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Approach to Inspecting Large Diameter Concrete Pressure Pipe, Bar-Wrapped, Steel Cylinder Type (AWWA C-303)

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ABSTRACT: Contra Costa Water District operates and maintains, on behalf of the US Bureau of Reclamation, a 5 mile long, 42''- 60'' concrete pressure pipe, bar-wrapped, steel cylinder type pipeline (AWWA C-303). This pipeline, known as the Shortcut Pipeline, is the backbone of the primary conveyance system that continuously provides untreated water to the City of Martinez and several industrial facilities. The pipeline is rarely taken out of service so as to minimize customer impacts. Access for inspection, maintenance, and repairs is restricted as the Shortcut Pipeline transverses wetlands, sensitive habitat, and several waterways. Due to the criticality of the pipeline, history of differential settlement and prior leaks, and the potential for settlement or displacement during an earthquake, the District embarked on a Rehabilitation and Inspection Program to replace valves and appurtenances, build access to high-priority locations, and inspect the pipeline. Inspection of the pipeline reflects a multifaceted approach that includes visual inspections, CCTV inspection, analysis of pipe coupons, and acoustic leak detection. Results from these inspections will allow the District to prioritize areas for further investigation and ultimately to recommend improvements that will provide the required system reliability.

Development of an inspection plan should be strategic and specific to the pipeline. The applicability of different tools largely depends on the risk and failure mechanisms, shutdown constraints, location and accessibility. Opportunities to collect and evaluate pipeline information without incurring significant costs may also be identified. This paper identifies the District's approach to inspection of the Shortcut Pipeline.

1. INTRODUCTION

In 2008, the District embarked on a Rehabilitation and Inspection Program for the Shortcut Pipeline (SCPL), a 5 mile, 42''- 60'' concrete pressure pipe, bar-wrapped, steel cylinder type pipeline. The SCPL provides continuous untreated water to the City of Martinez and several industrial customers in Contra Costa County and, as such, is a critical facility for the District. The District felt that the Rehabilitation and Inspection Program was necessary due to a number of key factors:

- The pipeline has a history of prior leaks;

- Segments of the pipeline are located in areas prone to differential settlement;
- Access to the pipeline for inspection, maintenance and repairs was limited as the pipeline traverses wetlands, environmental habitat and several waterways; and
- Shutdowns of the pipeline were difficult due to the lack of operable valves and the need to provide constant service to the customers.

2. CONTRA COSTA WATER DISTRICT

Contra Costa Water District was formed in 1936, in response to the growing irrigation and industrial water demands of Contra Costa County. The District is now one of the largest urban water districts in California and a leader in drinking water treatment technology and source water protection. The backbone of the District's distribution system is the 48-mile Contra Costa Canal (Canal), which transports water from screened intakes in the Sacramento-San Joaquin Delta to its treatment plants and municipalities, industry, and local water companies. The SCPL bypasses the last 22 miles of the Canal and is the primary means of conveyance to local, untreated water customers. The District stores untreated water in four reservoirs, the largest of which, Los Vaqueros, has a capacity of 160,000 acre-feet. The District operates three water treatment plants: Ralph D. Bollman in Concord, and the Randall-Bold and Brentwood Water Treatment Plants in Oakley. The District delivers safe, high-quality drinking water to 500,000 people in Central and Northeastern Contra Costa County in Northern California.

The District's service area and major facilities are shown on Figure 1.

