

The project area is shown in Figure 1. The area consists of approximately 8.6 miles of sanitary sewers. All but a few hundred feet of these sewer lines are constructed of VCP. Most of these sewers were built in the early to mid-1970’s, and they are approximately 30 years old. The District had a sample of the scale material taken and analyzed to determine its composition. The analytical results reveal that the scale was predominately calcium carbonate, or calcite.

1.2 Objectives of the Study

The objectives of this study are:

1. Determine the cause of the mineral scaling.
2. Identify and evaluate up to five alternatives for scale removal.
3. Evaluate options to prevent future reoccurrence of scaling related blockages.
4. Prepare a report summarizing the results of the study.

This report presents a discussion of the analysis and the results and recommendations regarding of the formation, removal and future prevention of this scale.

STUDY AREA

FIGURE 1

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Section 2

Evaluation of Scale Formation in Sewers

2.1 Ground Water Permeation – Source of Scaling

The scale formation only occurs on the non-wetted internal surface of the VCP sewers. The scale is not caused by the wastewater in the sewers because the wastewater flow is never high enough to completely fill the pipe. The scale is caused by groundwater permeating into the sewers through the porous clay wall of the pipe.

The VCP sewers were installed approximately 30 years ago. Under high groundwater conditions, ground water will infiltrate the sewers through the porous clay pipe wall. We spoke with the National Clay Pipe Institute (NCPI) about the permeability of VCP. They confirmed that VCP is permeable, and that the VCP produced 30 years ago was much more permeable than the pipe produced today. There is no industry standard or test to measure permeability through the pipe wall. Field Acceptance Water Test (ASTM C1091) is a standard accepted procedure that measures the total rate of infiltration from joints, cracks, and through the pipe wall. The standard for this test 30 years ago was 1,500 gallons/inch diameter/mile/day. Today the same standard is much lower at only 50 gallons/inch diameter/mile/day. *According to the NCPI, permeation through the walls of the pipe is the primary means of infiltration.* The amount of infiltration through the pipe joints and cracks is only a small faction of the total infiltration measured in a field acceptance water test. The reduction in infiltration rates of VCP has been achieved through changes in the manufacturing process to reduce the permeability through the pipe walls.

2.2 Ground Water Sources and Elevations

We conducted a geologic evaluation for the project area and determined that naturally occurring springs and groundwater have been present since before the area was residentially developed nearly 30 years ago (Geotechnical Reconnaissance Study by Ninyo and Moore, dated November 20, 2003, Appendix 1). Old USGS records show that a water well was once located not far from the project area. Records of other geologic investigations have noted naturally occurring springs and seeps as well. Although groundwater has been historically present, the residential development of the area has probably contributed to the increase in groundwater elevations.

The project area consists of graded fill materials overlaying native materials. The underlying layers of the native material are relatively impermeable soils. Our analysis is that natural groundwater sources, combined with residential lawn irrigation water, and possible water leaks from potable water lines, have percolated down into the ground creating a perched aquifer and relatively higher groundwater elevations in this local area. In some places, the groundwater elevations are only two (2) to three (3) feet below grade. In fact, District staff has found groundwater to be only two (2) feet below grade during two excavations in this neighborhood. The high ground water elevations are apparently not uniformly high across the entire project area. Recent geotechnical borings in Alga Road, not far from the Luciernaga Street, found no groundwater at depths greater than 10 feet.

Most likely, groundwater in the area tends to collect in the more permeable fill soils that were used in grading the development and along the sewer lines themselves. The bedding and backfill material around the sewer lines act as a natural sump and conveyance channel for the groundwater. When the sewers were first constructed, the groundwater level was probably several feet below the elevation of the sewers. Over time, however, the groundwater has gradually increased to elevations above the pipe crowns resulting in its permeation/infiltration into the VCP sewers.

2.3 Groundwater Quality

The source of calcium in the groundwater is both the potable water used for irrigation and the naturally occurring groundwater. Potable water used in the Carlsbad area has an average calcium concentration of approximately 56 mg/L. High calcium levels in irrigation water percolating down into the groundwater naturally increase the calcium concentration of the groundwater.

A sample of the ground water collected in the project area on August 1, 2003, was analyzed. The noteworthy parameter is 2,679 milligrams per liter (mg/L) concentration of total dissolved solids (TDS) that can be considered high from the standpoint of typical values noted in groundwater. The calcium concentration in the ground water was noted to be 155 mg/L.

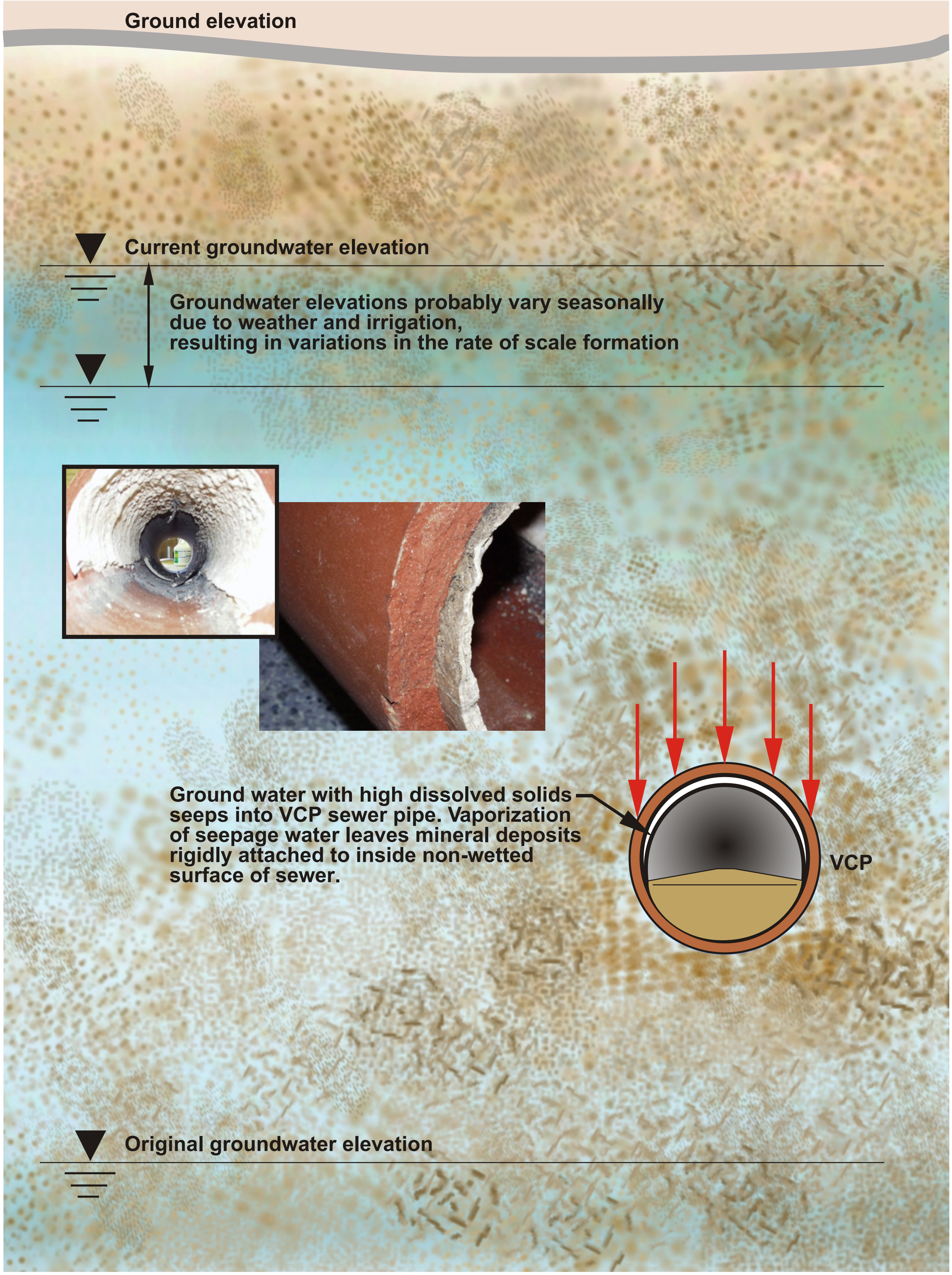
2.4 Phenomenon of Scale Formation

Ground water seepage through the non-wetted perimeter of the sewers evaporates and reacts with sewer gases leaving a mineral deposit on the interior surface of the pipe. This phenomenon is somewhat similar to the natural formation of stalactites in caves. A graphic schematic view of the potential scale formation phenomenon in VCP sewers is shown on Figure 2. The scale has likely not developed uniformly over the past 30 years. There is no way to determine definitively how fast the scale formed, but my analysis indicated that it has probably formed over the past 10 to 15 years , that is, once the groundwater elevation became high enough to exert the hydrostatic head required to cause significant groundwater infiltration.

It was logically assumed that the groundwater elevation was many feet below the elevation of the newly constructed sewers but then gradually began to rise as the new homes were built and landscape irrigation commenced. Had the groundwater always been at or near its present level, it would have been very difficult and costly to construct the sewers. Once homes were built and started irrigating, the groundwater elevation in the project area started to increase until it reached its present level. Additionally, groundwater elevation fluctuates seasonally with wet weather patterns, but it has remained sufficiently high for this scale formation to continue throughout the year.

The video inspections conducted by the District, show that thickness of the scale varies throughout the area. In some places, it is ¼ inch or more thick and completely covers the non-wetted portion of the pipe. While in other places, the scale is less thick, with coverage less complete or uniform. Finally, some locations show that the scale is only present in sporadic patches. The variation in scale thickness is likely caused by variations in groundwater depth and variations in vitrified clay sewer pipe (VCP) permeability. The fact that the scale varies in thickness will be important in evaluating and implementing scale removal methods.

The scale does not form on the wetted perimeter of the pipe because the groundwater that infiltrates in the wetted area of the pipe is naturally carried away by the sewage flow and the scale never has the chance to form.



Groundwater elevations probably vary seasonally due to weather and irrigation, resulting in variations in the rate of scale formation

Ground water with high dissolved solids seeps into VCP sewer pipe. Vaporization of seepage water leaves mineral deposits rigidly attached to inside non-wetted surface of sewer.

