Section 5 Instrumentation and Controls

5.1 General

The project is controlled through a telephone and microwave system from the Osage Plant at the Lake of the Ozarks, under the direction of the load dispatcher in St. Louis. Both units can be put on full load in a few minutes.

A description of Standard Operating Procedures for the project is in Section 1.7.

5.2 Instrumentation History

A written description of the water level instrumentation was provided by AmerenUE during the January 9-12 FERC Taum Sauk Investigation Team site visit. The original reservoir monitoring system consisted of: (1) three Warrick conductivity sensors at elevations 1501.00, 1506.0 and 1508.0, (2) a skate type system (i.e., a float riding on a cable guided roller assembly in a pipe) to monitor upper reservoir levels for normal shutdown of the units, and (3) a set of mercury switches tied to a float in a stilling well for High and High-High backup pump shutoff. There was an encoder and chart recorder on the skate system to provide level indication and recording. Components of the system were anchored to the concrete face of the dam.

In 1994, a differential pressure transducer was added to provide secondary level indication at the plant. In 2000, the original skate system, encoder, and chart recorder were replaced with a differential pressure level transducer, Programmable Logic Controller (PLC), and a digital level indicator at the upper reservoir.

All of the upper reservoir level control and protection devices were replaced when the geomembrane liner was installed at the end of 2004. Three General Electric Druck Model PTX 1230 100 psi piezoresistive micro machined silicon strain gauge pressure transducers (referred to as Druck pressure transducers or transmitters) were installed for normal shutdown of the units. The Low and Low-Low Warrick conductivity sensors were replaced in kind. The High and High-High mercury switches were replaced with Warrick conductivity sensors. The upper reservoir PLC was replaced with an Allen-Bradley PLC. The unit shutdown relays at the plant were replaced with Allen-Bradley PLCs. The level indicators, alarming, and data acquisition systems were replaced with a WonderWare Operator Interface.

At the time of the December 14, 2005 breach, the upper reservoir control system consisted of two sets of sensors sending the signals through three independent

PLC computers. One set of sensors were two Druck pressure transducers used to monitor reservoir levels (the third Druck pressure transducer was not used due to inaccurate readings).

The second set of sensors consisted of four Warrick Conductivity sensors. Two of the Warrick sensors (HIGH and HIGH-HIGH) were to determine if water levels in the upper reservoir were too high. The other two Warrick sensors were to determine if water levels in the upper reservoir were too low. Activating these sensors would start a hard shutdown of the generator/pump units.

5.3 Description of Instrument Structural Support System

The upper reservoir controls and structural support system were replaced in 2004 following the installation of the geomembrane liner. Four 4-inch-diameter High Density Polyethylene (HDPE) pipes were installed extending down the interior slope of the embankment from the metal box at the top of the parapet wall panel 50 near the gage house. Reservoir levels were monitored initially with three Druck pressure transducers which were placed at elevation 1500 ft. in one of the HDPE pipes. Four Warrick conductivity sensors were place a separate HDPE pipe for emergency shutdown should extreme low or extreme high water levels were to occur.

The HDPE pipes were tied to 1 inch by 48 inch by 12 inch HDPE flat stock which was set on, but not connected to a HDPE rub pad which was glued to the geomembrane liner. These pipes were not firmly attached to the face of the dam. Instead, stability was intended to be provided by a configuration of stainless steel unistrut section, steel bolts, turnbuckles, jam nuts, eyebolts and U-shaped cable lock bolts tied to two stainless steel cables. The cables were anchored only at the toe block at the base of the slope and at the interior base of the parapet wall (Figure 5.1). Down slope movement of the HDPE pipe assembly was limited by clamps placed on the cabled just down slope of the eyebolt connection to the pipe assembly. A similar restriction to movement upslope was not included.

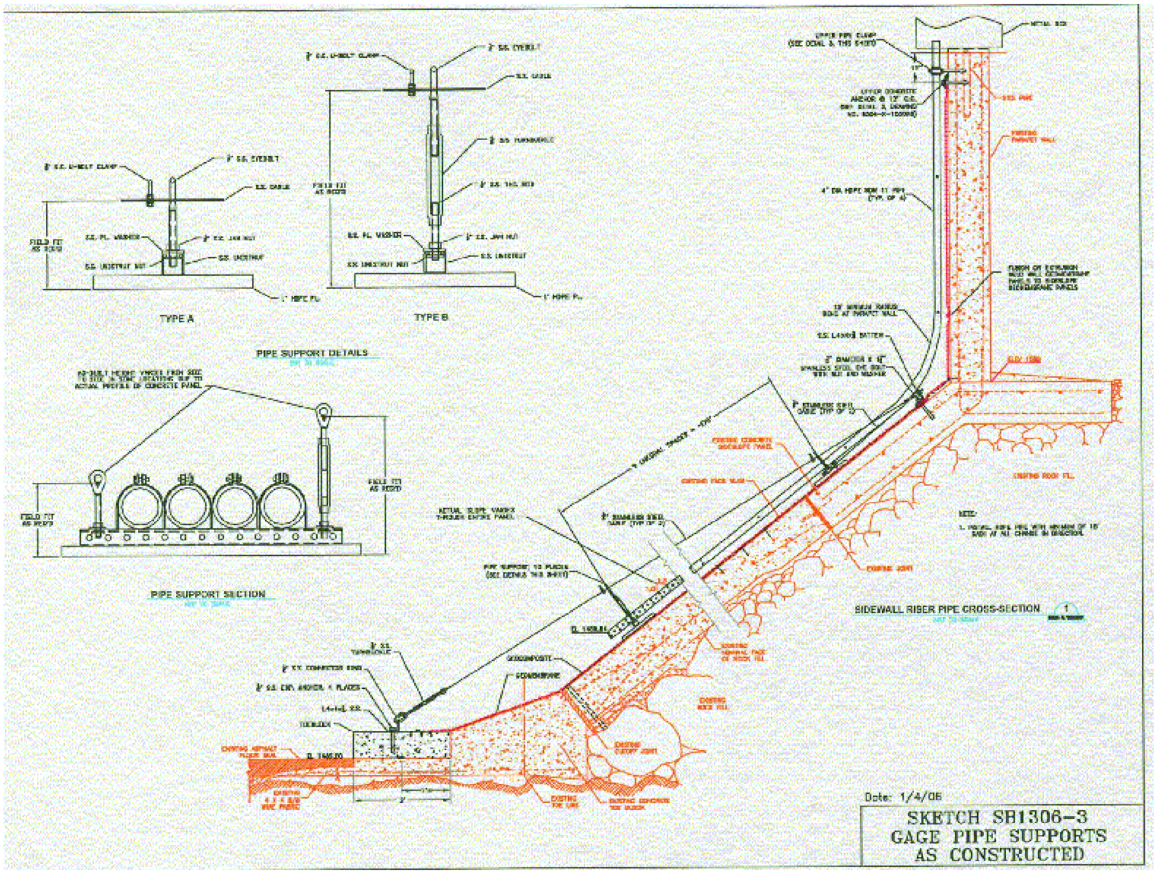

Figure 5.1 - Structural Design of the Upper Reservoir Control System December 2004

5.4 Upper Reservoir Overpumping Emergency Control

Following installation of new instruments in 2004, the elevations for normal shutdown via the Druck pressure transducers were 1592 for the first unit, 1596 for the second unit with a total shutdown to occur if the reservoir reached 1596.5 ft. This overlapped the original hard trip setting of 1596.0 for the HIGH and 1596.2 for the HIGH-HIGH Warrick conductivity sensor. The elevation of the conductivity sensors elevations were later changed to “avoid spurious trips” during the operation of the project after 2004.

The following shows the settings of the HIGH and HIGH-HIGH sensors from November 2004 through December 2005:

<u>November 2004</u>

HIGH Warrick Conductivity Sensor	1596.0 ft.
HIGH-HIGH Warrick Conductivity Sensor	1596.2 ft.

December 10, 2004 (from AmerenUE Drawing 8303-P-26648)

HIGH Warrick Conductivity Sensor	1596.7 ft.
HIGH-HIGH Warrick Conductivity Sensor	1596.9 ft.

September 30, 2005[2]-December 14, 2005

HIGH Warrick Conductivity Sensor	1597.4 ft.
HIGH-HIGH Warrick Conductivity Sensor	1597.66 ft.

Figures 5.2 show the configuration of the sensors within the instrument cabinet. The cabinet is located on the dam crest at the southwest end of the reservoir. Figure 5.3 shows distances from the Warrick Conductivity sensor tips to reference tapes placed on the wiring by AmerenUE staff. The tapes were used to place the sensors at the original design elevation (November 2004) and the as-found elevation on December 14, 2005.

Figure 5.2 - Cabinet containing the Druck pressure transducer and Warrick conductivity sensor wiring

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[2] Elevation as found by Ameren employees on September 30, 2005 (reference Ameren October 7, 2005 Email(See Section 6, page 94 of this report). Note that this change could have made earlier.