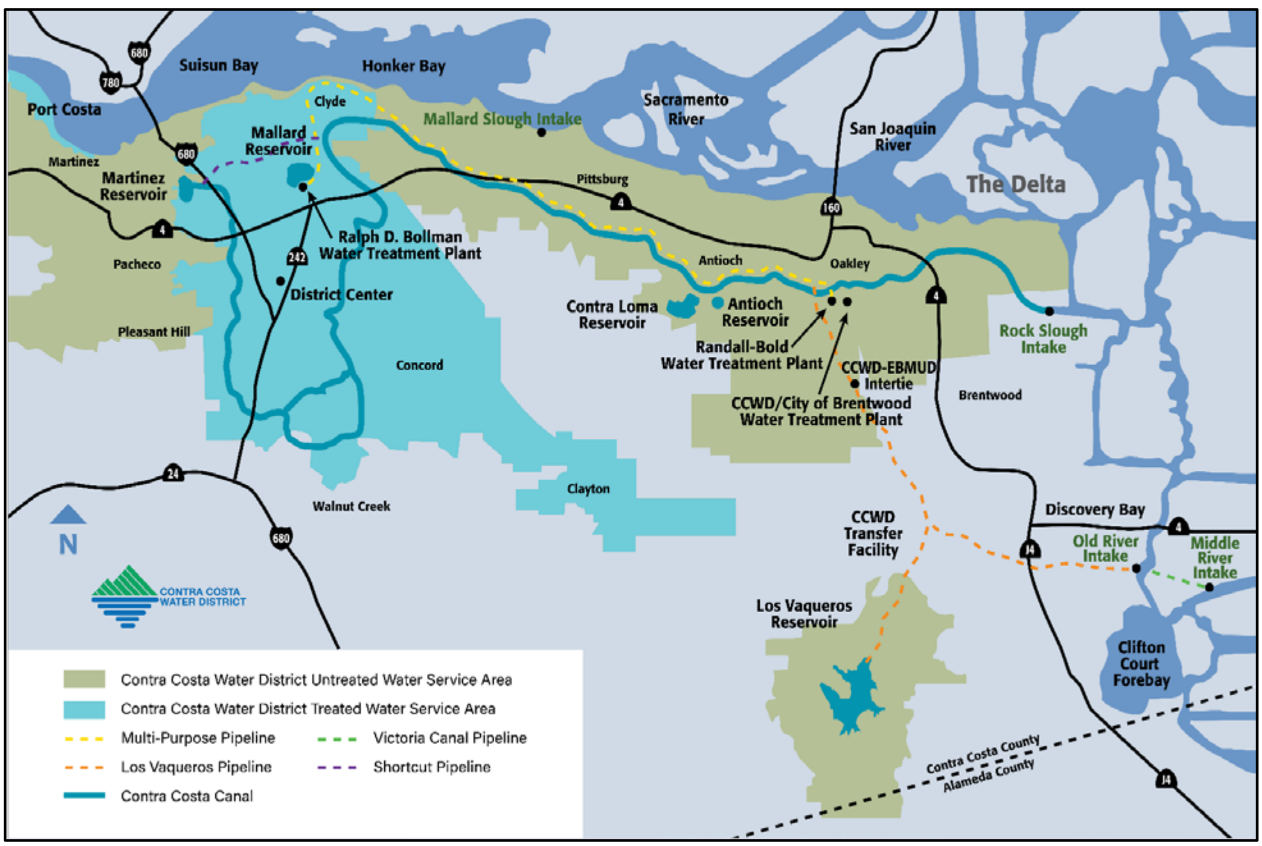

Figure1. CCWD Facilities and Service Area

3. SHORTCUT PIPELINE

SCPL was originally designed in 1970 by the U.S. Bureau of Reclamation and was constructed in 1971/1972 by McGuire and Hester. The SCPL is primarily constructed with 60-inch diameter, 48-inch diameter and 42-inch diameter concrete pressure pipe with some sections of welded steel pipe under levees at Walnut Creek and Pacheco Creek. The concrete pressure pipe has a steel cylinder that is helically wrapped with mild steel bar reinforcement. The pipe is generally referred to as bar-wrapped pipe (BWP) or bar-wrapped concrete cylinder pipe, and is thought to have been designed and manufactured to AWWA C303-70. BWP utilizes a cement-mortar coating placed on the exterior surface of the steel cylinder and reinforcing barwraps to provide protection to the pipe exterior from corrosion. The interior of the steel cylinder wall surfaces is lined with cement-mortar to provide protection to the pipe interior from corrosion. Failure of the interior lining commonly leads to corrosion of the steel cylinder, loss of water-tightness, leakage from the pipeline and accelerated corrosion of the bar-wraps. An excerpt of the pipe submittal is shown in Figure 2 as an example of fabrication approach.

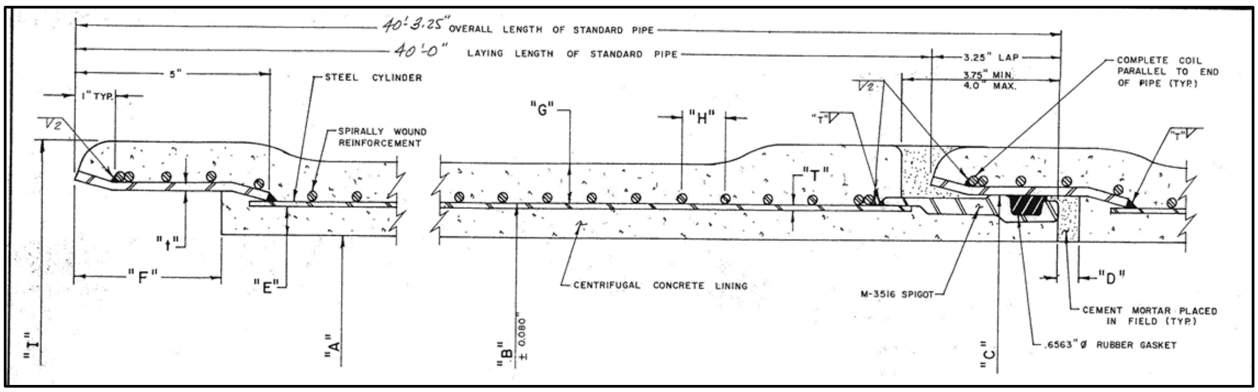

Figure 2. Bar-wrapped pipe

The SCPL alignment was designed for gravity flow conditions from the Contra Costa Canal to the Martinez Reservoir. The SCPL profile has multiple high and low points with corresponding air release and blow-off valves as shown on Figure 3. The pipeline appurtenances include combination air valves (CAVs), blow offs, and isolation valves.

