Condition Assessment of the Kaw Raw Water Transmission Main and Finished Water Supply Line - Phase 1 Final Report

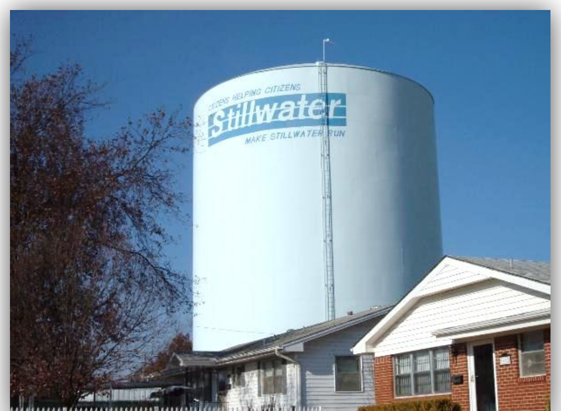
Prepared for

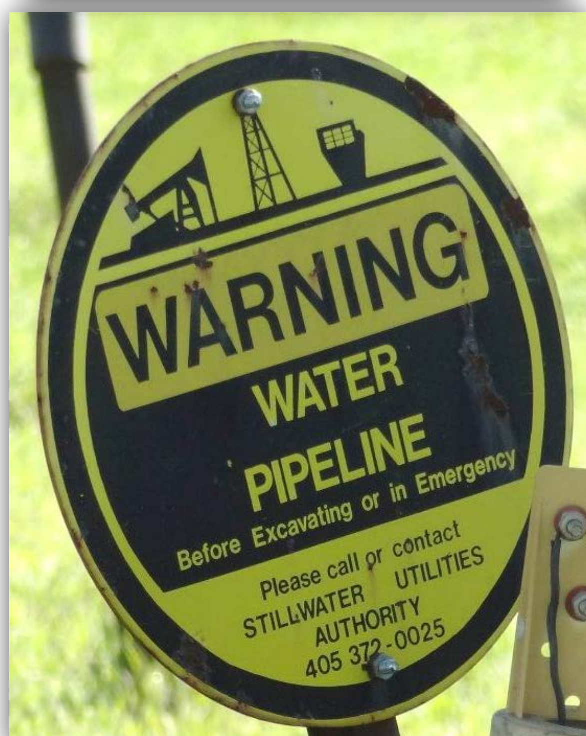
The City of Stillwater
Water Utilities
Stillwater, OK

By

Jason Consultants, LLC
OK PE Firm No. 6523

October 25, 2012





JASON CONSULTANTS

A Subsidiary of Pure Technologies

TECHNICAL MEMORANDUM

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Quality Assurance/Quality Control Statement

By my signature I attest that this report has been prepared and reviewed in accordance with Pure Technologies' Quality Assurance/Quality Control procedures:

Project Manager: Andy Dettmer, Ph.D., P.E. (OK PE No. 25899) Date

TABLE OF CONTENTS

1. Executive Summary

The City of Stillwater owns and operates a 36-inch diameter steel pipeline that transports raw water from Kaw Lake to the City's water treatment plant, a distance of approximately 36 miles, and then finished potable water from the City's treatment plant to the vicinity of the Oklahoma State University (OSU) Water Treatment Plant, a further distance of approximately 6 miles.

The pipeline was constructed in 1981 and is now 31 years old. To date, a total of 21 leaks have been repaired by City crews. The increasing frequency of leaks has raised some concern over the long term performance of the pipeline and raised the question of whether the City should spend approximately $90 million to replace the 42-mile pipeline.

Jason Consultants was retained by Stillwater Water Utilities to carry out an inspection and assessment of the Kaw Raw Water Transmission Main and Finished Water Pipeline. The assessment program was divided into three phases:

1. Phase 1: Leak and air pocket detection, evaluation of the cathodic protection (CP) system, pressure monitoring at the Kaw pump station and hydraulic modeling of the raw water system with subsequent transient pressure analysis.
2. Phase 2: Pipeline condition assessment using in-line direct assessment of internal and external corrosion utilizing magnetic flux leakage (MFL) technology, excavation and verification of MFL results, structural modeling of pipe wall strength, estimation of remaining useful life, and recommendations for repair and rehabilitation.
3. Phase 3: Design a new CP system for the pipeline.