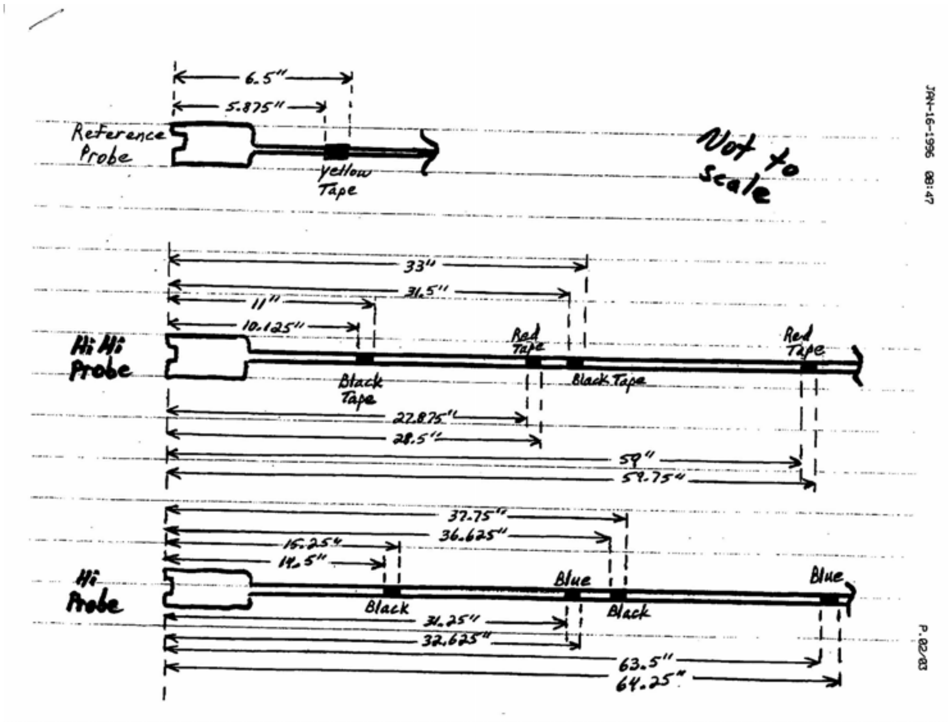

Figure 5.3 - Tape reference points on leads to the HIGH and HIGH-HIGH Warrick Conductivity Sensors (as Provided by AmerenUE)

5.5 Pre-Breach Events – Indication of Problems with Reservoir Monitoring System

At the time of the geomembrane liner installation in 2004, three Druck pressure transducers were installed to monitor reservoir levels and for shutting down the pump/generator units. The average of the three readings was used to monitor reservoir levels. The original elevations for normal pumping shutdown via the Druck pressure transducers were 1592 for the first unit, 1596 for the second unit with a total shutdown to occur if the reservoir reached 1596.5 ft.

5.5.1 September 2005 - Wave Overtopping

No problems were noted with the system until September 25, 2005 when an “overtopping” event associated with the winds generated from the remnants of Hurricane Rita. The overtopping was witnessed by project personnel at the northwest section of the reservoir (panels 90-96). Erosion occurred along the base of the parapet wall and access road. Approximately 0.5 to 1-foot-deep erosions gullies were formed at the base of the parapet wall. Five truck loads (79 Tons) of gravel were required to repair the damage.

It should be noted that although the reservoir level was close to the top of the low section of the parapet wall during this event, no signals were received from the Warrick conductivity sensors.

On September 27, 2005, AmerenUE employees inspected the upper reservoir and instrumentation. They estimated the Druck pressure transducers were 0.4 ft different than the actual reservoir elevation. The programming logic was modified to account for the 0.4 ft difference by adding 0.4 ft to the average of the instrument readings. Also, one of the three Druck pressure transducers was removed from the average. This value was then documented by the PLC.

AmerenUE did not verbally or formally report the wave overtopping, damage assessment, repair, and modification to the reservoir monitoring programming to the FERC until it was discovered by the FERC Taum Sauk Investigation Team following the December 14, 2005 breach.

5.5.2 October 2005 – Deterioration of Instrument Structural Support System

An October 3, 2005 inspection by AmerenUE of the reservoir monitoring system revealed the HDPE pipes were bowed out to one side an estimated 3 feet. (Figure 5.4 shows bowing after the breach) The bowing of the instrumentation pipes coincided with the failure of the fasteners holding the pipes to the stainless steel cables. The intake in the upper reservoir is about 125 ft from the location of the HDPE pipe and instrumentation.

The effect of the pipes bowing out to the side was to raise the elevation of the Druck pressure transducers. The pressure transducers were no longer at a known elevation to accurately report the water surface elevation of the reservoir. On October 7, 2005, the system was adjusted by resetting the stop pumping operations to elevations 1591.6 for the first unit and 1594.0 for the second unit. AmerenUE believed the adjustment was sufficient to prevent overtopping. Following this adjustment, the operating staff visually monitored the reservoir elevation with the staff gage, but only once a week. AmerenUE employees used check marks on their inspection sheets to verify the monitoring was performing properly.

Per AmerenUE staff, the design for a stiffer mounting system was completed October 25, 2005. Scheduling of the diver and a low water period for installation was not finalized with the last schedule for work being set for a spring 2006 drawdown.

AmerenUE did not verbally or formally report the results of the visual inspections of the HDPE pipes or the modifications to the pump/generator controls to the

FERC until it was discovered by the FERC Taum Sauk Investigation Team following the December 14, 2005 breach

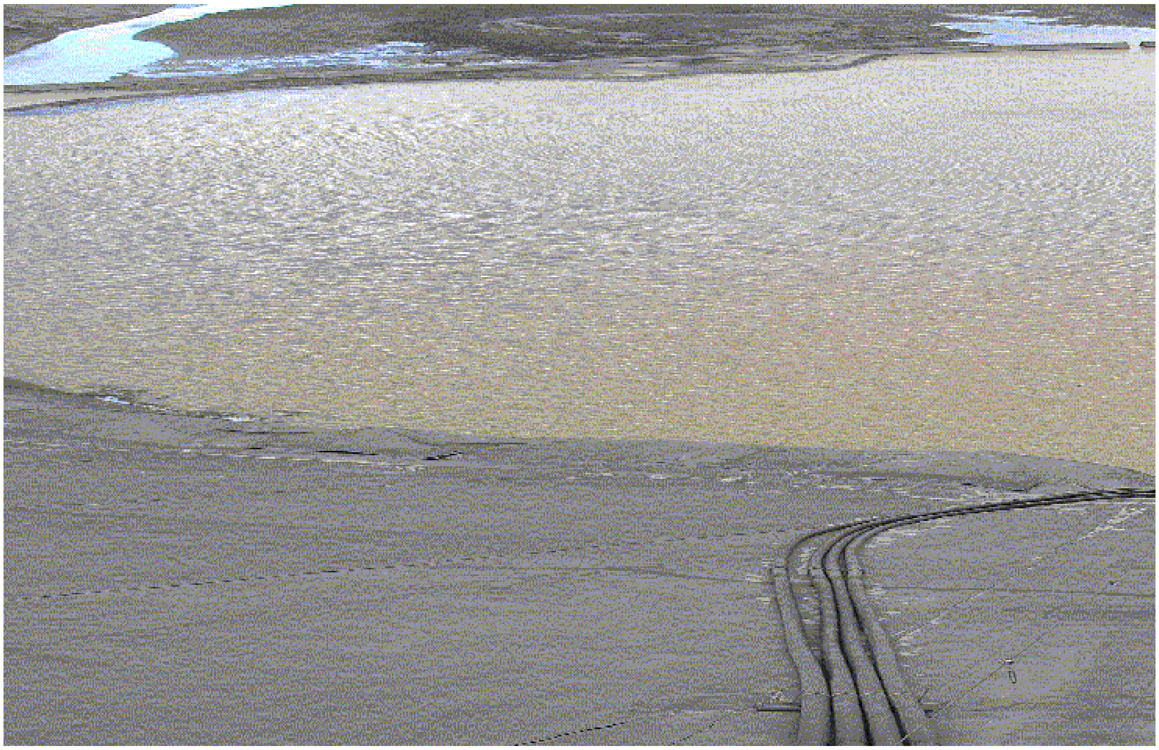

Figure 5.4 - Bowing of HDPE Tube position on December 15, 2005

(Courtesy of Missouri DNR)

5.6 Programming Logic Controls for the Upper Reservoir Controls and Emergency Controls

General

Two primary PLC devices – manufactured by Allen Bradley - comprise the reservoir control system. They are called the Common PLC and the Upper Reservoir PLC. Both of these devices are programmed using the RSX logic language. The Druck pressure transducers and the Warrick conductivity sensors are connected to these two devices. In the case of the Warrick sensors one sensor is connected to the Common PLC and the other sensor is connected to the Upper Reservoir PLC to provide redundancy for the safety backup system. During normal plant operations the operators access these two PLCs via the WonderWare Human Machine Interface (HMI). If changes are needed to the actual PLCs then selected personnel who have the appropriate access log into the PLC itself and make the required changes which are then downloaded into the PLC.