GRAPHIC VIEW OF POTENTIAL SCALE FORMATION PHENOMENON IN VITRIFIED CLAY PIPE

FIGURE 2

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Section 3
Description and Evaluation of Alternatives

3.1 Description of Alternatives

To eliminate the mineral scale in the District's VCP sewers, the following alternatives were considered.

1. No Action
2. Rehabilitate the Sewers
3. Replace the Sewers
4. Mechanical Cleaning
5. Chemical Cleaning Using Plug, Acid Fill, and Hydro Flushing with Water
6. Chemical Acid Cleaning Using Wayne Ball
7. Chemical Acid Cleaning Using Hydro Flushing Nozzles

Alternative 1 – No Action

This alternative assumes no action is taken. There is no cost or effort involved, however, the potential for future sewer blockages and spills will remain and may increase with time.

Alternative 2 – Rehabilitate Sewers with Scale Problem

This alternative assumes that all the existing VCP sewers (approximately 8.6 miles) in the project area affected by scaling will be rehabilitated using methods like slip lining. The existing scale deposits will not be actually removed, but covered by an impervious lining that prevents infiltration of groundwater. During future cleaning and maintenance activities in these slip-lined pipes, the scale deposits will be held in place behind the lining, thus eliminating the potential for blockages caused by them.

Alternative 3 – Replace Sewers with Scale Problem

This alternative assumes that all the existing VCP sewers in the project area affected by this scaling phenomenon will be abandoned and replaced with new sewers constructed of PVC that will not allow groundwater infiltration, thus eliminating the formation of scale in the future.

Alternative 4 – Mechanical Cleaning of Sewers

This alternative assumes cleaning of the scale deposits in all the existing VCP sewers in the project area. Special grinding and scrapping devices are used in the sewers to grind or dislodge the scale deposits. The District staff has tried several mechanical cleaning devices with little or no success. PBS&J evaluated other mechanical sewer cleaning tools available in the market, but did not find them practically suitable for this project. This alternative does not prevent the formation of future scale and would have to be repeated on a periodic (perhaps as often as bi-annually) basis.

Alternative 5 – Chemical Cleaning Using Plug, Acid Fill, Followed by Hydro Flushing with Water

This alternative assumes cleaning of scale in all the affected existing VCP sewers in the project area using a mixture of hydrochloric (HCl) and citric acid. A bench test was conducted to test the effectiveness of the dissolution of the calcite scale using hydrochloric acid (HCl), citric acid, and a mixture of HCl and citric acid. The bench testing showed that the scale dissolved in 4 to 8 hour period using the mixture of HCl (2 to 3% solutions) and citric acid (5 to 10 % solution). Using HCl or citric acid by themselves did not prove effective.

Sample coupons of the scale dissolved vigorously in the HCl and citric acid solution, generating a proportional volume of off-gas, primarily carbon dioxide. This should pose no adverse health or nuisance problems during cleaning. The gas generated during cleaning should naturally vent out of the manholes and through the lateral connections to the residence plumbing vents. The two (2) to three (3) percent acid concentration was chosen specifically to provide a slower rate of reaction. Higher acid concentration would provide a faster rate of reaction, but could result in a gas build up in the collection system that could damage piping or cause sewer gases to back-up into residences at an unacceptable rate and push water out of toilets.

Details of the theory of dissolution, experimental method, and results are presented in Appendix 2 (Leucadia Calcite Dissolution Report, by McGuire Environmental Consultants). A small field test of this method in one or two reaches of the sewer system is recommended to confirm the effectiveness of the selected acid and to refine the application approach for a larger scale operation.

This alternative consists of plugging and filling individual reaches of sewers (300 to 400 feet) with an HCL-citric acid mixture. A plug will be inserted in the inlet side of the upstream manhole, and the outlet side of the downstream manhole. A vacuum truck and crew will be stationed at the next upstream manhole to monitor the depth of sewage in the manhole and to pump it out as needed to prevent flooding or overflow. This method is illustrated in Figure 3.

The isolated reach of sewer will be filled with the acid mixture to a level in the upstream manhole that is just above the top of pipe. This will ensure the pipe is completely submerged, and that no flooding of homes will occur. The chemical delivery truck will be used to fill the reach. The truck's hoses that are normally used off loading the chemicals will be lowered into the manhole, and the reach slowly filled. The flow will be controlled by using the off loading valves on the truck. This method of application will minimize the hazards of handling the chemicals.

The acid will be held in the reach approximately 4 hours giving the acid time to dissolve the scale.

The spent acid solution will be disposed of by removing the downstream plug and releasing the acid to flow into downstream sewers and ultimately the Encina Water Pollution Control Plant.

After the cleaning solution is released, the sewer should be cleaned using fresh water and normal high-pressure hydro-flushing method. This activity should remove any remnant pieces of the scale and complete the cleaning process. An after-cleaning CCTV Inspection will validate this alternative and its effectiveness.

Alternative 6 – Chemical Acid Cleaning Using Wayne Ball

This alternative is a variation of the Alternative 5. The type of acid mixture and concentrations are the same as described in Alternative 5. Instead of inserting a plug in the outlet of the downstream manhole, a Wayne Ball is used as the downstream plug. The ball would be inserted into the pipe and the upstream manhole and fed down the line slowly until it reaches the inlet of the downstream manhole. Acid mixture would be fed into the upstream manhole behind the plug (Wayne Ball), which provides the head pressure to push the ball through the line. Just before the ball exits the pipe reach at the downstream manhole it would be pulled slowly back through the pipe. The spinning action of the ball, combined with the flow of cleaning solution around the ball, is expected to remove the softened scale. The ball could be traversed up and down the pipe several times as needed to remove the scale. A schematic of this procedure is shown on Figure 4.

Alternative 7 – Chemical Acid Cleaning Using Hydro Flushing Nozzles

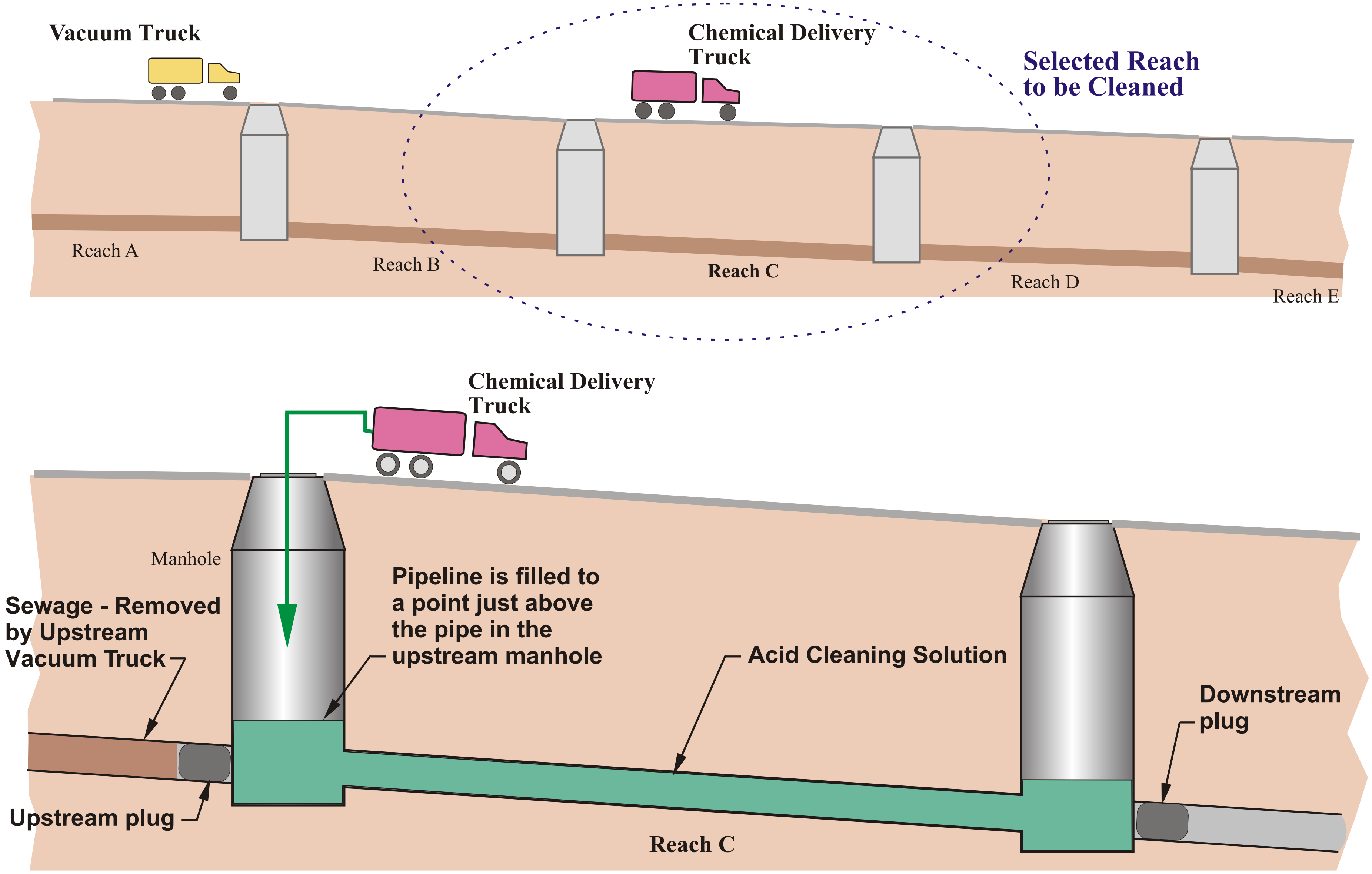
This method uses hydro-flushing equipment to apply the acid. The water supply tanks on the hydro-trucks would be filled with the acid mixture instead of water. A cage-like attachment would be used to hold the nozzle near the center of the pipe. High pressure jet of cleaning solution would be used to pull the hose and nozzle through the line as is normally done using water. Then, instead of pulling the hose back through the pipe under high pressure, a much lower pressure would be used, just enough to wet the scale with the acid. The nozzle would be traversed up and down the reach of sewer repeatedly until all of the scale is dissolved or loosened. A normal high pressure fresh water flush would then be used as a final cleaning phase to remove any remaining pieces of scale. A schematic of this procedure is shown on Figure 5.

3.2 Evaluation of Alternatives

The following parameters were considered to compare and evaluate the alternatives.