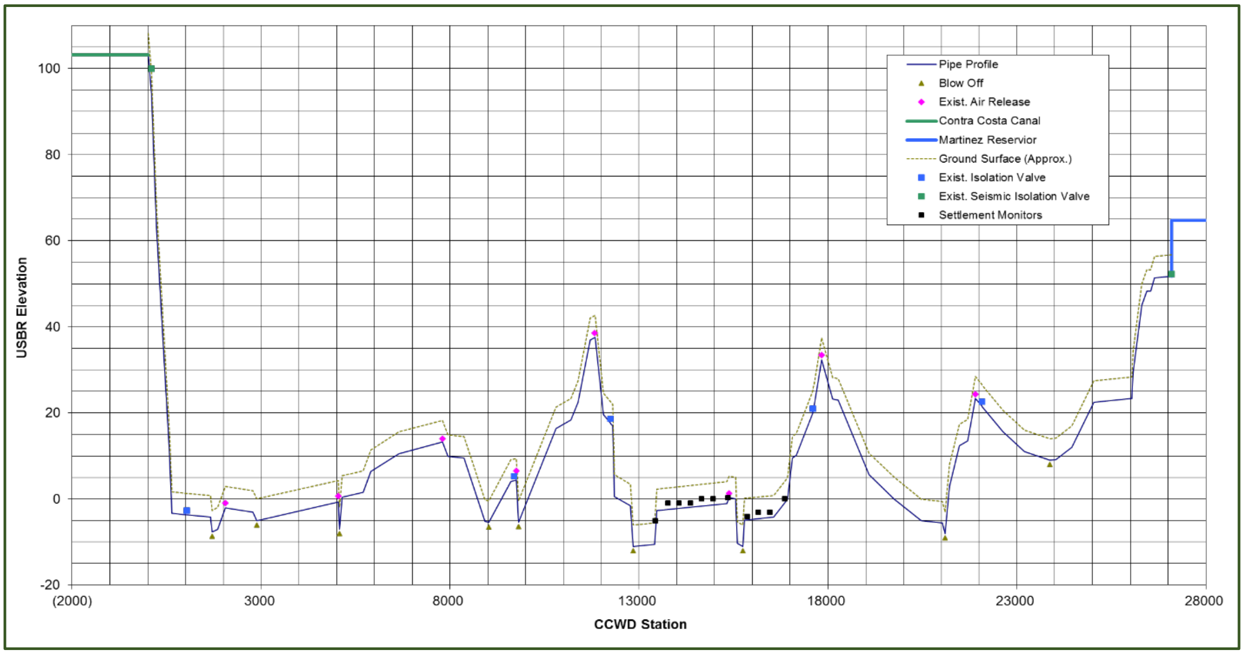

Figure 3. SCPL Profile

The pipeline traverses several environments including wetlands, creeks, and industrial sites that limit access to the pipeline. The pipeline also crosses the Concord Fault in the vicinity of Walnut Creek. Much of the pipeline is inaccessible during wet weather because of standing water and environmental concerns related to wetlands.

The SCPL incurred two failures since construction. In 1989, a failure occurred between Walnut Creek and Pacheco Creek in an area that had storage ponds. The break was located under a storage pond levee that was constructed after the SCPL. A field investigation exposed approximately 100 feet of pipe and found three cracks in the concrete casing of the pipeline and damage to the steel cylinder. The investigation report concluded that the cracks found in the concrete casing may have been caused by the additional weight created by constructing the levee and that the damage to the steel cylinder was consistent with earthquake damage.

A second failure occurred in 2013 near Port Chicago Highway. The pipe failed at the bottom of a steep downhill section. The failure was projected to occur from high stresses. Corrosion was determined to not be a factor.

Figure 4 shows the environments identified above as well as the two failure locations.