The basic operation of the project is controlled via the PLCs, with the primary sensors being the Druck pressure transducers. These pressure transducers determine the level of the Upper Reservoir and then determine if it is within the operational limits as selected by the operators from the HMI menus. If it is within the operational limits the system will continue to allow the plant operations to proceed (e.g., generating, pumping, or quiescent). The minimum operational level is used to "control" the generation cycle of the plant and the maximum operational level is used to "control" the pumping cycle of the plant.

In generation mode the plant will continue operations as long as the Upper Reservoir level does not reach the pre-set minimum operational level or until the operator commands generation to cease. In the pumping mode the plant will continue operations as long as the Upper Reservoir level does not reach the pre-set maximum operational level or until the operator commands the pumping to cease. If either of these levels is reached in its respective mode the PLC programming would shut down the operation smoothly. This basic operational structure is solely based on the Upper Reservoir Level as determined by the Druck pressure transducers.

The Warrick sensors are used as a safety mechanism. There are two Warrick sensors for a safety during generation and there are two Warrick sensors for a safety during pumping operations. These Safeties are designed to shut down operations when activated if for some reason the normal operational shutdown does not occur. In all cases, this shutdown is a "hard" emergency stop vice a "ramp" down method used for normal shut down operations. In normal operations these sensors should never be contacted unless something has gone wrong.

The two Warrick sensors used to shutdown the generation cycle are designated LOW and LOW-LOW. According to a comment in the Common PLC code the one sensor (LO-LO – as quoted from the code) is set to an elevation 1524 ft. Where as, in the Upper Reservoir Code the other sensor (LO) is set to an elevation of 1524.5 ft.

The two Warrick sensors used to shutdown the pumping cycle are designated HI and HI-HI. According to a comment in the Common PLC code the one sensor (HI) is set to an elevation of 1596.5 ft. Whereas in the Upper Reservoir PLC code, the other sensor (HI-HI) is set to an elevation of 1596.7 ft. (NOTE: At the time of the breach the "believed as found" physical locations of the Warrick sensors was 1597.4 ft (HI) and 1597.66 ft. (HI-HI), respectively.) There was redundancy built into the design as one sensor for each mode was available at each PLC. In addition, the design as implemented had each PLC having one of the critical sensors (e.g., LO-LO, HI-HI) on it so that no one PLC had both critical "hard" stop sensors. The initial code as developed would allow either of the Warrick sensors to trigger a “hard” stop as another form of redundancy (e.g., either HI or HI-HI could trigger a “hard” stop).

The initial code indicates the main control of the plant was via the Druck pressure transducers. If for some reason those transducers did not operate correctly when the first Warrick sensor was encountered (LO or HI) the process would be immediately terminated. If for some reason the process was not terminated (i.e., the first Warrick sensor had a failure that kept it from operating) when the second Warrick sensor was encountered (LO-LO or HI-HI) the system would again perform a “hard” emergency stop of the operations by tripping out a relay which results in a two phase operational approach to the shutdown of operations: first a normal automatic operations based on the Upper Reservoir Level as determined by the Druck pressure transducers, and then a “hard” emergency stop by either of the Warrick sensors in the event of a failed normal shutdown.

However, based on interviews with AmerenUE personnel and examination of the final code several changes had been made that affected this two tiered approach.

60 Second Delay

A 60 second time delay was added to the Warrick Sensor readings to minimize false trips of the relay. The Warrick sensor had to be activated for 60 seconds in order for the activation to be considered “real” and the relay for a “hard” stop tripped. This change was brought about due to several false trips of the relay ostensibly from “wave action”. No documentation was obtained that discussed the technical ramifications of this solution or the technical rationale for why 60 seconds was chosen as the appropriate delay length.

A typical PLC has a scan time of 200 microseconds or below which means that the PLC is checking states 5000 times a second. One scan pass with a new state will start the time cycle over again. (Note: From interviews we were informed that the PLC scan time was around 40 microseconds). It is doubtful a wave would maintain contact with the Warrick Sensor for more than a few seconds. Using typical pumping rates for the project, a 60 second delay would result in the reservoir level rising more than 1.5 inches for two pumps running and about 0.75 inch per minute for one pump operating. If a 10 second delay was used, the rise in reservoir level would be slightly more than ¼ inch (or 1/8 inch for one pump approximately 374 thousand gallons or 187 thousand gallons of water respectively). A smaller delay would agree more with the intent of the Warrick sensors (HI and HI-HI) use as part of the safety system to prevent overtopping.

Series v. Parallel Code

Sometime after initial installation, the PLC was modified to tie the Warrick conductivity sensors in series rather than in parallel. For a “hard” emergency stop to occur, programming now required both Warrick sensors to be activated (e.g., LO and LO-LO would have to be contacted for 60 seconds before a “hard” stop of the generation process would occur assuming that both PLCs are functioning properly). However, if communications with one of the PLCs was not available then when the Warrick sensor on the “alive” PLC was activated (after the 60 second time delay) the system would perform a “hard” emergency stop regardless if it was the “first” or “second” Warrick sensor in the process.

Based on interviews, the LO-LO and HI-HI sensors were wired into the system to both alarm and perform a “hard” emergency stop. The LO and HI sensors were wired into the system but they would not generate an alarm, and if water contacted the sensor the PLC historian would NOT record in the logs that the sensor had been activated. This modification (basing the activation of the “hard” emergency stop on the Warrick sensors operating in series) was in response to false relay trips. No documentation was found that discussed the technical issues of this problem or the technical rationale for tying the sensors in series. In addition, it was discovered that the HI and HI-HI sensors were also tied in series rather than parallel. Again, no documentation was found that discussed the technical issues or the technical rationale for tying the HI and HI-HI sensors in series. One hypothesis that was postulated during interviews was that this modification was performed to keep the control processes “consistent”.

Instead of having two separate systems for emergency shutdown for true redundancy, the programming changes resulted in only one system. This also led to a flaw in the operational logic of the plant processes. The code is contained in the two main modules that control the Unit 1 and Unit 2 pumps and generators (TSM01Unit1Main and TSM02Unit2Main respectively). The PLC code looks to see if a variable “Comm2UpperFault” is set (signifying that a PLC was not communicating) and if this variable is not set, the code requires both Warrick Sensors to be activated before it would trip the relay to stop the process. The flaw in the operational logic is as follows: Assuming that both PLCs are operating correctly, if one of the Warrick sensors fail in a manner that would not impact the Comm2UpperFault variable (e.g., the sensor is capable of sending the appropriate voltage level for non-activation but the circuitry for activation does not work so the “additional” voltage is not placed on the line.) then the relay would never be “tripped” to stop the process as one of the conditions would not be met (i.e., both sensors must be activated in order to trip the relay). So this change in the code could result in the safety system not activating upon the failure of one of the Warrick sensors.

Combination of Series Logic and Delay

Tests on the Warrick sensors after the December 14th incident showed that both Warrick sensors were capable of proper operation. Based on the "believed as found" physical locations, the Warrick Sensors were installed at 1597.4 ft. (HI) and 1597.67 ft. (HI-HI) which was higher than the height of the lowest panel. However, the HI sensor was below the estimated maximum reservoir level (1597.6 – 1597.8 ft). Because of the modification to have the Warrick sensors to operate in series, the PLC logic for the "hard" emergency stop was never executed. Due to the incorrect placement of the Warrick sensors the height of the HI sensor was 4.92 inches higher than the lowest panel of the parapet wall. However, if the Warrick sensor had been in parallel operation (with only a 10 second time delay), the HI sensor would still have shutdown the pumps and kept an additional 3.6+ inches of water from overtopping the wall (assuming a maximum pool of 1597.7 ft. during overtopping).

Other Code Discrepancy

Another flaw that was discovered by AmerenUE in the after incident investigation was that a coding modification located in Unit 2 Main PLC resulted in the disabling of the Unit 2 shutdown from the Warrick sensors. The Unit 2 Main PLC program was looking for the message tag "TSComWmgUrsLvlCtrl" instead of the correct message tag of "TSComWmgUrsLvlSwCtrl", (note missing "Sw"). This mistake meant that Unit 2 Main PLC program would never read the Warrick Sensor inputs so it would not know if the sensors had ever activated. During the incident the Unit 2 pump had already been shutdown several minutes before the HI Sensor contacted water

PLC Configuration Control Process and Testing Process

Based on interviews and other materials, there was no formal, robust Configuration Control Process for the PLC at the Taum Sauk facility. That meant that there was little control or oversight on changes that were made to the operational system. Due to this there is little to no documentation that discusses the problems that were encountered in the system, the technical rationale for proposed solutions, nor information concerning why a specific proposed solution was chosen.

It was also found that no formal testing program or procedures existed to test modifications made to the PLC code. The only testing that was performed was done by the individual who made the changes and only to the extent that they believed was necessary. The only documentation of any modifications was contingent on the individual who was responsible for implementing those changes. As a result there is little to no documentation on the problems that needed to be fixed, the technical ramifications of those problems, the technical rationale behind the proposed solution, and the testing that was performed to ensure that everything worked properly once the proposed solution was implemented.