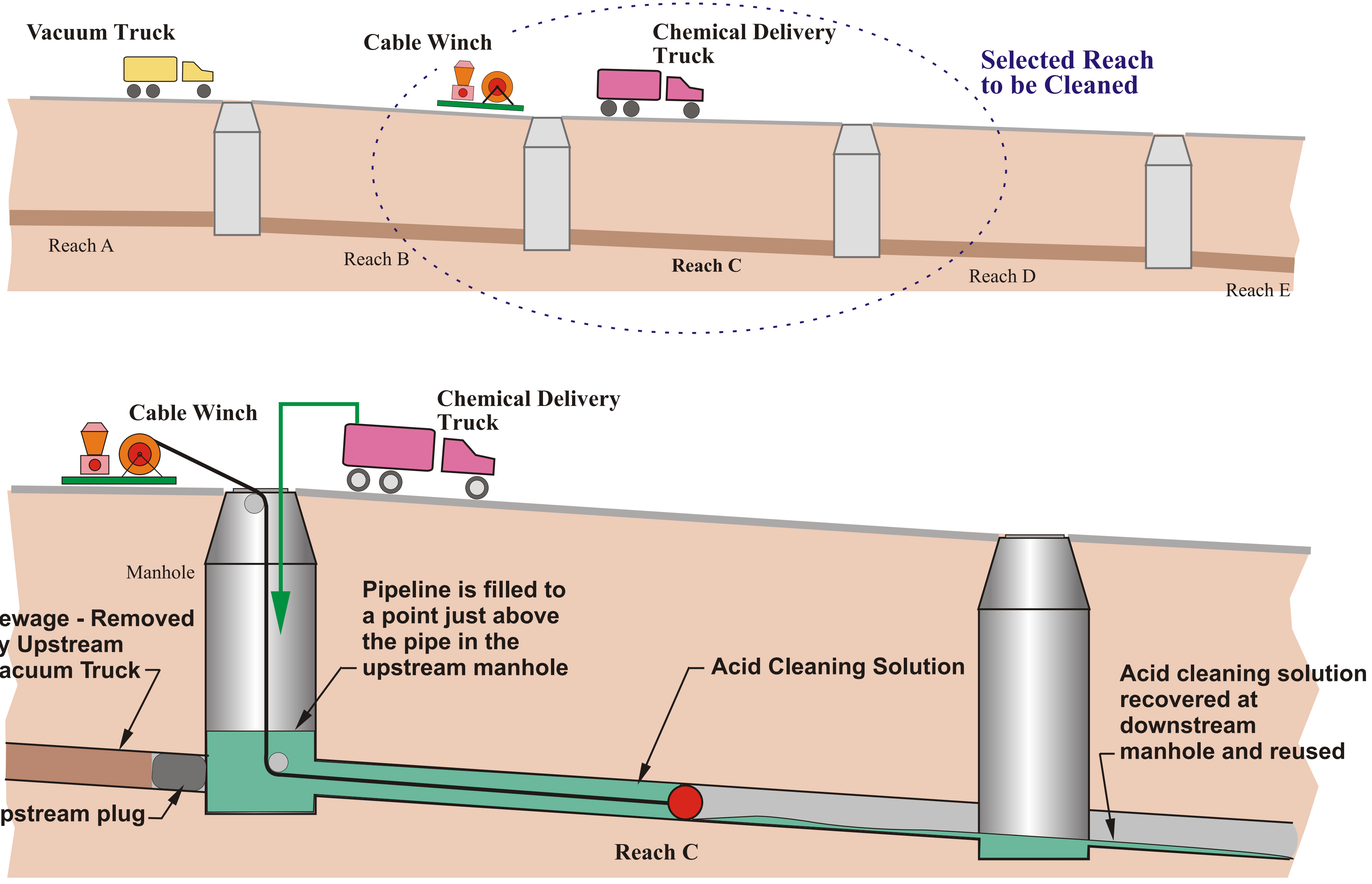
- Difficulty in application
- Time required for completion
- Potential for property damage
- Effectiveness in removing scale problem
- Effectiveness in preventing future scale deposits
- Potential for nuisance complaints of slow drains??
- Impact on downstream water quality
- Health and safety (Both resident and worker) considerations
- Cost

Each of the seven alternatives described above was evaluated on the basis of these parameters. ***Low***, ***moderate*** and ***high*** ratings were assigned to these parameters for each alternative. Except for cost, the values assigned are qualitative, based on engineering judgment, and relative as compared among the considered alternatives.



ALTERNATIVE 5 - PLUG AND FILL ACID CLEANING

FIGURE 3



ALTERNATIVE 6 - ACID CLEANING WITH WAYNE BALL

FIGURE 4

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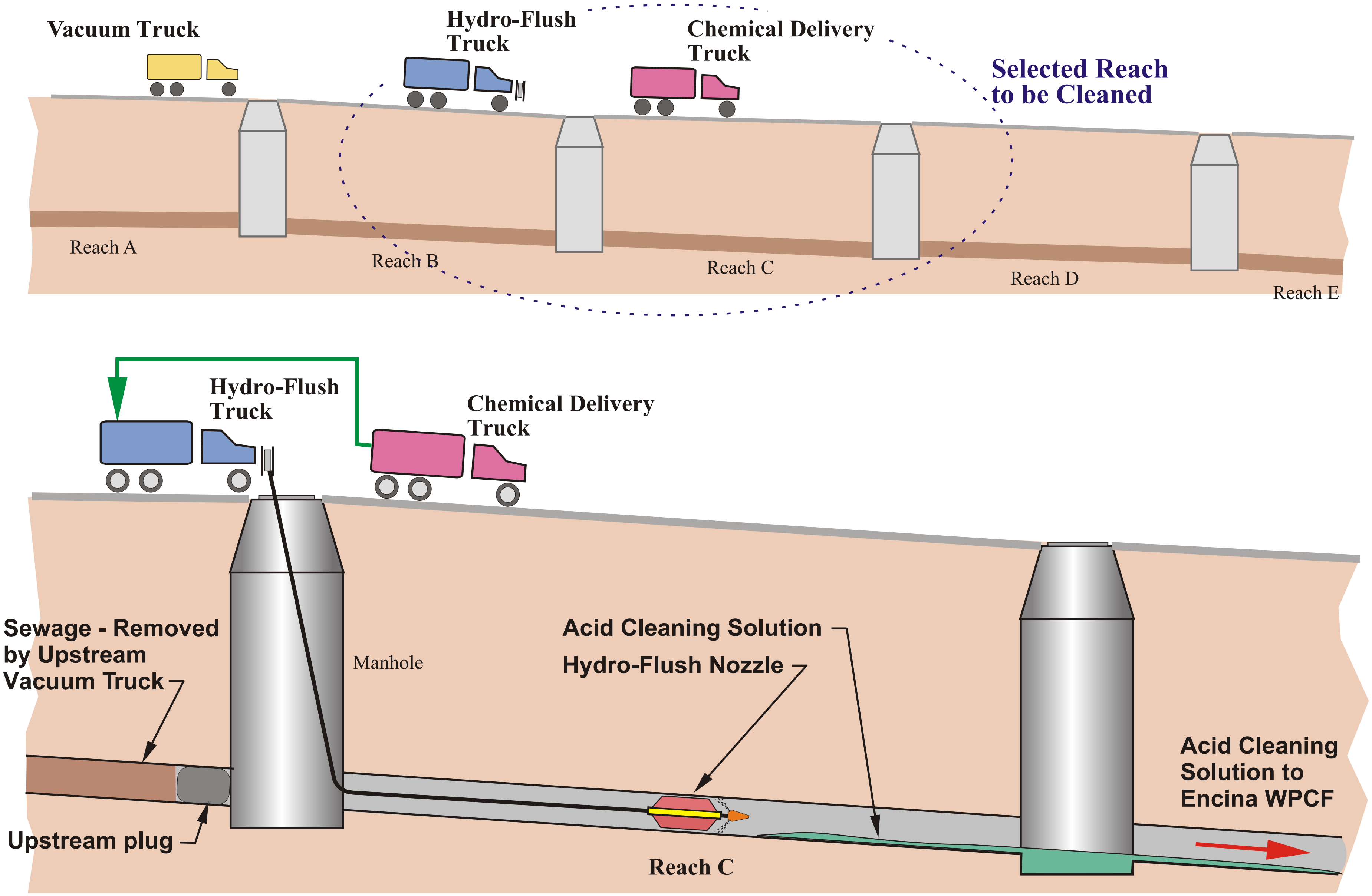

ALTERNATIVE 7 - ACID CLEANING WITH HYDRO-FLUSHING NOZZLES

FIGURE 5

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3.3 Discussion of Comparison of Alternatives

A summary of the alternatives evaluation is included in the matrix presented in Table 1. The overall alternative costs are also listed in Table 1. More specific details of these cost estimates are presented in Tables 2 and 3. It is important to note that only Alternatives 2 and 3 are permanent solutions to this scale formation problem. Alternatives 4, 5, 6, and 7 are cleaning alternatives that will require future monitoring and special acid cleaning of the collection system impacted by the scale in the future.

Alternative 1 – No Action

This alternative does not eliminate the potential of future sewer blockages and spills. On the contrary, the frequency and magnitude of scaling and associated problems are likely to increase with time. Therefore, this alternative is not considered acceptable.

Alternative 2 – Rehabilitate Sewers with Scale Problem

A disadvantage in this alternative is reduction in the pipe inside diameter, and consequently some reduction in maximum flow that can be carried by lined sewer pipe. The cost is high as compared to the cleaning alternatives. Therefore, this alternative is considered less attractive than the cleaning alternatives.

Alternative 3 – Replace Sewers with Scale Problem

This is the most costly alternative with maximum disruption to community during the implementation of the alternative. Therefore, in spite of its high effectiveness in eliminating this scale problem, its high cost makes it the least desirable alternative. This alternative could be considered attractive if the existing pipes were near the end of their useful life, but such is not the case with the District collection system in the affected area.

Alternative 4 – Mechanical Cleaning of Sewers

The calcite scale in the District collection system is so hard that it literally takes a hammer and chisel to break samples of scale out of the pipe. Once it breaks free, the scale falls out in large sheets and chunks. Additionally, a precise application of this force along the edge of the scale at the pipe wall was needed to knock the scale loose. Mechanical sewer cleaning machines are not designed to operate with this type of force and precision.

