UTILIZING AUTOMATED MONITORING FOR THE FRANZEN RESERVOIR DAM SAFETY PROGRAM

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INTRODUCTION

The need for automated performance monitoring systems is increasing as the resources available for safety monitoring continue to be stretched. A properly designed and implemented automated monitoring system can save labor and improve the dam owner's ability to detect a developing safety condition.

In this regard the City of Salem, Oregon decided to improve their existing dam safety monitoring program for Franzen Reservoir. Franzen Reservoir is an uncovered, asphalt concrete lined impoundment, located above the town of Turner, Oregon. It provides storage for about 100-million gallons of potable water for the City of Salem. It was designed by the City of Salem and constructed in the 1950's by a combination of city forces and outside contractors. The reservoir was created by a combination of excavation and filling, with the excavated material used to form an embankment along the south side of the impoundment. The most likely mode of failure for the embankment was determined to be increased leakage through the asphalt liner leading to a piping and internal erosion failure. In fact, this failure mode was observed in 1979 along the outlet conduit for the overflow structure. Leakage was observed emerging from the downstream toe of the embankment and the reservoir was lowered to prevent further development of what was determined later to be piping erosion features.

Engineering evaluations performed in 1999 indicated that improvements were needed to continue to operate the reservoir in the future. These improvements included modifications to the seepage control design elements for the embankment, dividing the reservoir into two cells for more operational flexibility, and lining and covering the reservoir to improve the quality of the supplied water. Early in 2001, the design of these improvements was underway and the dam safety monitoring program was divided into two distinct phases for the project. The first phase was called the short term monitoring program and involved implementing improvements to the City's existing dam safety monitoring program for the existing reservoir conditions. The short term program was used to monitor the on-going performance of the reservoir until it was taken out of service for construction of the rehabilitation measures. The second phase of the monitoring program was to be implemented after the reservoir construction was completed and the project was put back into service. The monitoring for this post construction phase was called the long term monitoring program. The intent of the long term monitoring program was to obtain the information needed to verify that the rehabilitation improvements perform as expected, and to allow for detection of seepage related problems if they develop in the future.

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Photograph 1: Franzen Reservoir before the Rehabilitation Construction (Standing at the northwest end and looking southeast).

WHY INCLUDE AUTOMATED MONITORING?

The purpose of enhancing the existing dam safety monitoring program was to improve the City's ability to detect and respond to developing conditions in the embankment that could lead to piping and internal erosion. The City desired to accomplish this by more closely monitoring the on-going seepage performance of the embankment without increasing the labor effort required for the dam safety program. The City also wanted to be better prepared to respond in a timely manner to a developing condition of concern, if it occurred in the future. To accomplish these objectives an automated monitoring system was designed and implemented for the short term monitoring program.

SHORT TERM MONITORING PROGRAM

The short term monitoring program consisted of the following items:

1. Weekly visual observations of the embankment and reservoir;
2. Piezometers installed in the embankment and underlying foundation to monitor for changes in piezometric levels;
3. Flow measurements from the reservoir under drain system to monitor for increases in liner leakage;
4. Seepage collection trenches with weirs for measurement of seepage flows exiting the downstream toe area;
5. Reservoir level and rainfall measurements;
6. A database tool for evaluation and management of the collected data; and
7. An alarm notification and alarm response plan.

The monitoring instruments were outfitted with electronic sensors, and automated data acquisition system (ADAS) equipment was used for data collection. The ADAS equipment collected instrument readings every 15 minutes and compared the results to predetermined threshold levels. If a threshold level was exceeded, the ADAS was programmed to provide an alarm notification to the on-site supervisory control and data acquisition (SCADA) system, which would then relay the dam safety alarm signal off-site to the City's operations center in Salem, Oregon. A response plan to evaluate the safety of the project would then be initiated by the operator. The ADAS equipment also stored a set of readings every 24 hours for use in evaluating performance trends. A custom database application was used as the "front end" interface to the ADAS. The database was an easy to use Microsoft Windows® application that was utilized by City personnel to reduce and evaluate the on-going performance of the embankment. Data downloading from the field, plotting, and review of the plotted results were typically accomplished in ten minutes. The system also included automated monitoring of reservoir level and rainfall for comparison with the instrument readings. Other weather parameters were monitored by the ADAS for use in the design of the storm water system for the new reservoir floating cover, which was part of the planned rehabilitation improvements. In addition to rainfall, the wind speed and direction, temperature, and relative humidity were monitored. Figure 1 shows the general layout for the short term monitoring system. The northeast side of the reservoir is the cut slope and excavation from which the material was obtained to construct the embankment. The embankment is the topographic feature along southwest side of the reservoir.