Boundary Checking

From the pumping data there were several instances that the data reflected unusual activity like both pumps operating but the water level was not rising. In most instances, it takes only 7-8 minutes to raise the reservoir level one foot (with both pumps operating). The PLC system did maintain these values and they are displayed by the HMI, but there does not seem to be any "boundary checking" for values that did not make sense. In other words, the system did keep track of rate of level change but did not alarm if that rate of change was not within a "normal" range. For instance, on 13 December at 23:20 the reservoir was at 1549 feet, it took 20 minutes with both pumps working for the reservoir level to rise 1 foot to 1550 feet. Assuming a 1 foot rise per 8 minutes of pumping in 20 minutes the level should have increased by 2.5 feet. While this data was obviously recorded, the system did not highlight this abnormal situation. If the system would have included this type of "boundary checking" it is possible that an operator could have investigated the situation and taken corrective action. There was some boundary checking in the PLC logic. In fact, it was this boundary checking that allowed AmerenUE to determine that a Druck pressure transducer was out of alignment with the other two transducers and remove it from the Upper Reservoir level calculation.

5.7 Post Breach Inspection of Instrumentation and Analysis of Operations Data

5.7.1 Bowing in HDPE Tubes

The licensee reported that the offset and length of the arc of the HDPE pipes measured after the breach were 14 ft and 119 ft, respectively (see Figure 5.4). This was estimated to raise the reservoir control sensors approximately 2.5 feet. Due to the fact that the pipes have a tendency to straighten after the water is drawn down, it is not known what the maximum deflection was at the time of the breach. The estimate of peak pool level of about 1597.7 ft verses the Druck pressure transducer reading of 1593.72 indicates the transducers were about 4 feet higher in elevation than the original design. The following table presents the results of a geometric analysis of the bowing in the HDPE pipes showing several variations of offset and arc lengths and the resulting increase in elevation. Chord lengths were limited due to a cut in the rock outcrop where the pipes tended not to move laterally (see Figure 5.5).

Horizontal Offset (ft)	Chord Length (ft)	Arc Length (ft)	Delta Increase in Elevation (ft)
5.0	100	100.67	0.44
12	100	103.8	2.3
15	100	105.9	3.63
15	119	123.98	3.04
17.25	119	125.56	4.0
16.0	113.54	119.45	3.61
18.0	113.54	120.99	4.54

Figure 5.5 - Instrumentation location relative to the water conveyance shaft

5.7.2 High Water Marks on the HDPE Pipes

Evidence of the monitoring system not operating as designed was found at the gage house with water marks noted on the HDPE pipes. The elevation of the watermarks indicates the peak reservoir level may have been routinely above elevation 1596 ft. Figures 5.6 and 5.7 are a photograph and schematic of the high water marks, respectively.

Figure 5.6 - High Water marks on HDPE Tubes

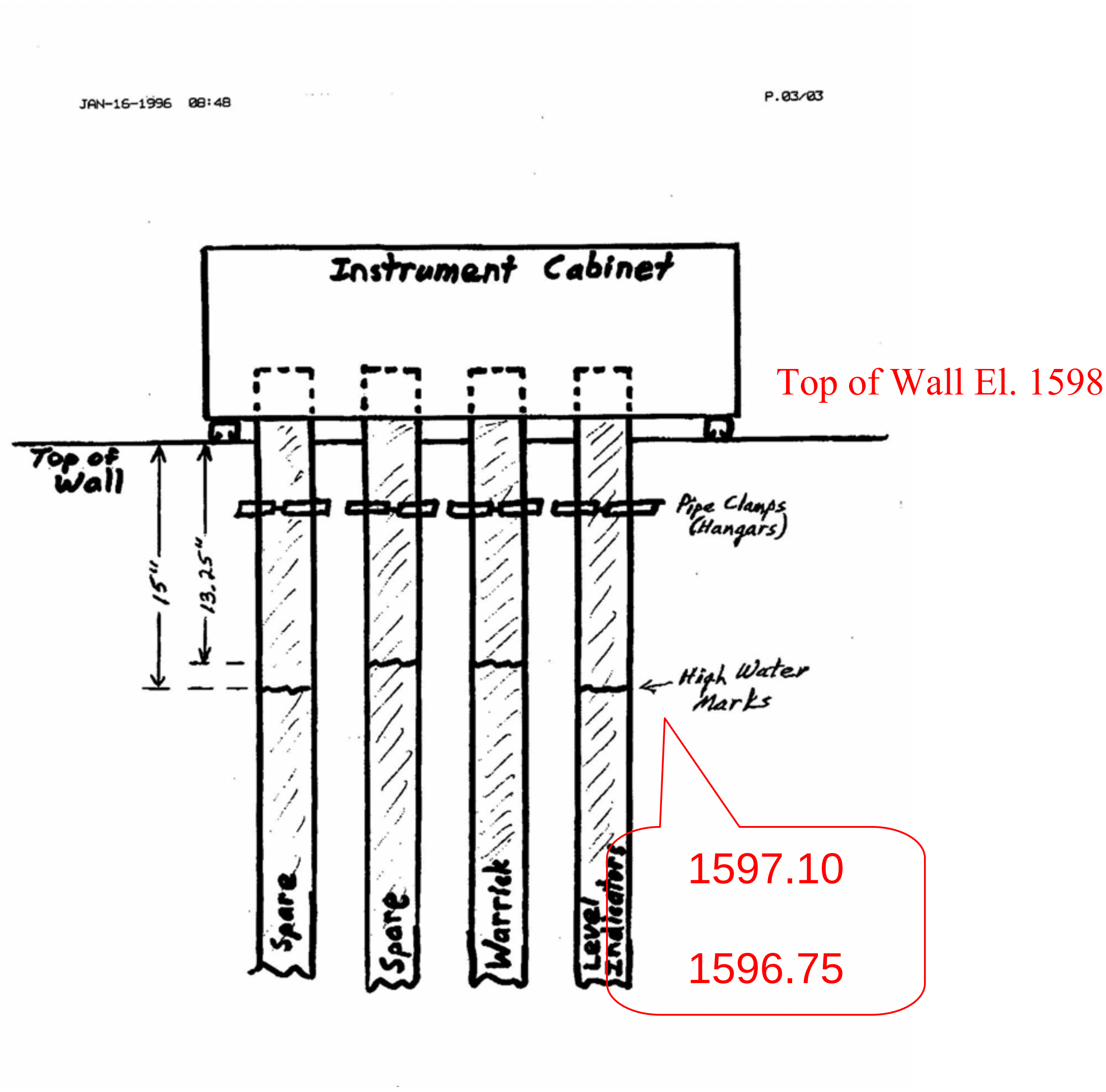

Figure 5.7 - Elevation of high water marks

5.7.3 Comparison of Penstock Transducer and Druck Pressure Transducer

Figure 5.8 plots the average difference between the penstock transducer and druck pressure transducer readings as provided by AmerenUE's letters dated December 27, 2005 and February 7, 2006. The chart plots the daily average differences on the first and fifteenth of each month from February 1 to December 1, 2005

The data points are the weighted average of readings for every minute during periods when the units were not operating (i.e., steady state). This was done because there are inconsistencies in the penstock readings when the units are operating. Readings were also neglected for 15 minutes before the units are put on-line and after they were taken off-line to ensure all readings had leveled off.

The bi-monthly plots show a sharp negative trend in the differences of the readings between April and August, reaching a low point in August. The differences then have a positive trend from August to December, approaching the readings experienced the previous winter. AmerenUE’s February 7, 2006 submittal notes that the trend between the difference of readings correlates with the trend in water temperature. That is, the difference of readings became larger as water temperatures increased during the spring and summer and the difference became smaller as water temperatures decreased in the late summer and autumn.

