APPENDIX A

SIEMENS' REPORT
MARCH 24, 2006
AmerenUE

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L286001 Rev. 1

AmerenUE Taum Sauk Incident Instrumentation and Controls Root Cause Investigation Report

March 24, 2006

Document Status: Preliminary: ☐ Final: ☒

This report contains Critical Energy Infrastructure Information.

For Release outside of Siemens

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0. Revisions

Revision	Date	Section	Description Of Change
1	2006-03-24	All	Original Issue

1. About this Report

In the early morning of 14-Dec-05, at around 5:15am, according to information provided by Ameren, the retaining dam of the upper reservoir of Ameren's Taum Sauk pump storage plant breached and released approx. 1 billion gallons of water.

Ameren employees from the Taum Sauk plant and the engineering department in St. Louis reviewed and inspected the instrumentation and control system after the incident and provided information to the review team.

The Federal Energy Regulatory Commission (FERC) started an incident investigation immediately after the event (FERC P-2277).

During the ongoing investigations of the incident, Ameren has been represented by Foley and Lardner LLP. Foley and Lardner LLP retained the instrumentation and controls division of Siemens Power Generation, Inc. ("Siemens") as a consulting expert to Foley and Lardner to perform a root cause analysis of the incident with a focus on the instrumentation and controls system at the Taum Sauk site. Foley and Lardner LLP also retained Paul C. Rizzo Associates, Inc. as a consulting expert to perform a root cause analysis of the dam structure. This report is provided under and in accordance with the letter agreement between Siemens Power Generation Inc. and Foley and Lardner dated 30-Jan-06

This report represents the result of the root cause analysis performed by Siemens. The analysis was started on 9-Jan-06 with a kickoff meeting with Ameren employees at Ameren's headquarters in St. Louis. The information on which this report was based consisted of: raw data, drawings, reports and interviews, provided by Ameren employees; interviews with the instrument suppliers; retrieved data sheets from the supplier's web sites; and performed calculations based on the data provided by Ameren. In addition Siemens visited the Taum Sauk site on 12-Jan-06 and 26-Jan-06. Siemens did also perform interviews with the operators of the site located at the Osage plant on 17-Jan-06.

As requested by Foley and Lardner LLP, the report was completed by 10-Feb-06 and later revised to include level transmitters testing and analysis performed between 27-Feb and 24-Mar-06. This report is focused on technical aspects.

2. Abbreviations, Definitions, Symbols

2.1. Abbreviations

Abbreviation	Explanation
AB	Allen Bradley, a supplier of PLC systems
GE	General Electric Company
ESO	Energy Supply Operation: An Ameren department dispatching the generation assets of Ameren
FERC	Federal Energy Regulatory Commission (see www.ferc.gov)
HDPE	High density polyethylene, the material used for the instrument pipes. HDPE is lighter than water.
LAN	Local Area Network
LDS	Load Dispatch System: A computer system supplied by Areva which can be also used for remote monitoring and operation of the Taum Sauk plant.
LR	Lower Reservoir of the pump storage plant
MISO	Midwest Independent System Operator: An entity independent from Ameren which operates the Midwest power grid. Ameren is part of this organization.
PLC	Programmable Logic Controller
TR	Tail Race, water level at the entry to the power house, in relatively close proximity to the pumps
UR	Upper Reservoir of the pump storage plant
WAN	Wide Area Network

2.2. Definitions

Term	Definition
Generation cycle	Taum Sauk plant operation mode which releases the water stored in the upper reservoir into the lower reservoir to generate electricity.
Pump cycle	Taum Sauk plant operation mode which pumps water stored in the lower reservoir into the upper reservoir to be used for future Generation cycles.

2.3. Persons Interviewed

Name	Function
Robert Powers	VP Generation Technical Services
Mark Birk	VP Operations
James Witges	Manager Generation Project Engineering
Robert Ferguson	Managing Supervisor Generation Engineering
Chris Hawkins	Project Engineer
Tom Pierie	Project Engineer
Rick Cooper	Taum Sauk Plant Superintendent
Phil Thomson	Osage Plant Superintendent
Ed Dobson	Osage Hydro Plant Technician and Operator Trainer
Steve Bluemner	Project Engineer

3. The Taum Sauk Plant

3.1. Overview

3.1.1. About the Plant

The Taum Sauk plant is a pump storage plant located near Lesterville, MO. It consists of four main elements:

- the upper reservoir atop 1590 foot Proffit Mountain,
- a 7,000 foot-long shaft and tunnel inside the mountain;
- a power house containing two reversible pump-turbine generators;
- a lower reservoir formed by a dam across the East Fork of the Black River.

Taum Sauk stores water by pumping it to its upper reservoir when demand (and cost) for electricity is low (pump cycle) and then releases the water to generate electricity when the power is needed (generation cycle).

3.1.2. Plant Operation

Taum Sauk is operated remotely by the Osage hydro plant. All network communication is routed through the Ameren headquarters in St. Louis. The Energy Supply Operations (ESO) department located in St. Louis can also monitor the plant; however the operational responsibility is with the Osage plant.

The following map shows the approximate location of Taum Sauk, Osage and the Ameren headquarters:

Figure 1: Overview Map

The following diagram shows the approximate driving distances between the Ameren facilities directly involved with the incident.

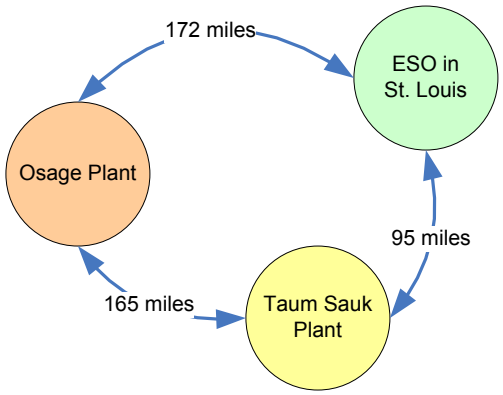


Figure 2: Approximate Driving Distances

There are no video cameras installed at Taum Sauk which could be used by the operators located at the Osage plant to visually monitor the reservoir levels.

The following sketch provides an overview of the Taum Sauk plant.

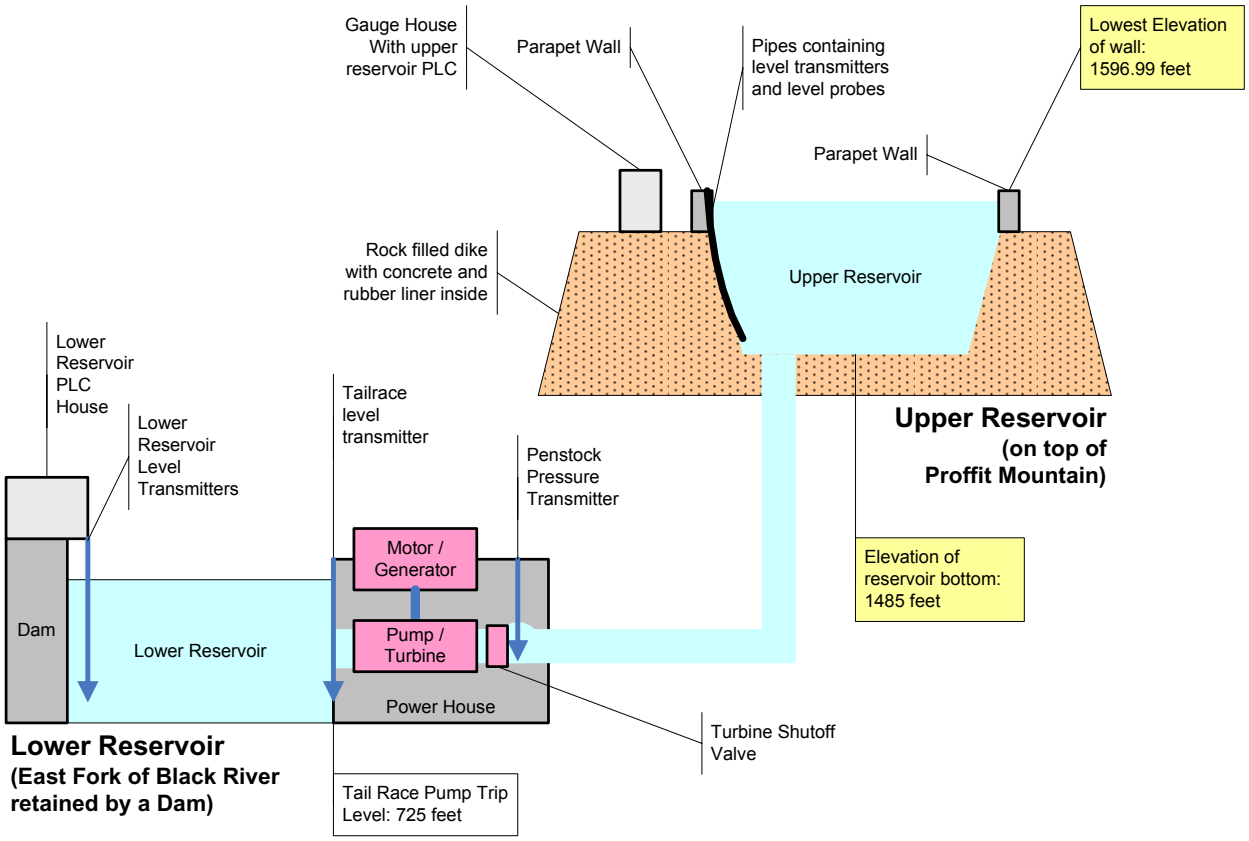


Figure 3: Taum Sauk Overview Sketch

The transmitters used for the upper reservoir level control and protection are installed at the following locations:

- Three level transmitters in one of the instrument pipes attached to the upper reservoir wall. These transmitters are intended to measure the water level in the Upper Reservoir. The control system is intended to use these measured values to control the filling of the Upper Reservoir while the Units are operating in “pump mode”.
- Four level probes (LO-LO, LO, HI and HI-HI) in a separate instrument pipe for level protection.
- One tailrace level transmitter located at the water entry at the power house. This transmitter is intended to measure the water level at the pump intake. The control system is intended to use the measured value to make sure the water level in the tail race exceeds the minimum level allowed for pump operation.
- Two lower reservoir level transmitters located at the lower reservoir dam. These transmitters are intended to measure the water level in the lower reservoir. The control system is intended to use these measured values to control the elevation of the lower reservoir.

The approximate distance between the upper reservoir gauge house and the power house is 7800 feet. The approximate distance between the lower reservoir and the power house is 11300 feet. The main PLC units, the local HMI and the engineering system are located inside the power house. The plant superintendent and the production supervisor have access to the PLC network from their laptops in the supervisor’s office. The plant superintendent has also access to the PLC network from his residence which is located on the plant property.

3.2. Upper Reservoir Level Monitoring, Control and Protection Overview

The following narrative overview was included in the report to provide a better understanding of the event sequence and the system overview. It is focused on the pump cycle because the incident to be investigated is related to this cycle. A more detailed description can be found in the subsequent chapters of this report.

3.2.1. Monitoring and Control

The upper reservoir water level is measured by three GE Druck PTX 1230 submersible transmitters. The transmitters are connected to analog inputs of an Allen Bradley (AB) PLC system, which consists of several individual PLCs communicating with each other via a local area network (LAN). The as-designed logic in those PLC systems allows the operators to view the average value generated by the three transmitters. However, the individual values generated by the three transmitters were not displayed through the control system to the operators. Neither were the operators able to remove a failed transducer from the average calculation without a programming change. The control system used the average Upper Reservoir data for all control functions[1]. In closed loop control, the PLC system provides logic to stop the pumps automatically if the average reading of the level transmitters reaches the operator selectable shut off setpoints. These setpoints include the upper reservoir water level, the lower reservoir water level and the tail race water level. The operator can also stop the pumps manually. This manual shutdown is usually requested by the energy supply operation based on grid load and financial considerations. All control is performed via the PLC system. The pumps are started by the operators on request by the energy supply operation.

[1] Analysis of the as-found logic revealed that only two transmitters were used for the calculation of the average value on the day of the event.

There is no hardwired control for the operators at the Osage plant. The pump cycles are usually performed at night. The Taum Sauk plant is not staffed at night.

The operators can also monitor and operate through the LDS system which is installed in parallel to the Allen Bradley system. However, the LDS system uses the Allen Bradley PLC systems as a data source to read the level transmitter values. The close loop control logic for automatic pump shutoff is implemented in the Allen Bradley PLCs exclusively.

3.2.2. Protection

The overflow protection system utilizes two Warrick Series 1 probes (HI and HI-HI). Additional two probes are used to indicate Low and Low-Low level. These two level probes trigger input channels of the AB PLC system when the water level reaches a setpoint which is determined by the elevation of the probes. This setpoint is determined by the physical elevations of the two probes. In the as found logic, the AB PLC system is to trip pump #1 if both level probes are in contact with water simultaneously for longer than one minute. The program logic as reviewed by Siemens indicated that Pump #2 would not trip on protection. The PLC system is to generate an operator alarm if the water level reaches the HI-HI probe. It is not to generate an alarm or record an event, if it reaches the HI probe.

In addition, the PLC system also stops both pumps if the tail race level falls below a setpoint configured in the PLC program.

There is no hardwired protection.