VCP sewer is not perfectly round. The industry standard allows up to three percent variation in the diameter of the sewer pipes, so for an eight-inch sewer pipe, the diameter can vary plus or minus ¼-inch in diameter. This is greater than the thickness of the scale in most cases. The mechanical cleaning devices evaluated do not have the ability to continually and accurately adjust to variations in pipe diameter.

The potential for an unacceptable level of damage to the VCP sewer is another serious disadvantage of using a mechanical cleaning device. Slightly offset joints are common in VCP sewers. Running a mechanical cleaning machine through the pipe could damage the VCP at the joints. Additionally, the interior of the VCP also has a smooth layer called the “dye skin”. The dye skin helps prevent the grease and oils from adhering to the interior of the pipe. A mechanical cleaning machine could damage or completely remove the dye skin and make them more susceptible to future grease clogging.

Because of the above-mentioned concerns and the limited success by the District in testing these tools to remove the scale, this alternative is not considered suitable for effective scale removal in the District collection system.

Alternative 5 – Chemical Cleaning Using Plug, Acid Fill, Followed by Hydro Flushing with Water

Based on bench test results, this alternative seems to offer a high potential for removing the scale in the existing District sewers. It is less expensive than sewer rehabilitation and replacement alternatives (No. 2 and 3). Disruption to community will also be much less as compared to either alternative 2 or alternative 3. We have also confirmed that the acid mixture (HCl and citric acid) of desired concentrations can be prepared in the factory and delivered as one chemical to the site compared to dealing with two different acids at the site of application.

The spent acid will have a pH of 2.7 or 3.0. The effect of the low pH water in the sewers and at the Encina Plant is a legitimate concern. A pH of at least 6 is considered necessary prior to discharge at the Encina Plant. Fortunately, there are several ways to address the potentially low pH issue.

The simplest is to rely on the dilution of the spent cleaning solution with the other wastewater flow in the sewage collection system. The amount of spent cleaning solution is small compared to the volume of remaining wastewater flow. McGuire Environmental Consultants calculated that 5,000 to 6,000 of wastewater with a pH of 7.2 would be needed to raise the pH of 900 gallons of spent cleaning solution to the recommended pH of 6. (There are about 900 gallons of acid in one 300-foot reach of sewer.)

It is difficult to model the actual dilution through the sewer. How quickly the spent cleaning solution is released has a significant affect on the downstream dilution. Also, the location and volume of remaining flow combining with the low pH “slug” and the volume and holding time in pump station wet wells will markedly affect the dilution rate. The actual amount of dilution that takes place can be estimated during the field test by monitoring the pH of the wastewater entering the Batiquitos Pump Station. Additionally, travel time between the cleaning location and the pump station can be calculated. If the pH is determined to remain lower that the recommended pH of 6, other dilution and neutralization methods could be utilized.

Potable water could also be used to dilute the spent acid in the pipe as the spent cleaning solution is released. As with the case above, about 5,000 to 6,000 of potable water would be needed to neutralize the spent cleaning solution from one reach of sewer cleaning.

Another alternative is to use a strong base such as sodium hydroxide to neutralize the spent cleaning solution in the pipe. Spent cleaning solution should not contain any alkalinity, so only about ½ gallon of a 10% sodium hydroxide solution would be needed to raise the pH of the approximately 900 gallons of spent cleaning solution to a pH of 6. The sodium hydroxide would have to be slowly fed to the spent cleaning solution as it is released.

The acid supplier has offered the option of removing the spent acid and hauling away for off-site disposal. This option would have additional chemical disposal cost, but can be easily implemented. The cost of removal and disposal will be about equal to the cost of purchase and delivery of the new acid.

Alternative 6 – Chemical Acid Cleaning Using Wayne Ball

The reason to consider this alternative involves the mixing and abrasive action provided the spinning of the Wayne Ball. Mixing of the acid will improve dissolution of the scale, and the abrasive action of the spinning ball may work to dislodge the scale in less time than it takes to let it completely dissolve. The use of a Wayne Ball is more complex than Alternative 5 and requires additional special equipment and more experienced cleaning crews. Also due to leakage of acid around the Wayne Ball, it will use more chemical than Alternative 5.

The cost of this alternative has not been estimated because the amount of additional chemical use and labor required is difficult to estimate. However, it is likely that the cost of this alternative will be higher than for Alternative 5, but again, much lower than the replacement or rehabilitation alternatives.

This alternative is not recommended at this time. It might be worthwhile for the District to test this method on a selected reach of sewer if staff is interested in considering this method.

Alternative 7 – Chemical Acid Cleaning Using Hydro Flushing Nozzles

There are several drawbacks of this method. The compatibility of acid use in the hydro-flushing equipment would have to be carefully checked. The chemical resistance of the tanks, pumps, hoses, and seals would have to be carefully checked to prevent equipment damage. The hydro-flushing equipment operators would have to take special precautions while operating the equipment. They would need Tyvek protective suits, face shields, and respirators to protect them from being sprayed or splashed by the acid and to prevent inhaling the vapors. The contact time between the acid and the scale is short, thus resulting in inefficient use of chemical.

The amount of acid required to use this method is difficult to determine since it is not known how many passes of the nozzle it would take to dissolve all of the scale. The effectiveness is also questionable since there is a limited contact time between fresh acid and the scale. Field testing would have to be conducted to develop the requirements for this method.

For these reasons, it is not considered a practical and efficient cleaning alternative. The cost of this alternative has not been estimated. The amount of additional chemical use is difficult to estimate. However, it is likely that the cost of this alternative will be higher than for Alternative 5, but much lower than replacement or rehabilitation alternative.

Table 1 - Alternatives Evaluation Matrix(1)

Description of Alternatives	Difficulty in Application	Time Required for Completion	Property Damage(2) Potential	Effectiveness in Removing Scale Problem	Effectiveness in Preventing Scaling	Potential for(4) Nuisance Complaints	Impact on Downstream Water Quality	Health and Safety Impacts	Cost ($)	Overall Effectiveness/ Remarks
1. No Action	None	None	High	None	None	Moderate	None	None	None	Because of potential for sewer spills, blockages and consequent damage, the alternative is not acceptable.
2. Rehabilitate sewers with scale problems	Moderate	Moderate	Low	High(3)	High	Moderate	None	Low	$3.3 M ($73/LF)	Overall moderate impacts, but high cost; reduced flow capacity because of reduced inside diameter of pipe (6 to 8%).
3. Replace sewers with scale problems	High	High	Low	High(3)	High	High	None	Low	$6.4 M ($143/LF)	Overall high adverse impacts. High disruption to community and high capital cost.
4. Mechanical cleaning of sewers.	Moderate	Moderate	Low	Low	None	Low	None	Low		Limited effectiveness of method because of scale rigidity and irregular pipe shape. High probability of damaging the pipe
5. Chemical cleaning using plug, acid fill, followed by hydro-flushing with water	Low	Low	Low	High	None	Moderate	High(5)	High	$0.57 M ($13/LF)	Potential adverse impacts on downstream wastewater pH, and Encina Plant secondary process, unless controlled. Requires testing and evaluation.
6. Chemical (acid) cleaning using Wayne Ball	Moderate	Moderate	Low	High	None	Moderate	High(5)	High	>$0.57 M(6)	More costly and difficult due to leakage of acid around the ball.
7. Chemical (acid) cleaning using hydro-flushing nozzles	Moderate	Low	Low	Low	None	Low	High(5)	High	>$0.57 M(6)	Low effectiveness due to low contact time between acid and scale, acid not fully utilized, possible imcopatibility of hydro-flushing equipment and acid.

1) Assigned ratings of ***Low, Moderate, High*** are qualitative and relative as compared among listed alternatives.
2) Includes property damage resulting from not implementing alternative as well as potential of property damage resulting from implementation of alternative.
3) "Scale" per se is not removed in these alternatives, however, the sewer blockage problem caused by scale is removed by these alternatives.
4) Examples of Nuisance complaints include traffice disruption, odors, acid fumes, noise, etc. In case of "No Action" alternative, sewer blockages triggered by scale material can result in sewer spills or back-up complaints.
5) Spent acid, if discharged as a slug load has significant potential to depress pH of downstream wastewater. However, with control, such as, proper dilution or neutralization, the adverse impact can be minimized.
6) Because of leakage of acid around the Wayne Ball and less utilization in the Hydro Flushing method, acid quantities higher than Alternaive 5 will be required. The actual quantity of additional acid needed is not known and would require field testing. However, the costs of these alternatives are expected to be significantly lower than rehabilitation and replacement alternatives.

Table 2 - Pipeline Replacement and Rehabilitation Costs

Pipeline Replacement

	Quantity	Unit	Unit Cost	Cost
Install Pipe	45,000	LF	$20.0	$900,000
AC Demolition and Replacement	45,000	LF	$40.0	$1,800,000
Trench Excavation and Backfilling	45,000	LF	$10.0	$450,000
Shoring and Dewatering	45,000	LF	$18.0	$810,000
			Subtotal:	$3,960,000
Engineering				$594,000
Construction Management				$396,000
Contingency				$1,485,000
	Total Estimated Project Cost:			**$6,435,000**
				$143 per LF

Pipeline Rehabilitation

	Quantity	Unit	Unit Cost	Cost
Rehabilitation	45000	LF	$50	$2,250,000
Engineering				$225,000
Construction Management				$45,000
Contingency				$756,000
	Total Estimated Project Cost:			**$3,276,000**
				$73 per LF

Table 3 - Pipeline Cleaning Cost Estimate

Alternative 5 - Plug, Fill & Flush Method

Item	Quantity	Unit	Unit Cost		Total
Flow Monitoring	3	Locations	$2,000	Location	$6,000
Video Inspection					
Before	45,000	LF	$1.00	LF	$45,000
After	45,000	LF	$1.00	LF	$45,000
Cleaning Chemicals	150,000	gallons	$0.45	gallon	$67,500
Chemical Delivery	*75	loads	$250	load	$18,750
Cleaning Crew	**450	hours	$135	per crew	$60,750
Vacuum Crew	**450	hours	$250	per crew	$112,500
Hydro-Flush Crew	90	hours	$250	per crew	$22,500
Supervision	**450	hours	$50	per hour	$22,500
				Sub-Total:	$400,500
Engineering (10%)					$40,050
Contingency (30%)					$132,165
			Total Estimated Project Cost:		**$572,715**
					$13 per LF

* 2,000 gallon loads

** 56 days

Section 4

Recommended Alternative, Project Planning and Implementation

4.1 RECOMMENDED ALTERNATIVE

Based on the analysis presented in Section 3, Alternative 5 is considered to be the best alternative in terms of cost and impact on area residents. Considering the significant remaining life of the sewers in the project area, rehabilitation and replacement options are significantly more expensive than cleaning and maintaining the sewers.