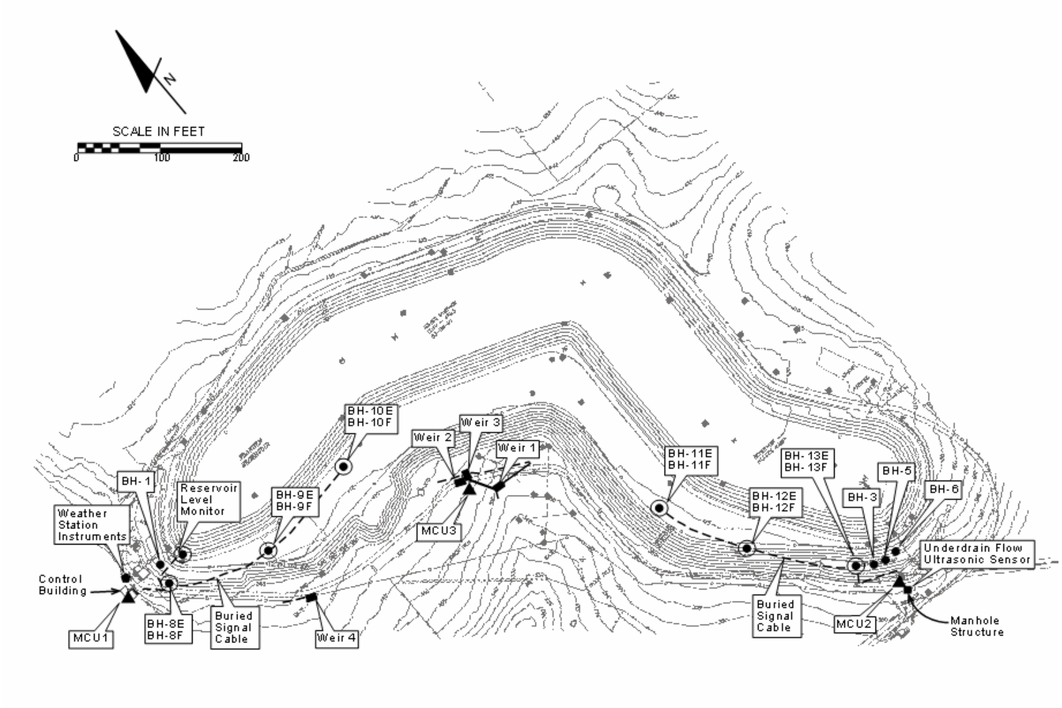

Figure 1. Franzen Reservoir Site Plan and General Layout for the Short Term Monitoring System

The following is a more detailed discussion of the different elements of the short term monitoring program.

Visual Observations

Weekly visual inspections of the embankment condition were a key part of the short term monitoring program. These inspections were performed to look for changes in the seepage conditions, sinkholes/depressions, slope deformations, ground cracking, and surface erosion features. The inspections consisted of a walking observation of the downstream toe area and downstream slope, the crest area, the reservoir slopes, and the inlet and outlet structures and collecting readings on five manually read piezometers.

The reservoir was also drained for cleaning twice per year, once during late spring and also in the fall. During this time the reservoir asphalt liner was visually inspected for cracks, holes or slumping. If a problem was identified, repairs were initiated to minimize impacts to the embankment.

A visual observation checklist was developed for use in performing the weekly inspections. The procedure for performing the inspections included providing the information requested in the fourteen blocks of the checklist form. As with all monitoring information, maintaining an accessible historical record of the observations is critical to identifying and evaluating developing conditions of concern. This was accomplished for the visual observation data by maintaining a paper file of the weekly checklist results and photographs of identified areas of concern.

Piezometers

A total of 16 standpipe piezometers were read as part of the monitoring system. Readings in 12 piezometers were automated with vibrating wire pressure transducers. The other five were read manually using a well sounder during the weekly visual inspections. The purpose of the piezometers was to provide a general indication of the piezometric levels within the embankment and in the foundation materials underlying the embankment. Large increases in the water levels in the piezometers could indicate a developing condition of concern, such as increased leakage from the liner system.

