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MEMORANDUM

May 18, 2010

TO: North Beach CSO Program Project Team
FROM: Mika Kaplan, PE
SUBJECT: North Beach Pump System Test 11-03-09

This memo includes a description of the pump system testing performed on November 3, 2009 at the North Beach Pump Station, and a discussion of the test results and analysis.

Summary

- The maximum capacity achieved by each of the two large pumps at North Beach was about 2.5 mgd and 2.3 mgd
- The maximum capacity achieved with both pumps running was about 3.0 mgd
- The system curves developed from the test results have very steep slopes compared to the system curve for a new, clean pipe, indicating that there probably is significant degradation in the force main, major blockage, or both
- The lower than expected capacity is most likely primarily due to the force main condition rather than the condition of the pumping equipment

Background

The pumping system at the North Beach Pump Station consists of two sets of two pumps arranged in parallel, installed in 1998. The two smaller pumps have a rated capacity of about 1.3 million gallons per day (mgd) each and are operated at constant speed in a "fill and draw" system. The two larger pumps have a rated capacity of about 3.5 mgd each and are operated through a variable speed drive system. Both the small and large pump systems discharge into a 14" steel pipe force main. There is no in-station flow meter; the North Beach flow is monitored in a vault near the end of the force main at the Carkeek Pump Station with an ultrasonic insertion meter, however, those measured volumes include inflow from an un-metered basin. There has not been any historical testing to monitor station capacity or pump and piping system conditions at North Beach. WTD Engineering was asked to run pump system tests for the larger pumps to determine the ultimate capacity of the existing system at the station, and to provide any other relevant information about the condition of the station equipment and the existing force main.

Testing was performed on November 3, 2009, by Mika Kaplan and Zhong Ji from Engineering & Technical Resources, and Rick Salsbery from Operations. Three months prior to the tests, Greg Vogt from Maintenance overhauled and rebuilt the pumps, including replacing the wear rings (there is no "impeller clearance" to set with these models). According to Greg, there was only about 5% wear on the impellers, and no significant wear around the "cut line" in the pump volute, which is below normal wear for 15 year-old pumps. As the pumps were in as good condition as possible, the tests reflect typical performance conditions for the North Beach station.

During the tests, each large pump was operated individually over its speed range in approximately 100 RPM increments, while the team collected pressure, wet well level, elapsed time and other data. Due to the discharge piping configuration and limited space available, a portable ultrasonic flow meter experienced signal interference and could not be used to monitor flow. Instead, flow was calculated later using the change in wet well volume over time. After the pumps were tested individually, both large pumps were operated together to test the combined capacity. The wet well drained too quickly to test both pumps together over their full speed range, so only their full speed maximum capacity was measured.

Test Results

Data collected at the station and SCADA data retrieved after the tests were used to determine the flow rate and total dynamic head of the pumping system at each of the different tested pump speeds. This information was used to plot system curves, which reflect what is happening in the force main as the pumped volume at the station changes. Then, the variable speed test data was combined and converted to reflect single-speed operation using "affinity laws" in order to plot a pump curve, which was compared with the manufacturer's curve to evaluate the condition of the pumping equipment.

Existing Systems

Figure 1 shows the system curves for both pumps, what the system curve would be for a new, clean 14" steel pipe force main, the manufacturer's full-speed pump curve, and the actual pump curve calculated using affinity laws. The single data point for maximum capacity with both pumps operating is also shown. Following are the highlights of this chart, with an explanation and potential conclusions below:

- The maximum capacity achieved with a single pump operating at full speed was about 2.3 mgd and 2.5 mgd for Pump 1 and Pump 2
- The maximum capacity achieved with both pumps running was about 2.9 mgd
- The actual system curves rise quickly (have a very steep slope) compared to the system curve for a new steel pipe as the flow rate increases beyond 1 mgd
- The actual pump curve is consistently about 17% offset below the manufacturer's curve at the rated maximum speed of 1184 RPM

The offset between the actual pump curve and manufacturer's curve indicates that the pumping equipment may be degraded, however, note that the manufacturer's curve is based on a factory test with clean water. We have no in-station test data from when the equipment was newly installed to compare with our current conditions. This is common with WTD pump stations, and historically, most performance tests have resulted in a similar offset. Since the equipment was removed and rebuilt shortly before this test, it's not clear what can be done to improve performance aside from replacing the pumps entirely. The remainder of this evaluation is based on comparisons with the actual pump curve, which represents the existing system performance and capabilities.