Of the cleaning alternatives , mechanical cleaning is the least desirable, while the issues discussed about acid cleaning using either a Wayne Ball or Hydro Flushing equipment, make alternatives 6 and 7 less attractive. Therefore, our strongest recommendation is for using *Alternative 5, the plug, fill and flush method*.

The recommended acid mixture (provided by McGuire) for this alternative is HCl (2 to 3 % solution) and citric acid (5 to 10 % solution). A bench test has shown very promising results that this mixture is effective in dissolution of the existing scales in the District VCP sewers.

4.2 PROJECT PLANNING AND IMPLEMENTATION

Prior to implementation of this alternative throughout the affected system, the following additional tasks are recommended. The primary objectives of these tasks are a more refined quantification of the problems and gathering information to assist in better planning and scheduling of the cleaning activities.

Field Testing

A small field test on a 300 to 400-foot reach of the sewer system is recommended. This test should be conducted by the District staff. The purpose of the test would be to confirm the effectiveness of the method and to better understand and refine the application method. The quantity of scale dissolved and the time required to dissolve it within the sewers actually affected by this scale is a critical step in validating alternative 5's feasibility. . As previously discussed, the dissolution of scale will produce carbon dioxide gas. Actual quantities of the carbon dioxide gas generated and its effect on the sewer, along with resultant pH and alkalinity of the spent acid mixture, should be tested in the field. This resultant information will confirm the actual effect of the remaining sewage to raise spent acid pH to 6, so that there are no adverse effects to downstream system and Encina plant processes.

There is the potential to reduce the cleaning costs by optimizing the use of acid cleaning solution. The bench testing showed that with 1 liter of acid (HCl + Citric) cleaning solution, 18 grams of scale could be dissolved in 4 hours and 25 grams of scale in 8 hours. This equals 0.15 lb of scale per gallon of acid cleaning solution in 4 hours and 0.21 lb in 8 hours. Table 4 shows the estimated volume of scale per unit length of sewer for various scale thickness. Areas with thicker scale may require multiple applications to be thoroughly cleaned. Areas with thin layers of scale might allow the same acid solution be used on multiple reaches. For cost estimating and planning purposes, it is assumed that acid cleaning solution is used only once for each reach of the sewer. **This should be evaluated in the field to optimize chemical use and minimize the cleaning costs**.

Table 4 - Scale Volume

Scale Thickness (in)	**Scale per Unit Length of Sewer** (lb/ft)	**Scale per Unit Volume of Pipe** (lb/gal)
1/16	0.38	0.15
1/8	0.76	0.29
3/16	1.14	0.44
1/4	1.51	0.58
5/16	1.88	0.72
3/8	2.24	0.86

Scale Density = 2.23 gram/cc

Flow Monitoring

A short flow monitoring program is recommended to determine the wastewater flow rates and diurnal variations in the wastewater flow for the project area. Chemical cleaning will require plugging and isolating sections of sewers for 4 to 8 hour periods. A good understanding of the wastewater flows generated by the neighborhoods at various times of the day is important to determine how long the sewers can be safely plugged and to determine the operational requirements for vacuum trucks and crews, which will be needed to temporarily pump and dispose of the accumulated sewage during the acid cleaning operation.

Flow monitoring should be conducted at a downstream location that conveys flows from the entire project area and, at two additional locations upstream of this location, to determine the flow contributions for major segments of the project area. Continuous flow measurements should be conducted during normal flow conditions for a period of 3 or 4 days. These data will provide pertinent information for the implementation of any of the cleaning alternatives. The recommended locations of the flow meters are shown in Figure 6. The cost of flow monitoring is included in the cost estimates.

Video Inspection of the Sewers

Implementation of a video inspection program is also recommended as part of the cleaning project. The program would include video inspections before and after the major cleaning effort in the entire area. The inspections prior to the cleaning would provide quantification and the extent and magnitude of the existing scale. This information is important for prioritizing areas of cleaning and to determine the project duration and acid quantities required for cleaning the project area. The invert elevations of the sewer manholes should also be measured as part of the initial video inspection so that a fairly accurate profile of the sewer can be verified. . These profiles will be important in controlling water depths in each segment that is plugged and cleaned, thus avoiding possibility of overflows and flooding of homes.

Post-cleaning video inspections will provide a verification of the effectiveness of the scale removal. These inspections should be made soon after major segments of the system have been cleaned so that re-cleaning can be conducted if necessary and the application methods modified to improve cleaning effectiveness. After the initial field-test, we recommend that a video inspection be made immediately to determine the effectiveness of the method and to assist in refining the method and techniques used.

An outside contractor for the video inspection work is recommended. Although the District has the CCTV equipment, the magnitude of this project will most likely require external resources be used.

In the time frame of completing this evaluation, we have not been able to locate any local contractors that provide this type of chemical cleaning services. This is not unexpected since scale removal from public sewer system is a fairly unique project. For cost estimating purposes, we have assumed that a local contractor can be found to do the work, and we have based our cost estimates on rates for similar types of sewer maintenance activities. The cost of video inspection is included in the cost estimates.

Public Outreach

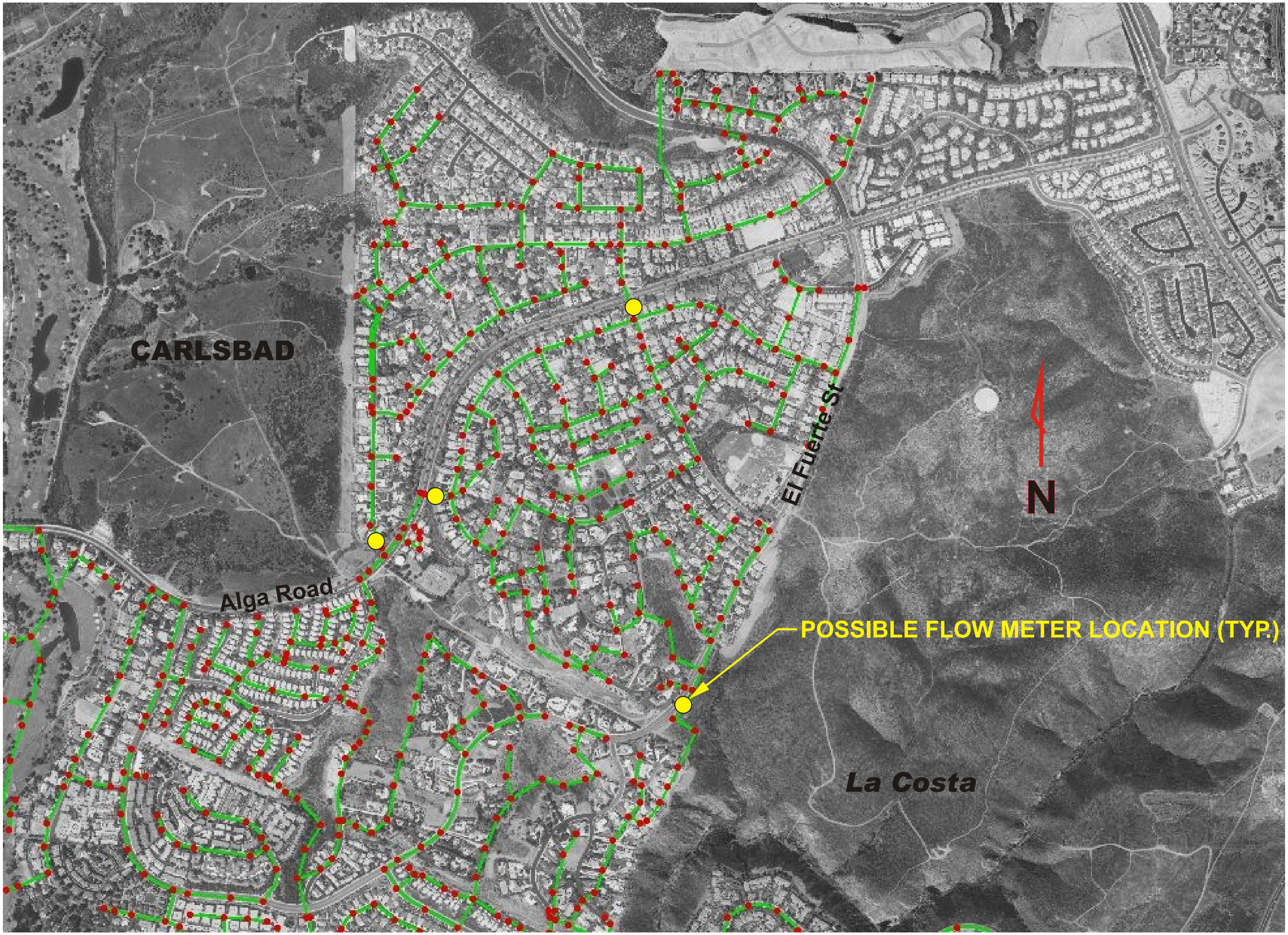
Development of a public outreach program is also recommended. The program would include notification to the local residents using door flyers, similar to notification for a smoke-testing program. The flyers should advise the residents of the time and dates the work is scheduled, the reason for this work, and the requirement to run water in all their drains to ensure the traps are full. This will prevent gases from entering their homes (predominately carbon dioxide). The flyer may include notification that that the District will be removing their clean-out caps as an added measure of safety. The flyers may also request that they not use their toilets and drains between 12:00 am and 6:00 am while the cleaning operations are in progress.

Preventative Maintenance Program

The District should develop a preventative maintenance program for the project area once the pipelines have been cleaned. An annual program of video inspection should be implemented. The inspections should focus on the areas that were found to have the greatest amount of scale formation.

