

9.0 OPERATION AND CONTROL AT TAUM SAUK

At the time of the event, the systems and controls were in-place to allow for the operation and control of the Taum Sauk Plant and to maintain the safety of the Upper Reservoir. We have conducted an analysis of the operation and control systems utilized at the Taum Sauk Plant as they apply to the Upper Reservoir by reviewing records, interview transcripts, the Siemens Report (*Attachment A*), and discussions with AmerenUE management.

The initial sub-sections presented below discuss the instrumentation and control systems. Following this we provide an overview of the AmerenUE organization as it relates to the operation of the Taum Sauk Plant. Based on this information, we evaluate the last three Upper Reservoir Barriers as listed on *Table 6-1*; namely, Instrumentation, Operator Action, and Management Oversight.

9.1 INSTRUMENTATION

The Taum Sauk Plant is operated remotely from the Osage Power Plant. Instrumentation at the site was designed to provide the Osage Operator with sufficient information to be able to control the pump and generation cycles for the Taum Sauk Plant. With regard to the instrumentation, two modes of failure were investigated. The first, failure of the instrumentation and controls system, was investigated by Siemens and a summary of their investigation is included herein. The second, investigated by RIZZO, contemplates a structural and/or mechanical failure of the instrument supports. Either could potentially lead to a loss of water level control of the Upper Reservoir.

9.1.1 Instrumentation and Controls System

Siemens was retained to perform an analysis of the Event with a focus on the instrumentation and controls system at the Taum Sauk Plant. A copy of the Report prepared by Siemens is included in *Appendix A*. The Siemens investigation reviewed the instrumentation in the as-found condition following the incident. The instrumentation and controls system had been recently upgraded by AmerenUE during the Fall 2004 outage. The instrumentation upgrades were performed concurrently with the liner installation to take full advantage of the outage. A summary of the main points and conclusions from the Siemens Report is presented below.

9.1.1.1 Upper Reservoir Level Controls

Two independent monitoring devices were in place to monitor the water level of the Upper Reservoir at the time of the Event. The first, referred to as level control, was the primary means utilized to control the pump and generation cycles on a daily basis. The second, referred to as level protection, provides an additional means to stop the pump cycle when a certain water elevation is reached.

The level control of the Upper Reservoir was achieved through three level control transmitters. An average of the three level control transmitters is recorded at the Osage Hydro Plant on a continuous basis. Control of the pumps is set by the operator or when the auto stop elevation is reached. On the day of the Event, the first pump was set to auto stop at El. 1592 and the second at El. 1594. Either pump can be set as the first pump to auto stop. On the day of the Event, Pump No. 2 was set to auto stop first and Pump No. 1 was set to auto stop second.

The overflow protection system utilized two probes designed to activate when the water reached the level of either probe. On December 14, 2005 the observed elevations of these probes were El. 1597.4 (HI Probe) and El. 1597.7 (HI-HI Probe), as opposed to the designed elevations of El. 1596.0 and El. 1596.2. Also, these probes were designed to operate independently, but the programming was altered such that both level probes would have to be in contact with water for 60 seconds to turn off the pumps. Incidentally, due to a programming error, the HI-HI Probe would only shut off Pump No. 1. This was not an issue on the day of the incident because Pump No. 2 had also stopped. Had the HI-HI Probe activated, Pump No. 1 would have been shut down.

The overflow protection probes were designed to trigger a rapid shutdown of both pumps. As such, significant stresses would be generated in the water conveyance system, as opposed to the gradual shutdown that occurred through the use of the level control system. The probes were designed to act in the case of an emergency such that the additional stresses in the system would be justified. However, continual trips by the protection probes could significantly reduce the life of the plant equipment.

It is important to note that no distinction was made between “*operational instrumentation*” and “*dam safety instrumentation*.” Operational controls for the reservoir (i.e., level control transmitters) were set based on the operational procedures desired by plant management

personnel. For example, operational procedures were set to assure a gradual shutdown of the units by avoiding the activation of the protection probes. Therefore, the auto stop elevations of the level control transmitters (operational instrumentation) should be adjusted to prevent this occurrence. On this basis, a failure of the operational instruments might result in operation problems, but would not have a significant effect on dam safety if the overflow protection instrumentation is fully functional.

