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MEMORANDUM

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DATE:	May 4, 2023
TO:	Azalea Mitch, PE and Matt Fabry, PE (City of San Mateo)
FROM:	Leif Coponen, PE (CA CE #70139), and Cameo Tsui, EIT
SUBJECT:	Marina Lagoon Storm Water Pump Station Study

Introduction

The City of San Mateo contracted Schaaf & Wheeler to investigate the performance of the Marina Lagoon storm water pump station during the storm event on December 31, 2022 (New Year's Eve). The purpose of this memorandum is to summarize the storm event rainfall, lagoon water level and tidal data, discuss the operational strategy of the pump station and its operational limits, the alarms and pump system operation during the New Year's Eve storm, and compare the modeled scenario of the pump station running as intended and the pump station running as operated during the storm event. Finally, short-term and long-term recommendations are provided.

Below is an outline of Schaaf & Wheeler's scope of work.

- Review December 31, 2022 storm event data provided by the City. This includes SCADA alarms, lagoon water level, and pump run data.
- Attend a field meeting with the City's pump station operations and engineering staff and discuss the events during the storm, historical operation of the pump station, and level sensor accuracy and reliability.
- Discuss pump hydraulics and lagoon water levels with pump manufacturer.
- Develop system curve for pumps to determine impacts from adjusting lagoon levels.
- Prepare a memorandum with findings and recommendations for immediate action.

Storm Event Summary

The rainfall and Marina Lagoon water level during the storm event on December 31, 2022 is shown in Figure 1. The rainfall data is provided by gage AU981 (near Laurel Creek) and shows that there were two back-to-back peaks, each peak being close to a 100-year event. The two peaks together represent approximately a 200-year 12-hour event. The lagoon water level data is recorded via an ultrasonic level sensor located adjacent to the pump station. The level sensor is only able to reliably read up to a lagoon level of 97.0 ft on the City of San Mateo datum (CSM) due to the placement of the sensor. The bottom of the sensor is located at an approximate elevation of 98.0 ft CSM according to visual reference to a staff gage mounted next to the sensor. During the storm event, an eyewitness reported that the lagoon level was at 98.4 ft CSM based on the same staff gage.