3.2.3. Upper Reservoir Pump Shutoff Levels and Elevations on 14-Dec-05

The following table summarizes the pump shut off levels and elevations for the upper reservoir. All values are given in elevation above sea level. The first pump to be shut off in automatic control can be selected by the operator. This pump can be either pump #1 or pump #2.

Data Point	**Action**	**Setpoint Value at incident**	**Source**
UR Level Average	First Pump Auto Stop	1592.0	Process data archive[2]
Lower Reservoir Level Average[3]		736.5	Process data archive
Tail Race Level		730.0	Process data archive
UR Level Average	Second Pump Auto Stop	1594.0	Process data archive
Lower Reservoir Level Average		736.0	Process data archive
Tail Race Level		729.0	Process data archive
UR Level Average	Both Pumps Auto Stop	1594.2	Process data archive
Lower Reservoir Level Average		736.0	Process data archive
Tail Race Level		728.0	Process data archive
Elevation of HI Probe in UR	None	1597.4 (as found) 1597.3	Ameren's report to FERC submitted on 27-Jan-06 (as designed: 1595.9) Siemens calculation based on on-site measurements and survey data
Elevation HI-HI Probe in UR	Both Pumps Trip and Alarm	1597.7 (as found) 1597.7	Ameren's report to FERC submitted on 27-Jan-06 (as designed: 1596.2) Siemens calculation based on on-site measurements and survey data

The lowest point of the dam and wall structure as surveyed by Ameren on 6-Nov-04: 1596.99 (Source: IMG059025).

[2] The process data archive values at the day of the incident were presented to Siemens by Ameren engineers on 19-Jan-06.
[3] Average of two transmitter readings installed in the lower reservoir. However, only one transmitter was used at the day of the event.

Based on the information above, the HI and the HI-HI probes were located in a position too high to be effective at the day of the incident. This observation is supported by the fact that no HI-HI alarm was recorded at the day of the incident.

3.3. Key Events

Date	Event	Source
June 1960	Construction of the plant begins	Ameren web site
20-Dec-63	Plant fully operational, begin of commercial operation, mostly used as a peaking unit	Ameren web site
1998	Updated runners with increased efficiency installed, begin of almost daily use of the plant	Ameren web site, Interviews
September 2004	Begin of installation of a liner to reduce water leakage from the upper reservoir. In parallel the instrumentations and control system is significantly upgraded.	Ameren documents
November 2004	The plant resumes operation	Ameren documents
September 2005	Taum Sauk employees report overtopping of the upper reservoir caused by high winds. Plant changes PLC logic to lower pump shut off level.	Ameren emails
4-Oct-05	Ameren discovers bow in instrumentation pipe and the pump shutoff level for the last pump is lowered from 1596ft to 1594ft above sea level. Similarly, the setpoint for stopping both pumps is lowered from 1596.2ft to 1594.2ft.	Ameren's report to FERC submitted on 27-Jan-06
13-Dec-05 22:33	Pump #1 is started	Process data archive
13-Dec-05 23:13	Pump #2 is started	Process data archive
14-Dec-05 04:42	Pump #2 stops automatically	Process data archive and Operator log
14-Dec-05 05:15	Pump #1 is stopped by operator upon power dispatcher request	Process data archive and Operator log
14-Dec-05 05:15	Upper Reservoir level begins to fall rapidly	Process data archive

4. Control System Overview

4.1. WAN Overview

The following sketch summarizes the wide area network structure based on information provided by Ameren engineers.

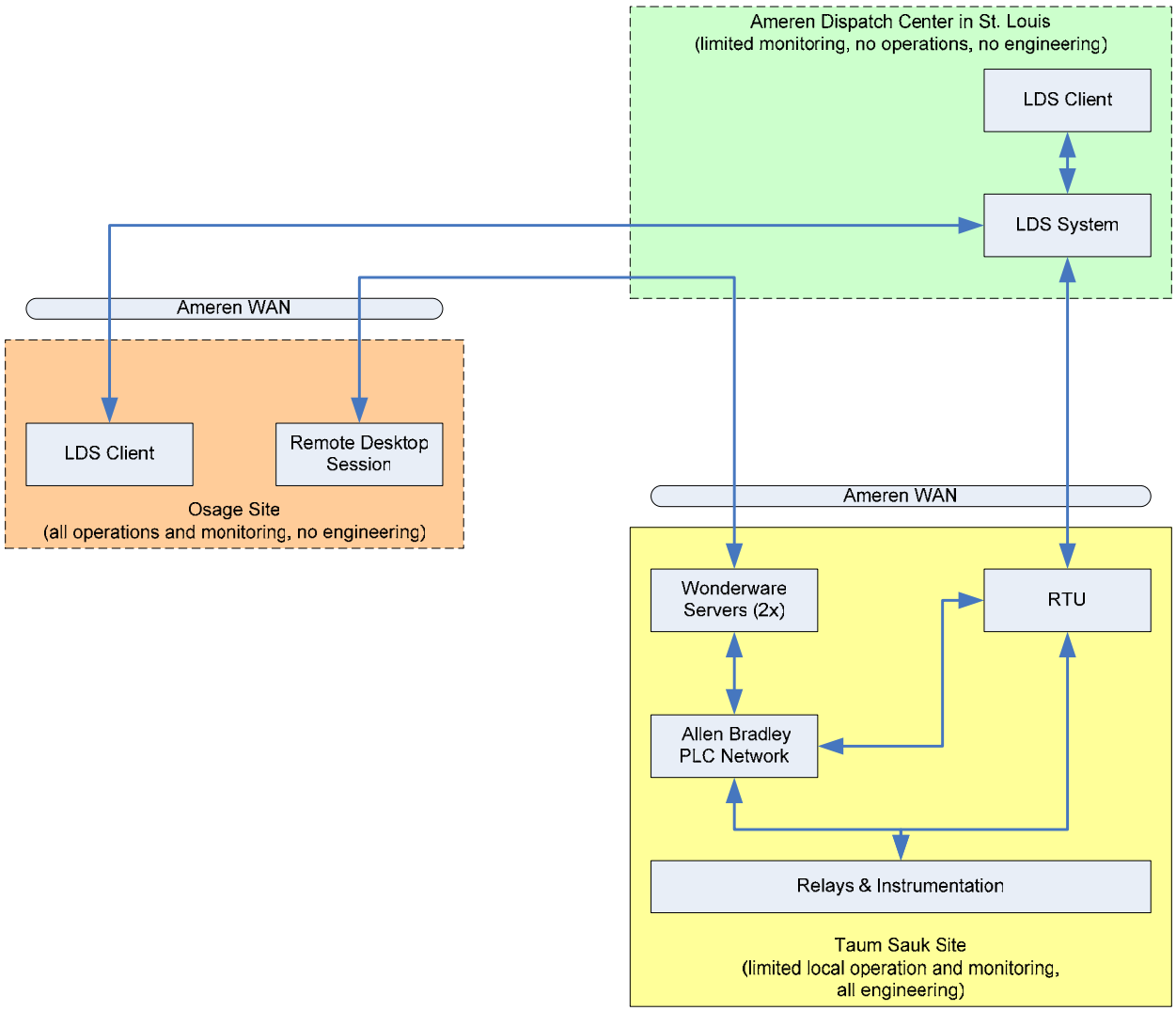


Figure 4: Taum Sauk WAN Overview

All engineering systems were located at the Taum Sauk plant. According to Ameren, remote access to those engineering systems was not permitted. According to operator accounts, the WAN was functional during the incident.

4.2. LAN Overview

The following sketch provides an overview of the local area network installed at the Taum Sauk plant based on sketches provided by Ameren engineers. The remote upper reservoir gauge house and the lower reservoir were connected through a Fiber Optic link and a DSL backup line. The Cisco switch 2 did automatically transfer to the DSL line if the fiber optic connection failed. The historical process data submitted to Siemens indicated that the communication between the PLCs was operational during the incident.

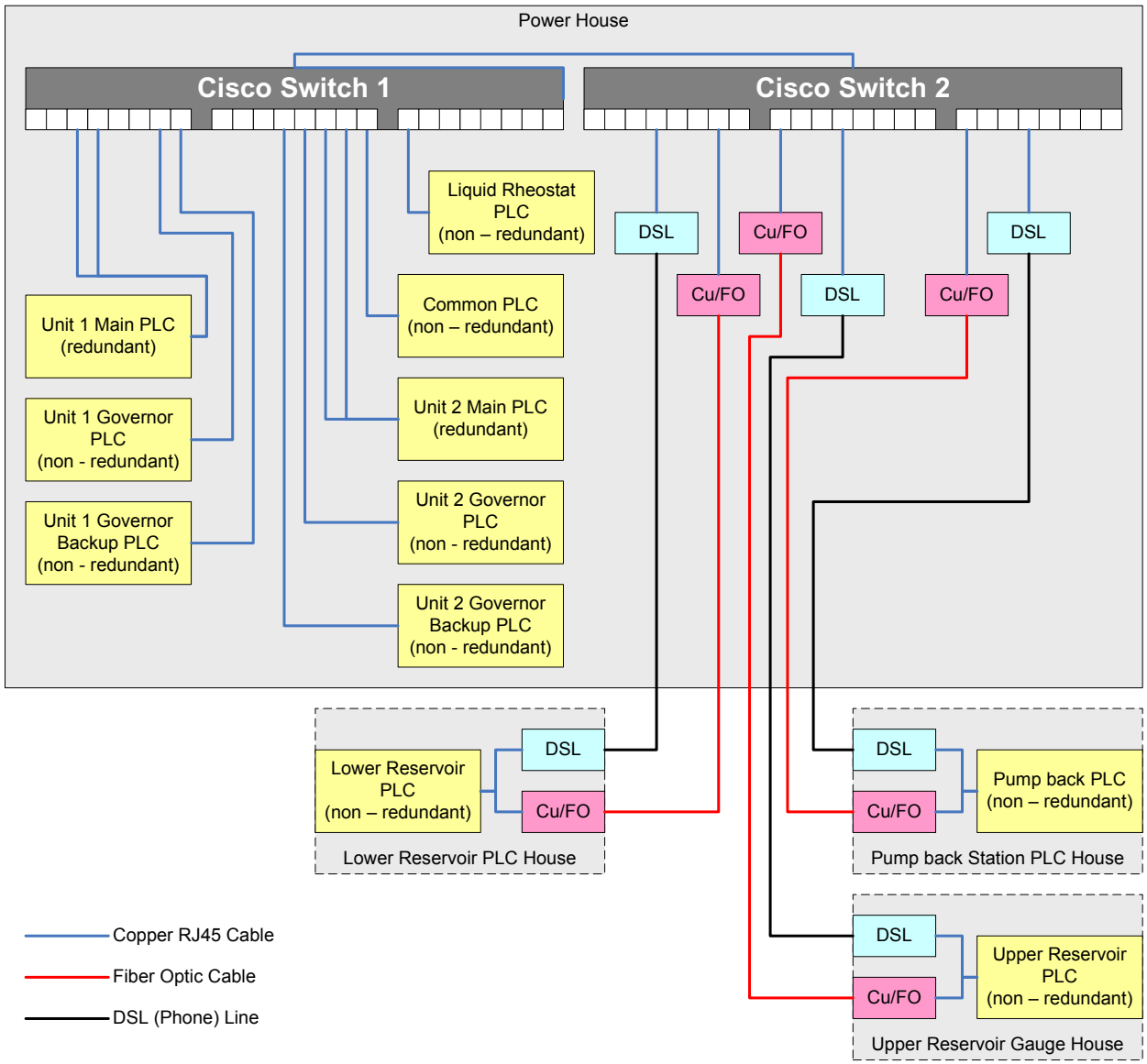


Figure 5: Taum Sauk LAN Overview

4.3. Power Distribution

4.3.1. General

Refer to IMG082735 - Schematic Diagram Upper Reservoir level drawing 8303-P-26648 r15 and IMG059220- Interconnection Diagram Level Controls Upper Reservoir & Lower Dam drawing 8303-X-26348 r8. Ameren engineers stated that no fuses were replaced nor circuit breakers reset after the incident.

4.3.2. Power Sources

4.3.2.1. Uninterruptible Power Supply

Per schematic and interconnection diagram referenced above: One 2-phase power feed provides power to Distribution Cab 4 located in the Upper Reservoir control house. Breaker 1 in distribution Cab 4 provides 120VAC to a receptacle. The 120VAC Uninterruptible Power Supply (UPS) under the table in the Upper Reservoir control house is plugged into this receptacle.

Loss of power to the UPS for more than 8 hours would disable the upper reservoir (UR) PLC, the analog level transmitters, all 4 Warrick level controllers (for the level probes), the Ethernet switch and communications to the Common PLC . This loss would immediately generate an "Upper Reservoir Loss of UPS Power - Com" alarm for operator indication. UR level control and protection would be disabled; Siemens turned off the UPS and observed the generation of the "Upper Reservoir Loss of UPS Power - Com" alarm. Although the alarm appeared at the proper time and was the proper color, name and comment the wording of the value of the alarm was backwards. – i.e. When the alarm was active the Wonderware screen showed NORMAL and when UPS power was turned back on the screen showed ALARM. The "Upper Reservoir Loss of UPS Power – Com" alarm does not appear in the Wonderware alarm log during the time of the event indicating that UPS power was on.