To provide notification of a developing condition, each piezometer was assigned an alarm threshold value based on the expected performance of the embankment and on calculated phreatic surface profiles that would result in unacceptable factors of safety for the initiation of piping/internal erosion. A finite difference computer model for predicting seepage performance was used to evaluate these performance parameters.

The locations of the piezometers are shown on Figure 1. Each of six piezometer boreholes includes two nested 2-inch diameter Schedule 40 PVC standpipe piezometers. The uppermost standpipes are screened within the embankment fill. The lower standpipes are screened within the underlying native foundation soil or rock. Figure 2 presents a typical cross section view of the piezometer installations. Within each standpipe piezometer, a Roctest model PWS, 25-psi vibrating wire pressure transducer was installed to measure water levels.

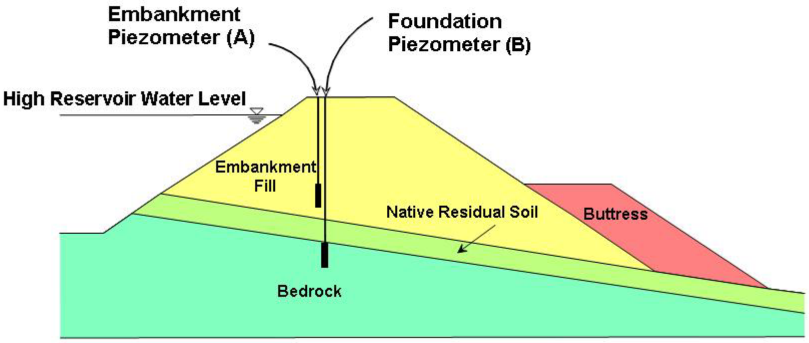

Figure 2. Typical Piezometer Installation Detail

Seepage Flow

Collection trenches were constructed along the downstream toe of the embankment to allow monitoring of the seepage that was exiting the toe area. The purpose of monitoring the seepage was to develop a general understanding of the seepage conditions within the embankment. Changes in the seepage quantity or turbidity could indicate a developing condition of concern within the embankment such as increased leakage through the upstream liner, or piping and internal erosion occurring within the embankment.

The collection trenches consisted of a 6-inch diameter perforated pipe in the bottom of a 2-foot deep trench. The pipe and trench were backfilled with gravel and wrapped overall with a nonwoven filter fabric. The intent of the trench design was to collect the near surface water that was seeping from the downstream toe of the embankment. The trenches were constructed shallow so that the deeper groundwater would not be intercepted. A trench design was selected in lieu of an open ditch to reduce the maintenance requirements and allow for easier mowing of the vegetation in the toe area. The collection trenches were located in the areas where existing seepage was observed. The trench locations are shown on Figure 1.

Flow from the seepage collection trenches was measured using weir boxes. The weir boxes included a 25-degree v-notch weir plate. The water level upstream of the weir plate was measured electronically in Weirs 1, 2, and 3 using a Geokon Model 4675LV vibrating wire water level sensor. A staff gauge was used to manually read the water level for Weir 4. The staff gauge was graduated in hundredths of a foot. Discharge from the weir boxes was collected in an outlet pipe, which conveyed the water to a culvert that discharged down gradient of the toe area. As with the piezometers, alarm threshold values were determined for each weir based on the expected seepage performance. These values were then adjusted based on the historical data that was collected.

Photograph 2: Typical Weir Box for Monitoring Flows from the Seepage Collection Trenches (Weir 2 during installation including seepage collection piping entering and discharge piping exiting the weir box)

The original embankment construction included the installation of subdrains in the base of the reservoir below the liner system. A 15-inch Palmer-Bowlus flume was used to monitor the discharge from the reservoir subdrainage system. The purpose of the subdrain system was to intercept and convey water that leaks through the liner to the overflow outlet at the south end of the reservoir. The location of the outlet and the Palmer-Bowlus flume is shown on Figure 1. The City's records indicated that the subdrain system consisted of 10-inch diameter perforated corrugated metal pipe that was placed in a trench and backfilled with sand. The trench was hydraulically connected to a 5-inch thick gravel layer that was constructed beneath the asphalt liner over the base of the reservoir.