Phase 1 of the overall program has now been successfully completed. Based on the data obtained during Phase 1, the following conclusions can be made:

1. The pipe did not have any leaks or air pockets at the time of inspection.
2. The internal lining of pipeline is failing in some locations.
3. The rate of leak occurrences is increasing.
4. The external coating appeared to be in very good condition at the sites excavated.
5. The pipeline has inadequate cathodic protection and should be upgraded.
6. The raw water pipeline has inadequate surge and vacuum protection and requires upgrades to the pump motors and larger air release and vacuum valves installed.
7. The internal and external condition of the steel pipeline is still unknown. As a result, it is recommended to perform an in-line direct assessment of internal and external corrosion as part of Phase 2.
8. Add two tasks to the Phase 2 scope to address the steel and wooden spikes that were driven into the pipeline during some of the leak repairs. Additional scope items would include internal closed circuit television (CCTV) inspection and running an in-line gauging pig to locate and shear off the protruding stakes prior to running the MFL tool.

2. Project Overview

The Kaw Water Supply Pipeline was designed by William Brothers Engineering Company and constructed by Willbros Energy Services in 1981. The pipeline is now 31 years old. The entire pipeline is 42 miles long, beginning at the Kaw Lake Dam Pump Station just east of Ponca City and proceeds generally south-southwest to the Stillwater Water Treatment Plant (WTP), and then on to the City of Stillwater and the Oklahoma State University (OSU) Water Treatment Plant.

The pipeline is 36-inch diameter (OD) steel pipe, grade API 5L X60, with a 5/16-inch (0.312 inches) wall thickness. The maximum allowable operating pressure (MAOP) for this pipe with no distress would be 520 psi though the fittings were only designed for 300 psi. For corrosion protection, the pipe was coated internally and externally with 3/32" of coal tar enamel, and externally tape wrapped. In addition, the entire pipeline is cathodically protected by an impressed current system.

Stillwater has experienced a number of leaks in both the raw water and finished water sections of the pipelines. To date, a total of 21 leaks have been found and repaired by City crews. The increasing frequency of leaks has raised some concern over the long term performance of the pipeline. Jason Consultants was retained by Stillwater Water Utilities to carry out an inspection and assessment of the Kaw Water pipeline. The assessment protocol was broken up into three phases. The completed first phase included leak and air pocket detection, evaluation of the cathodic protection (CP) system, pressure monitoring at the pump station and creating a hydraulic model of the raw water system with subsequent transient pressure analysis. The purpose of the first phase was to determine if there were significant leaks in the pipeline that might be of an urgent concern, determine if the CP system is providing adequate protection to the steel pipeline, and determine the susceptibility of the pipeline to extreme transient pressure conditions. Phase I of the overall program has now been successfully completed. Copies of the technology provider and subconsultants reports may be found in Appendices A, B and C. The results of these four tasks, along with conclusions and recommendations for future evaluation efforts are included in this Technical Memorandum.

3. Preliminary Findings and Observations

The Kaw pipeline has experienced 21 total leaks to date. The first leak occurred in 1988 at Station 520+00 (Evans take off) and there have been 4 leaks since March 2012 of this year. The City's operations staff anticipates new leaks at the beginning of each high demand season. New leaks tend to surface when the higher head and flow pumps are put into service. During start-up of the high head pump, line pressure increases and the results pressure surge causes the corroded area in the pipeline to "blow out". During startup the surge is most likely caused by the pump starting up and could be exasperated by air pockets that accumulate in the pipeline.

The pipeline right-of-way (ROW) was inspected for any unusual geotechnical features that might influence the long term performance of the pipeline. Nothing unusual was observed aside from the three water body crossings, two under the Arkansas River and one under OG&E's reservoir

(Sooner Lake). Transition areas, where the pipe is continually being subjected to changing wet and dry conditions can be sources of increased corrosion activity. The pipe thickness in these areas was increased to ½-inch (0.500 inches) and the pipe is encased in 4-inch of concrete.

The pipeline has 22 high points that are not vented by a mechanical combination air/vacuum valve. Manually operable 2-inch air release valves were installed at 21 of these high points. These valves have never been used to bleed off air and their current operating condition is unknown. Entrapped air pockets can reduce the capacity of the pipeline as well as serve as sources for internal corrosion.