The scale forms slowly over time (4 to 5 years). It is likely that prior to significant formation of the scale, it might be possible to remove it using normal hydro-flushing techniques. The hydro-flushing crews would need to be briefed on this special concern and enhanced cleaning requirements for the scale-prone sections of the sewer. In general, the crews would need to operate the hydro-flushing equipment at maximum pressure and at a slow enough feed rate to ensure removal of the scale. Selection of a hydro-flushing nozzle with the appropriate angle and flow velocity of the jets will also be important. Testing of different nozzles is recommended to determine the best one for this scale removal application.

If hydro-flushing proves to be ineffective, the District should continue to monitor the scale formation on an annual basis. If the scale becomes l re-established, chemical cleaning should again be implemented. It is estimated that a chemical cleaning program would be needed no more than once every three to five years.



POSSIBLE FLOW METER LOCATIONS

FIGURE 6

I:\design\59 Riverside\590085\590085flow-meter.cdr Jan. 19, 2004

Appendix 1

Ninyo & Moore

Geotechnical Reconnaissance Study

Ninyo & Moore
Geotechnical and Environmental Sciences Consultants

November 20, 2003
Project No. 105072001

Mr. Mark E. Iverson
PBS&J
3610 Central Avenue, Suite 500
Riverside, California 92506

Subject: Geotechnical Reconnaissance Study
Leucadia Water District Pipeline Scale Project
Carlsbad, California

Dear Mr. Iverson:

In accordance with your request and authorization, we have performed a background study and geotechnical field reconnaissance of the subject study area located in Carlsbad, California (Figure 1). The purposes of this evaluation were to review readily available background data regarding the geotechnical subsurface and groundwater conditions at the site and to provide this report presenting our findings and conclusions. Our scope of services included; a field reconnaissance, review of topographic and geologic data published by the California Geological Survey (formerly the California Division of Mines and Geology), review of geotechnical reports prepared by Ninyo & Moore and others, review of stereoscopic aerial photographs, and geotechnical analysis of the data obtained.

Based on discussions with you, we understand that the Leucadia Water District (LCWD) is concerned about the formation of mineral deposits (scale) within some vitrified clay sewer pipelines near the eastern portion of Carlsbad. Recently a backhoe was used to excavate a section of the subject pipeline along Cebu Place. After the pipe was removed from the trench, scale deposits were reported coating the inside of the pipe. We understand that the composition of the mineral scale will be evaluated by others. During the excavation and removal of the pipe, significant groundwater was reported in the trench excavation. A map depicting the approximate extent of the scale problem area was provided to us by you, and is depicted on Figure 1.

5710 Ruffin Road ▪ San Diego, California 92123 ▪ Phone (858) 576-1000 ▪ Fax (858) 576-9600
San Diego ▪ Irvine ▪ Ontario ▪ Los Angeles ▪ Oakland ▪ Las Vegas ▪ Salt Lake City ▪ Phoenix

The project area, which has been graded and developed, consists mostly of single family residences, and is situated in an area consisting of a gently sloping broad valley surrounded by rolling hills and moderately steep terrain with numerous incised drainage courses. Much of the scale problem area, particularly in the east, is bounded on the north, east, and south, by higher ground. Elevations across the project generally range from approximately 300 feet relative to Mean Sea Level (MSL) near the southwestern portion of the site, to over 700 feet MSL near the south-southeast portion of the project area. Prior to development, the mid- to west portion of the project area consisting of gently sloping terrain apparently was utilized as an agricultural area. The surface water flow is generally toward the west and, also prior to development, a small reservoir was present near the west side of the project area, which is visible in stereoscopic aerial photographs dated April 11, 1953. Also, a historical document (United States Geological Survey, 1919) indicates that there was a water well, nearby west of the site. Unfortunately, there was no information as to depth to groundwater in the document.

Our review of published geologic and topographic maps and boring data indicates that fill materials, the Eocene-age Santiago Formation, and the Santiago Peak Volcanics locally underlie the project area. The Santiago Formation, mapped in western portions of the problem area, generally consists of weakly indurated, fine-grained sandy claystone, and weakly cemented, clayey to silty fine- to medium-grained sandstone with local conglomerate lenses. The Santiago Formation is in turn underlain by the Jurassic-age Santiago Peak Volcanics, which generally consists of resistant metavolcanic and metasedimentary rock. These rocks are expressed topographically as the somewhat prominent ridges and outcrops on the east to southeast portion of the project area.

During pre-development geotechnical evaluations at nearby sites to the north (Geocon, 1993), groundwater was reported in several exploratory trenches and borings. In these pre-development evaluations there were also reports of small springs and seeps. Hence, there are reports of naturally occurring groundwater at relatively shallow depths in the project vicinity. During our field reconnaissance of the local neighborhoods, we did observe very well watered yards. In addition, irrigation water was observed draining off residential properties and flowing down the street gutters. Based on our findings, the source of groundwater at the project area can be from natural occurring sources and/or manmade sources, such as irrigation water and pipeline leaks.

As discussed, the subject problem area may be underlain by local fill soil situated over a relatively impermeable subsurface basin, as rocks of the Santiago Peak Volcanics are present on the east, north, and south, and likely underlies the Santiago formation and fill materials. Accordingly, irrigation run-off, or preexisting subsurface water may be collecting in this area and pooling in the relatively permeable sewer trench backfill. The trenches may be performing a similar function as a French drainage system with no outlet.

Based on our geotechnical field reconnaissance and background review, it is our opinion that the groundwater observed in the subject sewer trench is likely due to a perched groundwater condition where water from either manmade and/or natural sources has collected in the trench backfill and has ponded or pooled due to a relatively impermeable geologic rock. This material may consist of claystone bedding in the Santiago formation, or may be a resistant unit in the Santiago Peak Volcanics. Our opinion is based on the reported presence of groundwater, geologic structure, and topographic features and elevations in the vicinity of the problem area. Our data do not indicate that there are high groundwater conditions throughout the scale problem area. A review of our in-house data base revealed that two borings were drilled in Alga Road, one just north of where the sewer pipeline was potholed and one nearby to the west of the pothole area. These borings were drilled by Ninyo & Moore (2002) for a proposed recycled water distribution pipeline. One boring was located in Alga Road just east of Corintia Street and was drilled to a depth of 11.5 feet, whereas, the other boring was drilled in Alga Street near Cazadero Drive to a depth of 8 feet. Neither of the two borings encountered any groundwater. It can be speculated that the source of the water, either natural or manmade, in the sewer trench is from a point source(s) up gradient (to the east) of the pothole location. This water could migrate down gradient through the backfill materials, particularly if they are very permeable and there are no cut off walls. We recommend that construction documents such as geotechnical technician reports or contractor or City reports be reviewed for any mention of groundwater seepage during construction of the sewer pipeline.

Please note that our evaluation did not have the benefit of a site-specific subsurface evaluation and associated laboratory testing. Variations may exist and conditions not observed or described in this report may be present which would change our conclusions. Uncertainties relative to subsurface conditions may be reduced through project-specific subsurface exploration. A subsurface evaluation may be performed upon request.

If you have any questions regarding this report, please call the undersigned at your convenience. We appreciate the opportunity to be of service.

Sincerely,
NINYO & MOORE

Randal L. Irwin, C.E.G.
Chief Engineering Geologist

Randal L. Irwin
Certified Engineering Geologist
Exp. 9/30/05

RI/msf

Distribution: (1) Addressee

Attachments: Figure 1 – Site Vicinity Map
Selected References

SELECTED REFERENCES

California Division of Mines and Geology (CDMG), 1996, Geologic Maps of the Northwestern Part of San Diego County, California: Open File Report 96-02.

Geocon, Inc., 1993, Preliminary Geotechnical Investigation for Rancho Carrillo Villages F,G, L. M. and P, Carlsbad, California: dated August 27.

Geocon, Inc., 1993, Preliminary Geotechnical Investigation for Rancho Carrillo Villages N, O, Q, R, T, and U, Carlsbad, California: dated February 16.

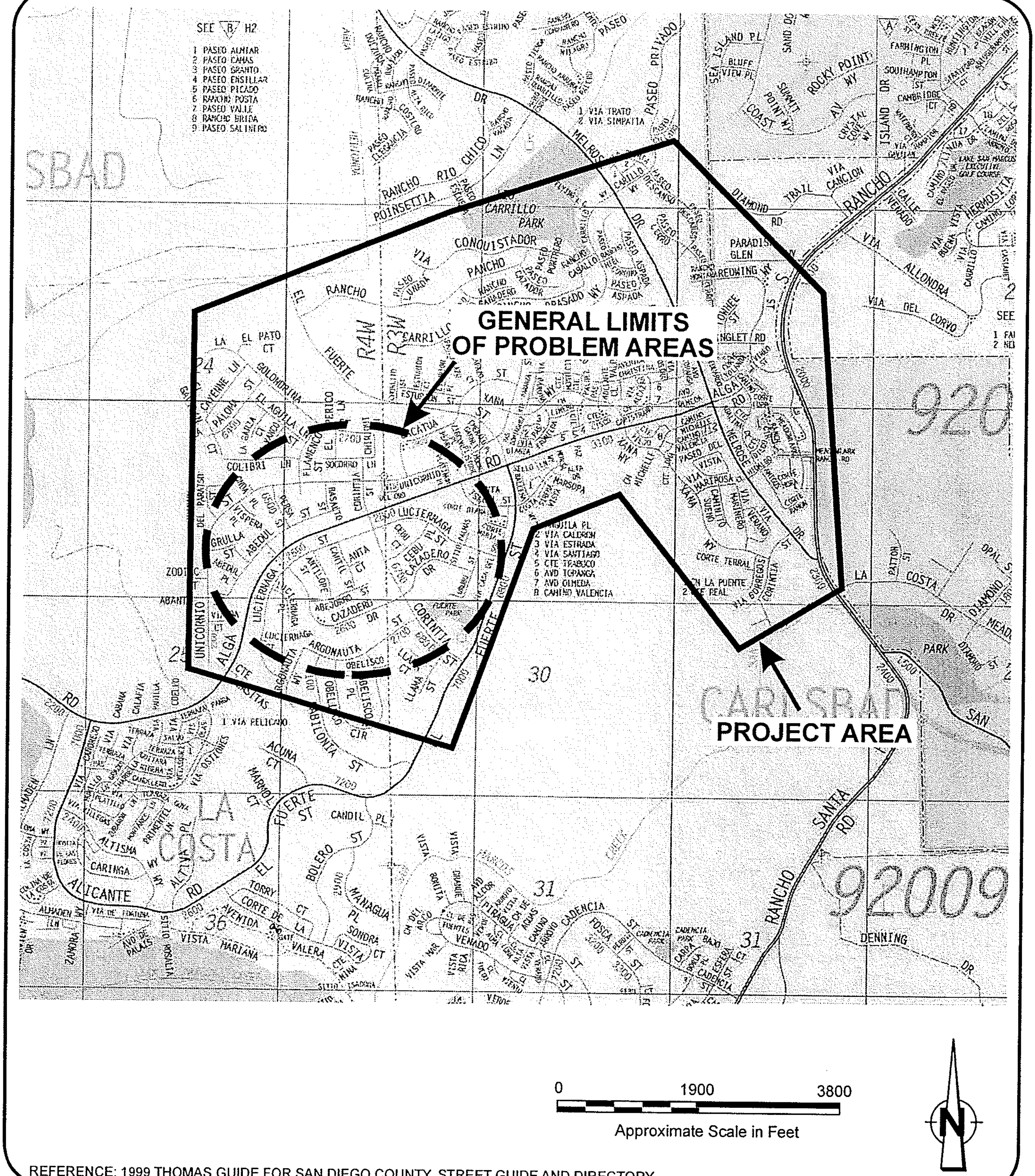
Ninyo & Moore, 2002, Geotechnical Evaluation El Camino/Alga Road Transmission Pipeline, Encina Basin Water Reclamation Program, Carlsbad, California: dated May 3.