During the period from 1981 to 1984, the outflow from the subdrain system was monitored and evaluated relative to reservoir level and rainfall (Foundations Sciences, 1984). The conclusions from the evaluation were that the subdrain flow responded directly to changes in the reservoir level and also responded to heavy rainfall events. It was concluded that heavy rainfall can cause a rise in the ground water table sufficient to intercept the subdrain system and produce increased flows. Historically, the depth of water in the flume was measured every five minutes by the City's SCADA system. The data was then reduced to a flow measurement using a flume equation and compared to a threshold value of 400 gallons per minute (gpm). This comparison has historically been used as an assessment of the reservoir lining system performance. The threshold value was established in 1981 (Foundation Sciences, 1981) based on a comparison of measured hydrostatic pressures beneath the reservoir liner with flows from the subdrain. The results of the 1981 testing indicated that at flow rates less than 400 gpm, excess pressures did not build up beneath the lining. Therefore, historically, the threshold level was set at 400 gpm, based on the assumption that a build up of pressure beneath the lining could allow excess seepage through the embankment and foundation that could lead to piping and internal erosion concerns.

The existing water level sensor in the flume was replaced with a Milltronics Model PL-511 Loop Power ultrasonic level sensor which was connected to the ADAS. The ultrasonic sensor emits a sonic pulse at the water level within the flume and then measures the time for the pulse to travel to the water and back to the sensor. The measurement is then temperature-compensated and converted into distance for a current (mAmp) signal output the can be read by the ADAS. The sensor was mounted lower and in a different horizontal position than the previous SCADA sensor to provide more accurate readings of water level fluctuations in the flume. Readings were collected by the ADAS every 15 minutes and compared to an alarm threshold value. Water stage and flow data was also logged once per day for historical evaluation purposes.

Photograph 3: Ultrasonic Level Sensor with Palmer-Bowlus Flume (Subdrain outlet manhole)

Reservoir Level

The level of water within the reservoir was also monitored for use in evaluating the piezometer and seepage flow data. Readings were collected using the ADAS simultaneously with the piezometers, seepage collection weirs, and under drain flow instruments. The reservoir level was monitored using a Geokon Model 4500AL vibrating wire pressure transducer which was installed in a standpipe located in the reservoir. The standpipe was attached to the intake structure and was capped and perforated near its base for hydraulic connection to the reservoir. The top of the standpipe terminated in a junction box that was located on top of the intake tower. The pressure transducer was installed in the standpipe using a hanger assembly so that it could be removed for servicing.

Weather Station

A system of instruments was installed to gather weather-related data. The instruments provided data regarding daily rainfall, wind speed and direction, air temperature, and relative humidity. Each of the instruments was connected to the ADAS.

An R.M. Young Model 52202 tipping bucket rain gauge was installed to measure the daily rainfall to assist in evaluating the piezometer and seepage flow data. During a rain event, the bucket is filled to a predetermined volume, which then causes it to tip over and empty the water out through a drain in the bottom of the instrument. Each time the bucket tips, the sensor sends a signal (count) to the ADAS. By counting the number of tips, a calculation of total precipitation is determined by the ADAS. The rain gauge was also equipped with a heater to provide precipitation readings in snow and ice conditions.

Data regarding horizontal wind speed and direction was measured using an R.M. Young Model 05103V wind monitor. The wind speed sensor was a four-blade propeller. The propeller rotation produced a signal with a frequency directly proportional to wind speed. The wind direction sensor consisted of a vane connected to a potentiometer. When a known voltage is applied to the potentiometer, the output voltage is directly proportional to the vane angle. The wind data was collected to evaluate the effects of surface winds on the proposed reservoir floating cover system. The prevailing wind direction and wind speeds were used to design the storm water collection system for the cover. Readings for wind speed and direction were collected once per hour using the ADAS. The daily minimum and maximum wind speeds were then logged for historical purposes along with the wind direction data on an hourly basis.

The relative humidity and air temperature was measured using an R.M. Young Model 41372VC/VF relative humidity and temperature probe. The probe combines a high accuracy humidity sensor and a platinum resistance temperature device (RTD) temperature sensor into one probe. The probe was installed within a radiation shield to reduce the affects of solar radiation and precipitation on the readings. Instrument readings were collected using the ADAS on an hourly basis and the daily highs and lows of temperature and relative humidity were logged for historical purposes.