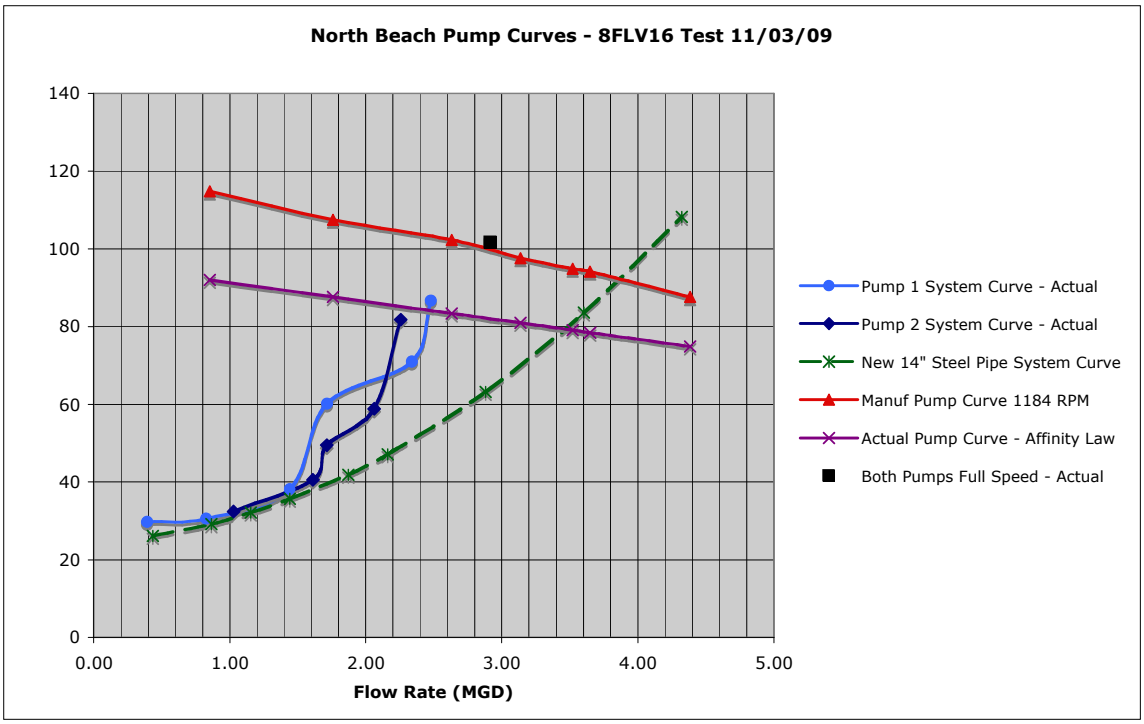

Figure 1: Pump and system curves for existing North Beach systems

Returning to Figure 1, the actual system curves intersect the (actual) pump curve about a full mgd to the left of the new steel pipe system curve intersection. This difference is even greater using the manufacturer's pump curve. What these curves demonstrate is that the pressure in the force main increases with the flow rate more quickly than it is designed to, which shifts the operating point for the pump system to the left of its design curve, to a lower capacity than expected with this equipment. The clean steel pipe system curve intersects the pump curve at about 3.5 mgd, which is the expected design capacity of these pumps. The steep slope and quick rise of the actual system curves compared to the system curve for a new pipe indicates that significant friction losses or pressure gains are occurring in the pipe as the flow rate increases. That is, the pipe is probably either extremely degraded, has large obstructions, or both. If the existing force main can be cleaned, it may be possible to achieve an increase in capacity that approaches the 3.5 mgd indicated by the clean pipe curve.

According to O&M, a large amount of sand and gravel accumulates in the wet well at the

North Beach station, which must be vactored at least once per year. This supports the possibility that the pipe is significantly obstructed. According to the "North Beach Force Main Inspection Report" prepared as part of the "Seattle Metro Final Design Engineering for the Carkeek Transfer/CSO Facilities Project" in 1989, the force main was in very good condition at that time. Their "worst case, conservative estimate" was that "the force main could operate for another 31 years before complete penetration of the pipe wall occurs, resulting in a leak".(p 5). It has been 20 years since that analysis, so based on their estimates the force main would need to be replaced in 11 years, and their projections support the possibility that degradation of the force main pipe is contributing to the reduced station capacity.

Potential Improvements

Engineering & Technical Resources was asked to evaluate if the North Beach station capacity might increase based on improving the condition of either (or both) the pumping equipment or the force main. This evaluation is represented in Figure 2, which shows a system curve for the existing steel force main, what the system curves would be for new, clean 14" and 16" cast iron force mains, the manufacturer's full-speed pump curve, and the actual pump curve calculated using affinity laws. The system curve shown for the existing force main is a "curve fit" calculation based on combined test data for both pumps.