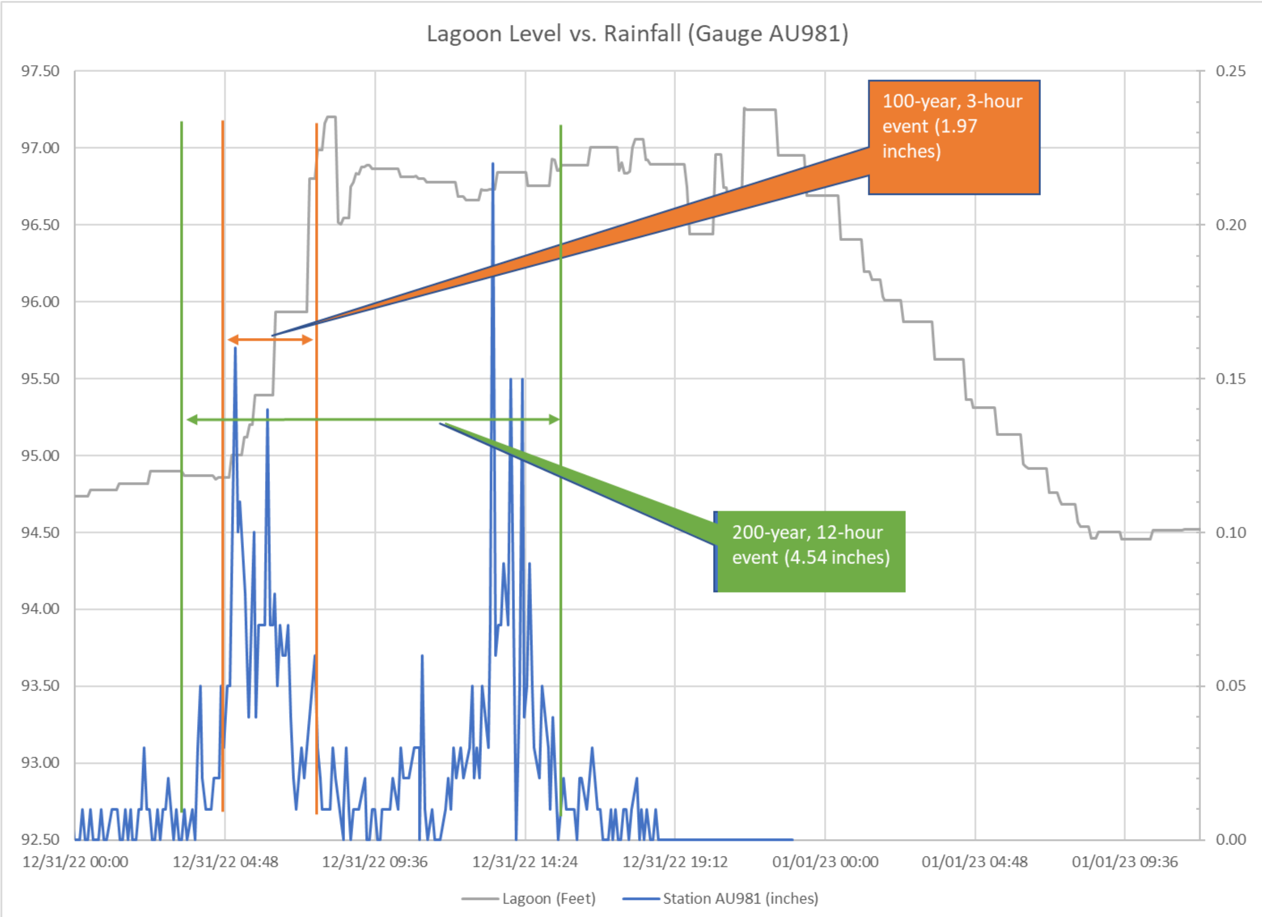

Figure 1: Storm event on New Year's Eve and Marina Lagoon Level

Figure 2 shows the tide data reading at Redwood City provided by NOAA. During the storm event, the tide peaked at 7.8 ft NAVD (102.7 ft CSM). The 100-year tide elevation of 105.1 ft CSM did not occur during the storm. The Redwood City tide elevation is reasonably similar to that of the Marina Lagoon Pump Station and therefore considered equivalent for this analysis.

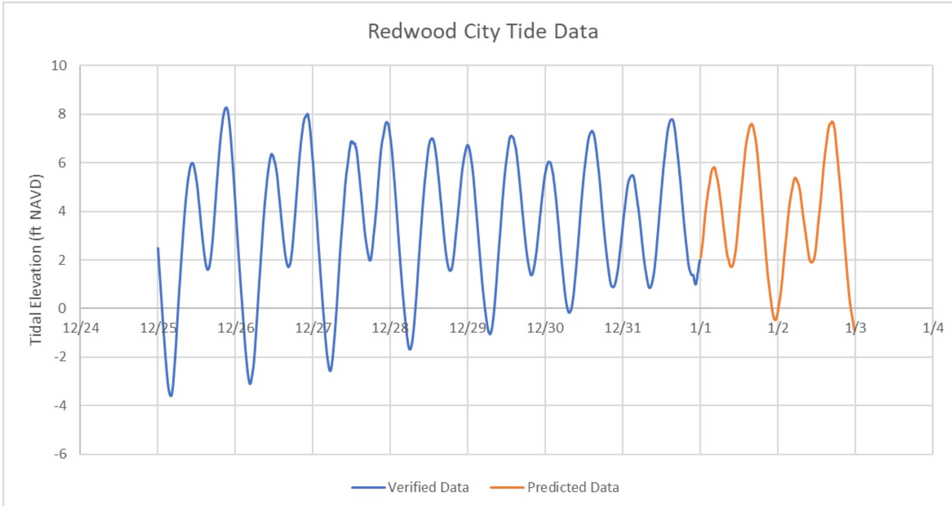

Figure 2: Redwood City Tide Data

Marina Lagoon Storm Water Pump Station Operation

The Marina Lagoon Pump Station was originally constructed in 1985 and is equipped with five 150,000 gpm capacity axial flow pumps driven by diesel engines with power transmitted through right-angle gear reduction boxes that discharge water from Marina Lagoon into San Francisco Bay. The pump station is equipped with a Programmable Logic Controller (PLC) system that operates the pumps based on the lagoon water level. The ultrasonic level sensor that monitors the lagoon level is located at the lagoon on the wing wall of a bridge adjacent to the pump station intake as shown in Figure 3. This lagoon level sensor also provides data to the PLC system to trigger high and low-level alarms.

Figure 3: Location of the Marina Lagoon Pump Station and Lagoon Level Sensor

Figure 4: Marina Lagoon Level Sensor

The wetwell is not equipped with a level sensor to gauge the change in water level across the trash rack located at the wetwell entrance; however, there is a mechanical float in the wetwell that triggers a separate high-level alarm.