Transient Protection

Transient protection was provided for all of the electronic instruments and the data acquisition equipment. The devices that were used were Model MTA2's and MTA20's which are manufactured by Geomation Inc. The MTA units are multi-stage transient arrestors using a gas tube for the first stage and a series inductor for the high frequency components of the transient waveform. The transient protection was installed within NEMA 4 rated junction boxes that were located in the well heads for the piezometers, in the weir boxes, and in the manhole for the subdrain outfall flume. For the data acquisition equipment, the transient protection was provided in the NEMA 4 rated equipment enclosures. Eight foot steel rods were driven into the ground to provide grounding for each transient protection location.

Data Collection, Evaluation, and Management

The ability to collect, reduce, evaluate, and present the results of the data was very important to the decision making process regarding the ongoing safety of the embankment. If the data was not managed properly, its reliability for use in making decisions would have been compromised. In addition, the use of a properly designed data collection and evaluation system saved many labor hours in the reduction and presentation of the data during the short term monitoring program. A Data Flow Diagram showing the flow of data from the instruments to the ADAS and then to the data evaluation/management tool in the City of Salem office is presented as Figure 3.

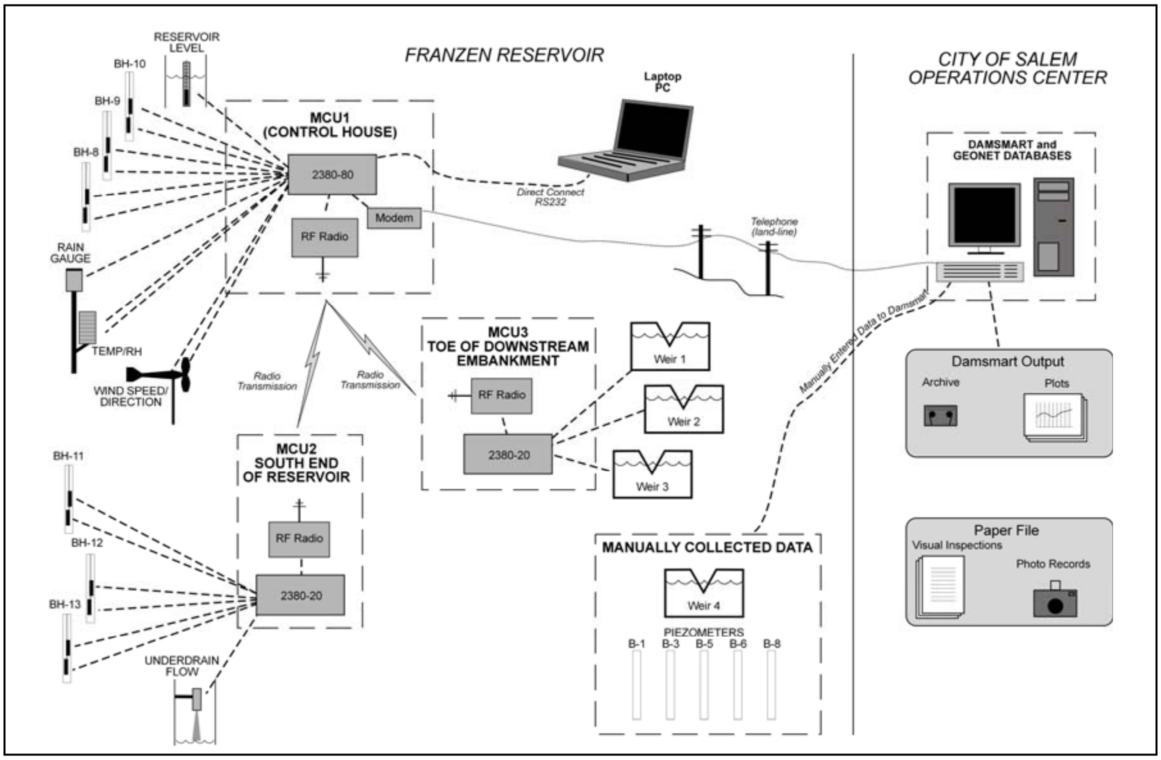

Figure 3. Data Flow Diagram for the Short Term Monitoring System

The ADAS includes three Model 2380 measurement and control units (MCU's). The MCU's are programmable microprocessor controlled units that are manufactured by Geomation Inc. The purpose of each MCU was to collect, evaluate, and temporarily store data from the instruments that were connected to each MCU. MCU1 was located within the Control Building near the northwest end of the reservoir. The weather station instruments and the piezometers in the western portion of the embankment were connected to MCU1. MCU2 was located within a manhole structure near the southeast corner of the reservoir. The under drain flume and the piezometers in the eastern portion of the embankment were connected to MCU2. MCU3 was located at the downstream toe of the embankment near the center of the reservoir. The three weir boxes that monitor flow from the seepage collection trenches were connected to MCU3. Figure 1 shows the locations of MCU1, MCU2, and MCU3.

MCU1 was also the communication gateway for all historical data collection and alarm notifications. The transfer of data between MCU1, MCU2, and MCU3 was accomplished using UHF radio communications.