The level protection probes, used synonymously herein with the term dam safety instrumentation, should have been designed and specified to prevent overtopping of the reservoir. The elevation of these probes should have been set to prevent the reservoir from exceeding the normal maximum elevation. As per the original drawings, the Upper Reservoir was designed to allow two feet of freeboard. At the time the new instrumentation was installed, the low point on the Parapet Wall was El. 1597.0. Therefore, the level protection probes should have been set to stop the pumps whenever the freeboard was reduced to less than two feet.

Based on RIZZO's understanding, the as-designed levels of the protection probes of El. 1596 and El. 1596.2 do not satisfy this design intent. The probes, in the as-designed configuration, would allow the freeboard to be reduced to less than one foot before stopping the pumps. Shortly after installation, the actual elevation of the protection probes was modified such that they were set at El. 1594.0 and El. 1597.7 or above the low point of the Parapet Wall. RIZZO speculates that this change was made to improve plant operation. In hindsight, rather than adjusting the elevation at the protection probes, the level control transmitters should have been adjusted to safely alter the operation of the plant. Moreover, the dam safety instrumentation should not have been altered without significant input from people familiar with dam safety requirements. Changes made to the instrumentation were not well documented and adequate quality checks were not performed prior to making changes. Where dam safety issues are concerned, additional quality control checks are appropriate.

9.1.1.2 Effects of Dike Settlement

Some additional comments are necessary to fully characterize the normal operating water level in the Upper Reservoir. Most earth and rock fill dams settle with time. As part of routine inspections, this settlement is monitored and documented over time. When the crest settles to below the design elevation, remedial measures are required to reinstate the crest elevation or to revise the operational procedures. At Taum Sauk, the designed crest elevation was El. 1599 and measured and recorded the initial operating level was El. 1597. The operating level (prior to the

Fall 2004 outage) was via a staff gage attached to the parapet wall. Operating level was reduced to El. 1596 as measured by the staff gage, presumably due to settlement following the initial construction. However, settlement of the parapet wall and staff gage reduced the actual operating level by an additional foot to El. 1595. Operating levels continued to be read from the staff gage and were recorded as El. 1596.0. As a result, Taum Sauk was operated with two feet of freeboard (as per the design) until the upgrade of the instrumentation and controls system during the Fall 2004 outage.

Following installation of the synthetic liner and the upgraded instrumentation and control systems, plant operation resumed at El. 1596.0. However, the elevations now recorded were actual elevations rather than the through the old staff gage which had settled one foot. This resulted in a one foot increase in the normal operating level and the loss of one-half of the design freeboard. This inadvertent reduction in the freeboard substantially increased the likelihood of overtopping in the event of instrumentation (or other) problems.

In summary, the exact purpose of each instrument installed is a critical component necessary to assure the correct function of the instrument. In the case of Taum Sauk, the level protection probes should have been documented in terms of their purpose, i.e., assure safety of the Upper Reservoir Dike by providing a fail-safe mechanism to prevent overtopping. Any changes to these instruments should then consider the documented intent and purpose of the instrument. Adjustment of the level protection probes should be based on dam safety considerations.

9.1.1.3 Programmable Logic Controller

Both sets of instruments are controlled by the same Programmable Logic Controller (PLC) and there is no fail-safe path to shut down the pumps in the event of the failure of the PLC. Based on Siemens investigatory work, there is no evidence of a hardware failure in either the PLC network system or in the wide-area network. Nevertheless, it is our view that a fail-safe should be considered if the project is rebuilt.

9.1.2 Instrumentation Support Systems

RIZZO has reviewed both the design and as-built system for securing the level controls. Refer to *Appendix H* for copies of the drawings showing the as-designed and as-built configuration of the instrumentation supports.

The instrumentation support system was designed by Shaw-Emcon in conjunction with the installation of the geosynthetic liner in 2004. The purpose of the liner was to reduce seepage through the Upper Reservoir Dike. The liner project was expanded to include the installation of four HDPE Pipes to house the new reservoir control instruments. The reservoir instrumentation and controls system was also upgraded during the Fall 2004 outage.

The level control transmitters were installed inside perforated HDPE Pipes. Four pipes were provided, two were to be for the level control transmitters and one was filled with concrete for ballast and one was to be used as a spare. All four were to be secured together to increase rigidity. The initial design of the upgraded instrumentation and controls system (see *Appendix G* – rev. 1 through 4) called for anchoring the four pipes to the liner with an HDPE strap welded to the HDPE liner. The liner installation contractor raised a concern that the weld would create a stress point and reduce the expected life of the liner.