The pumps can be controlled automatically with set-points or turned on or off manually on the pump control panel (Figure 5) in the pump station. If any of the pump or engine alarms listed below are triggered, the pump will automatically shut off. Triggered alarms will light up indicating the specific issue on the engine control panel (Figure 6) in the pump station, while only being logged as “engine general failure” in the SCADA system. When a pump fails, the PLC system is programmed to turn on another pump as a replacement within 3 minutes.

Pump or engine alarms:

- Pump shaft lubricator failure
- Engine Overcrank
- Engine Overspeed
- High water temperature in the engine heat exchanger
- Low engine oil pressure
- Low gear box oil pressure

Figure 5: Pump Control Panel

Figure 6: Engine Control Panel

Typically, the City of San Mateo operates the pump station to control lagoon water surface elevations (WSEL) for summer recreation and winter flood protection, during the winter the City draws the lagoon water level down further for a dock maintenance level for a duration of approximately four weeks. During the summer months, the lagoon's WSEL is roughly 96.9 ft. During the winter months, the lagoon's WSEL is lowered to roughly 94.9 ft. The dock maintenance period draws the lagoon down to a WSEL of roughly 93.4 ft.

New Year's Eve Pump Station Operation

During the New Year's Eve storm event, there were several issues that resulted in higher-than-usual lagoon levels. The City operations staff has reported that a lot of debris washed down to the lagoon and blocked the trash rack at the pump station. They had to constantly remove the debris during the storm because the lagoon water had difficulties draining into the wetwell once the trashrack became clogged.

Other problems included pump and engine failures along with SCADA system issues. The operations staff arrived at the pump station at approximately 8:00 am on 12/31/22, finding pumps not running as specified by pump set-points and engine failure alarm lights illuminated at the engine control panel. The pump and alarm set points for New Year's Eve are shown in Table 1 and Table 2. Only Pump 3 was running around 8:00 am. All other pumps should have been operating as well, since the water level was higher than 97.00 ft. After approximately thirty minutes, operations staff were able to restart an additional three pumps, and for the majority of the remaining storm, four out of the five pumps ran continuously.

Table 1. New Year's Eve Pump Station Set-Points

Pump	Pump Start (feet CSM)	Pump Stop (feet CSM)
Lead	94.90	94.40
Lag1	95.00	94.40
Lag2	95.30	94.40
Lag3	96.00	95.00
Lag4	96.90	95.50

Table 2. New Year's Eve Pump Station Alarm Set-Points

Pump	Alarm Level (feet CSM)
High	95.20
Low	94.38

Leading up to the time when operations staff arrived at the pump station, pumps had issues starting or remaining running during the early portions of the storm event. The below description is based on SCADA records of pump run status and lagoon water levels provided by the City.

Pump 4 had triggered an engine failure alarm in SCADA around 2:25 am on New Year's Eve. It had turned on momentarily for less than 5 minutes possibly as the Lead Pump at 94.89 ft. The control panel showed that the overcrank alarm was triggered when the staff arrived at the pump station. Operations staff tried to get Pump 4 restarted but the engine had problems and was out of order for the majority of the storm. Operations staff were able to later replace the engine starter and return the pump into service.

Pump 5 was turned on around 2:55 am when the water level was at 94.90 ft. It may have been turned on as back-up pump to Pump 4 or it may have been the actual Lead Pump and Pump 4 turning on was an anomaly, historical data is not sufficient to determine. Pump 5 failed around 4:35 am due to a pump lubricator failure. The staff found that it was out of lubricant and were able to restart the pump once the grease for the pump was replenished. The SCADA system did not record an engine or pump failure alarm for the pump.

Pump 2 had turned on at 5:00 am as the Lag 1 Pump when the water level was at 95.00 ft, but then turned off at 7:45 am with a pump lubricator alarm. The pump lubrication system was malfunctioning, and the staff had to override the pump shut-off control and bypass the pump lubricator in order to restart the pump. The SCADA system did not record an engine or pump failure alarm for the pump.

Pump 3 had turned on at 5:45 am as the Lag 2 Pump when the water level was at 95.40 ft and continued to run without an issue during the storm event.

Pump 1 should have turned on at 7:25 am as the Lag 3 Pump when the water level was at 96.00 ft, but the pump did not start until 8:25 am once operations staff arrived at the pump station. The SCADA system did not record an engine or pump failure alarm for the pump.

Besides mechanical pump and engine issues, there appear to be issues in the SCADA system. The SCADA alarm log only registered the high-level lagoon alarm and Engine 4 general failure alarm. It did not register general failure for Engine 1, 2, and 5. When asked about SCADA system issues, the operations staff mentioned that the PLC and new SCADA system pump and alarm set-points must be adjusted separately. It is possible that sometimes set-points are not coordinated between the two systems when changes are made. Also, the staff may not be notified of certain alarms at the pump station due to SCADA alarm priorities being incorrectly registered as a low priority. The SCADA alarm log could not be cross-checked with the PLC data log because the New Year's Eve data had already been overwritten in the local PLC's stored memory at the time the data was requested.