Upper Reservoir 24VDC Power Supply
Fuse FU-2 provides UPS power to this power supply. If this fuse was open or the power supply failed the 3 analog level transmitters would be inoperative (0 mA output) and the Ethernet switch would be inoperative. The level transmitters continued to track the falling water level for at least thirty minutes after the incident which suggests that this fuse and power supply was likely functioning. Output of the power supply was measured to be 24.0VDC on 2-2-06. The status of this fuse is not monitored.

Redundant 125VDC Power Supplies - Primary
If only the primary 125VDC power supply fails or loses its 120VAC input power the secondary 125VDC power supply is switched in by via relay 83X-1. The loss of the primary power supply alone does not affect the system's ability to perform a Hi/Hi-Hi shutdown. The operators at the Osage plant will receive a common alarm when the primary power supply fails.

Redundant 125VDC Power Supplies - Secondary
If only the secondary 125VDC power supply fails or loses its 120VAC input power the primary 125VDC power supply continues to supply its loads unaffected. The loss of the secondary power supply alone does not affect the system's ability to perform a Hi/Hi-Hi shutdown or generate a Hi-Hi alarm. The operators at the Osage plant will receive a common alarm when the secondary power supply fails

Redundant 125VDC Power Supplies - Both
If both 125VDC power supplies failed or lost their 120VAC input power the system would lose its ability to shutdown the pump on Hi/Hi-Hi and the ability to generate a Hi-Hi alarm. This event would generate a Lo-Lo alarm and an "Upper Reservoir Loss of UPS Power – Com" alarm. Neither of these alarms appear in the Wonderware alarm log during the time of the event which suggests that at least one of these power supplies was likely functioning.

4.3.2.2. Circuit Protection Devices

Analog Level Transmitters
Each of the three analog level transmitters has an individual unmonitored 1A fuse providing 24VDC power to its loop. Wonderware data logs show individual analog signals though the incident suggesting that all transmitters were powered through the incident. The level transmitters continued to track the level falling for at least 30 minutes after the incident, which suggests that these fuses were functioning.

Hi Warrick Level Controller
Fuse FU-4 provides uninterruptible 120VAC power to both the HI controller, LO controller and their associated Upper Reservoir PLC inputs. If this fuse blows it would prevent a pump trip on HI/HI-HI however it should not prevent the HI-HI alarm.

Hi Hi Warrick Level Controller
Fuse FU-3 provides uninterruptible 120VAC power to both the HI-HI controller and LO-LO controller. If this fuse blows it would prevent a HI/HI-HI trip and HI-HI alarm but should cause a LO-LO alarm to be generated. The LO-LO alarm was not present in the Wonderware alarm log during the time of the event which suggests that this fuse was active.

The contact output of the HI-HI controller utilizes redundant 125VDC power to drive an input of the Common PLC. The power for this input passes through the FU-8 fuse pair and four 0.5A fuses. If any of these 6 fuses were lost the input would be prevented from turning on preventing a HI/HI-HI trip and preventing a HI-HI alarm. Loss of either of the FU-8 pair of fuses should also cause a "Loss of Upper Reservoir Loss of UPS Power" alarm because they also power the normally energized input associated with that alarm. The "Loss of Upper Reservoir Loss of UPS Power" alarm was not present in the Wonderware alarm log during the time of the event which suggests that the FU-8 pair of fuses were active. The Common PLC input was operational upon examination by Ameren and Siemens engineers on 1/12/06 which suggests that all six of these fuses were active.

Upper Reservoir PLC
Fuse FU-1 provides UPS power to the UR PLC. Loss of power to the UR PLC would have prevented the HI signal from reaching the Common PLC and caused an "UR to Common PLC communication" alarm. The "UR to Common PLC communication lost" alarm was not present in the Wonderware alarm log during the time of the event which suggests that the fuse FU-8 pair of fuses was active.

4.4. Operator configurable Setpoints for Pump Stops

The operators can change setpoints for the pump stops. These setpoints are used in level control. The operators can also select which pump will stop automatically when the setpoints for the first pump to stop are reached. Level protection is not affected by these setpoints.

Variable	Explanation	Reported Value at Event[4]
URSP1 TSM01WmgUrsLvlPmp1SDStPt TSM02WmgUrsLvlPmp1SDStPt	Upper reservoir level setpoint for first pump to stop	1592.0
LRSP1 TSM01WmgLrsLvlPmp1SDStPt TSM02WmgLrsLvlPmp1SDStPt	Lower reservoir level setpoint for the first pump stop	736.5
TRSP1 TSM01WmgLrsTrcPmp1SDStPt TSM02WmgLrsTrcPmp1SDStPt	Tail race level setpoint for the first pump to stop	730.0
URSP2 TSM01WmgUrsLvlPmp2SDStPt TSM02WmgLrsTrcPmp1SDStPt	Upper reservoir level setpoint for second pump to stop	1594.0
LRSP2 TSM01WmgLrsLvlPmp2SDStPt TSM02WmgUrsLvlPmp2SDStPt	Lower reservoir level setpoint for the second pump to stop	736.0
TRSP2 TSM01WmgLrsTrcPmp2SDStPt TSM02WmgLrsTrcPmp2SDStPt	Tail race level setpoint for the second pump to stop	729.0
URSPT TSM01WmgUrsLvlPmpAllSDStPt TSM02WmgLrsTrcPmp2SDStPt	Upper reservoir level setpoint for both pumps to stop	1594.2
LRSPT TSM01WmgLrsLvlPmpAllSDStPt TSM02WmgUrsLvlPmpAllSDStPt	Lower reservoir level setpoint for both pumps to stop	736.0
TRSPT TSM01WmgLrsTrcPmpAllSDStPt TSM02WmgLrsLvlPmpAllSDStPt	Tail race level setpoint for both pumps to stop	728.0
U1STOPFIRST TSM01WmgUrs1stUnitShtdwnCmd TSM02WmgUrs1stUnitShtdwnCmd	Unit 1 Pump to be stopped first automatically on high or low levels	FALSE (means: stop Pump 2 first)

[4] The values were provided by Ameren engineers.

4.5. PLC Logic Diagrams

The following PLC logic diagrams generated from PLC logic listings provided by Ameren provide an overview of the logic implemented inside the PLCs for pump trip and pump stop. The PLCs have other tasks besides these two functions which are not discussed here.

4.5.1. Upper Reservoir PLC Logic for Pump Trip and Stop

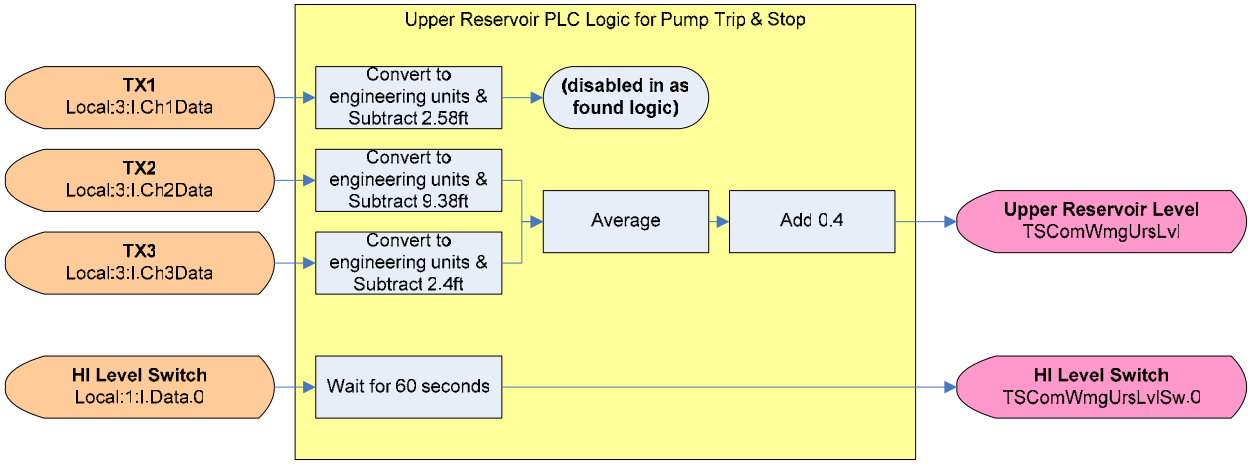


Figure 6: Upper Reservoir PLC Logic Diagram

The upper reservoir PLC is to read the three level transmitter signals through channel 1, 2 and 3 of the analog input card in slot 3. In the as found logic, the level transmitter signals are converted from 0.10000 integer range into actual engineering units. After this conversion, constants are subtracted. These constants were determined during the initial installation of the system in November 2004. The as found logic forms the average value of the two transmitters TX2 and TX3 and adds a constant of 0.4 to the average value. Transmitter TX1 is not used. The PLC also reads the HI level switch through channel 0 of the digital input card in slot 1. If the value becomes a 1 (e.g. the contact is closed), the PLC is to wait for 60 seconds before it makes this value available to other PLCs.

4.5.2. Common PLC Logic for Pump Trip and Stop

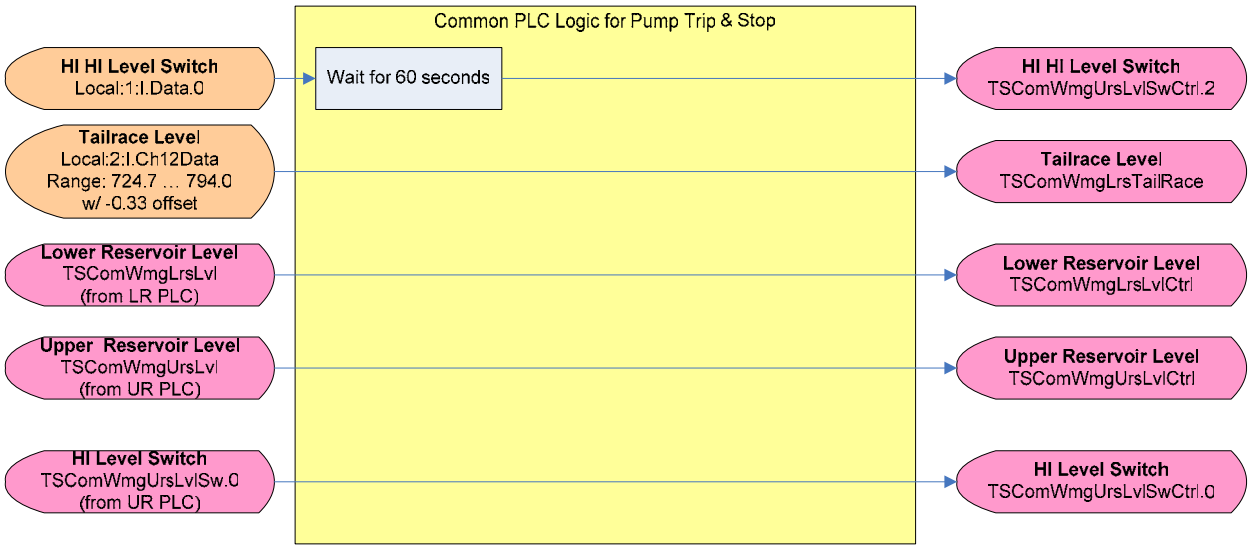


Figure 7: Common PLC Logic Diagram

The common PLC reads the HI HI level switch through channel 0 of the binary input card 1. The cable for the HI-HI signal is wired through the phone system from the UR PLC cabinet in the UR gauge house to the common PLC. The HI HI level signal needs to be active for 60 seconds before it is made available to other PLCs. The tailrace level transmitter is connected to the common PLC. The conversion to engineering units is performed in the input card.
The common PLC is also to receive the UR level average, the LR average from the LR PLC and the HI signal from the UR PLC. It does not perform any logic or conversions with these values; it passes them to other PLCs.

4.5.3. Lower Reservoir PLC Logic for Pump Trip and Stop

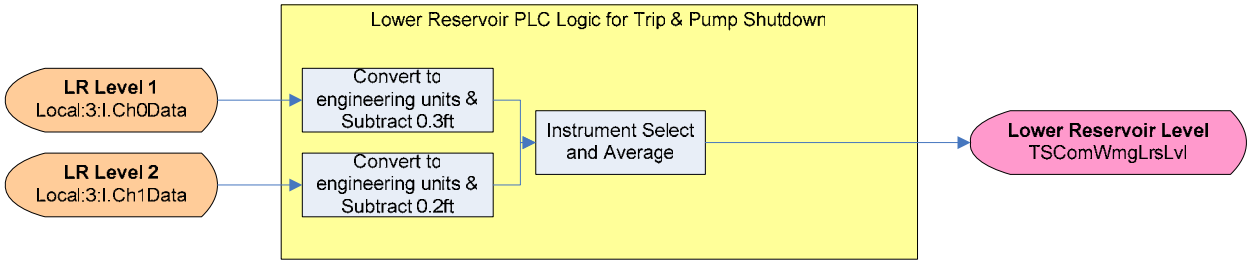


Figure 8: Lower Reservoir PLC Logic Diagram

The lower reservoir PLC is to read the LR level transmitters and converts the values into engineering units. Then it performs an average calculation of these two values. The operators can also choose to use either one of the two values instead of the average. According to the operator logs, transmitter #2 was not operational on 12-Dec-05, so transmitter #1 was selected as the sole source.