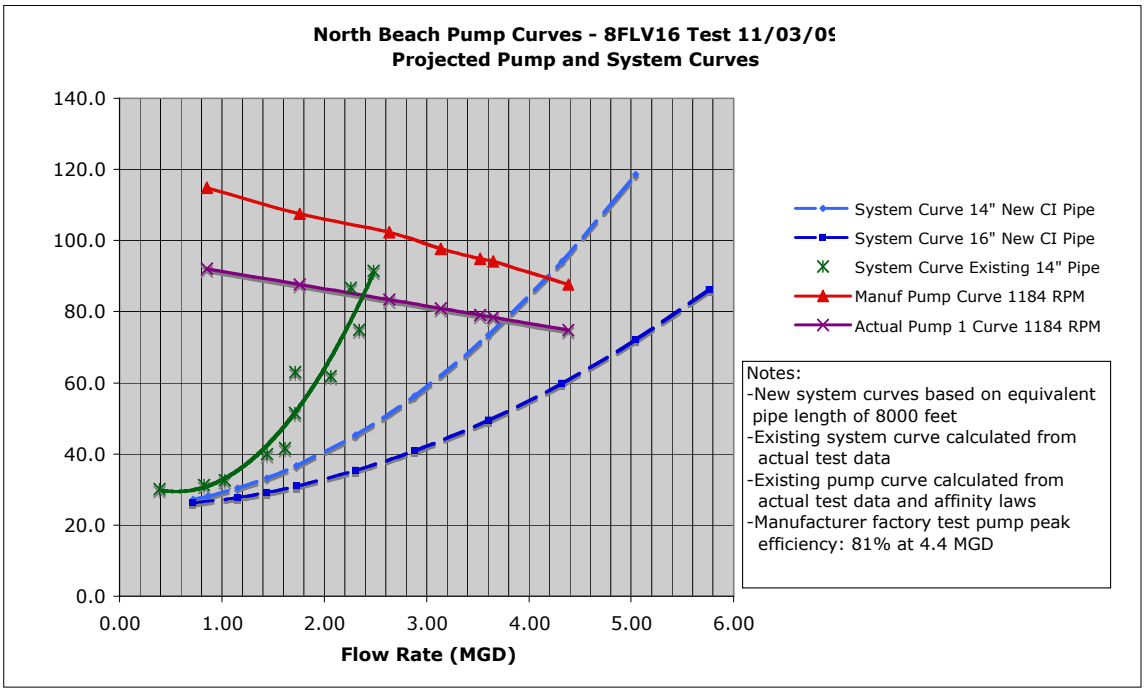

Figure 2: Pump and system curves for alternative North Beach systems

There are two main purposes of this chart. First, consider the possibility that these existing pumps could be rehabilitated at the factory such that they perform according to the ideal, manufacturer's pump curve. Perhaps the volute could be coated, impellers and other components replaced, everything short of upgrading the station by purchasing

entirely new pumps. In that case, the existing system curve would intersect the pump curve at a maximum capacity of about 2.6 mgd. This would only result in a 0.1 to 0.3 mgd increase in capacity compared to existing conditions.

Next, consider the possibility of replacing the existing force main with a new 14" or a new 16" pipe. As seen on Figure 2, the 16" pipe has less friction loss, which translates to a more gradual-sloped system curve. In this case, the lower friction, larger pipe would move the required operating point too far to the right of the manufacturer's pump curve, thus is beyond the acceptable (or possible) operating range of the existing pump system. However, the system curve for the 14" pipe intersects the actual pump curve at about 3.8 mgd. This projection indicates the new force main could result in a 1.3 to 1.5 mgd increase in capacity using the existing pump station equipment. In summary:

- A complete overhaul of the existing pumps could potentially increase system capacity by about 0.1 to 0.3 mgd, using the existing force main.
- A new 14" CI force main could potentially increase system capacity by about 1.3 to 1.5 mgd, without upgrading the existing pump system.
- A new 16" CI force main would be too large for the existing pump system.

Note that the conclusions drawn from this pump system testing event clearly support the "North Beach Pump Station Overflow Control Predesign Report" (2004), which states:

> "Engineering analysis of the existing pump station and transmission system identified three major constraints that limit the options to reduce overflows by upgrading the station's pumping capacity. These constraints include the design and condition of the North Beach force main, the piping configuration at the downstream portion of the force main, and the physical design of the existing pump station."
>
> "System assessment revealed that energy losses due to friction in the force main are the primary cause of the station's current reduced capacity. Potential energy losses in the force main also limit the upgrade options. If the station were upgraded without reducing energy losses in the force main through modifications such as replacing a portion of the main, unacceptably high working pressures would be required. This working condition, coupled with potential peak surge pressures, would significantly increase the risk of a future catastrophic pipe failure." (p 3-4)

Other Test Results

- The two test engineers evaluated certain test data and SCADA data separately; analysis results conformed to each other, indicating that the information that was collected during the test is reliable.
- The un-metered inflow that enters the force main between North Beach and the meter located at Carkeek was determined to be roughly 0.5 mgd. This quantity represents both wastewater flow from the Broadview basin as well as potential I&I into the aging pipe.

Recommendations

- Based on these test results, as well as previous reported analyses of the North Beach force main, a CCTV inspection of the existing force main is needed to confirm whether the pipe is significantly degraded and/or obstructed.
- Station capacity can most effectively be increased by rehabilitating or replacing the existing force main. Future flows should be evaluated to determine if a larger force main should be installed, in which case the existing pumps must be speed controlled to avoid overload, or the pumps and motors should be upgraded at the same time as the force main.
- Rehabilitation of the existing pumps (with no work on the existing force main) does not appear to be a cost effective option for increasing capacity of the station as the increased flow would be negligible.
- Replacement of the existing pumps (with no work on the existing force main) is not recommended as the increased pressure would result in an increased risk of rupturing the existing force main.