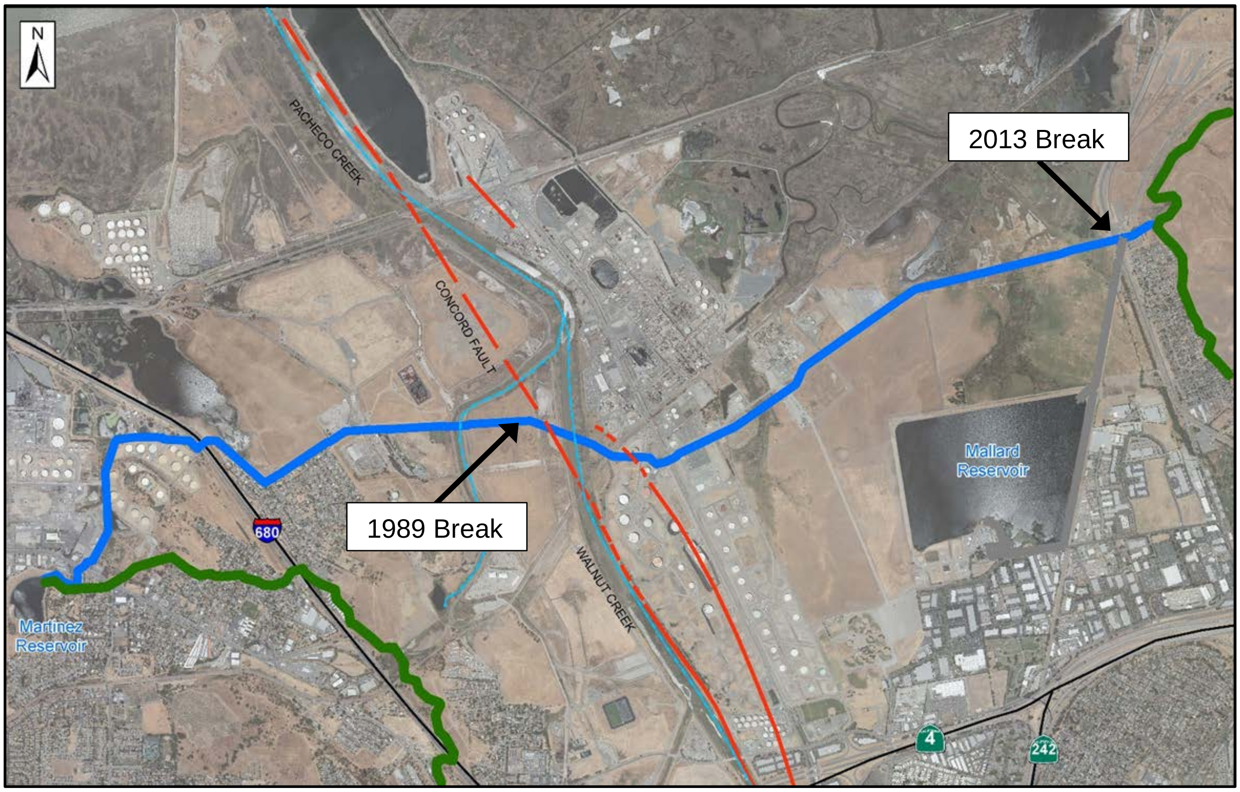

Figure 4 SCPL Alignment

4. RISK ASSESSMENT

The consequences of failure for the SCPL would be significant from a water supply perspective and drove the direction of the risk assessment. The primary consequences of failure are:

- **Service interruption**: Service interruption would impact deliveries of water to Martinez Reservoir, Mallard Reservoir, and several major industrial customers. This would be particularly impactful during summer months when municipal water demand is highest. Impacts to industry would be relatively constant throughout the year.
- **Untreated water discharge**: Untreated water discharges typically have minor impacts on the environment since no toxic chemicals are present in the water. It is anticipated that a significant loss of water delivery would be noticed within a short period of time and the SCPL would be taken out of service and repaired before the fresh raw water would disrupt saltwater marshes or cause significant damage.

The SCPL risk assessment focuses on potential physical failures of the SCPL that could result in substantial leaks or complete loss of untreated water conveyance. The potential pipeline failure mechanisms identified were:

- Differential Settlement
- Corrosion
- Seismic Activity
- Air Management
- Creek Crossings

The impact location of seismic activity and creek crossings is already known, as are exiting air management devices. The key potential failure mechanisms relative to inspection were differential settlement and corrosion and they are discussed below.

<u>Differential Settlement.</u> SCPL is susceptible to differential settlement because of the native soils Bay mud and later fill. Earthquake activity would exacerbate the impacts of Bay mud and fill on the pipeline. These geotechnical hazards are highlighted on Figure 5. Bay mud is located along portions of the pipeline between Walnut Creek and Pacheco Creek and the wetlands between Port Chicago Highway and the Tesoro refinery. The original construction of SCPL included 11 settlement gages located between Walnut Creek and the Martinez Gun Club. Survey data from the settlement monitors is shown on Figure 6 and demonstrates that extensive differential settlement has occurred. The 1989 break in SCPL occurred in this area.