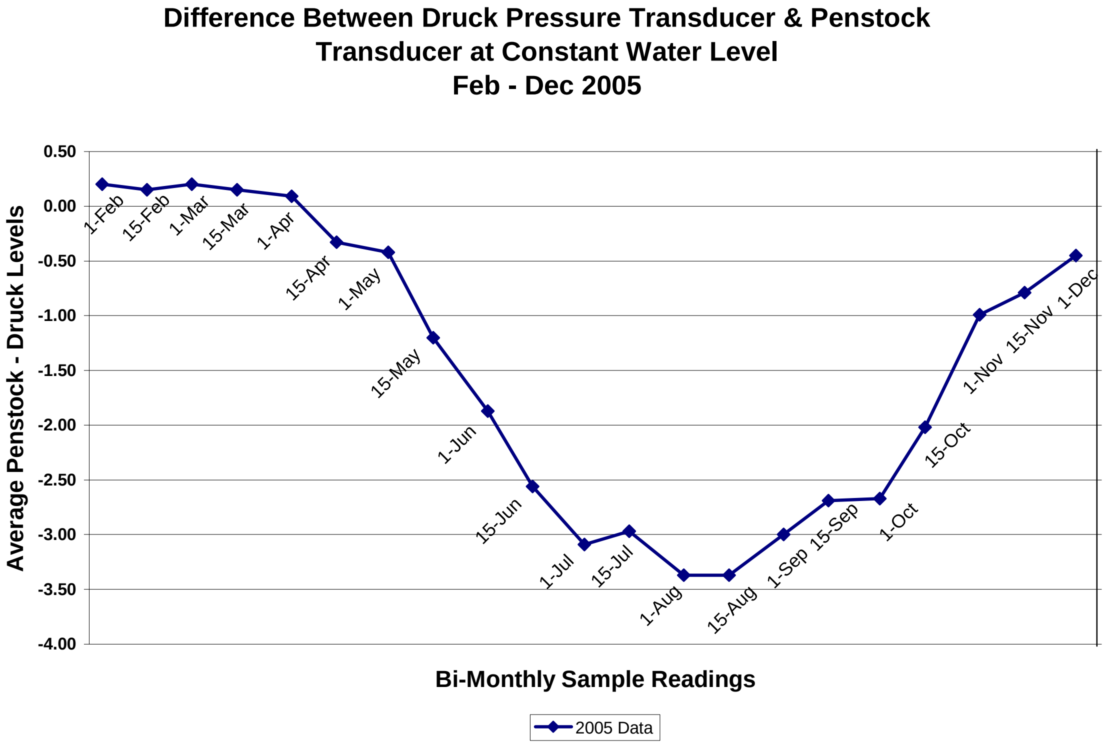
Difference Between Druck Pressure Transducer & Penstock Transducer at Constant Water Level
Feb - Dec 2005

Figure 5.8

AmerenUE’s February 7, 2006 filing also provides charts comparing the Druck pressure transducer (referred to as transmitter) readings and the penstock transducer readings, to determine if movement of the Upper Reservoir transducers could be detected. These charts give more specific information for each day in 2005 until December 14. Figures 5.9-5.12 show the graphs provided by AmerenUE for September through December 2005. September 27 shows a significant movement which coincides with the date one Druck pressure transducer was removed from averaging and a 0.4 foot correction was made in the PLC to the Druck pressure transducer readings. Significant and larger movements appear in December 2005, with increases in the differences on December 2 and December 13.