Based on the pump station local PLC programming records, when a pump fails while running or fails to start, a replacement pump should be started within 3 minutes. As mentioned before, when Pump 4 failed, Pump 5 may have turned on as a replacement pump. The SCADA log shows that the Engine 4 general failure alarm was registered at 2:28 am; however, Pump 5 turned on 30 minutes afterwards instead of 3 minutes. When Pump 5 failed at 4:35 am, a replacement pump did not start, Pump 2 started at the Lag 1 setpoint and Pump 3 started at the Lag 2 setpoint; meanwhile there was no replacement Lead pump running. Effectively the pump station was deficient one pump from 4:35 am to 7:40 am, then deficient four pumps due to failures until 8:25 am.

Investigation Findings

Schaaf & Wheeler collected pump station equipment information, consulted with the pump manufacturer engineers, developed pump system curves, and conducted computer modeling of the storm event and storm drain infrastructure to help determine operational capacities of the pump station and lagoon system as well as operational constraints. Schaaf & Wheeler has reviewed documentation that provides the original pump station design parameters for performance during storm events, and the design storm statistics related to the original lagoon and pump station design.

Pump Station Equipment Information

The Marina Lagoon Pump Station was originally constructed in 1985. The pump station is comprised of five individual pump assemblies each consisting of a diesel engine driver, right-angle gear reduction box, and axial flow pump. The City replaced three gear boxes in 2005 due to original gear box failures, and the City rebuilt the five axial flow pumps within the last five years. The diesel engines are routinely maintained but status of substantial rebuild of the units is unknown. The pump control system was also replaced in the past and included removal of the original level sensing bubbler system and pump controller with an ultrasonic level sensor and PLC-based pump controller. The main components of the pump assemblies are summarized below.

Pumps

The five main stormwater pumps have individual 72-inch diameter flap-gated discharges with invert elevations of 97.0 feet CSM. Each pump has a 102-inch diameter intake bell at elevation 83.0 feet CSM.

- Patterson Pump Company: PO Box 790 Toccoa, GA 30577; Phone: (706)886-2101
- Size: 72x72; Type: AFV
- Capacity: 150,000 gpm @ 10 ft TDH; Shutoff @ 41 ft TDH
- Speed: 275 RPM
- Serial No.: 85 BT 8490-G72
- Minimum pump submergence elevation: 95.0 ft CSM

Diesel Drivers

- Cummins: 14775 Wicks Blvd. San Leandro, CA 94577; Phone: (510)351-6101
- Model: VT A28P (VTA-1710P) V-12
- Rating Point: 545 Hp @ 1800 RPM
- Idle Speed: 800 RPM
- Maximum No Load Speed: 2000 RPM

Right Angle Gear Drives (Original on Pumps 1 and 2)

- TWG Thyssen Getriebe-Und Kupplungswerke GMBH: Sudstrabe 111 D 4690 Herne 1; Phone (023 23) 49 71; Fax: 08 229 868 taw d
- Model: KBV 315/S/So
- Gear Ratio: 6.3 to 1
- Anti-reverse rotation mechanism (back-stop mechanism)
- Horizontal input, vertical output
- Water cooled heat exchanger
- Lubrication via positive displacement oil pump
- AGMA service factor: 1.25

Right Angle Gear Drives (Replacement on Pumps 3-5)

- Flender Corporation: 950 Tollgate Road Elgin, IL 60123; Phone: (847)931-1990
- Model: B2SV09
- Gear Ratio: 6.391 to 1

- Anti-reverse rotation mechanism (back-stop mechanism)
- Horizontal input, vertical output
- Water cooled heat exchanger
- Lubrication via positive displacement oil pump
- AGMA service factor: 1.25

Power Take-off

- Twin Disc Inc.: 1328 Racine St. Racine, WI 53403; Phone: (262)638-4000
- Model: SP318PO – 3002097, dry clutch PTO
- BOM: 37019
- Serial No: 199555

Figure 7: Marina Lagoon Pump Station Interior

Pump and System Curve

To determine how the pump is operating for the site-specific installation, a system curve is prepared based on as-built drawings and known field conditions. The record pump curve is plotted against the system curves to determine pump operating points. The system curve analysis typically includes a design, high head, and low head curve to better understand the potential operating band of the pump in all plausible conditions.

Figure 8 shows the low, high, and design head system curves for typical pump operation and the low and high tide system curve when the lagoon level is drawn lower for dock maintenance.