4.5.4. Unit 1 Main PLC Logic for Pump Trip

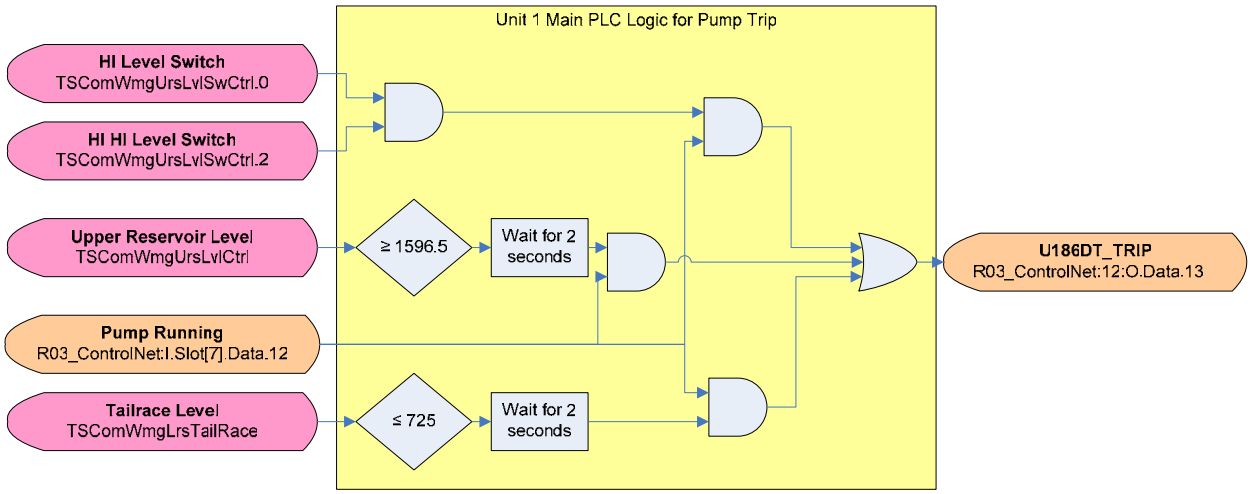


Figure 9: Unit 1 Main PLC Logic for Pump Trip

The Unit 1 main PLC performs the trip logic as outlined in the above sketch. Either a combination of the HI and HI-HI level switch, an indicated upper reservoir level of greater or equal than 1596.5 feet or a tailrace level of less or equal than 725 feet for more than 2 seconds is to trip the pump. The trip levels for the tailrace level (725 feet) and for the upper reservoir level (1596.5 feet) are coded into the PLC program and therefore not changeable by the operator.

The trip is performed by energizing the coil of relay 186DT which triggers an input signal of the governor PLC. This is to cause the governor PLC to trip the pump and to close the wicket gates. Since the historical process data indicates that the inputs for the trip signals were never satisfied (e.g. HI-HI alarm was never present, the maximum indicated upper reservoir level was 1593.72 which is below 1596.5 feet and the lowest tailrace level logged in the process data archive was 730.0 which is above 725.0 feet) during the incident, it is likely that relay 186DT was never energized and the trip circuit was therefore not further analyzed.

On the day of the incident, the Unit 2 pump was automatically stopped 33 minutes before the Unit 1 pump was stopped by the operator.

4.5.5. Unit 1 Main PLC Logic for Pump Stop

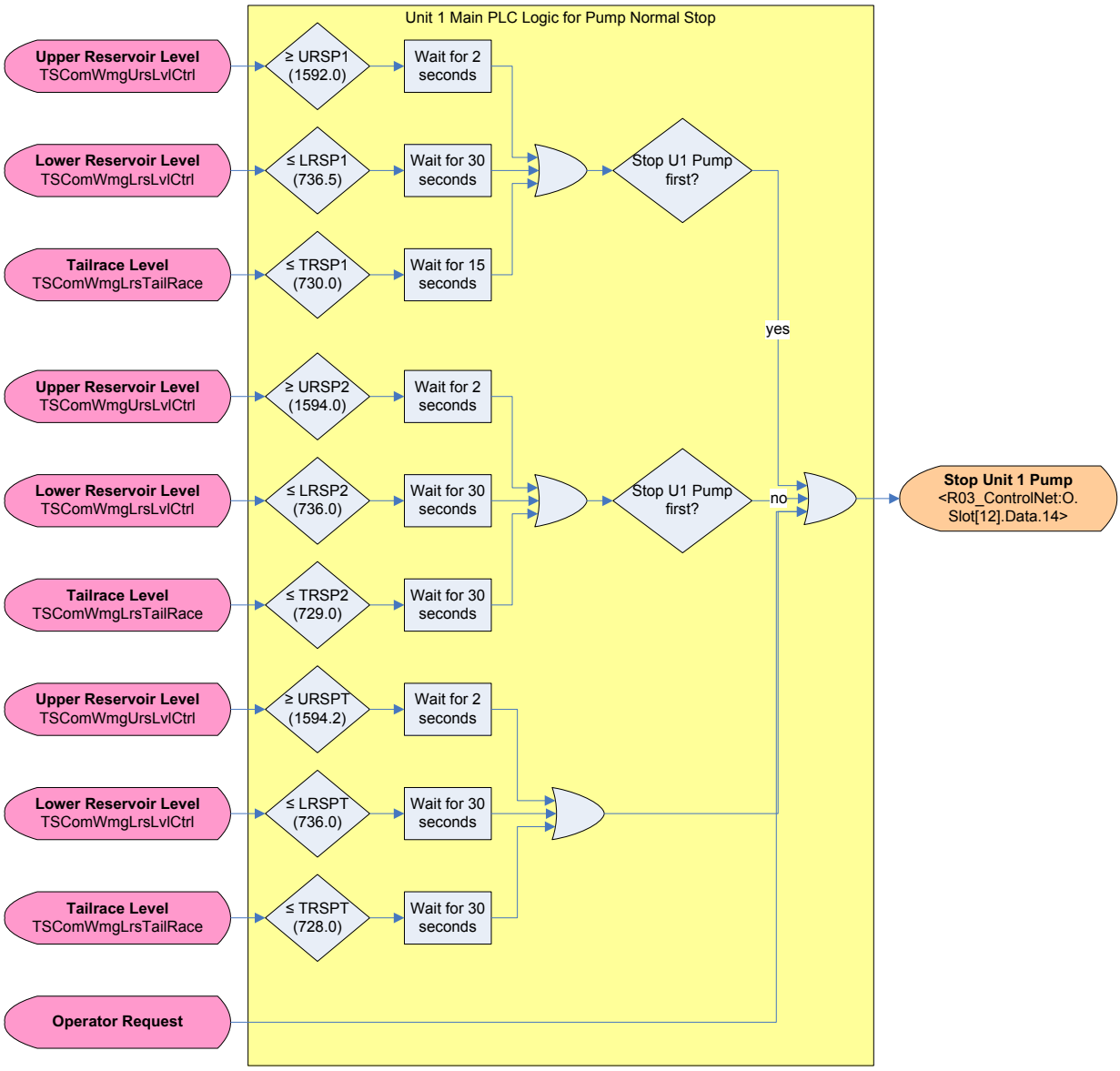


Figure 10: Unit 1 Main PLC Logic for Pump Stop

The logic for normal pump stop implemented in unit 1 main PLC is intended to stop pump #1 if the operator selectable set points for pump stop are exceeded. The effective set of setpoints is determined based on whether unit 1 is the first or the second unit to be shut down. The third set of setpoint is to shut down unit 1 regardless whether it has been selected to be shut down first or second. In any case, the signals need to exceed those setpoints for a pre-programmed period of time.

4.5.6. Unit 2 PLC Logic for Pump Trip

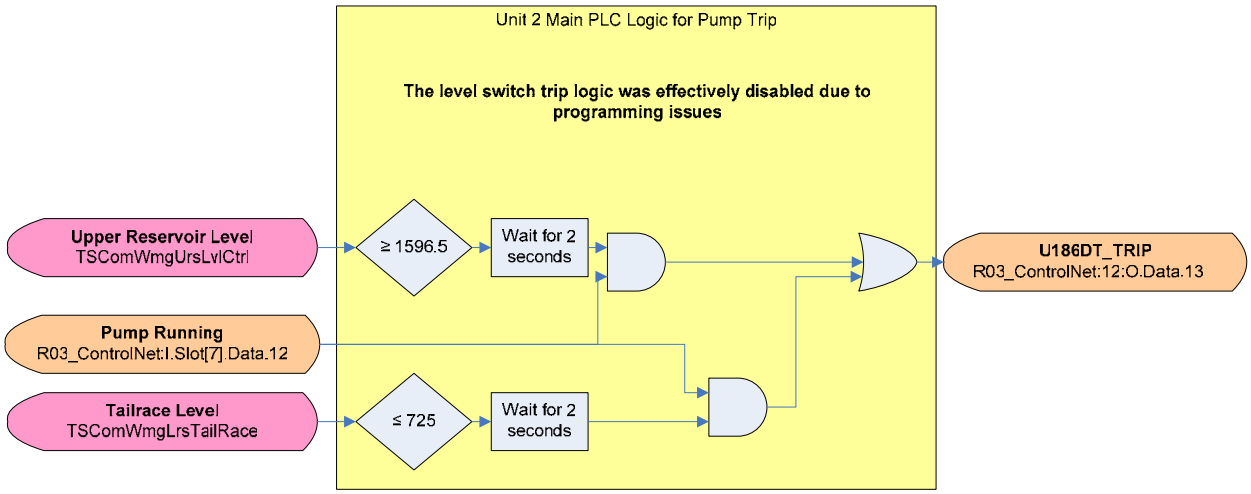


Figure 11: Unit 2 Main PLC Logic for Pump Trip

The trip logic implemented in the unit 2 PLC considers only the tailrace level and the upper reservoir level. The signals for the HI and HI-HI probes are not transmitted into the PLC. The logic for receiving the probe signal addresses the level transmitters; this appears to be in error. A review of the unit 2 main PLC program indicated a possible spelling error which led to this situation.

4.5.7. Unit 2 PLC Logic for Pump Stop

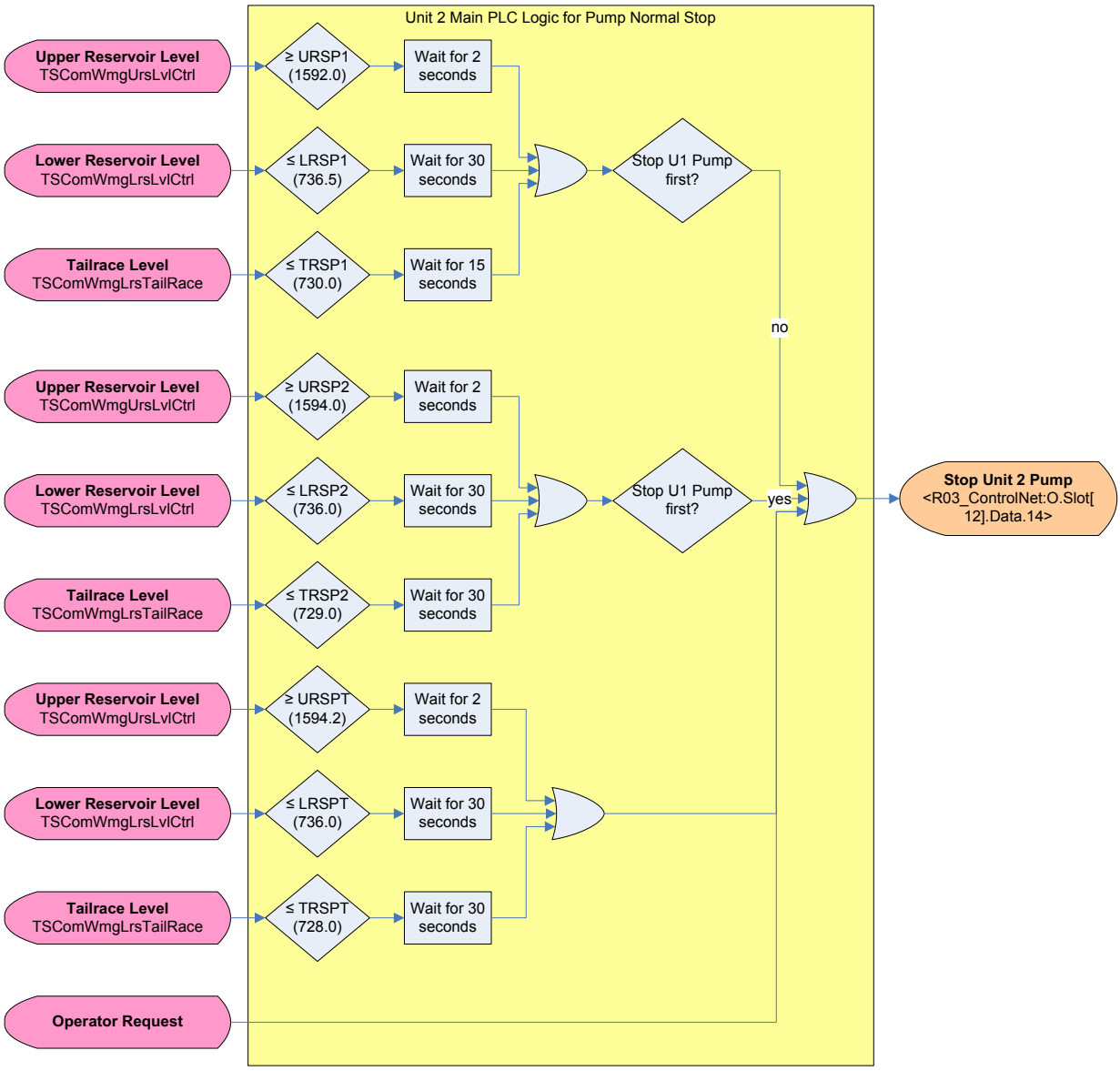


Figure 12: Unit 2 Main PLC Logic for Pump Stop

The logic for normal pump stop implemented in unit 2 main PLC is intended to stop pump #2 if the operator selectable set points for pump stop are exceeded. The effective set of setpoints is determined based on whether unit 2 is the first or the second unit to be shut down. The third set of setpoint is to shut down unit 2 regardless whether it has been selected to be shut down first or second. In any case, the signals need to exceed those setpoints for a pre-programmed period of time.