In order to carry out the SmartBall leak and air pocket inspection, it was determined that six additional 6-inch taps would be required in the pipeline. The optimum location of these taps was determined during the ROW inspection. Under Jason Consultant’s supervision, Hanson Pressure Pipe made four hot taps in the raw water line and two hot taps in the finished water line. In advance, the City excavated and prepared all locations for the tapping operation. 6-inch flanges outlets were welded to the pipeline and topped with 6-inch gate valves. After the SmartBall inspection, the City installed 2-inch air release valves at these six locations:

- New taps and air release valves installed on the Kaw Raw Water Pipeline:
  - Station 0+00
  - Station 633+48
  - Station 1307+92
  - Station 1931+68
- New taps and air release valves installed on the Kaw Finished Water Pipeline:
  - Station 0+00
  - Station 321+33

Tracking of the SmartBall was performed by attaching 28 SmartBall receiver (SBR) sensors to the pipeline at existing manholes or by new excavations performed by a separate contractor working for the City of Stillwater. Twelve-inch diameter PVC risers were installed on top of the pipe at the locations where an excavation was required to install the SBRs.

The external pipe coating in the vicinity of the hot taps was observed to be in good condition. Five of the six coupons removed for the taps were examined. The steel pipe thickness was measured and confirmed to be 5/16” as specified, with no signs of any external or internal corrosion. Portions of the internal coal tar enamel lining were missing. It is not known if the tapping operation caused the lining to flake away or if the lining was already missing. Coal tar enamel is a distillate and will become brittle with age. During deployment of the capture net to retrieve the SmartBall after each run, pieces of the pipeline lining were collected in the netting. The lining specimens were very angular with sharp edges suggestive of a brittle fracture. The quantity of lining specimens found in the raw water line diminished closer to the Stillwater Water Treatment Plant. None were found in the finished water line. Scott Taylor, Superintendent, states that he has not observed lining specimens in the raw water tank. As the lining ages it becomes more brittle and loses flexibility and adhesion. A sudden transient pressure event (water hammer) would subject the lining to excessive tensile strains that could crack the lining and weaken it. Subsequent transient waves of negative pressure (vacuum) could then pull the lining away from the steel pipe inner wall. The lining shards may break up into smaller and smaller particles as they tumble along the pipeline or portions of the lining may have settled in the low points which might explain why large specimens have not been observed in the raw water tank. The accumulation of large amounts of lining shards at low points could pose a problem to the passage of any full bore intelligent pig such as a magnetic flux leakage (MFL) tool.

The operation of the three DC rectifiers used to provide cathodic protection to the pipeline was checked during the ROW inspection. Two of the three rectifies were not in operation. The two rectifiers were not in service because one had a blown fuse and the other a loose connection. Both were quickly repaired and placed back in operation by City crews. The out of service duration was not known.

4. SmartBall Leak and Air Pocket Detection

SmartBall surveys were performed on the 42-mile Kaw Pipeline to identify and locate any leaks and/or pockets of trapped gas (i.e., air pockets) in each of the pipelines. The SmartBall is a passive device that collects and records acoustic data as it travels through the pipeline. Pure Technologies performed the SmartBall surveys via four deployments occurring between Wednesday, August 15, 2012 and Friday, August 23, 2012.

Review of the acoustic data identified one instance of acoustic activity of potential concern; however, upon further investigation, the acoustic activity was determined to have been caused by a 24-inch lateral (“The Evans Tee”) on the Kaw Water Transmission Main (Station 511+92). The data did not identify any other acoustic activity that resembled a leak or a pocket of trapped gas. The quality of acoustic data was verified at the end of each run through the use of simulated calibration leaks before the SmartBall was retrieved. Additional information on the deployment and execution of the SmartBall inspection can be found in appendix A

5. Cathodic Protection (CP) System Assessment

Det Norske Veritas (DNV) was retained by Jason Consultants to carry out the inspection of the CP system. Initially, DNV found two of the three DC rectifiers not in service. The City staff restored operation within a few days, replacing a fuse in one and correcting a connection in the other.

In an earlier 2006 report, the rectifiers were also found to be out of service. The reliability of these old units is now questioned. Two of the rectifiers are over 30 years old and finding replacement parts is becoming difficult.

Fortunately, no evidence of electrical isolation was found along the pipeline. All metallic structures (manways, vents and blow-offs) also appear to be electrically continuous with the pipeline.

After the rectifiers were placed back in service, DNV carried out their evaluation of the CP effectiveness by measuring the electrical potential between the pipe (at each test station) and a reference copper-copper sulfate electrode placed in contact with the ground. NACE recommends that a minimum negative potential difference of -0.85 volts is needed for proper polarization and protection of any bare steel surfaces from electrolytic corrosion. 65% (20 of 31) of the test stations met the NACE criteria, while 35% (11 of 31) failed. Of the six total test stations on the finished water line, five did not meet minimum standards. The output of the rectifiers had to be increased to their maximum levels in order to provide even these minimum levels of protection.