Table 3 explains parameters the system curves are based on. The black line represents the pump curve obtained from the pump manufacturer and is documented as the “model curve” for the specified pumps. The solid orange line shows the brake horsepower curve of the pump. The dashed orange line shows the brake horsepower required at the engine assuming the gearbox has 95% efficiency.

The system curve confirms the original design rating point for the pump system of 150,000 gpm at 10 ft TDH and 520 HP is very close to the current “winter” operating parameters at the station. The original pump station Contract Documents show pump operating lagoon levels between 95.0 and 97.0 feet. The pump manufacturer was contacted to determine the minimum allowable submergence for the installed pumps, which was confirmed that lagoon water level of 95.0 ft CSM is the lowest permissible water level recommended by the pump manufacturer.

The pump engine is rated for 545 hp. Figure 8 shows that operating the pumps at higher-than-design system heads will exceed the rated horsepower of the engine. The original pump station Contract Documents specify pump horsepower rating of 520 BHP, which is likely also the approximate rating of the right-angle gear box.

Table 3. System Curve Parameters

Pump	Wetwell Pumping Elevation	Forcemain Discharge Elevation
Low Head	Design summer lagoon level	Forcemain discharge crown elevation
High Head	New Year’s Eve lead pump stop level	100-year tide elevation
Design Head	New Year’s Eve lead pump start level	Forcemain discharge crown elevation
Dock Maintenance – Low Tide	Dock maintenance lagoon level	Low tide
Dock Maintenance – High Tide	Dock maintenance lagoon level	High tide