4.6. Instrumentation

4.6.1. Overview

The upper reservoir level instrumentation consists of 3 analog level transmitters and 4 discrete level probes, Low-Low, Low, Hi, and Hi-Hi. Only the Hi and Hi-Hi discrete sensors are utilized in the scheme to shut down the pumps on Hi reservoir level. In normal operation the PLC is to shut pumps off one at a time when the average of 2 of the analog level signals (one signal was disabled before the event) reach operator set setpoints. As a backup to the analog signals, the pumps are to be tripped if both the Hi and Hi-Hi probes sense water simultaneously for 60 seconds. A Hi-Hi level alarm is to be generated when the Hi-Hi probe senses water.

The 3 level transmitters and the Hi and Hi-Hi level probes were removed prior to the arrival of Siemens so information on this matter is based solely on interviews with Ameren personnel and documentation provided by Ameren.

4.6.1.1. Level Instrumentation Pipe Installation

Two HDPE pipes are utilized to hold in place and protect all of these instruments. Four pipes are installed (two are spares) into the upper reservoir and held against the liner per IMG121866 - Sketch SB1306-3 “Gage Pipe Supports As Constructed“. Also see the sidewall riser pipe cross-section detail on IMG013196 - Side Slope Relining Details III drawing 8304-X-155099 r5 for specifications of where holes were drilled into pipes. Also see the 15-Nov-04 photo of the pipe installation.

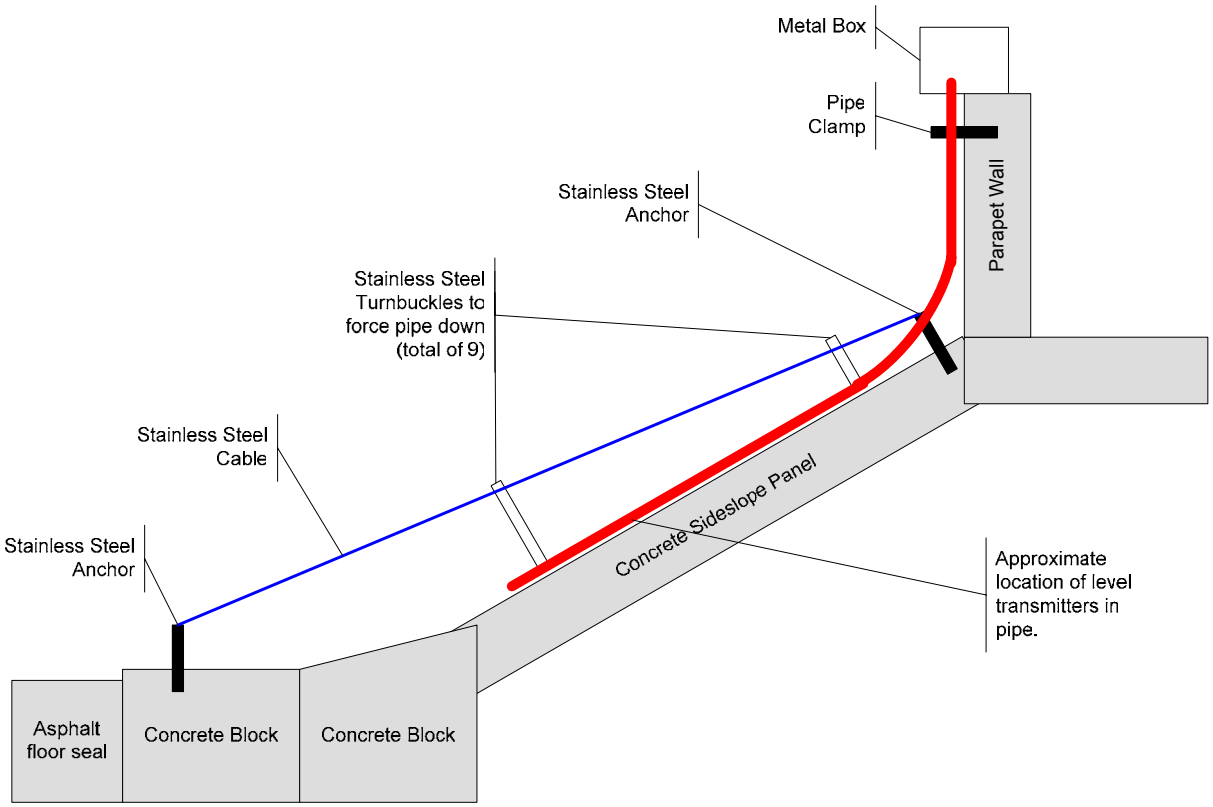


Figure 13: Instrumentation Pipe Installation Sketch

4.6.2. Analog Level Transmitters

4.6.2.1. Instruments Utilized

All 3 transmitters are GE Druck model PTX 1230 per IMG089629.01. This document also specifies their serial numbers and the PLC tag names associated with each. These transmitters are 4-20mA loop powered gauge pressure transmitters which are suspended in the water by their integral cable. These transmitters were supplied with 200 foot long cables and were calibrated at the factory to 0-100 psig. They measure the level of the water by measuring the pressure generated by the water above them referenced to atmospheric pressure. Maintaining these transmitters at a consistent vertical location is critical to proper operation of these devices. See product cutsheets IMG089630-089631 & other cut sheets. Each transmitter's 200 foot cable contains an air tube to provide the atmospheric pressure reference and 2 signal wires.

4.6.2.2. Installation

General
Refer to pipe installation drawings and photos referenced above. Also see the 16-Dec-2005 photo of cable hanging technique in upper reservoir instrument box and the 15-Dec-05 photo of transmitter cable air tube ends.

The three transmitter cables were tied together and all lowered to the same elevation, 1500 feet, about 15 feet above the bottom of the reservoir, where they hang by their cables in the northernmost of the 4 pipes. The uncut 200 foot long cables ran from the transmitters up through the transmitter box where they are supported using wire mesh cable grips. From there the cables ran though a pull box located below the upper reservoir instrument box where excess cable length was coiled. The cables were then routed to interface terminal blocks in the upper reservoir PLC panel. The ends of the vent tubes are located near these terminals in the upper reservoir PLC panel.

Protection of Pressure Transmitter Vent Tubes/Compensation for Barometric Pressure
Water or dirt in the vent tubes could cause significant errors in ambient pressure compensation. The ends of the vent tubes were located in the Upper Reservoir PLC control panel (see 15-Dec-05 photo). The Upper reservoir gauge house is heated in the winter and air conditioned in the summer. This helps to prevent condensation from forming and getting into the vent tubes. The heater in the gauge house was reported by Ameren personnel to have been working after the incident, and appeared to be working at Siemens' inpection. The pressure transmitter's manufacturer also recommends in the product literature that a dessicant be located in the panel with the vent tube ends. Dessicant was present upon Siemens inspection of the panel on 12-Jan-06. The upper reservoir PLC control panel is a gasketed and rated Nema 12 which is intended to provide protection against the ingress of dust and dripping liquids. It could also provide protection against bug nests, but it is not completely air tight. A photograph dated 15-Dec-05 (represented to Siemens to be the "as found" condition after the event), shows that the vent tubes were angled up which could invite entry of any dust and/or condensation present, however, the ends of the tubes appeared to be clean and dry. Also, the interior of the upper reservoir PLC cabinet appeared relatively clean and dry on Siemens's 12-Jan-06 visit. Given that, Siemens does not expect condensation or dirt build up on or in the vent tubes to have been an issue.

Bending Radius of Cable/Compensation for Barometric Pressure
Ameren engineers stated that no kinks or serious abrasions were found in the cables after the event. Photos of cables dated 16-Dec-05 provided to Siemens by Ameren showed a bending

radius of approximately 2", i.e. about the same as the 4" diameter pipes (note these cables had been moved around after found). Although the instrument literature provided by Ameren and reviewed by Siemens did not indicate, Siemens contacted the manufacturer's phone support (Rich Espisito 203-746-0400 on 1/19/06), which recommended a bending radius 6" or greater. Wire mesh cable grips were utilized to hang the cables to prevent kinking at the point of attachment. No as-found photos were given to Siemens for review of the bending radius where excess cable was coiled in a pull box, however Ameren engineers stated it to be approximately 1 foot (a 2' diameter coil). A partial blockage could add some delay to the sensors ability to compensate for sudden atmospheric changes. A complete blockage could cause atmospheric pressure changes to be reflected as level changes by the transmitter. The weather data and the Wonderware data logs suggested no impact on level measurement due to change in barometric pressure. On 12/9/05 at 11:35 AM the instrumentation reading for Barometric pressure was 30.48 inches of mercury. The instrumentation indicated that barometric pressure fell steeply to 29.87 inches of mercury on 12/10/05 at 9 PM. During a portion of this time the UR fill level should have remained level since there was no generation or pumping activity. The Wonderware data for that time period did indeed (other than noise attributed to wave action) reflect no level change. Siemens therefore believes that the barometric pressure compensation of the transmitter was likely to be working properly.

Transmitter Cable Elongation effects
The cables are constructed with kevlar to prevent the cable from stretching due to the weight of the hanging transmitter. Siemens questioned the manufacturer's technical phone support (see reference above), who did not indicate that there were any additional inaccuracy issues due to expansion and contraction of the cable length with temperature.

Installation in Pipe
According to installation drawings and pictures presented by Ameren, the transmitters were installed into a pipe with the holes per the installation drawings. If clogged, these pipes could impact the ability of the transmitters to accurately measure the reservoir level. Ameren engineers reported that they found no significant clogging throughout the length of the as-found level transmitter pipe. They reported that they checked for clogging with a borescope and by cutting a few large holes into the pipe (see photo marked 15-Dec-05). Ameren engineers also reported that the as-found 0.5" water passage holes drilled in the pipes showed no significant signs of clogging. Based on these reports, Siemens does not believe that this pipe served as a stilling well.

Holes in Nose Cone of Transmitter
The transmitter is provided with a nose cone that has small holes in it to allow water pressure to reach the sensor. Ameren engineers reported that these holes were observed to be significantly clogged after post-event removal of the transmitters from the pipe. They reported that these holes became clogged during the removal process. Siemens would expect that a total blockage of these holes could prevent the transmitters from registering level changes. This would appear to be contradicted by the data logs which suggest that the levels were changing. A partial blockage may have resulted in delayed pressure sensing. If the clogging was significant it is possible that the amount of clogging of each of the transmitters could vary and thus the amount of delay could vary as well. Since the data logs show all 3 transmitters' outputs to be tracking well with one another it does not appear likely that the holes were clogged.

Expansion and Contraction of Pipes
The HDPE pipe experiences a broad range of temperatures throughout the year, from exposure to bright sunlight in the summer to cold winter air temperatures. At the 1500' elevation, where the transmitters are located, several holes are drilled into the top of the pipe that allow for visual

placement of the transmitters. There is a set of ½" holes around the pipe 1 foot (along the pipe) above and 7 foot below (along the pipe) the 1500 foot elevation. The 3 transmitters are each 0.69" in diameter and the pipe's inside diameter is 4.0" so they were not a tight fit. The pipe has a smooth interior and as reported to Siemens by Ameren engineers the transmitters slid easily up and down during installation and removal. Since the transmitters are suspended from the top and basically hanging in the pipe it is seems reasonable to assume that the transmitters would slide along the interior of the pipe without effect on their location even if the pipe's length changed considerably unless the expansion and contraction was enough to get them to hang up on the ½" holes located 1 foot above their normal height.

Loop Power Voltage
Proper operation of the transmitters is based on a proper loop power supply voltage. It was measured to be 24.0VDC on 2/2/06, and this is within the 10-30VDC range specified by the analog transmitter manufacturer's information provided by Ameren. Transmitter testing verified repeatable operation of the transmitter throughout the entirety of the supply voltage range.

Current Loop Load Impedance
The impedance of each current loop is the sum of the input impedance of the Allen Bradley 1796-IF4 analog input card (250 ohms) and the round trip resistance of the 200 foot cable. The cable was a 24AWG copper cable per GE Druck phone support (Rich Espisito 203-746-0400 on 2/3/06). The round trip resistance of the cable would be approximately 51 ohms. A total of 301 ohms falls within the operating area specified by the GE Druck instructions.