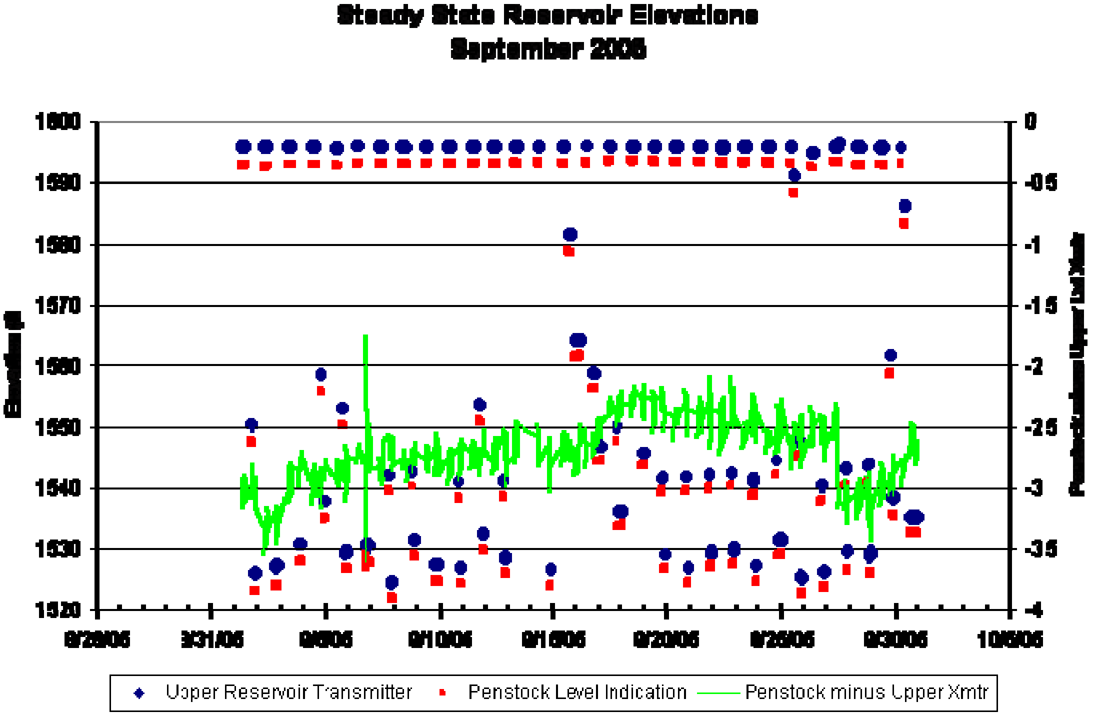

Figure 5.9

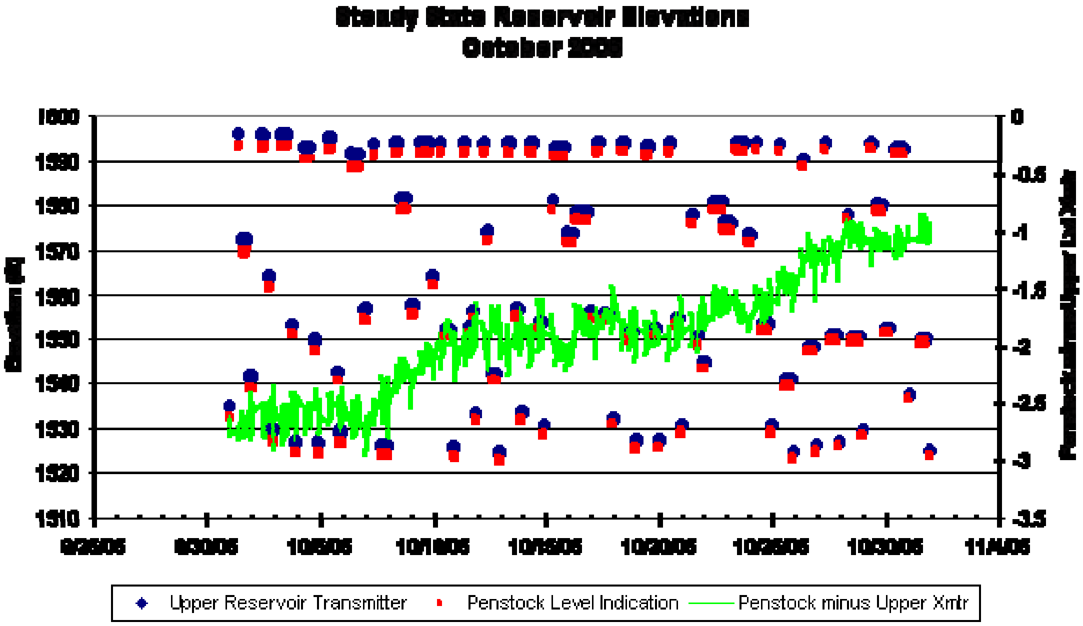

Figure 5.10

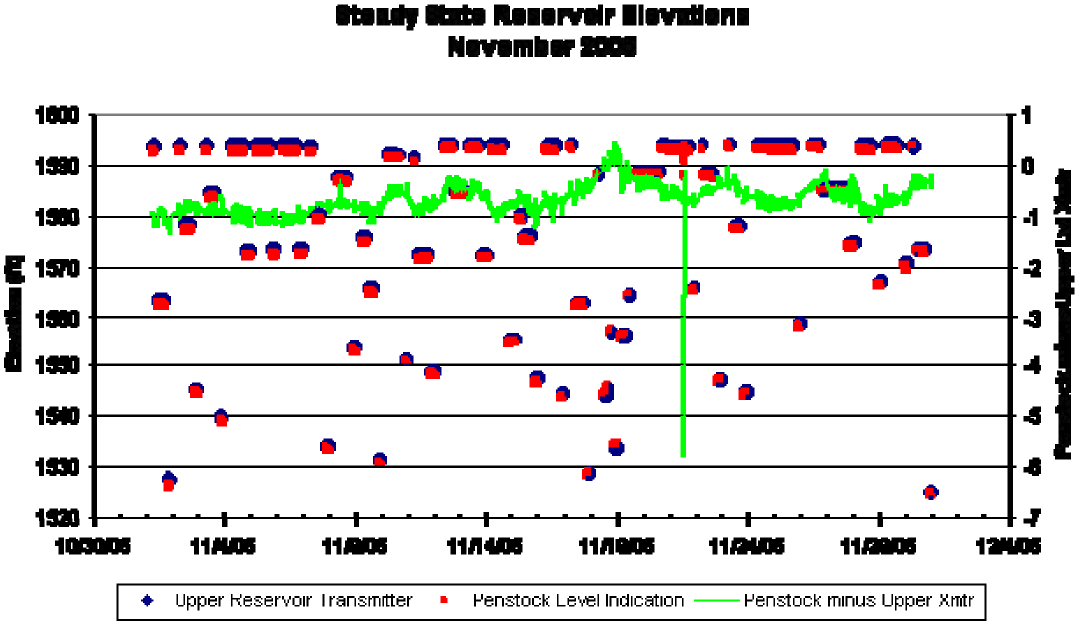

Figure 5.11

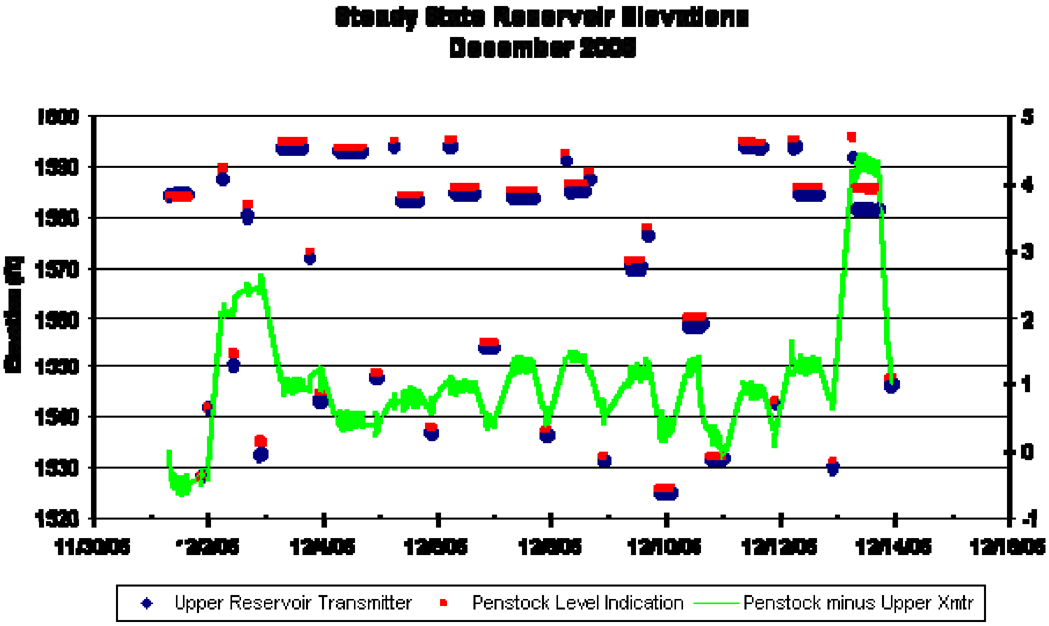

Figure 5.12

5.7.4 *Assessment of the Reservoir Level Indicator Readings versus the Pump Back Times on December 13th and 14th, 2005 of Taum Sauk*

5.7.4.1 Daily Operations

Typical daily operations at the Taum Sauk Upper Reservoir are illustrated for the period of September 1, 2005 to December 14, 2005 by the graphs found in Appendix B. A 1596 elevation line was added to the graphs for ease of monitoring the maximum reservoir pump back elevations. A written description of standard operating procedures is in Section 1.7.

5.7.4.2 Average Pump Back Times per Foot of Reservoir Level Increase

Appendix B – Figures B.9–B.14, examines pump back times on 6 random days in July 2005 for the purpose of determining the average pumping time in minutes it normally took to raise the reservoir 1 foot in elevation. The pump back times were examined for both one pump operating and for two pumps operating. The generating and idle times for the dates used were removed from the figures, since this data were not of interest for pumping times. A column with the calculated average pump back time was added at the right side of the AmerenUE data for the purpose of graphing this data and to identify normal and unusual readings. To reduce the scatter from one reading to the next due to waves and turbulence, the average pump back time was obtained by taking the difference between the reservoir elevation at a particular time and the reservoir elevation 20 minutes prior and dividing this difference into 20 minutes.

The pump back times for two pumps operating were observed to range from 5.5 minutes per foot to around 6.00 minutes per foot when the reservoir was below 1550 feet. From elevation 1550 feet to 1570 feet the time to raise the reservoir one foot with two pumps operating ranged from around 6:00 minutes to 7:00 minutes. The time to raise the reservoir one foot, from elevation 1570 feet to 1596 feet, generally ranges from 7:00 minutes to 8:00 minutes.

When one pump operated at the end of the pump back cycle in the early morning, the reservoir elevations were usually above the elevation 1589 ft with a constant reservoir surface area of 55 acres. The time to raise the reservoir one foot with one pump operating ranged from 14 minutes to around 18 minutes. The time for pump back with one pump operating was generally more variable than when both pumps were operating. These greater variations could be due to wave actions and turbulence influencing the actual reservoir elevations from minute to minute being used for calculations. Alternatively, greater turbulence could have caused the pipes with the reservoir sensors to move around.

The average pump back times were used as a base range to compare the pump back times on December 11 to 14, 2005 to observe for changes that may have been occurring.

5.7.4.3 Reservoir Operation on September 27, 2005

Appendix B – Figure B.15 shows data for the morning of September 27, 2005 during the idle mode after the reservoir had been pumped up to approximately 1596 elevation. As can be observed in the figure, the reservoir level indicator drifted downward by about 0.25 foot around 10:29 AM to 10:34 AM, which is reflected by an increased reservoir level reading of approximately 0.25 foot. Later around 11:15 AM there is another shift upward in the reservoir level reading of about 0.4 foot. This shift is probably the time at which the 0.4 foot adjustment was added into the PLC logic to shut the pumps off 0.4 foot short of elevation 1596 feet to account for observed differences in reservoir level indicator readings and staff gauge readings.

5.7.4.4 Pump Back Discrepancies

Event Discrepancies Chronology

An average pump back time per foot of reservoir increase was discussed above for 6 random days in July 2005. The pump back times ranged from around 6 minutes per foot of increase when the reservoir was at an elevation less than 1550 feet to a pump back time of 7.5 to 8 minutes per foot of rise as the reservoir elevation reached and exceeded 1570 feet. The normal fluctuations from one minute to the next could be attributed to variability in the sensor signals, wave actions and turbulence. Unusual pump back times that spike upward or downward out of the normal variation range can help identify reservoir sensor changes in and around that time.

Appendix B – Figure B.16-B.19 reviews pump back and reservoir data for approximately 72 hours prior to the breach of the upper reservoir. Graphs from this Exhibit are plotted for each day December 11th through December 14th.

In reviewing the reservoir pump back data for December 11th to 14th, several irregular pump back times were noted. On December 11th at 5:03 AM the reservoir level indicator read 1573.91 feet and 20 minutes later at 5:23 AM the reservoir level indicator read 1574.08 feet, which is a difference of only 0.17 foot. When this difference was divided into the 20 minute time period the pump back time rate is about 115 minutes/foot. During this period of time both pumps were operating and the rise in reservoir level over this 20 minute cycle should have been nearly 3 feet, not 0.17 foot. The HDPE pipes could have been moving during this time causing the reservoir sensors to show a nearly constant reservoir level over this 20 minute cycle, even though the reservoir was increasing by about 3.0 feet. At 5:24 AM, the reservoir level read 1575.45 feet which is a 1.4 foot increase from the 5:23 AM reading.

There were some extended pump times during the early morning hours of December 13th, when it took 12 to 14 minutes to raise the pond by 1 foot with 2 pumps operating. The accumulated increases during the morning of December 13th pump back, the night of December 13th, and the morning of December 14th could have raised the pond by more than 2 feet above what was actually being indicated.

An important point of interest also occurred on the night of December 13th between 23:20 hours and 23:21 hours. The reservoir level indicator dropped from 1548.97 feet to 1547.47 feet which is a 1.5 foot drop. This drop is shown on Appendix B - Figure B.8. This 1.5 foot drop could have been the result of multiple turn buckles coming loose and allowing the 4 HDPE pipes to move laterally to the extent that the lower ends of the HDPE pipes with the piezometer sensors were raised up 1.5 feet in elevation. This would have caused the reservoir level indicator to show that the reservoir was 1.5 feet lower than it actually was. There were fluctuations up, down, and laterally over the next 20 minutes while full pump back was going on with both pumps going. From the pumping and reservoir data one can see that the reservoir level was essentially at 1549 feet at 23:20 hours. It was not until 23:40 hours that the reservoir level reached 1550.15 feet. This indicates that it took 20 minutes of pumping with both pumps to raise the reservoir 1.15 feet. Again, the reservoir level increase during this period should have been approximately 3 feet due to the reservoir being around the 1550 level with a normal pump back time of 6 to 6.5 minutes per feet at this level.

5.7.5 Druck Pressure Transducers - Signal Variability

Specification for the Druck pressure transducers were +/-0.25% FSBSL (Full Scale Best Straight Line) for Combined Non-linearity, hysteresis and repeatability and +/-1.5% for temperature effects. Per the manufacturer's (General Electric Sensing) representative, the variability of the signals within the range of the instrument can be as high as +/- 0.25 % which is +/- 0.58 ft of head. Also, per the manufacturer's representative very little error would be introduced if the temperatures of the surrounding media are consistent. Variability of +/-0.58 ft of head is seen in the reservoir level data provided by AmerenUE at the start up of the new system and continues throughout 2005 (Figures 5.12-5.15). The accuracy of the Druck pressure transducers was 58% of the freeboard available at the lowest section of the parapet wall during the "normal" operations of the upper reservoir **if** the instrument structural support system was intact and properly functioning.