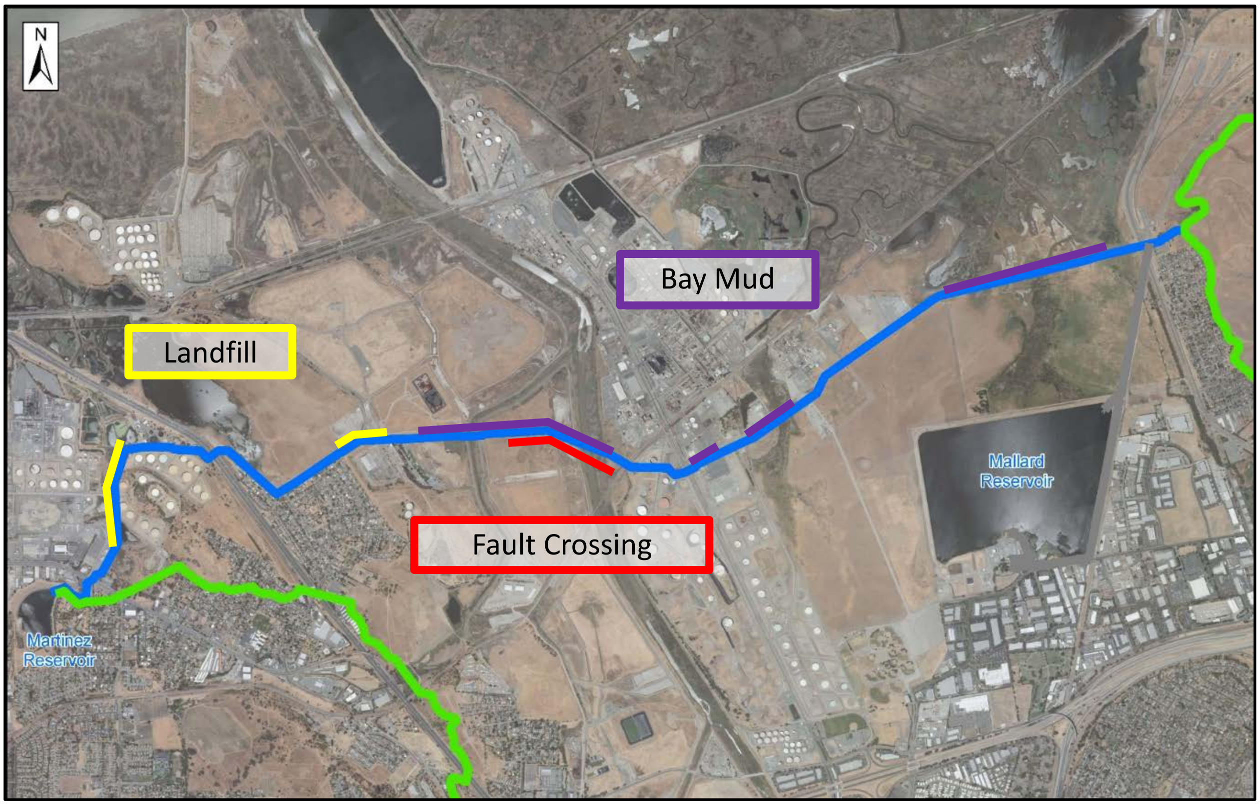

Figure 5. Locations of Potential Failure Mechanisms

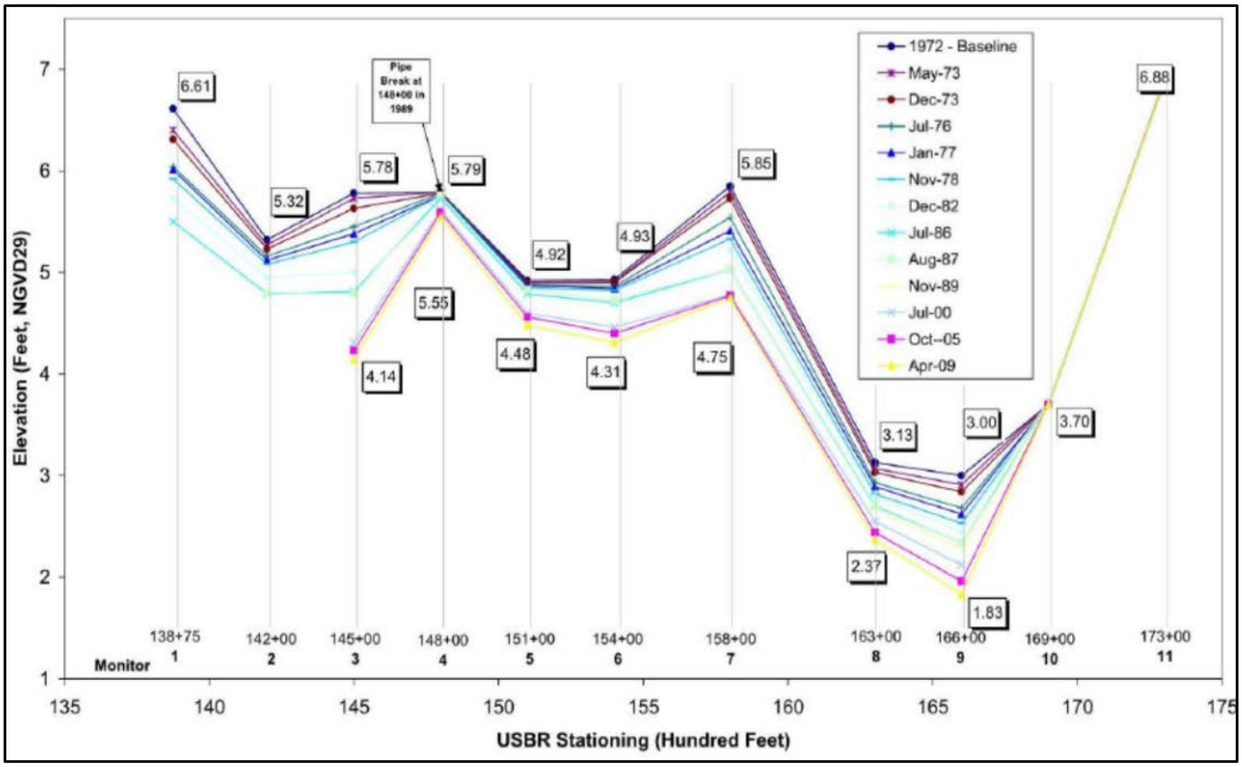

Figure 6. Differential Settlement from 1972 to 2009

Corrosion. The SCPL was constructed with an impressed current cathodic protection system that has been operational and maintained since 1975 and upgraded in 2002. The near-surface soils along the SCPL are classified as highly corrosive to uncoated steel and moderately corrosive to concrete. According to the most recent survey of the cathodic protection system, the SCPL is receiving adequate cathodic protection along its alignment. Accordingly, the potential for failure associated with external corrosion is low due to ongoing preventive maintenance of the cathodic system.

4. SCPL IMPROVEMENT PROGRAM

The District is utilizing a phased approach to improving the condition and reliability of the SCPL.

Phase 1. Phase 1 was constructed in 2012 and replaced air valves, blow-offs and isolation valves in areas that are not environmentally sensitive.

Phase 2. Phase 2 construction is nearing completion. It consists of builiding access roads and replacing air valves, blow-off valves, and isolation valves in environmentally sensitive areas; installing additional settlement monitors; and performing inspections of the pipeline. It also includes performing a condition assessment based on the collected inspection data.

Phase 3. Phase 3 will include repairs and reliability improvements based on results of the Phase 2 condition assessment and overall reliability assessment.

5. CONDITION INSPECTIONS

Inspections of SCPL conducted during Phase 2 construction focus on differential settlement and corrosion. Methods to identify differential settlement include:

- Review of survey records for settlement monitors;
- Acoustic leak detection to identify air pockets;
- Visual inspection at manways to identify sediment accumulation; and
- CCTV to identify sags and pipe defects.

Methods to identify corrosion include:

- Inspection of pipe coupons generated while installing new in-line valves;
- CCTV to identify rust spots through lining; and
- Review of corrosion test records.

To save on costs and impacts to customers, many of these inspection methods were coordinated with Phase 2 construction activities to take advantage of dewatered pipeline and open manways. Only acoustic leak detection required additional coordination with customers for their service line shutdowns.

Figure 7 provides an overview of many of the inspection locations.