United States Geological Survey, 1919, Geology and Ground Waters of the Western Part of San Diego County, California: Washington Government Printing Office.

United States Geological Survey, 1968 (Photorevised 1975), Encinitas Quadrangle, California-San Diego County, 7.5 Minute Series Map (Topographic).

AERIAL PHOTOGRAPHS

Source	Date	Flight	Numbers	Scale
USDA	4-11-53	AXN-8M	19 & 20	1:20,000



REFERENCE: 1999 THOMAS GUIDE FOR SAN DIEGO COUNTY, STREET GUIDE AND DIRECTORY

105072001 F SLM Fig 1

Ninyo & Moore

SITE LOCATION MAP

LEUCADIA WATER DISTRICT
PIPELINE SCALE PROJECT
CARLSBAD, CALIFORNIA

PROJECT NO.	DATE	FIGURE
105072001	11/03	1

Appendix 2

McGuire Environmental Consultants
Leucadia Calcite Dissolution Report

McGuire
Environmental
Consultants, Inc.

"Quality services that ensure safe drinking water"

Friday, January 16, 2004

Mr. Mark Iverson
PBS&J
3610 Central Avenue
Suite 500
Riverside, California 92506-5907

Re: Results of Leucadia Calcite Scale Dissolution Experiments

Dear Mr. Iverson,

McGuire Environmental Consultants, Inc. has completed our preliminary investigation for screening chemical cleaning techniques to dissolve in-situ calcite scale in the Leucadia sewer system. The following is a draft report detailing our selection of cleaning agents (two types of acid, singly and in combination), the methods used to conduct our trial experiments, the results, and our recommendations.

We are confident that the two-acid combination we recommend will remediate the build-up of calcite scale in the sewer pipes. However, conditions that cannot be duplicated in the laboratory require a demonstration in the field to determine parameters (effects of CO_2 gas production, in-situ mass of calcite, final pH, etc.) that will impact the logistics of conducting the main rehabilitation in the field.

Please call me with any questions regarding these results and their potential use in the field.

Best Regards,

Jon Loveland

Enc.

McGuire
Environmental
Consultants, Inc.

"Quality services that ensure safe drinking water"

In-Situ Chemical Cleaning Methods to Rehabilitate Accumulation of Scale in the Leucadia Sewer System

Unique hydrological and geochemical conditions are hypothesized to have caused precipitation and build-up of mineral scale in a portion of the Leucadia sewer system. The mineral scale sections removed from representative sections of the impacted portion of the Leucadia sewer system were found to be predominantly composed of calcium carbonate, also known as calcite. Experiments were conducted to investigate the potential for *in-situ* chemical methods of scale removal, primarily via scale dissolution, as a means of pipe remediation and maintenance.

Dissolution of Calcite

The dissolution of calcite is readily achieved in aqueous solutions, and is function of pH, carbonic acid concentration, and the relative degree of calcite saturation (solubility). The dissolution rate of calcite increases below pH 5 – 6, and at vary low pH values, the dissolution rate is diffusion-controlled. This means the dissolution rate is so fast that the rate becomes a function of how fast the newly dissolved ions are transported away from the mineral surface (thus allowing more dissolution to take place), and is a key consideration for providing mixing and turbulent conditions in the pipe such that the dissolution rate is maximized.

Solubility of Calcite

Calcite is a fairly soluble mineral with respect to the continuum of mineral and soil types, and is intermediate between more soluble minerals, such as gypsum (calcium sulfate), and more stable minerals, such as aluminosilicates like clays and quartz. The solubility of calcite is an important endpoint for this method of pipe rehabilitation, because it is desirable to solubilize as much of the calcite as possible in a single application of the cleaning solution. The solubility of calcite is described by its solubility product, which is a function of aqueous calcium and carbonate concentrations. Cleaning methods that result in the generation of carbon dioxide (that is free and able to dissipate from the system) instead of bicarbonate or carbonate species help increase the solubility of calcite and improve remediation efficacy. In addition, the further away from calcite saturation the system is, the greater the dissolution rate. For this application, since the dissolution process may produce alkalinity and increased pH, it is desirable to start at a low enough pH so that the neutralization process does not limit solubility or excessively slow down the dissolution rate.

Selection of Cleaning Agents

Two types of cleaning agents were considered for experimentation: acids, which accelerate the dissolution process, and chelating agents, which complex or bind with calcium and increase solubility. Strong acids, such as hydrochloric (HCl), nitric (HNO_3) and sulfuric (H_2SO_4) are the best candidates for economically producing low pH conditions. Dissolution rates are generally independent of the type of strong acid; the literature reveals that muriatic acid (another name for HCl) has been used for this application in the past; therefore, HCl was selected as a representative strong acid.

Citric acid was also screened as a potential cleaning agent, in part because it is acidic, but also because the structure of citric acid is composed of three carboxylate (COOH) groups, some of which may complex calcium. The trade-off when using citric acid is that it is considered a "weak" acid, and equivalent concentrations of citric acid will not produce as low a pH as the strong acids will.

Finally, in consideration of the benefits that both types of acids have for calcite dissolution, a mixture of HCl and citric acid was tested. From a practical standpoint, mixtures of these two acids is safe, provided that the acids are added to water to produce the desired concentrations, and that approximately equivalent (within an order of magnitude or a factor of 10) concentrations of acids are mixed.

Methods

Experiments were conducted by suspending sections of calcite scale in approximately 1 liter of cleaning solution in an open, continuously stirred beaker. Calcium release and pH were monitored over a 24-hour period. While the surface area and cleaning solution volume to surface area ratio may be greater under these conditions than what may be experienced in the field, these factors are considered less important than the order of magnitude effect pH values and cleaning agent selection may have on the efficacy of calcite dissolution.

Results

Conditions of Section After 8 Hours of Reaction

As expected, all three conditions tested resulted in calcite dissolution (Table 1), but only the combination of HCl and citric acid results in near-complete dissolution of the calcite scale. In all three cases, equilibrium was reached and dissolution progress ceased after 8 hours. The final mass of each section is only approximate; the sample was air-dried for 3 days and then weighed.

Table 1: Section Mass and pH

Experiment	Mass of Section (grams)		pH	
	Initial	Final	Initial	@ 8 hrs
5% Citric Acid	26	17.4	1.75	3.3
1% HCl	24	17.6	0.83	6.1
5% Citric + 1% HCl	23	***	0.62	2.7

*** *Impossible to determine, as only a few small fragments remained in the beaker. Mass loss is estimated at 90 – 95 %.*

Kinetics of pH change

Because the dissolution of calcite results in carbonate species, pH is a direct measurement of reaction progress. Changes in pH were markedly different for the cleaning agents tested (Figure 1). While the dissolution of calcite necessarily consumes acid, changes in pH are also a reflection of the type of surface reactions, i.e., proton adsorption in the case of HCl dissolution and proton and citrate adsorption for citric acid dissolution. In addition, the presence of citric acid acts as its own pH buffer due to its polyprotic, weak acid nature. Increases in pH were more rapid for the system containing only HCl, and reached a point fairly quickly where the rate of dissolution slows down and calcite solubility decreases. Increases in pH in the citric acid solution were slower, and remained in the region where calcite dissolution is more rapid.

Solubility

Solubility constraints for calcite can clearly limit effective scale removal for this application. While elevated pH is hypothesized to be responsible for incomplete scale dissolution in the HCl system, solubility clearly limited scale dissolution for the 5% citric as evidenced by the formation of a white slurry of calcium carbonate. The addition of HCl to citric acid increased solubility and allowed the near complete dissolution of the scale.

Calcium Release

Calcium release closely matches change in pH for the citric acid and HCl system where dissolution is nearly complete and calcite solubility was not a limiting factor (Figure 2). Calcium concentrations presented here are total calcium concentrations in solution, and do not differentiate between free calcium and calcium complexed by the citric acid.