Data retrieval, storage, and programming of the monitoring system was accomplished using two software systems loaded onto a workstation PC in the City of Salem's operations center. Geonet Suite was the software used to program, configure and coordinate the retrieval of data from the MCU's in the field. Using a modem on the workstation PC, the City of Salem staff used the Geonet Suite software to dial up and communicate with MCU1. Each time the workstation PC connected with MCU1, the Geonet software compared its local database with the data stored on MCU1 and any new data was automatically downloaded to the Geonet database. The other software was a relational database program by URS Corporation called DamSmart. DamSmart was linked to the Geonet database so that all new data could be electronically imported into the DamSmart database. Manually collected data were also entered into DamSmart using the manual data entry feature. The DamSmart software was configured as an easy to use interface for evaluating the data using preconfigured reports and plots. The DamSmart database was also used as the permanent storage location for the processed data.

Alarm Notification and Response Plan

The most likely mode of failure for the Franzen Reservoir embankment was considered to be an increase in leakage or seepage through the upstream lining system that leads to piping and internal erosion of the embankment material. Therefore, the focus of the short term dam safety program was to monitor for changes in the on-going seepage performance of the embankment. The intent of the program was to detect a condition that develops gradually and could become a safety concern, so that the reservoir could be drained and repairs made to the upstream liner system. The monitoring program was not intended to function as an early warning system for a rapidly developing failure condition.

As previously discussed, instrument readings were collected every fifteen minutes and compared to predetermined threshold levels. If a threshold level was exceeded then notification would be provided by MCU1. When MCU1 detects a threshold exceedance, a latching relay in an alarm box is activated through a 12VDC signal provided by the MCU. The latching relay then turns off the green (normal condition) LED and turns on the red (alarm condition) LED on the alarm box located within the MCU1 enclosure. The latching relay also provides a closed contact signal to the SCADA system in the Control Building.

When the SCADA system recognizes the closed contact signal, an audible alarm is activated in the City's Operations Center in Salem, Oregon. A text message indicating an alarm from the dam safety monitoring system at Franzen Reservoir is also displayed on the SCADA HMI screen in the Operations Center. The Operations Center personnel then respond to the alarm by contacting the Operator on Duty. A call out procedure is initiated by the operator to alert appropriate operations and engineering personnel. Figure 4 provides a summary of the Alarm Notification and Response Plan that was used for the short term monitoring program.