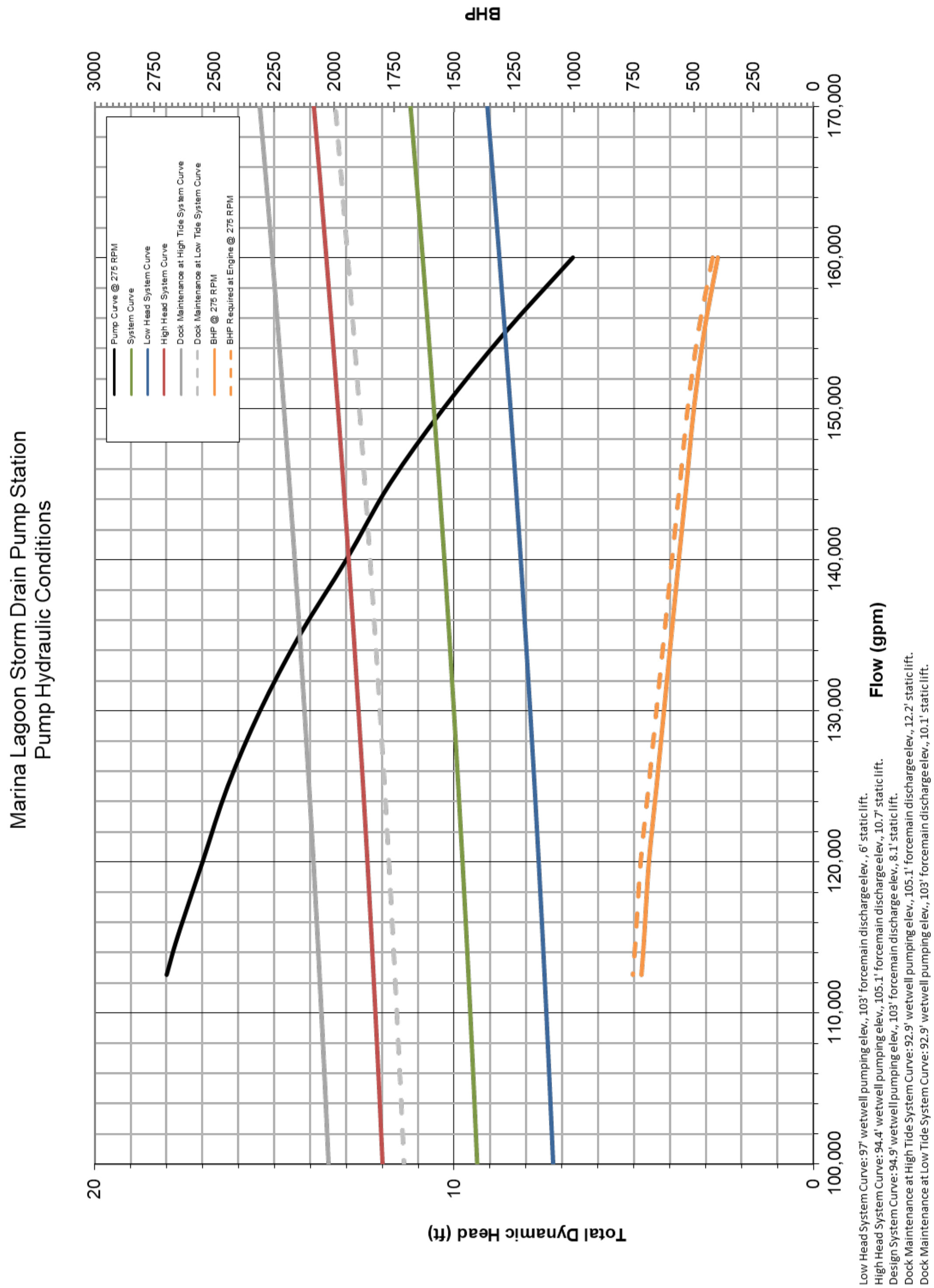

Figure 8: Pump and System Curves

Pump Station Structure

The Marina Lagoon Pump Station is comprised of an intake structure with a passive trashrack, a sloped approach structure, wetwell sump with pump bays, and a discharge structure. The pumps are located at the back of the wetwell sump in individual pump bays with pump intake near the bottom of the sump. The pumps lift lagoon water through the pump housing to individual discharge pipes that outfall through flap gates to the Bay. The intake trashrack is approximately the same width as the wetwell. The trashrack is located on the sloped portion of the approach structure and spans the vertical distance from floor slab to roof slab. The trashrack is comprised of fixed vertical steel flat bars with horizontal spacing between bars to allow water to pass through but stop debris from entering the wetwell, thereby protecting pumps from ingesting debris. During large station flows debris collects on the trashrack and restricts flow. The higher the pump station flow rate, the more debris tends to collect on the rack and more restriction develops. Once the trashrack becomes clogged, the pumps draw the wetwell water level down below the lagoon water level and the pumps begin to become starved of water. In some cases, the pumps can draw water below safe operating levels and can cause adverse conditions that may result in increased wear on pumps or mechanical failure.

Storm Model Findings

Schaaf & Wheeler prepared a hydraulic computer model of the City's storm drain, creek, and lagoon system to analyze the NYE storm and the outcome of having the pumps run with (1) the programmed set-points during the storm event with no pump failures, (2) the programmed set-points during the storm with the recorded pump failures, and (3) the pump station design set-points as described in Schaaf & Wheeler's 2014 memorandum. Figure 9 shows there is no substantial difference in simulated lagoon water levels between the NYE logbook settings and 2014 memorandum settings assuming all pumps operate when called. The results show that if all pumps were running as intended, the lagoon water levels would have remained within design parameters. Refer to Schaaf & Wheeler's Marina Lagoon New Year's Eve 2022 Hydrology and Hydraulics memorandum for more details on the hydraulic study.

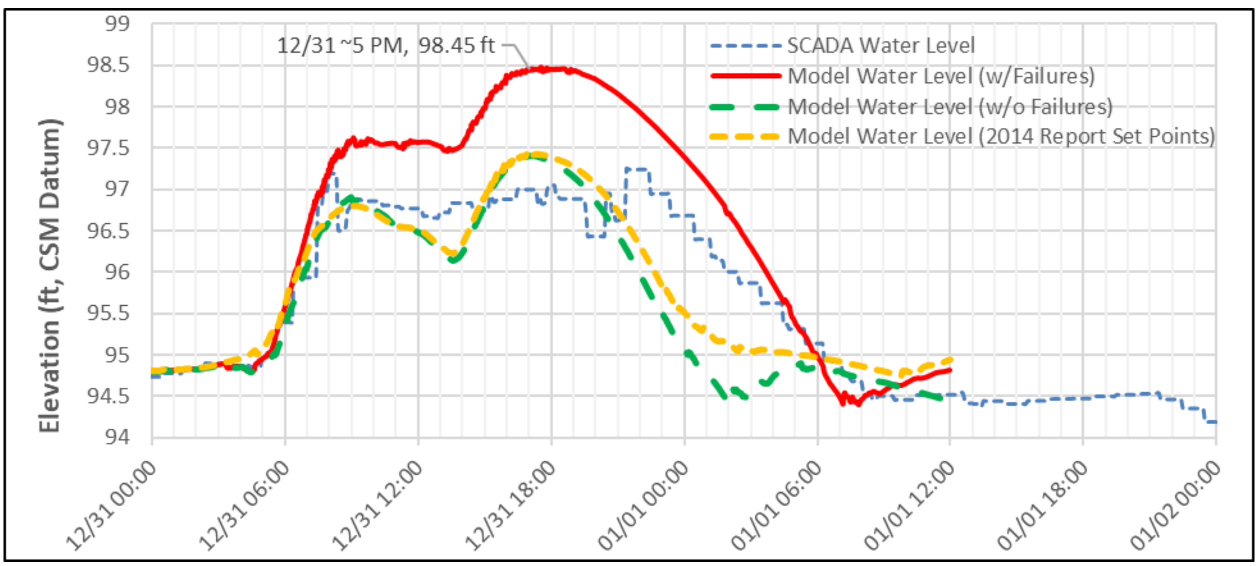

Figure 9: Simulation of lagoon and pump station system During the New Year's Eve Storm