Figures 5.12-5.15 are charts developed from the license's minute-by-minute output data from the reservoir monitoring system. Analysis of the PLC indicates the system recorded a signal at a specific point in time, not an average. The dark blue plot is the difference of the elevation of the reservoir from one data point minus the elevation data from the previous minute (Y_{n}- Y_{n-1}). A positive variability (Y_{n-}>$Y_{n-1)}$) greater than the sum of the instrument error plus the rate of reservoir rise during the pump cycle represents a drop in elevation (higher head). A negative variability (Y_n<$Y_{n-1)}$) represents an upward movement in elevation (lower head). The magenta lines in the figures are the reservoir elevation as determined from the Druck pressure transducers.

Important characteristics of this data examination are:

1. The variability in the system output when the reservoir was in pump mode appeared to be within the specification after initial installation.

2. Increases in variability of the Druck pressure transducer signals and output appear to increase from September 2005 through December 2005.

3. Variability appears to be greater than the sum of the electronic error and the rate of reservoir rise. Variability up to +/- 1.75 feet occurred December 13, 2005.

4. The greatest fluctuation in the output occurs during the pump cycle when the reservoir elevation is between 1545 ft and 1565 ft.

5. It is possible there is a relationship between the movement of the instrumentation pipes and the turbulence caused by the pumping cycle (Figure 5.16 – shows turbulence on first filling. Figure 5.5 shows proximity of pipes to the intake shaft.)