At the request of AmerenUE, Shaw-Emcon redesigned the anchor supports. The redesign (see *Appendix G* – rev. 5) included two steel guide cables running parallel to the HDPE pipes. The cables were to be anchored at the base of the Parapet Wall and at the toe berm concrete at the base of the slope. The pipes were to be connected to the cable via eye bolts. With the addition of the guide cables, the concrete filled pipe was eliminated and only three HDPE pipes are shown on the redesigned (Revision 5) drawing. However, as the parts were already on-site, all four pipes were installed with two remaining empty.

In the field (during construction) it was noted that the Revision 5 design included a slack cable that ran along the existing slope of the Reservoir. The slack cable would not have provided the necessary support to secure the instrumentation. Again, AmerenUE contacted the designer who recommended that the cable be tensioned. A revised drawing was not issued reflecting this change.

The tensioned cable resulted in a variable distance between the cable and the pipes. This made the use of the specified eye-bolts impractical. Discussions between AmerenUE and the designer resulted in a change from eye-bolts to turnbuckles. The turnbuckles could be easily adjusted to account for this variable distance.

In summary, during the installation of the liner, several modifications were made to the instrumentation support systems. These changes were required to minimize the potential for

damage to the liner and to better suit field conditions. All changes made were discussed with and received the approval of the designer, Shaw-Emcon.

The liner and new instrumentation system was put into service on November 15, 2004. A Final Construction Report (dated February 12, 2005) was issued to the FERC to document the completed liner installation project. However, the details of the instrumentation support (as contained in the Final Construction Report) are not reflective of the actual as-built conditions. The as-built condition of the instrumentation supports was resubmitted in February of 2006 reflecting correct information.

9.1.2.1 Field Change to Design

As outlined above, field changes were required because initial design was inadequate. The original design (Appendix H - Drawing # 8304-X-155099 Rev. 4) called for eye-bolts to attach the clamp baseboard/spacer to the guide cables. In the field, it was noted that once the guide cables are tensioned, the distance from the baseboard to the cable was quite variable. See *Figure 9-1* for an understanding of the turnbuckle locations.



FIGURE 9-1

TURNBUCKLE-GUIDE CABLE-INSTRUMENT CONDUIT SYSTEM

Since it would have been difficult and time-consuming to set the length of each eye-bolt to match the curvature of the embankment, the design was changed to accommodate turnbuckles in most clamp locations so that they could be field-adjusted as needed. The bottom anchor for the guide cable was changed to a turnbuckle also. We consider both changes to be a significant deviation from the original design. RIZZO's findings indicate that these field changes were poorly documented.

Overall, the substitution of a turnbuckle in a location where a bolt was originally specified was not adequate. From a generic perspective, the mechanism of bolted connections is such that the nut is held in place by the friction of the nut on the part being connected. The friction acting on the threads is not credited as there is an inherent gap between the threads of the bolt and of the nut that allows the nut to turn. This gap allows a slight vibration to release the friction in the thread-to-thread interface. In other words, to rely only on thread-to-thread friction to maintain the integrity of a bolted connection is not adequate and not consistent with function of the bolted connection.

At Taum Sauk, the turnbuckles were tightened, but no locking device, such as a locking nut or spot weld, was used to secure the fixity of the connection against vibratory effects. Thus, over time, the turnbuckle loosened and eventually was unscrewed completely. As can be seen in several photos available in the AmerenUE records, several turnbuckles were installed using less than one inch of thread.

9.1.2.2 Unistrut Failure

As may be seen in *Figure 9-1*, the bottom portion of the turnbuckle is connected to a horizontal steel member, called a Unistrut. A Unistrut is a U-shaped member with flanges that allow for a clamp to grasp the member. We observe on *Figure 9-2* that the Unistrut assembly failed to function as intended. The nut-Unistrut assembly became disengaged when the lateral displacement of the Unistrut became more pronounced (over one or two feet) as may be seen on *Figure 9-2*. It is RIZZO's opinion that the side to side movement of the instrumentation conduit allowed momentum to build up enough to create impact forces on the Unistrut-clamp connection. These impacts caused the clamps to slide off the Unistrut, leaving the instrumentation conduits to act as four individual elements instead of the much stiffer arrangement provided by the intended configuration.