Recommendations

Based on the findings of the Marina Lagoon Pump Station study, Schaaf & Wheeler has identified some short-term and long-term recommendations. The pump station is a terminal facility that is required to run during storm events to evacuate storm water from the interior drainage system and the recommendations provided are intended to help ensure reliable operation of the system.

Short-Term Recommendations

There are several short-term recommendations to improve pump station operation and reliability. We have separated the recommendations into two categories: maintenance / condition assessment, and improvements.

Maintenance and Condition Assessment

The pump station is nearing the end of its useful life, with many of the mechanical systems more than 35 years old. In order to maintain reliability of the pump station, the City has replaced or significantly overhauled certain major components including: pumps, gearboxes, electrical controls and level sensor over the years. In addition to the City's previous work, we recommend additional condition assessment and maintenance as discussed below.

The diesel engines have not had major overhaul work performed to-date. The engine run-times are below a typical overhaul cycle (5,000 to 6,000 hours are currently on the engines) but the age of the engines also factors into the potential need for overhaul. As a first step, the engines should have a comprehensive condition assessment performed by a qualified contractor to check all critical engine systems including starting, cooling, combustion chamber, lubrication, fuel, and exhaust. During engine inspections, the PTO components should also be inspected for proper operation and wear. Engine 4 has known overheating and starting issues and may be a precursor to other engine issues. Engine oil samples should be sent to an oil analysis laboratory on an on-going basis to identify if there are warning signs of internal wear developing in the engines. Oil analysis is best performed on an ongoing basis to first set a baseline and then a progress comparison that may alert staff to potential issues.

The fueling system is made up of several components including buried storage tank, day tank, piping, pumps, and filters. Ongoing maintenance and condition assessment of these components will help ensure there are not failures during storm events and clean fuel is adequately delivered to engines.

A vibrational assessment should be performed on the pumps, especially if the City plans to operate the pumps below minimum pump submergence recommended by the manufacturer. This vibrational assessment can help determine potential damage that can be caused by operating the pumps at lower water levels. The vibrational analysis can also identify mechanical components that are beginning to wear (bearings, shaft, propeller) and once a baseline is set, ongoing testing can help identify worsening conditions and allow the City to forecast preventative maintenance tasks prior to component failure.

The City previously replaced three of the five right-angle gear reduction boxes in 2005 due to failures of the original gear boxes. The replacement gear boxes were designed to withstand higher loads than the originals they replaced. The City may consider replacing the two remaining original gear boxes with new stronger units. When the pump system operates at higher hydraulic head conditions, increased stress is placed on all mechanical components and therefore can lead to premature failure of the components.

Lastly, the City should consider replacement of ancillary components that have a history of failures or reliability issues. Examples of components would be pump lubricators, electrical system relays and fuses, level sensors, batteries, and various systems' pumps.

Short-term Improvements

Several immediate improvements at the pump station will provide increased reliability and help protect critical pumping system components.

The ultrasonic level sensor at the lagoon should be moved to a higher elevation to be able to measure high lagoon levels and be calibrated to provide accurate readings in the CSM datum. A land surveyor should be hired to record lagoon water levels tied to local benchmarks that have been recently verified for accuracy and can be compared to City-utilized LiDAR ground surface data. During the land surveying work, fixed staff gauges at the lagoon should also be surveyed to confirm correct readings on City datum. City staff should adjust level sensor programming to calibrate readings based on the land surveying work.

There is currently no level sensor in the pump station wetwell. A new level sensor should be installed to allow monitoring of wetwell water levels. Wetwell water levels should be monitored to ensure pumps do not operate below the manufacturer's recommended minimum submergence due to clogged trashracks. The local PLC could be programmed to calculate the differential water level between the lagoon level sensor and the wetwell level sensor and alert City staff if the differential exceeds a predetermined maximum, thereby providing an alert that the trashrack likely requires cleaning.