UR Analog Input Card Accuracy/Repeatability/Temperature Effects
The analog input card utilized is an Allen Bradley 1769-IF4 per the electrical schematic and Interconnection diagrams. The specifications of this module are given on page A-3 of the Compact I/O Analog Module User Manual, Allen Bradley Publication 1769-UM002B-EN-P - July 2005. Separate specifications are given for the accuracy, temperature drift and repeatability of this module. Siemens assumed that any inaccuracy was compensated for during the commissioning of the equipment and Siemens therefore does not include it in its analysis. The manufacturer's repeatability specification provided to Siemens stated plus or minus .03% of full scale. The accuracy drift with temperature was plus or minus 0.0045% per degree C. No actual data was provided to Siemens regarding the temperature of UR building. Since the UR building is climate controlled (heated and air conditioned with a thermostat) and since Ameren engineers reported that the heater was working immediately after the incident, Siemens assumed an internal building temperature of 25 degrees C plus or minus 5 degrees. The UR PLC panel is equipped with a cooling fan that exchanges building air with internal panel air intended to minimize the temperature rise above ambient in the panel, however even with the fan the internal temperature of the control panel would be somewhat higher than the room. Siemens assumed a temperature rise of 10 degrees C which would result in a maximum assumed variation of plus 15 degrees C. Therefore, with the climate control working properly one could reasonably expect to see a variation in the level measurement of around plus or minus 1-3 inches of water due to the inaccuracies of the analog input card. If the heater, air conditioner or PLC panel cooling fan ever failed the affects would be much greater. As this variance is plus or minus, this could also have provided a small favorable margin. In summary, assuming that the HVAC and PLC cooling systems were functional and operating as intended at the time of the event, Siemens believes the effect of potential accuracy variation to be negligible.

Breakage of Instrumentation Pipe Supports
IMG069851 – photos marked 15-Dec-05 of the instrumentation pipes show breakage of pipe supports and significant bending of the pipes which would have raised the position of the

transmitter above its original elevation of 1500 feet and made it read a lower than actual level. Pipes in the photo marked as 16-Dec-05 were substantially straighter than those in the photos marked 15-Dec-05 and as observed by Siemens on 12-Jan-06, the pipes appeared to be further straightened. As reported to Siemens by Ameren engineers, these pipes straightened on their own. Ameren provided Siemens what they represented to be a rough calculation based on the 15-Dec-05 pipe position showing a rise in transmitter elevation of at least 2.54 feet at the time of the event (see sketch below). This rise would result in an analog reading of at least 2.54 feet low. Based on the straightening observations and the fact that the pipes were buoyant it is reasonable to assume that the pipes were even more curved at the time of the event causing an even larger corresponding error. Ameren engineers performed further analysis which considered the number of failed clamp/unistrut assemblies. Based on this analysis, the maximum lift could have been significantly higher. However based on the historical data analysis, a lift of more than 4 feet seems to be unlikely (see chapter 5.2.3).

The analog transmitter calibration was checked during the initial filling of the upper reservoir and an adjustment factors were put into the PLC code to compensate for the error in elevation placement or signal output of the transmitters. Another adjustment factor of 0.4 ft was added to the PLC's level calculation to recalibrate the transmitters on 9/27/05. This 0.4 feet may take into account some of this bend since just 1 week later on 10/03/05 the breakage of supports and bowing of the pipes was reported by Ameren to have been noticed.

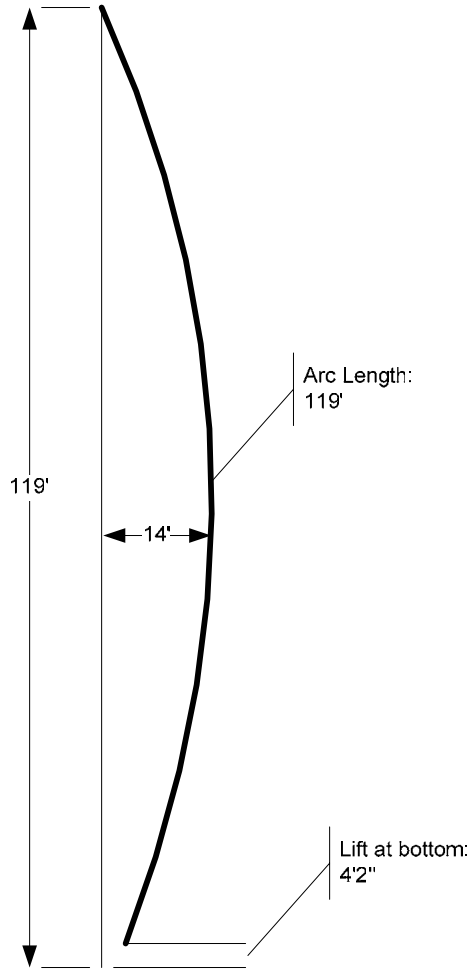


Figure 14: Instrument Pipe Bow Sketch

4.6.2.3. Level Transmitter Testing

Ameren and Siemens jointly designed and supervised testing of the level transmitters at the manufacturer's facility to determine the potential affects of transmitter repeatability, accuracy and sensitivity to temperature variations. The results of those tests are summarized in this section.
The analysis is focused on the transmitters TX2 and TX3 which were used for level control during the event.

Accuracy of test equipment

- The applied pressure had a variability of +/- 0.0075 psig
- The measurement device used to measure the signal output had a variability of +/- 0.0012mA which equals 0.0075 psig
- Total uncertainty (sum of the above): +/- .015 psig= 0.035 ft water

Transmitter Repeatability Tests:

In order to validate the repeatability of the transmitters, the mA output of the transmitters was measured three times at pressures between 0 and 100 psi. The measurements were made at a temperature of 5 degrees Celsius, the water temperature at the event.

As the following two charts demonstrate that the transmitter outputs were very repeatable:

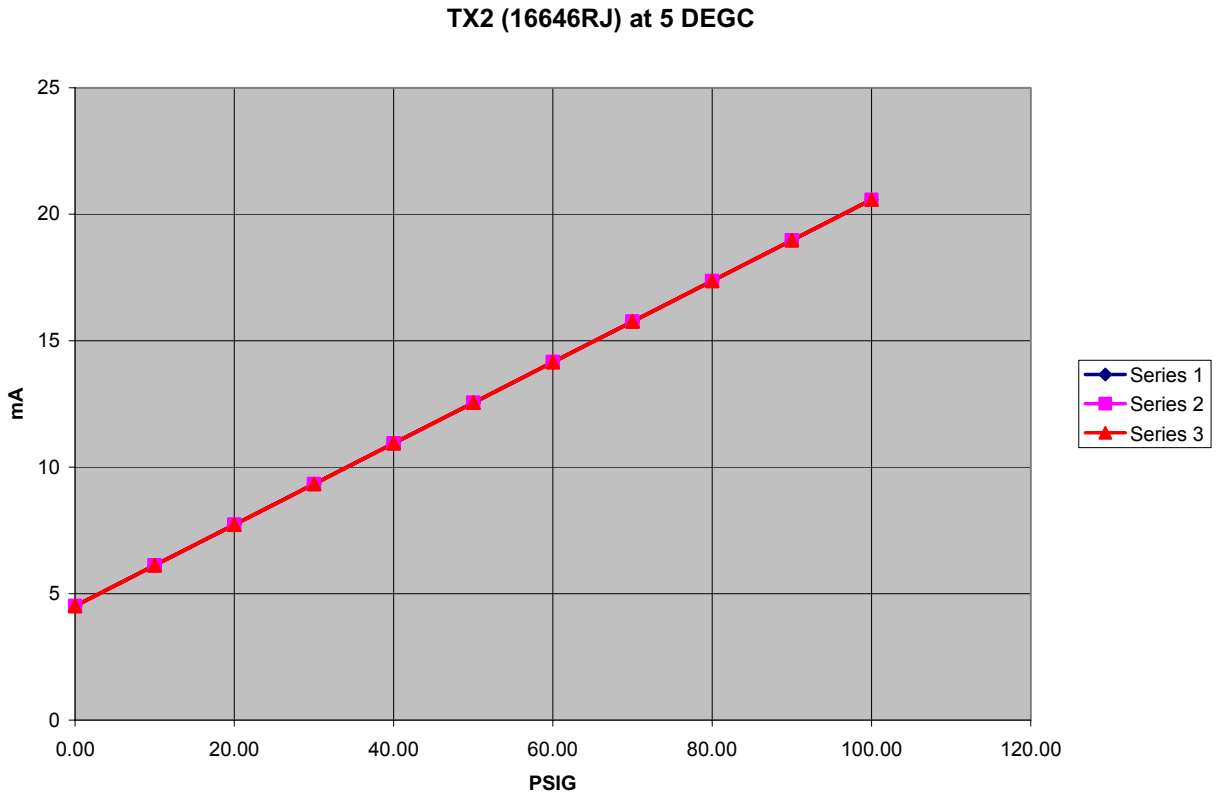


Figure 15: TX2 (16646RJ) Repeatability Test

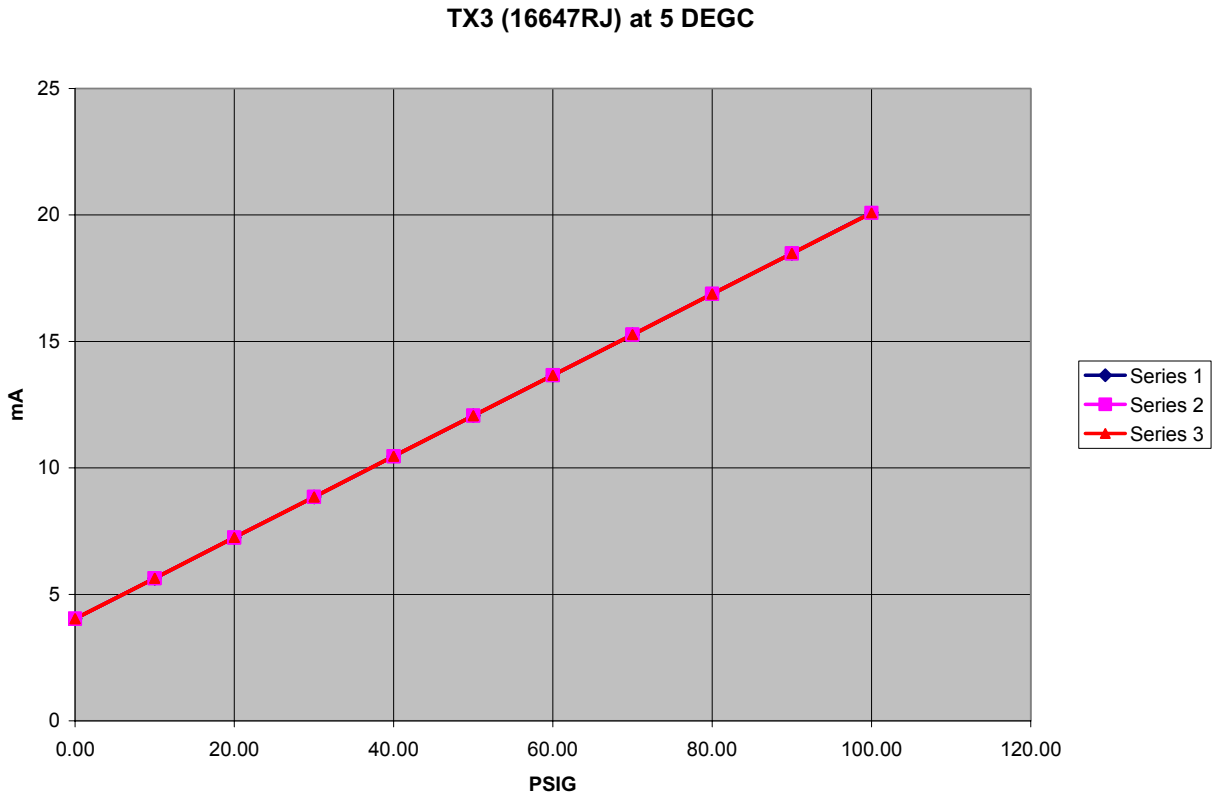


Figure 16: TX3 (16647RJ) Repeatability Test

Transmitter Linearity and Accuracy:

Since the transmitter range was 0 to 100 psig, an optimal transmitter would generate an output of 4 mA at 0 psig and 20 mA at 100 psig. The following two figures compare the measurement series 1 of the charts above for TX2 and TX3 with an optimal transmitter:

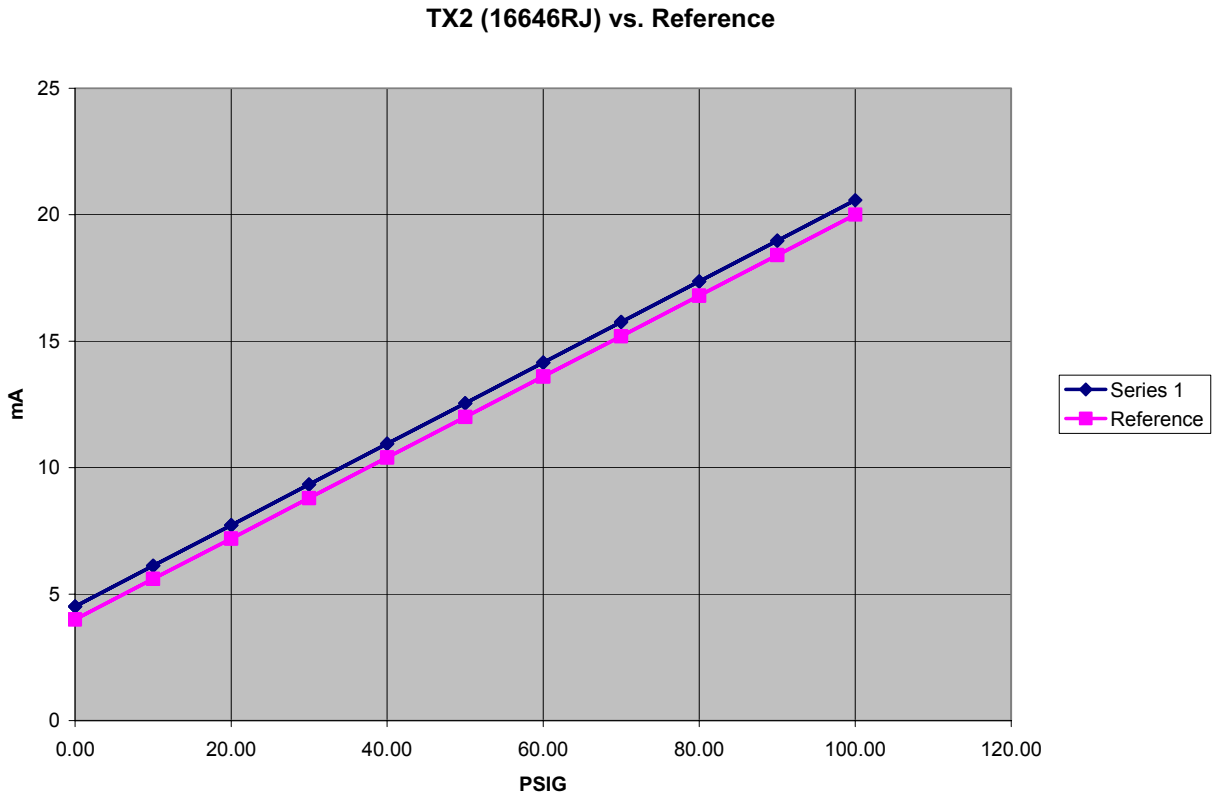


Figure 17: TX2 (16646RJ) vs. Reference

TX2 relates to the reference transmitter with a correlation coefficient of 0.99999994. This means that it is very linear. The average difference between TX2 and the reference transmitter is 0.545338 mA which equates to approx. 7.86 feet of water level at 5 degree Celsius.

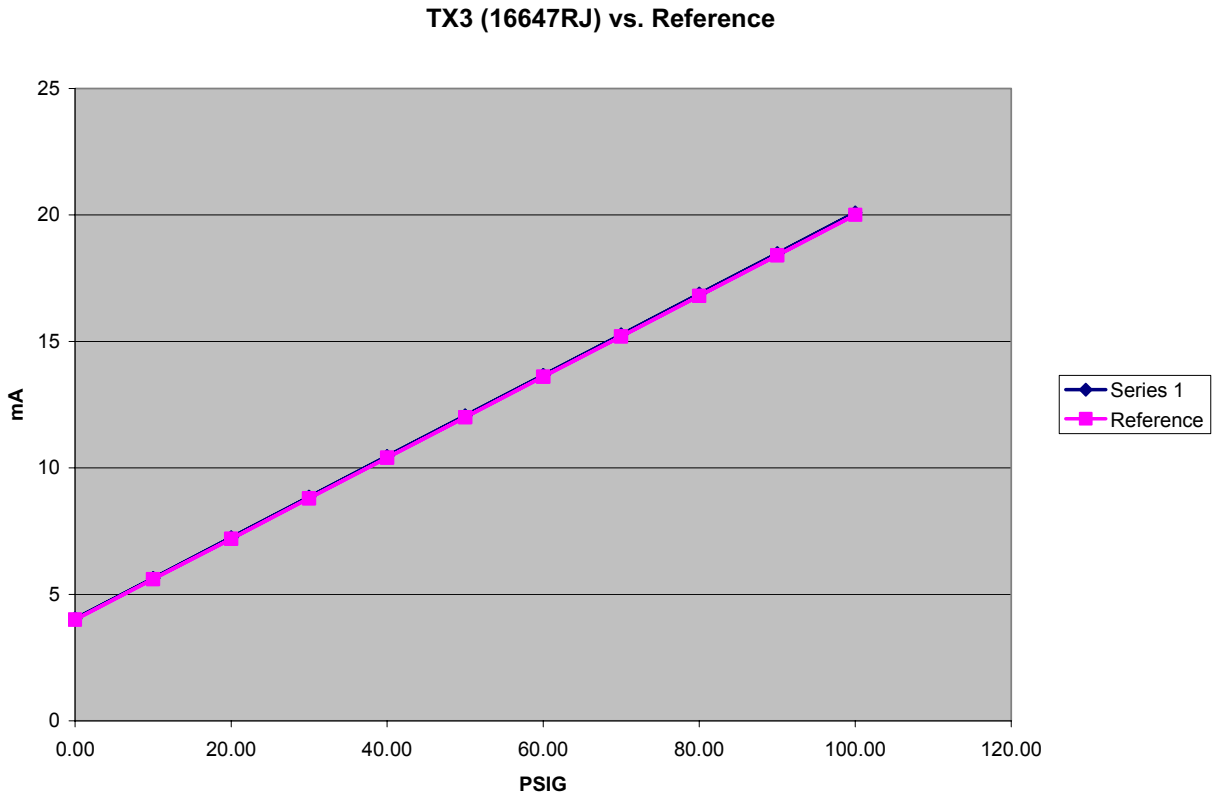


Figure 18: TX3 (16647RJ) vs. Reference

TX3 relates to the reference transmitter with a correlation coefficient of 0.99999996. This means that it is very linear as well. The average difference between TX3 and the reference transmitter is 0.059567 mA which equates to approx. 0.85 feet of water level at 5 degree Celsius.

Temperature Effects:

The following charts show the output of the transmitters TX2 and TX3 at 40 psig at different temperatures (two measurements for each temperature).

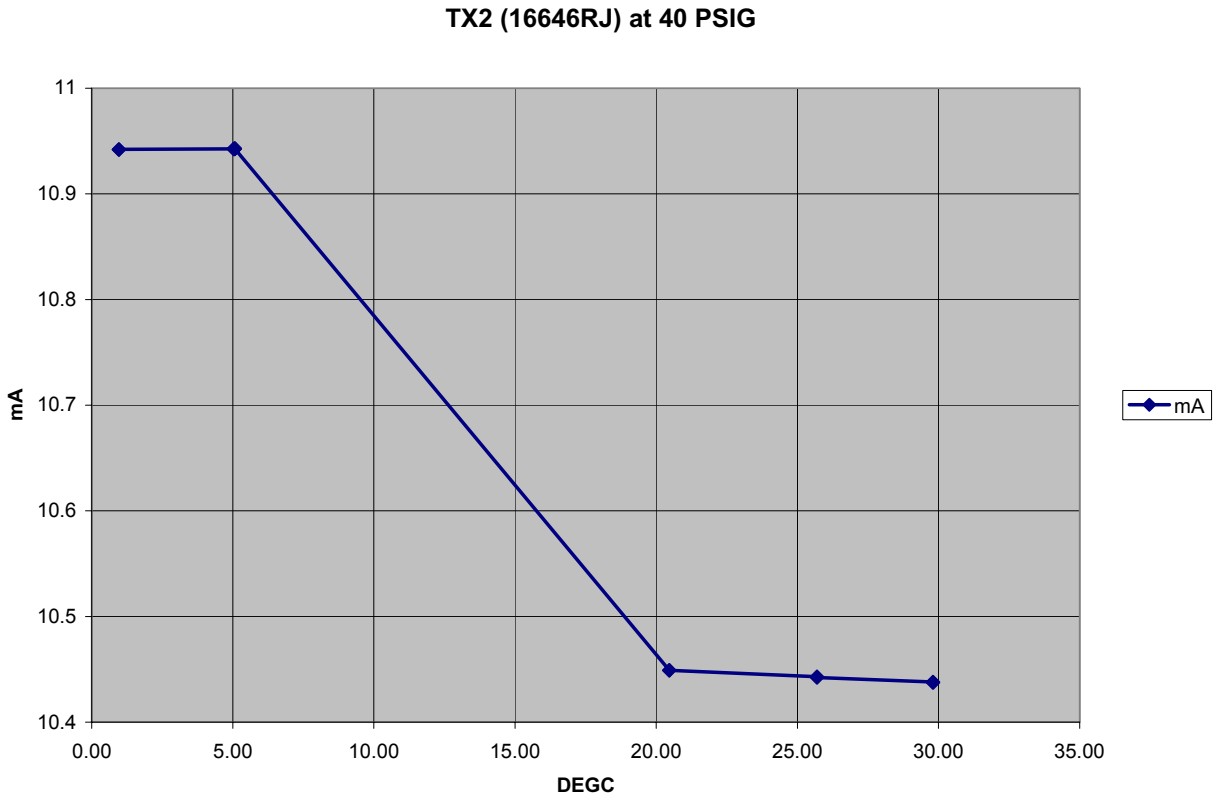


Figure 19: Temperature Sensitivity of TX2

One can see that there is a 0.5 mA step change between 5 degrees Celsius and 20 degrees Celsius. This 0.5 mA change equates to approx. 7.11 feet of water level (at 5 degrees Celsius).

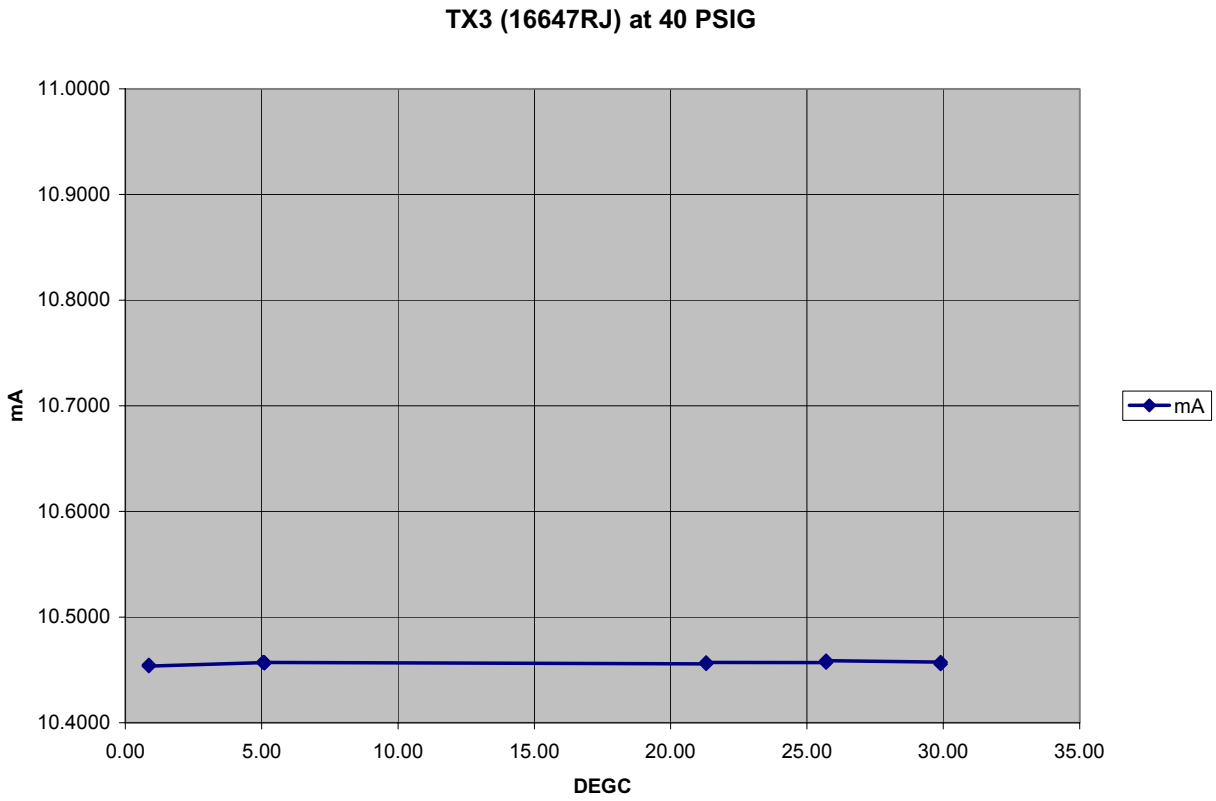


Figure 20: Temperature Sensitivity of TX3

TX3 is less sensitive to temperature changes.