FIGURE 9-2

LAYOUT OF INSTRUMENTATION CONDUITS AND UNISTRUTS

It has been postulated that movement of the instrumentation conduits in a back and forth swaying motion contributed to the failure of the turnbuckle-Unistrut-guide cable support system. This postulated behavior is difficult to quantify as it is not practical to ascertain the exact speed of the water flow in the vortex that forms around the “morning glory” inlet shaft. Indeed, the bottom surface of the Upper Reservoir around the “morning glory” was depressed to counter the possibility of vortex action during the generation cycle. In discussion with AmerenUE management, we understand anecdotally that vortex action occurs, possibly in the pumping mode as well. This is a difficult analytical problem to assess as regards the impact on the instrumentation conduits; therefore, we can only comment that no records or calculations were found that would document that this effort was undertaken.

If vortex action is postulated to cause circular flows around the “morning glory” resulting in tangential flows along the concrete facing on the Dike, the flow would have two negative effects on the support system.

Firstly, as the water flows around the turnbuckles, turbulence initiates a vibration in the turnbuckles. This, combined with the tension in the threads, can loosen the turnbuckles. *Figure 9-1*, taken immediately after the installation of the HDPE pipes and supports, shows that many of the turnbuckles were installed with little or no male thread protruding from the female thread. This means that as a few as a dozen revolutions of the turnbuckle could have failed the connection.

Secondly, the water flow produces a lateral thrust on the conduit, causing lateral displacement. Since the conduit spacers/clamps allow upward movement along the guide cables, this lateral displacement is not converted to an axial force as it would if the conduit had been anchored at both ends. Only the guide cables can offer any resistance to this lateral movement of the conduit. But once the turnbuckles fail, the conduit is free to swing.

Figure 9-2 shows the lateral displacement noticed in the conduits about two months before the overtopping failure of the Reservoir. Plant operators were aware that this lateral displacement would have the effect of raising the gage instruments and lowered the pump auto stop elevation by two feet after this observation. It is RIZZO's opinion that that this was not sufficiently conservative considering the level of uncertainty involved.

9.1.3 AmerenUE Response

As discussed above and prior to the Event during October 2005, AmerenUE discovered that a portion of the HDPE pipe supports (housing the level controls) had failed. A plan and schedule was developed by AmerenUE to correct the observed problems. The repairs were not implemented prior to the December 14, 2005 Event. Our review of the records suggests that the partial failure of the instrumentation support systems for the level transmitters was not viewed as an immediate dam safety concern by AmerenUE. We surmise that AmerenUE observed that the protection probes (HI and HI HI) were un-affected and AmerenUE believed that these protection probes would serve as a backup should there be a complete failure of the level control system due to continued failure of the instrumentation support system.

As an added conservatism, and based on the observed problems with the level controls, the operating level of the Upper Reservoir was reduced by two feet such that the last pump would auto stop at El. 1594. In hindsight, the two foot reduction was not sufficiently conservative.

9.1.4 December 14, 2005 Event

Due to a failure of the system securing the HDPE pipes, the HDPE pipes containing the level control transmitters shifted and caused a change in the instrument elevation. This led to actual water levels being about four feet higher than the elevation recorded by the level control transmitters. During the morning of December 14, 2005 the auto stop elevation for the second pump (El. 1594) was not reached until overtopping had occurred and the Upper Reservoir Dike was very near to or at a failed condition. The maximum level recorded by the level transmitter was El. 1593.7 whereas actual peak reservoir level (based on post-incident physical observations) was approximately El. 1597.6.

The level protection system was designed as a backup to the level control system. However, the probes were set above the low point in the Parapet Wall (El. 1597). The probes (at the time of the Event) were installed too high (1597.4 and 1597.7) to be effective. Had the protection probes been maintained at their as-design levels at El. 1596 and El. 1596.2, the uncontrolled release would likely have been avoided.

9.1.5 AmerenUE Organizational Structure

The following text was prepared to summarize the AmerenUE organizational structure as it relates to the operation and control of the Taum Sauk Project. Key management positions responsible for the Taum Sauk Plant are listed below. The first list contains positions which are directly responsible for the operation where as the second list shows positions responsible for providing engineering and technical support to operations.

Operational Personnel

- Vice President, Power Operations. This position oversees non-nuclear power operations and each of the four fossil plants report directly to him. The hydro-operations manager also reports to the VP of Power Operations.
- Manager, Hydro Operations. This position oversees and manages the operation of all of AmerenUE's hydro plants. Plant Superintendent's at each of AmerenUE's

three hydro plants report to the Manager of Hydro Operations.