In addition to the the wetwell level sensor, a wetwell low-level float switch should be installed and be configured to shutdown pumps at a safe water level and initiate an alarm condition regardless of PLC pump setpoints. The low-level float would operate as a mechanical backup to the PLC pump controls. The current wetwell high-level float should be calibrated to provide a mechanical backup alarm condition in case of PLC pump control failure.

Operations staff have indicated that the trashrack at the pump station becomes clogged with debris during storm events and when pumps are operational. The trashrack clogging increases as more pumps are operated and intake velocities increase. Since unrestricted flow to the wetwell is critical for reliable operation of the pump station, solutions to reducing debris load are recommended. One alternative is to install mechanical trashrack rake systems, which clean the racks on a continual basis. Installing mechanical rake systems requires comprehensive designs and potential electrical upgrades, in addition to structural assessments and site security provisions. A second alternative is to install floating log booms in the lagoon upstream of the trashrack to allow large debris to collect away from the trashrack and reduce clogging at the pump station. The floating log boom configuration would likely include two sections with each spanning from the island to the shoreline in front of the pump station intake.

Alarm and pump control issues during the storm event have indicated that the PLC and SCADA alarm systems need to be reviewed and coordinated. It should be investigated why engine general failure alarms were not triggered during the storm and why a replacement pump was not automatically started as back-up when a pump failed. Adjustments in the pump and alarm set points should be automatically communicated between the local PLC and SCADA systems. Once the PLC program is revised and integrated, the pump control and alarm system should be field tested to verify that both the Engine Control Panel and the Pump Control Panel are operating as intended. It is encouraged that the City and operations staff collaborate in reevaluating the priority of SCADA alarms to ensure that critical pump station issues are not overlooked.

As part of the local PLC and pump control logic is revisited, upgrades to the PLC are recommended to provide expanded memory storage capacity in order to save local alarms and statuses for adequate days after a significant event occurs. The ability for City staff to review detailed alarms and system status that are only available on the local PLC is critical to determine what failures may have occurred and what remedies should be performed. The City should also confirm if the PLC and level sensor has a UPS or battery backup system. A UPS should be installed if it is not already present in order to reliably operate the pump station during power outages and allow faster response once the pump station backup generator is started and operational.

There appears to be several homes built down into the lagoon (Figure 10) and are likely more prone to flooding at elevated lagoon water levels. A land survey may help determine the lowest finished floor elevation of the homes to assist in identifying potential constraints for lagoon operational protocols and allow the City to communicate with the homeowners so they are aware of potential risks.

Figure 10: Homes more prone to flooding on the banks of Marina Lagoon

Long-Term Recommendations

Long-term planning should include determining the preferred operational strategy for Marina Lagoon. The lagoon is a critical component of the overall storm drainage and flood control system maintained and operated by the City and therefore the operational strategy of the lagoon could have impacts on the overall performance of the City storm drain system. Once the lagoon operational strategy is determined, the Marina Lagoon Pump Station should be assessed for operational constraints and a preliminary design report should be prepared that outlines the alternatives for improvements to the station to meet the City's lagoon operational strategy goals. The pump station is nearing the end of its useful life, which should be taken into consideration as part of future long-term planning.

There are currently several operational constraints of the pump station that warrant further consideration. These constraints are summarized below.

The original pump station design anticipated lagoon water levels to operate between 95.0 and 98.0 feet CSM. The mechanical systems were designed around these operating parameters and there is not much, if any, flexibility for operating outside of these parameters for several reasons. The pumps are pumping at their minimum submergence at 95.0 ft. The required horsepower for the pumps (including gear box power consumption) is at the engines' horsepower rating at 95.0 ft. The original gear boxes are designed to withstand the rated power output of the engines. For axial flow pump systems, as head (lift) increases, horsepower requirements increase and therefore as the lagoon levels are pumped lower, horsepower requirements of the pumping system increase.

As lagoon water levels decrease, intake velocities increase and velocities across the trashrack increase. Increased velocities at the trashrack increase the headloss across the trashrack and result in the further lowering of the wetwell water level below lagoon levels when the pumps are operating. The increased intake velocities also tend to pull more debris towards the trashrack, compounding the headloss issue.

It is recommended that the pumps do not operate at wetwell water levels lower than the minimum submergence stated by the manufacturer. Pumping the lagoon level down to the dock maintenance level is not encouraged because it will shorten the life of the pump, diesel engine and gearboxes. If necessary, the engine and gearboxes should be upgraded to handle the extra horsepower requirements. Furthermore, a wetwell hydraulic study is recommended to examine the potential for vortices formation at low pumping levels to help ensure the pumps can reliably operate at the lower water levels. Mitigation measures, such as altering the pump sump and installing baffles or splitter plates, can be taken to reduce the potential for pump-damaging vortices.