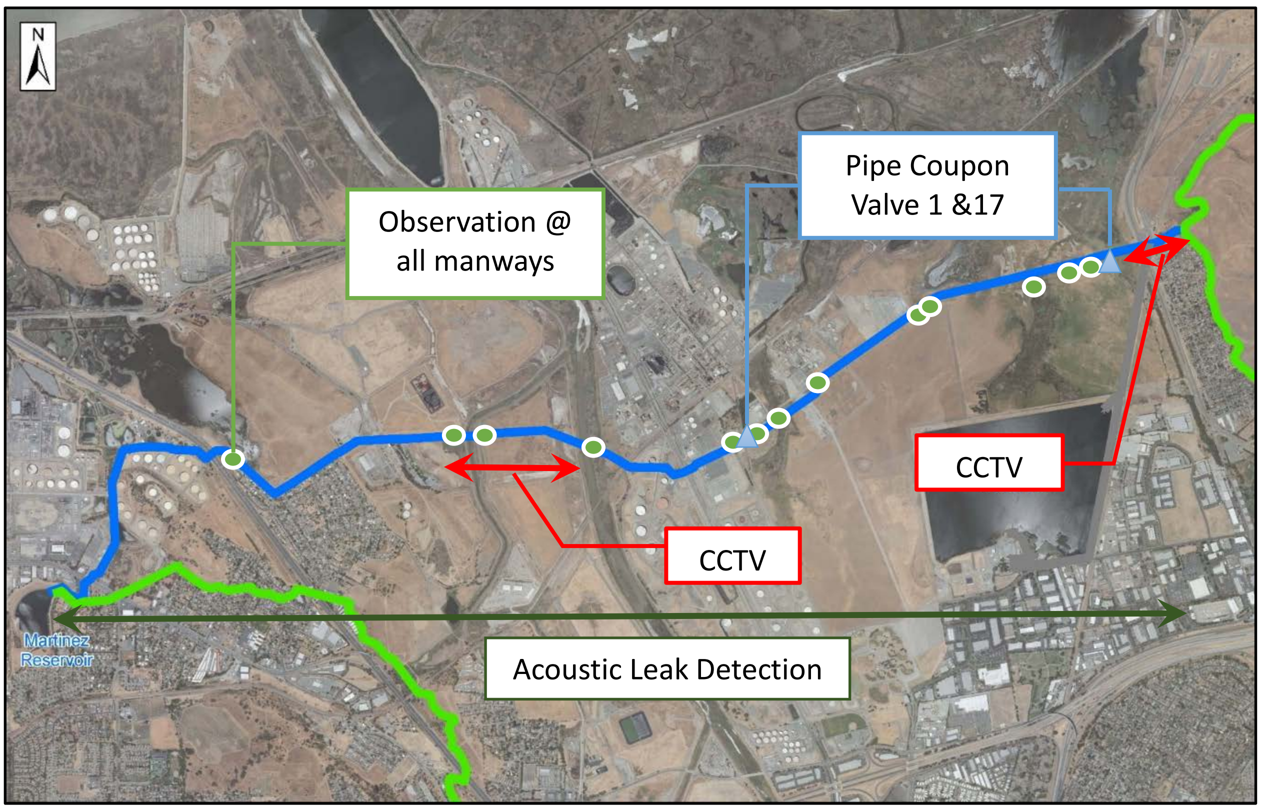

Figure 7. Inspection locations

6. RESULTS

Results of the inspections competed to date and not previously discussed are summarized below.

<u>Visual Inspections</u>. The benefit of visual inspections can be limited but, when the pipeline is accessible anyway, provides a potentially valuable point of information regarding pipeline condition and sediment

accumulation at blow-off locations. Visual inspections through manways found the pipe at those locations to be in very good condition with not loss of interior mortar lining or signs of rust from the pipe metal can. Several hairline cracks of no consequence were observed. The inverts were free of significant debris.

<u>CCTV</u>. CCTV inspection for C-303 pipe will not provide any information on the integrity of the steel cylinder or bars but signs of corrosion on the liner or damage to the liner are indicators of potential issues. Unknown sags are also indicators of potential issues. This inspection method was also coordinated with Phase 2 construction dewatering activities. CCTV inspection was performed for about 2900 lf from Walnut Creek to Pacheco Creek. The pipe was typically observed to be in good condition with the mortar lining in tack and no indications of rust. Several sags of about one foot or less were observed.

A major sag was found under the Walnut Creek levee. The sag is about four feet and over a short distance that includes the rising limb where the pipeline rises from dropping under the creek. The pipeline was constructed with welded joints in this area and significant cracks were observed at both ends of the sag. The sag is shown on Figure 8.