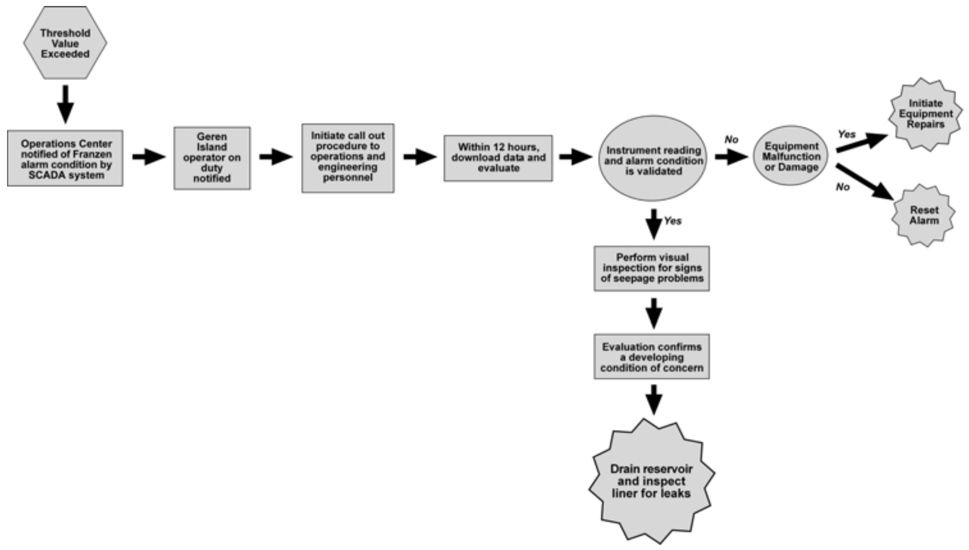

Figure 4. Alarm Notification and Response Plan for the Short Term Monitoring Program

PERFORMANCE OF THE SHORT TERM PROGRAM

The installation for the short term monitoring system was completed in September 2001. The system performed as intended until May of 2003 when the reservoir was taken off line for the rehabilitation construction. During this period of time, the City found the system interface to be very easy to use and required minimal labor effort beyond the weekly visual inspections. In addition, the City believed that the new automated monitoring system improved their ability to detect and respond to changes in the seepage performance of the embankment in a timely manner. However, no unexpected seepage behavior was observed and the system did not detect any instrument readings that exceeded the alarm threshold levels.

The reservoir was drained for cleaning a number of times between September 2001 and May 2003. During these draw down and refilling events the data collected by the system agreed well with the expected performance. As the reservoir was refilled, the piezometers were found to be very effective in detecting the line of seepage as it developed through the embankment to a steady state condition. In addition, the seepage flows downstream of the embankment responded to the emptying and refilling with a similar time lag. The under drain flows responded directly to changes in reservoir level which indicates that the asphalt liner system was leaky. This was consistent with visual observations of the asphalt liner when the reservoir was empty which identified cracks and isolated sinkholes that required patching before refilling. Overall, the performance of the short term monitoring system provides some confidence that future changes in the seepage performance of the embankment can be detected using a similar approach for the long term monitoring program.

LONG TERM MONITORING PROGRAM

The reservoir rehabilitation construction was completed in November 2004. Part of bringing the reservoir back into service includes implementing the long term monitoring program. At the time that this paper was written, Engineered Monitoring Solutions was in the process of working with the City of Salem to implement the long term monitoring program. Based on the success of the short term monitoring program, the City decided to continue to utilize automated monitoring in the future. The long term monitoring program will include the installation of additional piezometers to provide better coverage of the embankment seepage performance, monitoring of discharge from the new groundwater collection system using the weir boxes from the short term program, the addition of automated reservoir water quality monitoring, a permanent weather station, and improvements to the DamSmart data management system. The following provides a brief description of the planned improvements.

Photograph 4: Franzen Reservoir after the Rehabilitation Construction
(Standing on the southeast cut slope looking northwest)

Additional Piezometers

The piezometers that were installed for the short term monitoring program had a duel purpose of investigating the embankment properties for design of the reservoir improvements, and detection of changes in the seepage performance of the embankment near the abutment ends where the crest width was narrowest. Because the piezometers worked well for monitoring the phreatic surface within the embankment, additional piezometers are planned for the long term program. Nine new nested piezometer pairs (one screened in the foundation and one near the base of the embankment) will be installed at locations evenly spaced along the crest of the embankment. The old and new piezometers will be used to detect changes in the piezometric levels within the embankment and foundation. Based on past observations, it is expected that a significant leak in the new liner will result in increased piezometric levels.

Vibrating wire pressure transducers will be installed in the new piezometers and they will be monitored using the ADAS. Readings will be collected and compared to alarm threshold values every 15 minutes and will be logged once a day for historical evaluation purposes. The historical data will be reviewed by City staff to observe for subtle trends of increasing piezometric levels that could indicate increased leakage through the liner system.