- Plant Superintendent, Taum Sauk. This position oversees the operation of the Taum Sauk Plant. He is responsible for both operation and dam safety at the project. The Plant Superintendent oversees a Supervisor of Power Production and Engineering, as well as a number of hydro plant technicians.

Technical Services

- Vice President, Generation Technical Services. This position oversees the technical service group which provides engineering support for AmerenUE's coal, hydro, and gas (non-nuclear) generating stations including Taum Sauk. A number of managers report to the VP of Generation Technical Services covering a range of services.
- Manager, Generation Project Management. This position oversees and manages the engineering functions provided by the Technical Services Group. Managers covering mechanical, electrical, and civil/structural all report to the Manager of Generation Project Management.
- Managing Supervisor, Electrical and Controls Group. This position provides electrical and controls support services to all of AmerenUE's non-nuclear generating facilities including Taum Sauk.
- Managing Supervisor, Civil Structural Group. This position provides civil engineering support to AmerenUE's non-nuclear generating facilities including Taum Sauk.

According to discussions with AmerenUE personnel, the employee with primary responsibility for operation of Taum Sauk, including dam safety issues, is the Plant Superintendent. The Taum Sauk Plant Superintendent receives significant support from the Civil Structural Group and the Electrical and Controls Group (e.g., five-year Part 12 Inspections and design of plant modifications). Additionally, consultants are retained, as needed, to support AmerenUE's internal engineering function.

Daily and weekly inspections of the project, including the Upper Reservoir Dike, were completed under the direction of the Plant Superintendent. The checks were for the purposes of operation and maintenance as well as dam safety. However, it is RIZZO's opinion that the personnel completing these inspections were not adequately advised to dam safety issues. For instance, the design freeboard was two feet. Had this information been provided to the technicians performing the inspections, they would have been in a position to confirm that adequate freeboard existed during each inspection. Two instances where this information would have proved critical are highlighted below.

In one instance, during an inspection on September 27, 2005, AmerenUE personnel observed that the water surface of the Upper Reservoir was only about four-inches below the top of the Parapet Wall. As a result, the auto-stop position was lowered by two feet to El. 1594. Had dam safety considerations been thoroughly addressed, a more comprehensive review of the reservoir control systems would have been conducted. For instance, a review of why the level protection probes were not activated would have been appropriate.

During an inspection on September 30, 2005, AmerenUE personnel inspected the HI and HI-HI overflow protection probes and found the probes seven inches and four inches from the top of the Parapet Wall, respectively. The primary purpose of the protection probes should have been dam safety. Specifically, they should have been installed to ensure a minimum of two feet of freeboard. Accordingly, the probes should have been located about two feet below the crest of the parapet wall. Note that this change could have been affected without any knowledge of the variation in settlement along the Parapet Wall and without the need for any survey checks.

9.2 SUMMARY

The design and specification of the instrumentation and control systems were inadequate from a dam safety perspective. Furthermore, an inadequate initial design for the instrumentation supports led to field changes which led to the failure of the supports and errant readings of the water level in the Upper Reservoir. Additionally, the misplacement of HI and HI-HI Probes, as a result of human error, effectively disabled the as-designed level protection. These three items combined to allow the overtopping of the reservoir during the pump back cycle on the morning of December 14, 2005. Specific conclusions with respect to the Barrier Analysis are listed below.

- Design and specification of the instrumentation system was not sufficiently conservative. Had the protection probes been maintained at the design elevations, the overtopping event may not have occurred.
- Even given the loss of the level protection, overtopping still could have been prevented had the level control instrumentation supports not failed.
- Based on our judgment, plant operators and technicians were following operational and inspection procedures as provided by AmerenUE. However, we note that operator training in terms of dam safety was inadequate.
- Operation of the Upper Reservoir in terms of dam safety including maintaining the necessary freeboard was not adequately understood within the AmerenUE Organization.
- Responsibilities for plant operation and dam safety were combined under a single individual. Anyone with this job description may have to potentially balance dam safety and operational constraints.
- Adequate design quality assurance was not followed by AmerenUE and their consultants. Consultants and engineers, including software suppliers, should have followed an ANSI qualified program. This would include documentation of the intent of a design and would also require checks and verifications before making any changes to final design.

It is our overall conclusion that instrumentation failure and human error constitute primary and secondary contributing causes respectively to the Event. If AmerenUE elects to rebuild the Upper Reservoir, operational procedures and training in dam safety should be implemented. Also, consideration should be given to separating dam safety responsibility and operational responsibility.