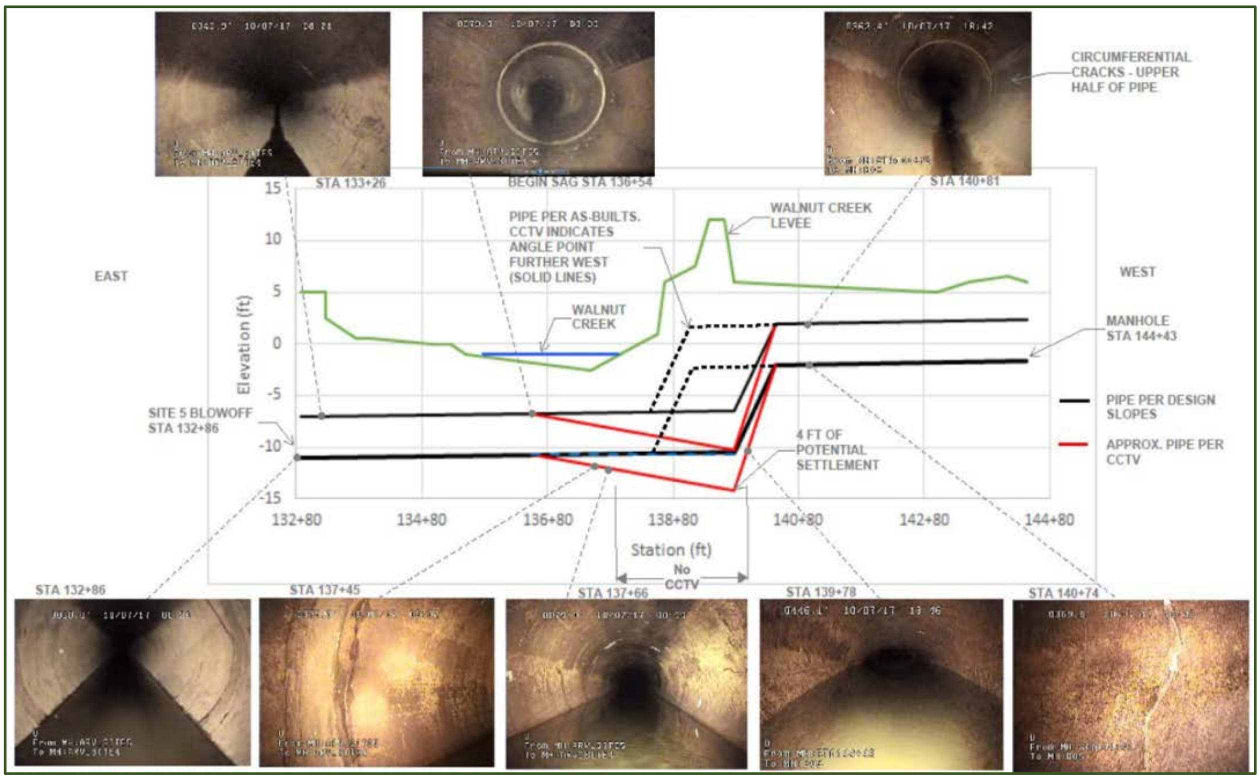

Figure 8. CCTV inspection at Walnut Creek levee

<u>Acoustic Leak Detection</u>. Internal acoustical sensor profiling is the only inspection method used that could identify leaks, which would indicate a failing pipe and condition that could require immediate repair. Acoustic leak detection was performed using a Smart Ball, an inspection product of Pure Technologies. A Smart Ball was used because it allowed inspection of the entire pipeline using a single mobilization while providing critical information (location and magnitude) of leaks and air. The inspection occurred while the pipeline was in service. The pipeline must be in service so that the water flow will propel the Smart Ball. Due to the passive propulsion of the device, all turnouts along the pipeline had to be isolated which impacted customers for a short time. The acoustic data obtained during the inspection are shown on Figure 9. One acoustic anomaly indicative of a leak was found at the downstream end of the pipeline. It was later determined to be caused by the valve used to throttle flow. The inspection did not locate any air pockets.

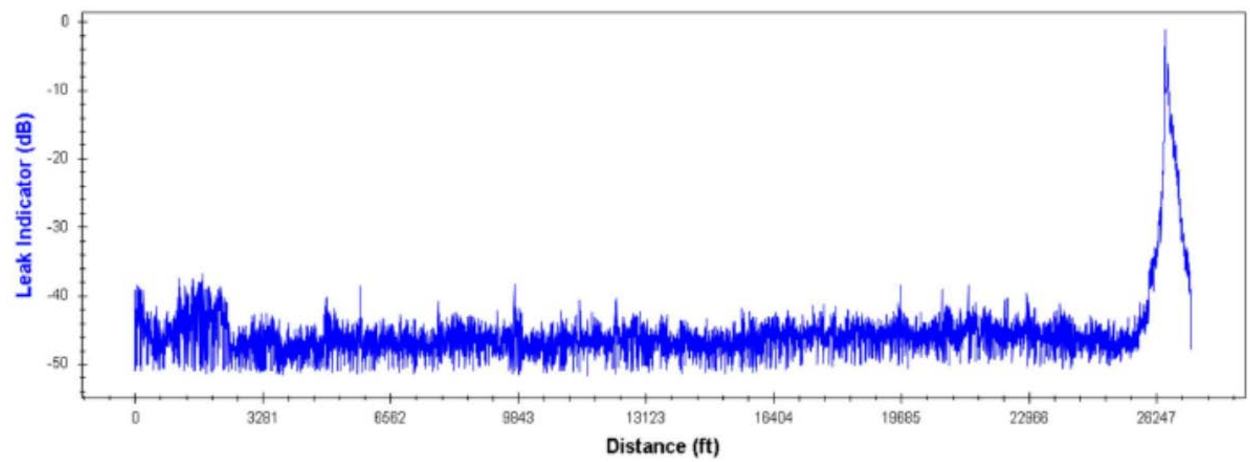

Figure 9. Smart Ball acoustic data

7. NEXT STEPS

Phase 2 construction is still underway. Inspection work to be completed includes:

- Additional visual inspections at manways;
- Second CCTV inspection segment; and
- Evaluation of pipe coupons.

Once these inspections are completed, results will be assimilated to provide an overall picture of pipe condition as well as locations of any defects or threats. Additional inspections may be recommended. If necessary, these inspections will be performed as part of Phase 3. Phase 3 is also anticipated to include:

- Update to cathodic protection test data;
- Update to settlement monitor data;
- Evaluation of long-term monitoring; and
- Develop and implement pipeline repairs.

8. LESSONS LEARNED

Looking back on the experience gained during Phases 1 and 2, several lessons were learned about performing condition assessment of SCPL. The lessons include:

- Develop your inspection plan based on what you need to know about your pipeline and your pipeline environment;
- Be opportunistic when collecting inspection data and take advantage of normal O&M activities and construction;
- Make reasonable interpretations of related data such as settlement data and cathodic test records;
- Use multiple sources of information to confirm facts and verify assumptions;
- Use advanced (aka expensive) inspection methods only where warranted;
- Be an active participant in a vendor inspection. It is important to understand how inspections are performed and quickly address changing conditions; and
- Be skeptical of results that don't make sense. Anomalies in data are common.