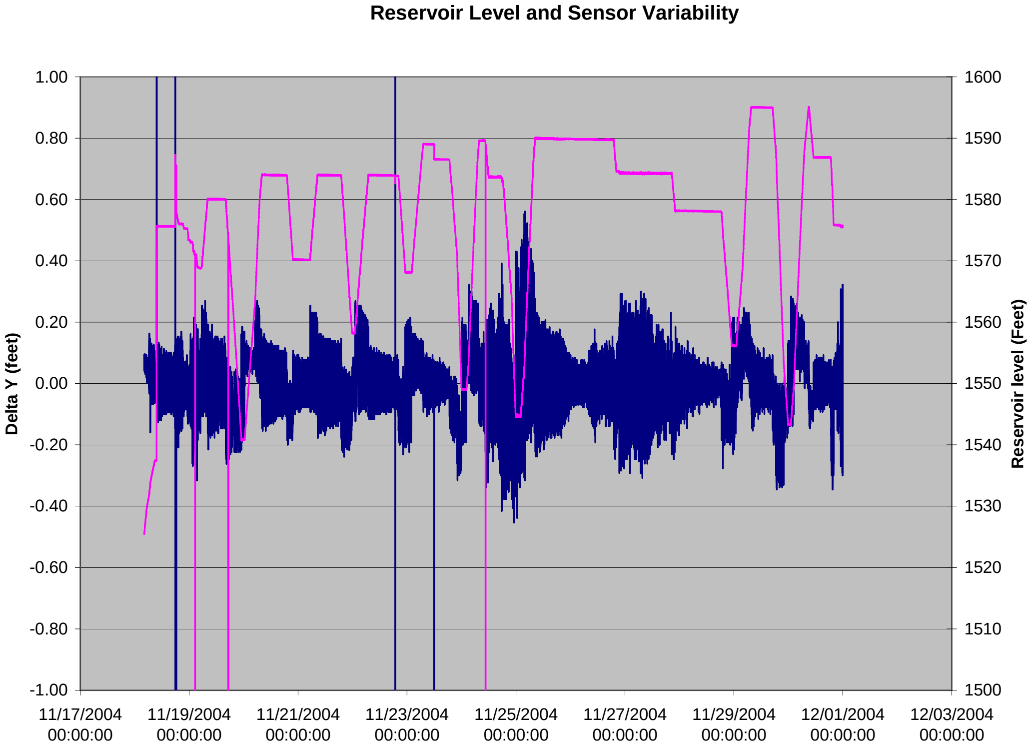

Figure 5.12 - System Variability November 2004 - After Installation

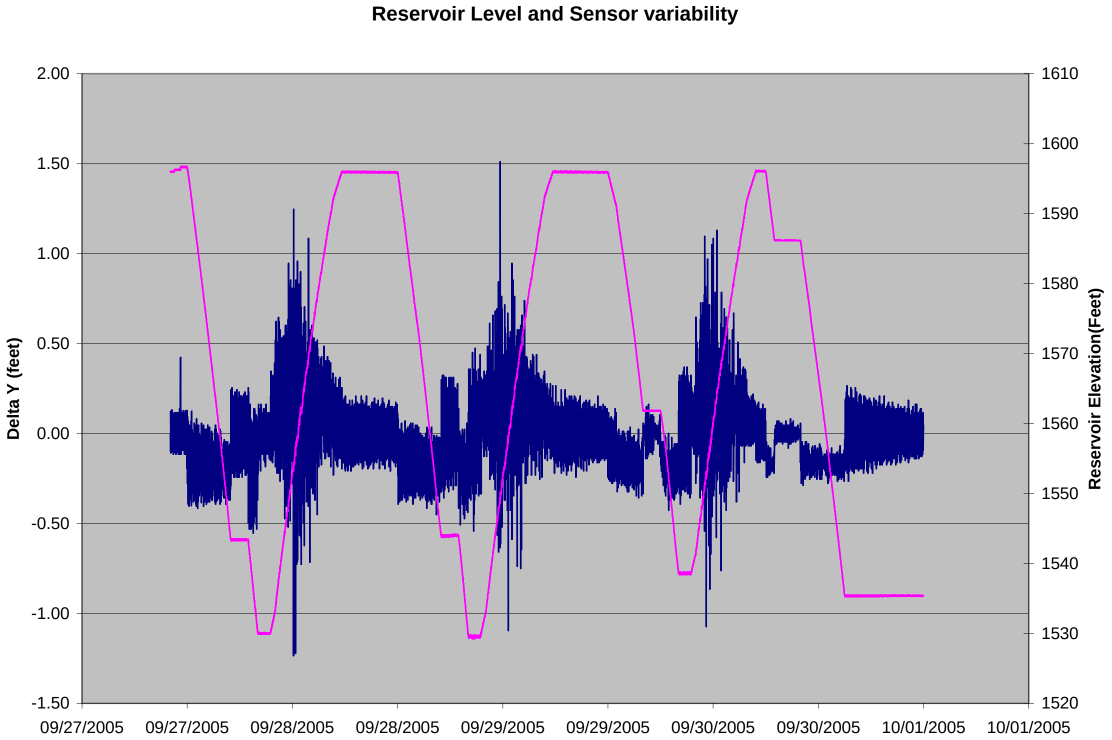

Figure 5.13 - System Variability September 27-October 1, 2005

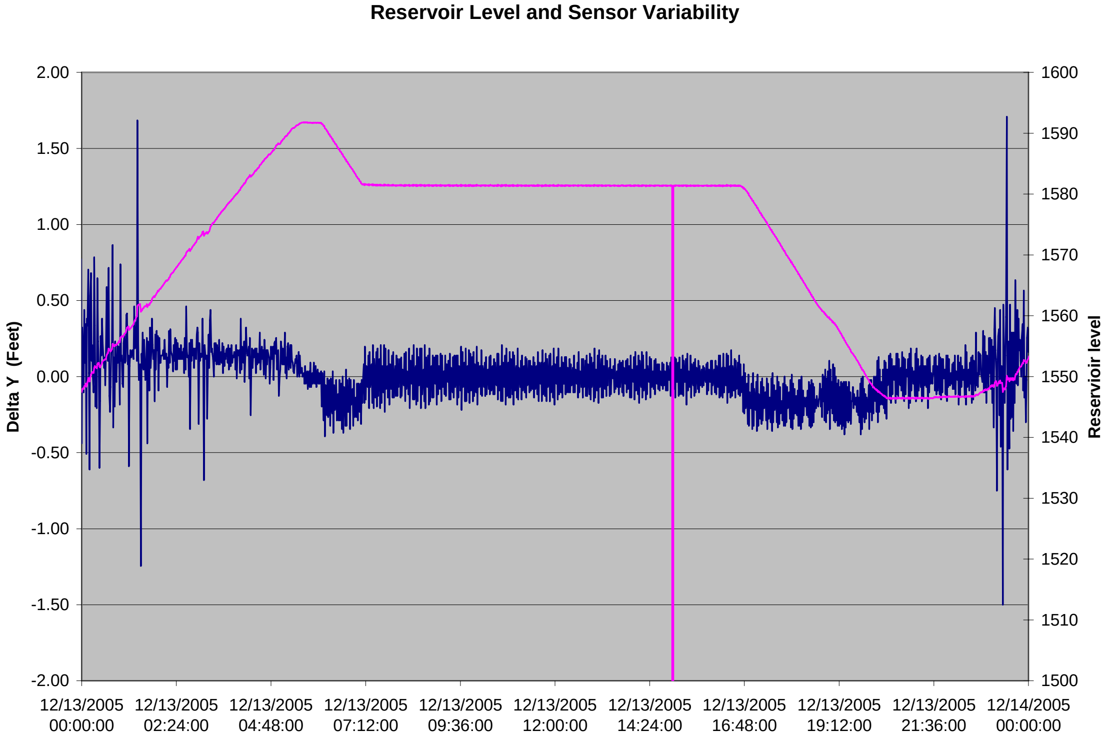

Figure 5.14 - System Variability December13, 2005

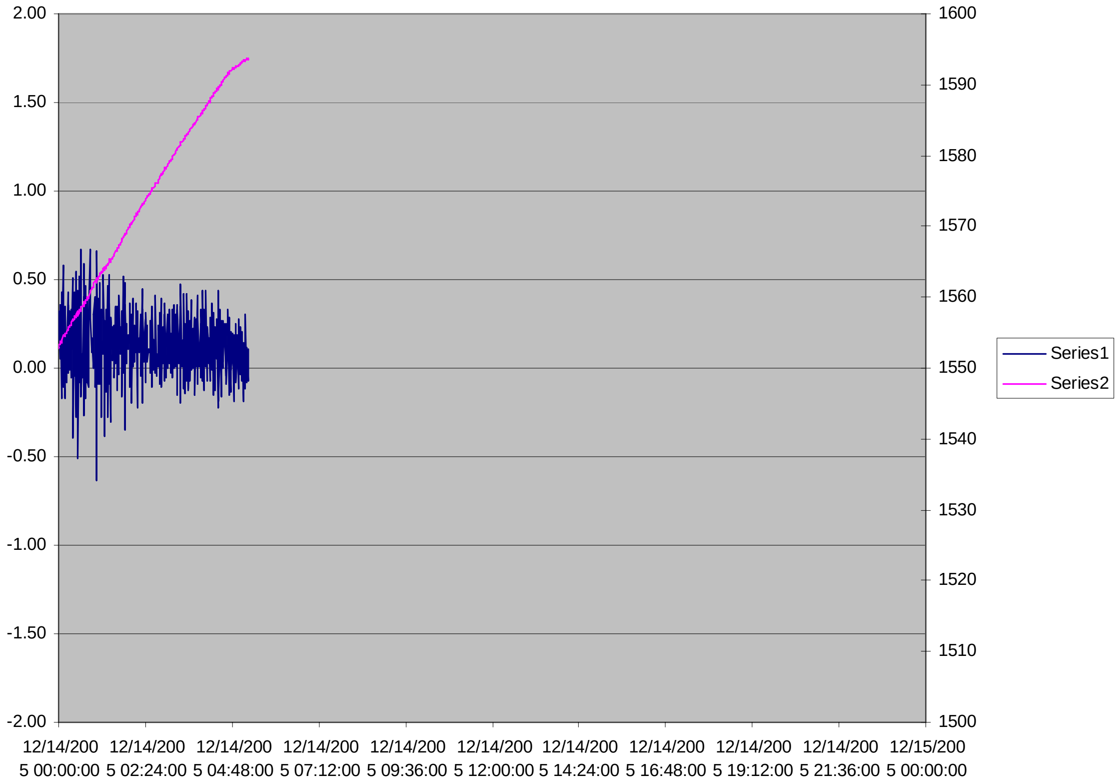

Figure 5.15 - System Variability December 14, 2005

Figure 5.16 - Turbulence on first filling (from AmerenUE)

5.7.6 Evaluation of Extended Seepage Pond Pump Back Times for September – December 2005

By email dated March 31, 2006, AmerenUE provided operation data of the seepage pond pumps from September through December 2005. The seepage pond pump information was examined to determine if days having extended operation times for the seepage pond pumps could indicate previous occasions when over pumping of the reservoir occurred. There were several days since mid-September when the seepage pond pump operated for extensive periods of time. Three of these days were September 25, November 15 and November 27.

There was no evidence; however, that water levels exceeded the top of the parapet wall on these three days. The extended pump back time on September 25th could be attributed to two factors: (1) 1.02 inches of rain that day and (2) wind-induced waves exceeded the top of the parapet wall after the reservoir was filled to within about 4 inches of the reservoir crest.

From the minute-by-minute generator-pump data from AmerenUE, the highest reservoir elevation on November 15th was about 1580 feet from 5:50 AM to 8:18 AM. The highest reservoir elevation on November 27th was about 1585.3 feet throughout the day until generating started at 5:01 PM. These elevations were taken from the Druck pressure transducer readings and are expected to be within about one foot of actual levels based on a comparison to the penstock transducer levels. Since the reservoir had over 10 feet of freeboard throughout the day on both of these days, over pumping did not occur. November 15th had 1.42 inches of rain and November 27th had 1.52 inches of rain, it is likely the long pump back time on these two days was due to rainfall.

The following chart shows daily rain totals at Farmington Airport, which is about 27 miles from the project, since mid-September 2005 and the number of hours that the seepage pond pump operated on the days when it rained. The days the pumps operated the most correlates with periods of high precipitation.

Date	Precipitation (inches)	Number of Minutes Seepage Pond Pump Operated
9/20/2005	0.89	175
9/24/2005	0.01	176
9/25/2004	1.02	452
9/28/2005	0.51	258
10/20/2005	0.02	334

Date	Precipitation (inches)	Number of Minutes Seepage Pond Pump Operated
10/22/2005	0.05	333
10/23/2005	0.31	442
10/31/2005	1.56	411
11/12/2005	0.06	388
11/13/2005	0.02	423
11/14/2005	0.60	448
11/15/2005	1.42	808
11/20/2005	0.03	540
11/27/2005	1.52	568
11/28/2005	0.36	816
12/8/2005	0.02	354
12/9/2005	0.03	400
12/14/2005 (to 5:16 am)	0.08	119

5.7.7 Seepage Collection - Pump Back Operation December 7 and 8, 2005.

Seepage pump back data was examined for several days in December prior to December 14th and for December 14th to evaluate whether a time for start of overtopping on December 14th could be observed. The following tables show seepage pump operation on December 7 and 8, 2005 (assumed to be normal days of seepage pump operation) and December 13 and 14, 2005. Comparisons were made to determine if any changes in the pump back cycle could be observed on the morning of December 14th. The first table shows pump on times between 63 minutes to 77 minutes. The off times ranged from 150 minutes to 237 minutes. The second table shows pump on times of 65 minutes to 82 minutes, until the breach occurred.

In comparing the On/Off times in these two tables, the seepage pump operation times for December 13th and 14th are similar to December 7th and 8th. The seepage pump had been off for 3 hours when it came on at 4:23 AM on December 14th, which is considered normal. The seepage pump had been operating for 53 minutes when the breach occurred at about 5:15 AM, which extended total pump operating times to 349 minutes.

Seepage Pump On-Off Data, December 7-8, 2005					
Date	**Time**	**On/OFF**	**Time On – Minutes**	**Time Off – Hours/mins**	**Time Off - Minutes**
12/07/05	01:36	On			
12/07/05	02:40	Off	64		
12/07/05	06:00	On		3:20	200
12/07/05	07:12	Off	72		
12/07/05	09:42	On		2:30	150
12/77/05	10:56	Off	74		
12/07/05	13:44	On		2:48	168
12/07/05	14:55	Off	71		
12/07/05	17:51	On		2:56	176
12/07/05	19:02	Off	71		
12/07/05	22:25	On		3:23	203
12/07/05	23:28	Off	63		
12/08/05	03:47	On		4:19	259
12/08/05	04:53	Off	76		
12/08/05	07:46	On		2:53	173
12/08/05	09:03	Off	77		
12/08/05	11:39	On		2:37	157
12/08/05	12:53	Off	74		
12/08/05	15:36	On		2:43	163
12/08/05	16:46	Off	70		
12/08/05	19:29	On		2:43	163
12/08/05	20:36	Off	67		
12/09/05	00:33	On		3:57	237

Seepage Pump On-Off Data, December 13-14, 2005					
Date	**Time**	**On/Off**	**Time On-Minutes**	**Time Off-Hours/Mins**	**Time Off-Minutes**
12/13/05	4:00	On			
12/13/05	5:12	Off	72		
12/13/05	7:45	On		2:33	153
12/13/05	9:07	Off	82		
12/13/05	11:40	On		2:33	153
12/13/05	12:56	Off	76		
12/13/05	15:38	On		2:42	162
12/13/05	16:52	Off	74		
12/13/05	19:37	On		2:45	165
12/13/05	20:47	Off	70		
12/14/05	00:18	On		3:31	211
12/14/05	1:23	Off	65		
12/14/05	4:23	On		3:00	180
12/14/05	10:12	Off	349		