DNV was also provided a copy of a City report dated 1988 where test station potential measurements had also been made. These measurements show that in 1988, at the time of the test station measurements, many locations in both the raw and finished water line failed to meet the -0.85 volt criteria.

The rectifier output was set to the maximum nominal amount for the evaluation. In many cases, the current output has increased considerably from 1988 and 2006, while still falling short of meeting minimum levels of polarization.

Soil resistivity measurements were also made at seven locations along the raw water pipeline. Although soil resistivity is only one of several soil and groundwater parameters considered indicative of a soil’s corrosion potential, it is generally considered the most important. Using the Wenner 4-pin method, the soil resistivity at four depths was measured. Considering the pipe is typically buried with 4 to 5 feet of soil cover, those measurements at a depth of 5 to 7.5 feet are the most useful. Based on the results from the testing, the native soil can be considered mildly corrosive to corrosive.

6. Pressure Monitoring

High-frequency transient pressure monitoring was carried out using a Telog LPR31i installed on a threaded outlet at the Kaw Pump Station. The purpose of the transient pressure monitoring was to identify and measure water hammer events that may be causing damage to the pipeline. The Telog pressure monitor was set to record pressure 20 times per second and was monitored between July 22, 2012 and September 7, 2012. The highest and lowest recorded pressure during the monitoring period was 197.8 psi and 0 psi respectively, even with a power outage reported by City Staff on August 25, 2012. The highest pressure of 197.8 psi occurred on August 20, 2012 during the startup of one of the large pumps. After the large pump was turned on, the pressure returned to the normal operating pressure of 140 psi within five minutes. During the investigation, City staff requested that the two large pumps not be run at the same time due to concerns of causing damage to the pipe. Since the lowest pressure was 0 psi at the pump station, it is likely that at high points a full vacuum was achieved. The effects of a full vacuum within the pipeline would be very detrimental to the internal lining as well as put the pipe at risk of collapse. These issues were addressed in the Hydraulic Modeling and Transient Analysis below.

7. Hydraulic Modeling and Transient Analysis

Carollo Engineers was retained by Jason Consultants to perform a hydraulic analysis, evaluation and provide recommendations for the Kaw Raw Water Pipeline. A hydraulic model was constructed, calibrated and computed for seven pumping scenarios to determine needed improvements for continued use of the Kaw Raw Water pipeline and mitigate any surge or transient pressures that may be occurring.

The following can be concluded based on the hydraulic and surge evaluation:

1. The current system does not have sufficient time to accelerate and/or decelerate the water column upon pump startup, pump switching, and pump shutdown scenarios particularly in the case where the transition involves the larger pumps.
2. The recently installed 2-inch air and vacuum valves do not have sufficient capacity to prevent vapor cavity formation during a surge event. Additional surge protection measures are necessary particularly in the scenario where both large pumps are operating prior to a power failure.
3. Flow and pressure measurements along the Raw Water Pipeline identified that the roughness coefficient is approximately 110.
4. The accuracy of the surge pressures predicted by the hydraulic model was validated by the Telog LPR31i transient pressure data gathered during the project.

8. Conclusions

Based on the data obtained during Phase 1, the following conclusions can be made:

1. The pipe did not have any leaks during the time of inspection. We expected to find, at a minimum, several small leaks. However, since the pipe experiences pressure surges near 200 psi, it is likely that leaks on this particular pipeline do not start small and gradually increase in size, but instead, leaks are initiated by larger areas of corrosion “blowing out” during the initial pressure spike during pump start-up.
2. The pipe did not have any air pockets at the time of inspection. It is possible that the air pockets are transient in nature and appear at different flow rates. It is unfortunate that air pockets were not identified since eliminating air pockets could have been a source of an increase in flow capacity. However, it cannot be concluded that air release valves are not needed on the Kaw Pipeline for reasons stated in the hydraulics conclusions below.
3. The internal lining of pipeline is failing in some locations. The CCTV video that was performed in 2001 near the leak repair at Evans Tee (STA 520+00) shows the lining to be

detached and missing in several locations. In addition, several pieces of internal lining were caught in the net used during the SmartBall extractions.