Figure 1: Change in pH

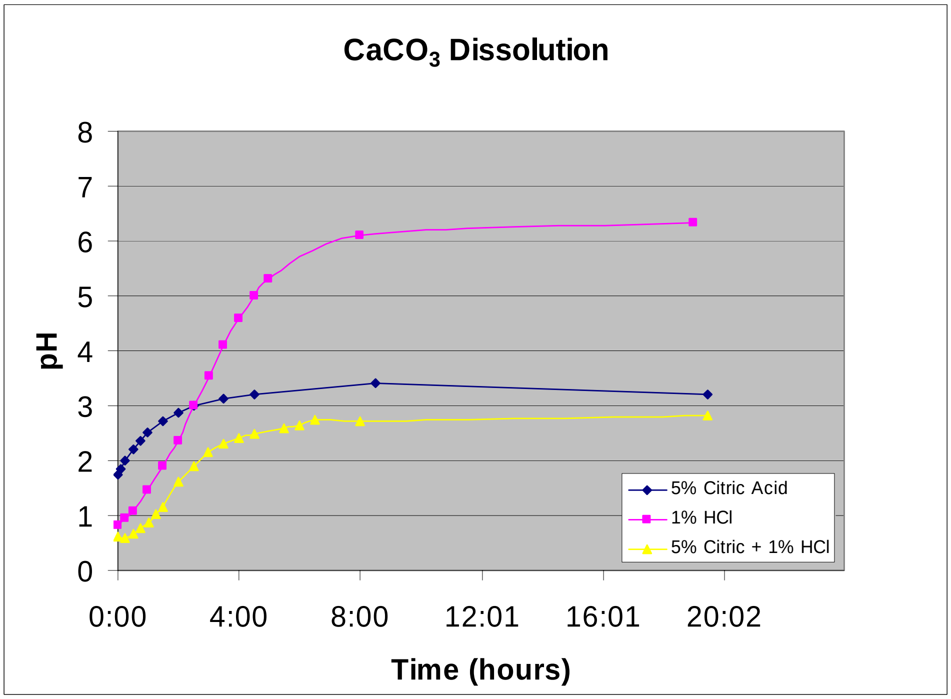
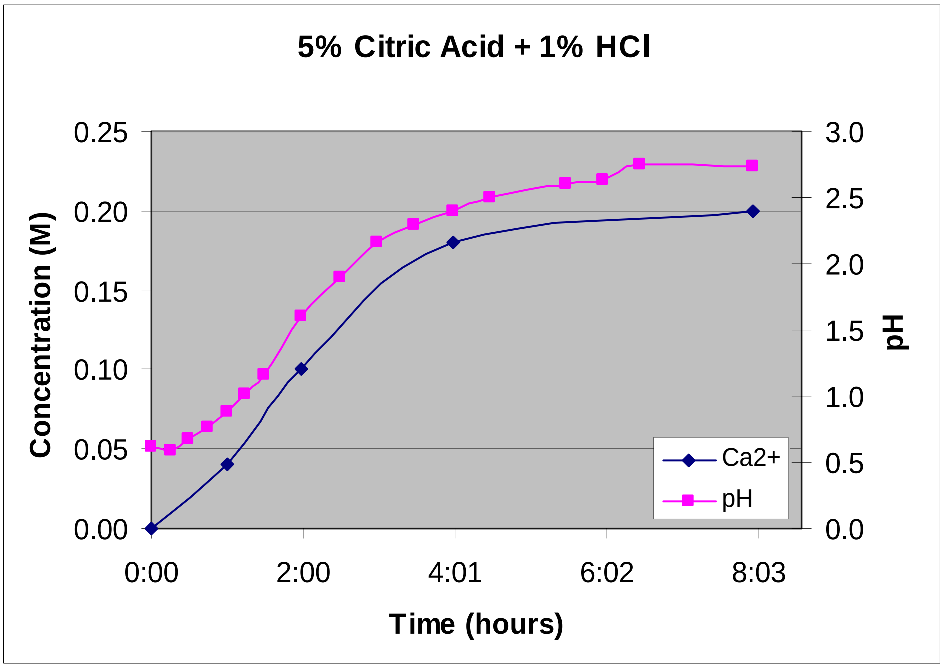


Figure 2: Total Calcium Release



Carbon Dioxide Formation

At the low pH values required for timely scale dissolution, carbon dioxide gas formation is inevitable. Carbon dioxide gas in the dominant carbonate species at these pH values, and rapid dissolution therefore equates to rapid gas formation and evolution. Very visible gas formation was evident in the citric acid experiments, and continued while calcite was present during the HCl + citric acid experiment. Gas production decreased with reaction progress and increasing pH for the HCl and citric acid-alone experiments. Gas production also resulted in the formation of a moderate foam-layer that likely consisted of surfactants and surfactant-like materials that were co-precipitated in the calcite scale. Gas production may aid in creating turbulent conditions and providing for transport of reactions products away from the calcite surface.

Recommendation

Sewer main rehabilitation to remove calcite scale using chemical dissolution techniques may be accomplished during a 4 – 8 hour time interval using a mixture of:

- 2 – 3% HCl
- 5 – 10% Citric Acid

The experimental results demonstrate that neither of these acids alone would accomplish a reasonable amount of scale removal in a reasonable time frame.

Use of these acids at these concentrations should be safe if proper handling and safety precautions are used. These concentrations should also represent some margin of excess over those concentrations tested that may account for deviations in conditions between those tested and those which will be encountered in the field. A demonstration test in the field on a representative section of sewer main would confirm that the experimental conditions tested are effective in the field.

Limitations of Method

The choice of acids, acid concentration, and experimental method have several important limitations that should be considered when extrapolating experimental results to in-situ conditions in a typical sewer main:

1.) Concentrations were selected that would result in safe operating conditions and scale dissolution within a reasonable period of time. Use of stronger, more concentrated acid solutions may result in faster dissolution and provide a larger margin of safety in guaranteeing complete scale dissolution, but also present a serious risk of effects related to rapid formation of carbon dioxide gas. The handling of carbon dioxide gas should be considered and provided for.

2) Real dissolution rates and extent of scale removal may deviate from those observed for a variety of reasons, including:

- the mass of calcite scale may be more (or less) in some sections of the sewer main than that tested;
- the surface area available and accessible to the cleaning solution may vary from that tested;
- mixing, turbulence, and diffusion may differ from the stirred conditions employed during experimentation; and
- carbon dioxide gas evolution may differ from the stirred conditions employed during experimentation.

Appendix 3
Cost Estimates

Leucadia Wastewater District
Scale Formation Evaluation
Pipeline Cleaning Costs

Alternative 5 - Plug, Fill & Flush Method

Item	Quantity	Unit	Unit Cost		Total	
Flow Monitoring	3	Locations	$2,000	Location	$6,000	
Video Inspection						
Before	45000	LF	$1.00	LF	$45,000	
After	45000	LF	$1.00	LF	$45,000	
Cleaning Chemicals	150,000	gallons	$0.45	gallon	$67,500	
Chemical Delivery	75	loads	$250	load	$18,750	
Cleaning Crew	450	hours	$135	per crew	$60,750	2 people
Vactor Crew						
Sewage Pump Out Crew	450	hours	$250	per crew	$112,500	2 people & Vac Truck
Hydro-Flush Crew	90	hours	$250	per crew	$22,500	2 people
Supervision	450	hours	$50	per hour	$22,500	
				Sub-Total:	**$400,500**	
Engineering					$40,050	10% of Implementation
Contingency					$132,165	30% Contingency
				Total Estimated Project Cost:	**$572,715**	
					$13	per LF

Cost Estimate Assumptions

Sewer Diameter = 8 inches dia
Area of Pipe = 50.27 sq in
0.35 sq ft
Volume/Foot of Pipe = 2.61 gal/ft
Volume/MH = 94 gal/MH
Total Length of Sewer = 8.6 miles
45,408 LF
45,000 LF Use for Planning Purposes
Estimated No. of MHs = 200 MH

Volume of Acid Required:
Pipelines 118,561 gal
Manholes 18,799 gal
Total: 136,295 gal
150,000 gal Use for Planning Purposes

Estimated Chemical Loads: 2000 per load
75 Loads

Estimated Project Duration
Average Work Day 10 hours per day
Average Production 1000 ft per day
Estimated Time to Complete 45 days
450 hours

Leucadia Wastewater District
Scale Formation Evaluation
Pipeline Replacement & Rehabilitation Costs

Pipeline Replacement

	Quantity	Unit	Unit Cost	Cost	
Install Pipe	45,000	LF	$20.0	$900,000	
AC Demolition and Replacement	45,000	LF	$40.0	$1,800,000	
Trench Excavation and Backfilling	45,000	LF	$10.0	$450,000	
Shoring and Dewatering	45,000	LF	$18.0	$810,000	
			Subtotal:	$3,960,000	Construction Cost
Engineering				$594,000	15% of Construction Cost
Construction Management				$396,000	10% of Construction Cost
Contingency				$1,485,000	30%
				$6,435,000	
				$143	per LF

Pipeline Rehabilitation

	Quantity	Unit	Unit Cost	Cost	
Rehabilitation	45000	LF	$50	$2,250,000	
Engineering				$225,000	10% of Rehabilitation Cost
Construction Management				$45,000	2% of Rehabilitation Cost
Contingency				$756,000	30%
				$3,276,000	
				$73	per LF

Leucadia Wastewater District
Scale Formation Evaluation
Pipeline Replacement Costs

Unit Cost Break-up (On 1000 ft length basis)

	Length (FT)	Width (FT)	Area (SF)	Area (SY)	Cost / SY	Total Cost	Cost / FT	
AC Demo	1000	8	8000	889	$4.75	$4,222.22	$4.22	Means / 2001

	Length (FT)	Width (FT)	Depth (FT)	Tons	Cost / Ton	Total Cost	Cost / FT	Means / 2001
Dispose of AC	1000	8	0.33	168	$70.00	$11,753.09	$11.75	

	Length (FT)	Width (FT)	Depth (FT)	V (CY)	Cost / CY	Total Cost	Cost / FT	
Trench Excavation	1000	3.5	7	907	$4.39	$3,983.52	$3.98	Means / 2001

	Length (FT)	Cost / FT	Total Cost	Cost / FT	
Shoring and dewatering	1000	$18.00	$18,000.00	$18.00	Industry Standards

	Length (FT)	Width (FT)	Depth (FT)	V (CY)	Cost / CY	Total Cost	Cost / FT	
Install Bedding	1000	3.5	0.33	43	$12.00	$513.33	$0.51	Means / 2001

	Length (FT)	Cost / FT	Total Cost	Cost / FT	
Install 8" Extra Strength VCP Pipe	1000	$20.00	$20,000.00	$20.00	get-a-quote.net/ manufacturer

	Length (FT)	V (CY)	Cost / CY	Total Cost	Cost / FT	
Backfill	1000	907	$5.58	$5,063.33	$5.06	Means / 2001

	Length (FT)	Width (FT)	Area (SY)	Cost / SY	Total Cost	Cost / FT	
Pavement Replacement	1000	8	889	$24.00	$21,333.33	$21.33	Means / 2001

Pipe unit cost	$20.00
Other Costs	$64.87
Add 5.4% for cost index	$3.50
Total Cost	**$88**