Groundwater Collection System

A new system of trench drains was installed in the bottom of the reservoir along the cut slope side as part of the rehabilitation construction. The trench drains are below the new liner and were installed to collect and convey the groundwater that seeps from the cut slope to a safe discharge location downstream of the embankment. The trench drains are also hydraulically connected to a drainage blanket layer that was placed over the bottom of the reservoir below the liner. The flow from these trench drains will be monitored for the long term program using the same weir box with ADAS setup that was used for the collection trenches in the short term program. The water stage for the weirs will be read every 15 minutes and compared to alarm threshold levels. Because the flow from the trench drains under normal operations will be primarily from groundwater sources, it is expected that the measured values will vary with rainfall and the seasons. However, if the liner develops a significant leak in the cut slope side or in the bottom of the reservoir then an increase in flow should be detected in the trench drains. Based on this expected performance, the threshold levels will be calculated by the ADAS as a function of rainfall with the intent of detecting a significant increase in flow over the expected seasonal performance. Historical data will be logged once per day for use in developing and refining the seasonal flow relationships and to observe for trends of increasing flow. However, it is likely that the variation in groundwater flows will mask the ability to detect small trends in increasing flow.

Water Quality Monitoring

As previously discussed, the rehabilitation construction included a geomembrane liner and floating cover system to improve the quality of the stored drinking water. For the long term monitoring program the quality of the reservoir water will be monitored using the ADAS installed for the dam safety program. The parameters that will be monitored include dissolved oxygen (DO), temperature, turbidity, and pH. To measure these parameters one YSI Model 6820 water quality multi-parameter datasonde will be installed within each reservoir cell. The datasondes will be suspended beneath the floating cover at two hatch locations using a winch device which can be used to raise and lower the datasonde and fix it at a given depth below the cover. Data will be transmitted from the datasondes using spread spectrum radios located at each hatch location to transceivers located at one of the ADAS MCU’s. The transceivers will transfer data to the MCU using an SDI-12 interface data port.

The water quality parameter readings will be made every 15 minutes and will be logged daily for historical evaluation purposes. The 15 minute readings will also be transmitted from the MCU to the project SCADA system PLC using 4-20mA output signals. The SCADA system HMI display will be used by operations personnel to monitor the water quality in the reservoir cells in near real time.

Reservoir Levels and Permanent Weather Station

The reservoir was divided into two separate cells as part of the rehabilitation construction. Therefore, two new reservoir level instruments will be installed for the long term monitoring. The new level monitoring will consist of standpipes installed in the inter-cell valve vault with vibrating wire pressure transducers to measure the water levels. Readings will be collected with the ADAS for use in evaluating the dam safety instrument data.

A permanent weather station will also be established for the long term monitoring program. The same weather instruments that were used for the short term monitoring will be mounted on a tower which will be installed on the crest of the embankment near the center of the reservoir. The daily rainfall data will be used for evaluation of the dam safety instrument data and the other instruments will be monitored to maintain a record of the weather conditions on-site.

Improvements to Data Management System

The DamSmart software worked well as an easy to use data evaluation interface for the short term monitoring program. Based on this experience, the City decided to implement a data evaluation/management interface for multiple projects throughout the City with varying data collection sources. To accomplish this objective a Microsoft SQL Server version of DamSmart was implemented using the City's WAN as the communications backbone.

This new data evaluation/management system is currently being used by City staff to successfully monitor a number of other projects. The long term monitoring program for Franzen Reservoir will be added as another project to the system. The new system allows users connected to the City's LAN (clients) to access data from multiple projects using their desktop PC's. The data is automatically loaded using schedulers from multiple data collection sources including Geomation Inc. equipment, as used for the Franzen Reservoir project, and the City's SCADA system historian software. After the data is loaded into the SQL Server databases, it is then served out over the LAN to any client PC's that has authorization to access the particular project data. Opening the project from the client PC using the DamSmart software is all that is required to view and evaluate the data using plots and reports.

CONCLUSIONS

The Franzen Reservoir project is a good example of how a well designed and implemented automated monitoring program can improve a dam owner's ability to detect developing safety conditions without increasing the labor effort required for the dam safety program. The project included adding instrumentation and automated monitoring to the City's existing dam safety program which consisted of weekly visual observations. The visual observations and automated monitoring were refined based on engineering evaluations performed on the existing reservoir embankment and liner system for the short term dam safety program, and on the designed rehabilitation improvements for the long term program.

The Franzen Reservoir project experience also demonstrates that an automated system implemented for dam safety can be used for other monitoring needs both related and unrelated to the dam safety program. For the Franzen Reservoir project this included automated monitoring for reservoir water quality and weather station instruments.

ACKNOWLEDGEMENTS

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