4. The rate of leak occurrences appears to be increasing which could be a result of the exponential nature of internal and external corrosion increasing over time.
5. The external coating appeared to be in very good condition at the sites excavated for new hot taps and access for installation of SmartBall Receiver (SBR) sensors.
6. The pipeline has inadequate cathodic protection which should be upgraded if the Phase 2 condition assessment determines the pipeline is worth preserving.
7. The pipeline has inadequate surge and vacuum protection. The pipeline requires upgrades to the pump motors controls and the addition of larger combination air vacuum valves.
8. The internal and external condition of the steel pipeline is still unknown. As a result, it is important to perform an inline internal and external corrosion direct assessment to locate and quantify areas of corrosion or “tomorrow’s leaks” as a part of Phase 2.

9. Recommendations

Although the inspections and analysis carried out in Phase 1 are important, additional work is still required to understand the condition of the steel pipeline. If the SmartBall leak detection inspection had found hundreds of leaks then we could assume the pipeline is in poor condition and probably near the end of its useful life. Fortunately, that was not the case. In order to structurally assess the condition of the steel pipeline, we recommend that Stillwater move forward with Phase 2 of the project, with some modifications to the original program. The elements that would not change are:

1. A cleaning pig (foam) of would be run through the raw and finished water lines to remove any loose sediment or tuberculation.
2. The Magnetic Flux Leakage (MFL) intelligent pig would be run to measure internal and/or external wall loss
3. Six test pits would be excavated confirming results of the MFL tool with broadband electromagnetic (BEM) or ultrasonic thickness (UT) measurements and visual assessment of pipe exterior
4. A structural model of the pipeline would be created with appropriate loadings to establish performance capabilities
5. Remaining useful life estimated
6. Rehabilitation recommendations developed

In view of the fact that portions of the inner lining have been picked up in the SmartBall retrieval net, and 2002 CCTV footage near the Evans take-off (Sta. 520+00) showed signs of lining deterioration, it is recommended that we perform limited CCTV inspections in the raw water pipeline. The purpose of the CCTV inspections would be to determine if large quantities of the lining are building up at low points in the pipeline, evaluate the condition of the lining, and determine if any of the steel pins used to plug leaks prior to repair are still protruding into the flow stream. This additional inspection service is not included in the original contract. Pure Technologies' robotic crawler, equipped with HD CCTV and sonar, can be inserted through any of the sixteen 24-inch flanged manways in the raw water line. The robotic crawler is capable of traveling up to 8,000 feet from one deployment location (less if bends are within the inspection limits or if adverse conditions are encountered). This task was not included in the original scope.

Given the nature of the method used to repair leaks, it has been recommended by Emtek that multiple cleaning pigs of increasing diameter be run as well as a gauging plate after the cleaning pigs. The gauging plate is an aluminum pig that is intended to break off any obstructions in the pipeline. The deformation of the aluminum plate provides an indication of the size of the obstruction. This task was also not included in the original scope.

Since the output of the rectifiers has increased significantly in recent years in order to maintain proper polarization, this would suggest that the external coating is deteriorating. Visual observations of the pipe during repairs and the six hot taps found the coating to be in relatively good shape. DNV has recommended that after the MFL inspection is complete, that Stillwater consider an enhanced external corrosion assessment which would consist of a Closed Interval Potential Survey (CIS) and DC Voltage Gradient Survey (DCVG). These survey techniques are designed to find locations along a pipeline that are anodic, that may be experiencing active corrosion. These would be areas where the coating is either missing (holidays) or has broken down. It is recommended that these surveys be conducted on a limited basis after the Magnetic Flux Leakage inspection, which will identify areas in the pipeline with metal loss.

As a result of the CP evaluation, it is apparent that the current CP system is now marginal at best and should be replaced within the next few years. The upgrade should also include provisions for remote monitoring of the rectifiers. This would eliminate extended out of service periods by sending an alarm to the WTP when a unit goes down. Jason Consultants proposal included an option for designing an upgraded CP system using computer modeling. Assuming the pipeline is found to have significant remaining useful life, we believe Stillwater should proceed with that option.

The hydraulic modeling and transient analysis has found two immediate deficiencies in the operation of the raw water pipeline. Vapor cavity collapse due to vacuum creation could result in buckling of the steel pipe and destruction of the inner lining. The addition of at least seven 4-inch combination air/vacuum release valves with surge check are needed at Stations 0+00, 190+29, 368+75, 525+00, 633+48, 1307+68 and 1931+68.

Automatic 2-inch combination air/vacuum release valves should be added to the other 15 high points along the raw water pipeline where manual valves now exist.

The two large 100 hp Fairbanks Morse pumps (Model 7000AW) should have 24-pulse or 18-pulse Variable Frequency Drives (VFD) with stepwise programming functions installed to reduce pressure spikes during routine startup, shutdown or pump transition.