Test Results Analysis:

As discussed in chapter 4.5.1, the as-found PLC logic in the upper reservoir PLC, computed the upper reservoir level as (((TX2 – 9.38) + (TX3 – 2.4)) / 2) + 0.4.
Since TX2 was reading an average of 7.86 feet too high and TX3 was reading an average of 0.85 feet too high, the PLC logic was subtracting more than necessary from the measured values. This would potentially cause the calculated average upper reservoir level reading too low. However, Ameren staff visually inspected the reservoir level on 27-Sep-05 and adjusted the PLC logic to match the upper reservoir level. This adjustment was performed at an approximate water temperature of 25 degrees Celsius. The temperature sensitivity of TX2 causes TX2 to indicate a lower water level at 20 degrees Celsius compared to a water temperature of 5 degrees Celsius (the approximate water temperature at the time of the incident). Therefore, the water level indicated by TX2 at the time of the event would be higher, which is favorable in this context.
Based on the test recordings and the other observations referenced above, it can be determined that the level transmitter repeatability, accuracy and temperature sensitivity did not adversely contribute to the incident.

4.6.3. Hi and HI-Hi Discrete Level Probes

4.6.3.1. Instruments Utilized

The electrical schematic and interconnection diagram state that the four conductivity based point level probes (Hi, Hi-Hi, Low and Low-Low) share a common reference probe and are each associated with their own individual controller. The cut sheet provided, IMG089629.01, states that all 4 level probes and the reference probe are GEMS Warrick Model 3W2 and that the controllers are GEMS Warrick Series 1 electromechanical type model 1H1DO. As reported to Siemens by Ameren engineers the insulated cable used was GEMS Warrick 3Z1A. IMG089629.01 also specifies the PLC tag names associated with each probe.

Each probe consists essentially of a piece of stainless steel rod suspended by an insulated wire. Each controller develops 300VAC between its unique probe and the common reference probe. This voltage is used to sense continuity between the probes. The sensitivity of the controllers selected is matched to the conductivity of natural lake water so that when water is present between the probes they energize their output relay to close a normally open dry contact which provides a signal to the associated PLC input. When no water is between the probes there is not enough conductivity and the controller's output relay de-energizes and returns its contacts to open state.

4.6.3.2. Installation

Refer to pipe installation drawings and photos provided by Ameren and referenced in the level instrumentation pipe installation section above. Also see the photo marked 16-Dec-2005 of cable hanging technique in upper reservoir instrument box. According to these drawings and photos, all five probes were installed into second northernmost pipe. According to the as-found black tape markers, the bottom of the probes were measured and calculated by Siemens to be installed at the following elevations: Hi probe 1597.3 feet and Hi-Hi probe 1597.7 feet (see sketch below). Ameren engineers stated that the as-found reference probe was located at 1515 feet, and that cables suspending the probes ran up the instrument pipe to the instrument box where they were supported with wire mesh cable grips. From there the drawings and photos indicate that the cables run through conduit to the Upper Reservoir PLC cabinet where they are terminated directly onto the terminals of their respective Warrick controllers. The ladder located a few feet from the Hi and Hi-Hi probes was reported to be grounded so it acted as an additional reference probe since the reference terminal of the Warricks was also tied to ground according to information provided by Ameren.

Probe Elevation with Respect to Top of Parapet Wall

The elevation reported of the top of the parapet wall at the instrument box is 1598.0 feet, however the elevation of the lowest part of the wall was only 1597.0 feet (according to drawings provided by Ameren), 0.3 and 0.7 feet below where the Hi and Hi-Hi sensors were located respectively. If this is the case, water would have passed over the lower portions of the parapet wall before these probes would have sensed water. No reference markings showing wall elevation and low point wall elevation were found near the location where the sensors would be adjusted.

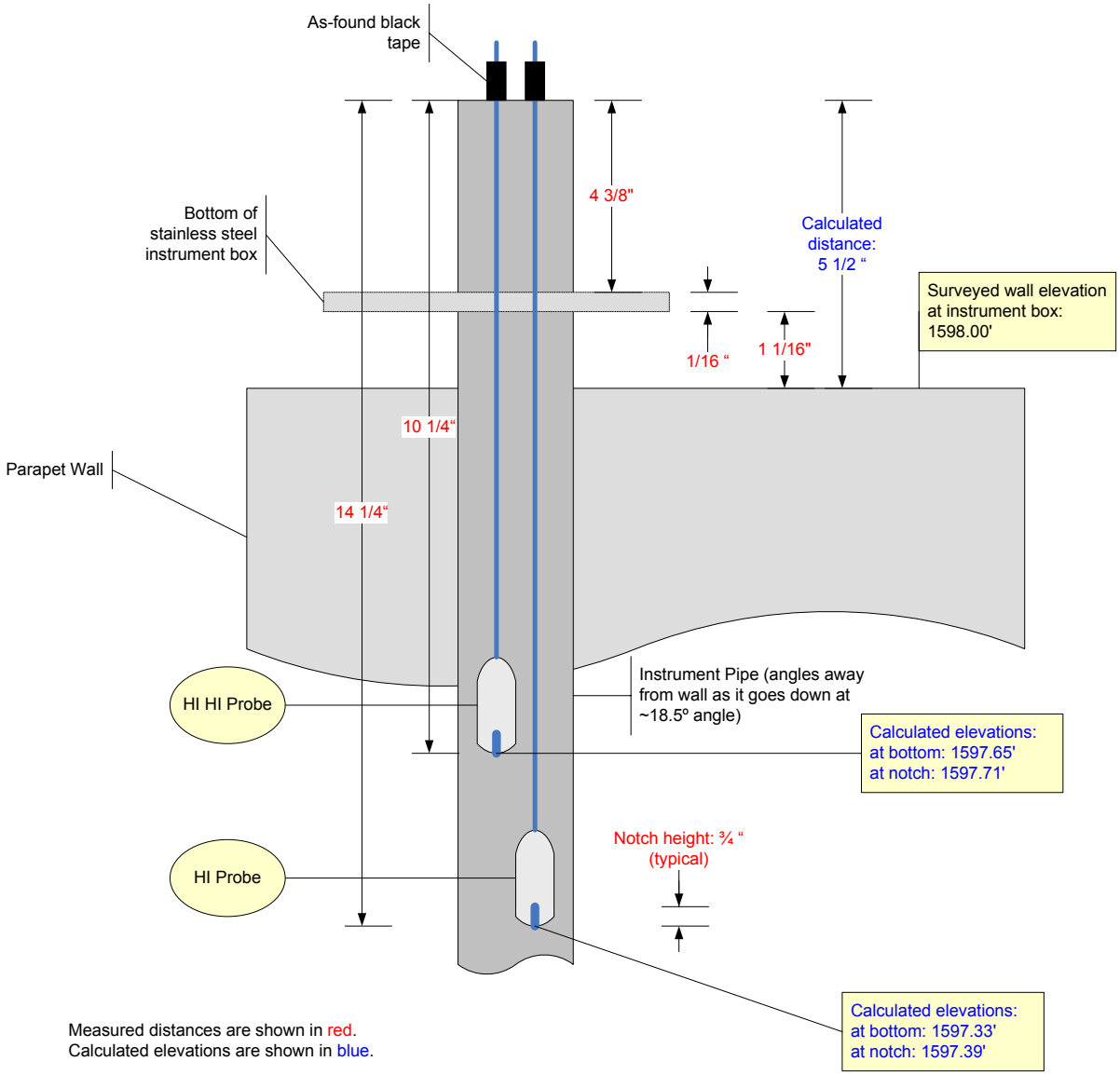


Figure 21: Level Probe Elevation Calculation

Distance between reference and sensing probe

Per the Warrick instruction manual page D3, Note 2 the total resistance must not exceed the sensitivity of the control. The letter D in the part number 1H1DO specifies the sensitivity of the control to be 7.0K ohms. The manufacturer's technical phone support person (Tom James 860-793-4545 1/27/06) said that the probes could be spaced up to four feet apart. The Hi-Hi probe was located worst case approximately 113 feet from the reference probe. The Hi probe was slightly closer to the reference probe. Ameren engineers stated that they successfully tested the operation of these probes by lowering them into the water when it was at a level of 1593.5 foot elevation (This tested an approximate worst case actual distance of 107 feet). Ameren engineers also stated that on 1/6/06 a spare controller operated properly at 125 feet in the lower reservoir using lengths of #10AWG wire stripped 1" from the end as the probes. Further post as-found testing conducted on 2/2/06 by Ameren and Siemens of the actual Hi and Hi-Hi probes and controllers showed that they were operational at a distance of approximately 200 feet.

Based on this test, Siemens believes that the probes would have operated correctly as intended if they had detected water.

Cable Length Limitations

The manufacturer recommends limiting the cable length of probes to a maximum of 500 feet with the 1H1DO controllers. Per 2/2/06 measurements perfomed by Ameren and Siemens the as-found cable lengths were: Hi - 37 feet 7 inches long, HI-Hi - 38 feet 3 inches and reference 196 feet long. The total length of cable is the sum of the reference probe and the signal probe. If these measurements are correct, these are within the manufacturer's stated maximum limit.

Potential Problems Due to Freezing

According to data provided by Ameren, temperatures were below freezing the evening of 12/12/05 starting at around 9 PM through noon on the 12/13/05 as well as the morning of the incident starting around 3 AM through the time of the incident. However, the plant was either generating or pumping during the entire time freezing temperatures existed. Water movement during these time periods would most likely have kept water from freezing in the instrumentation pipes. In the unlikely event that ice had formed on the probes, testing conducted by Ameren and Siemens on 2/2/06 suggested that the probes could have still worked regardless of the ice in the pipes.

5. Upper Reservoir Level Transmitter Data Analysis

All analysis is based on one minute archived data received from Ameren.

5.1. Upper Reservoir Transmitter Noise

The following chart shows the average transmitter reading (calculated in the PLC as the average of TX2 and TX3) on 11-Dec-05 between 09:20 and 09:46. The maximum variation is 0.1 feet. The last pump stopped at 07:50am on this morning. The data sample started 90 minutes after the last stop. It should be expected that there was no movement of the reservoir level.

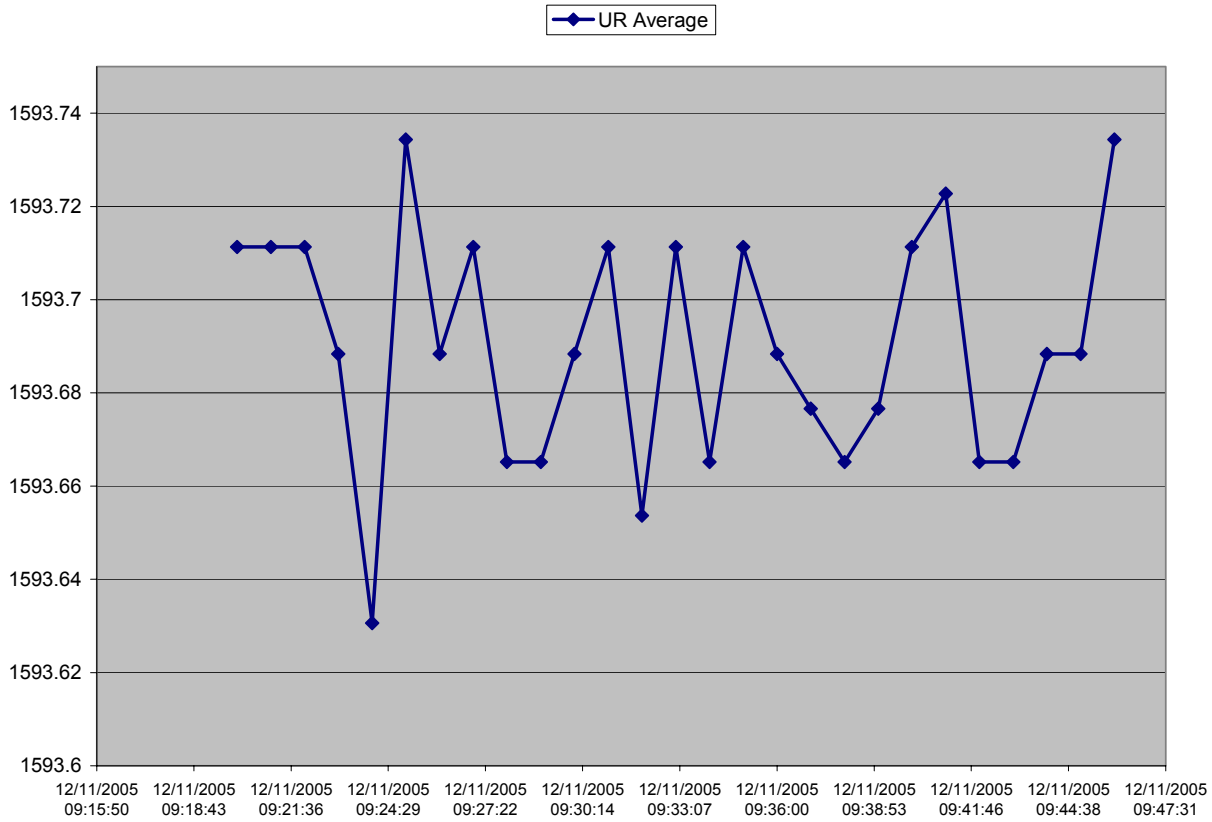


Figure 22: Average UR Transmitter Reading on 11-Dec-05 between 09:20 and 09:46

The following chart shows the individual transmitter readings for the same time period (note that TX1 was not used for the calculation of the average value):

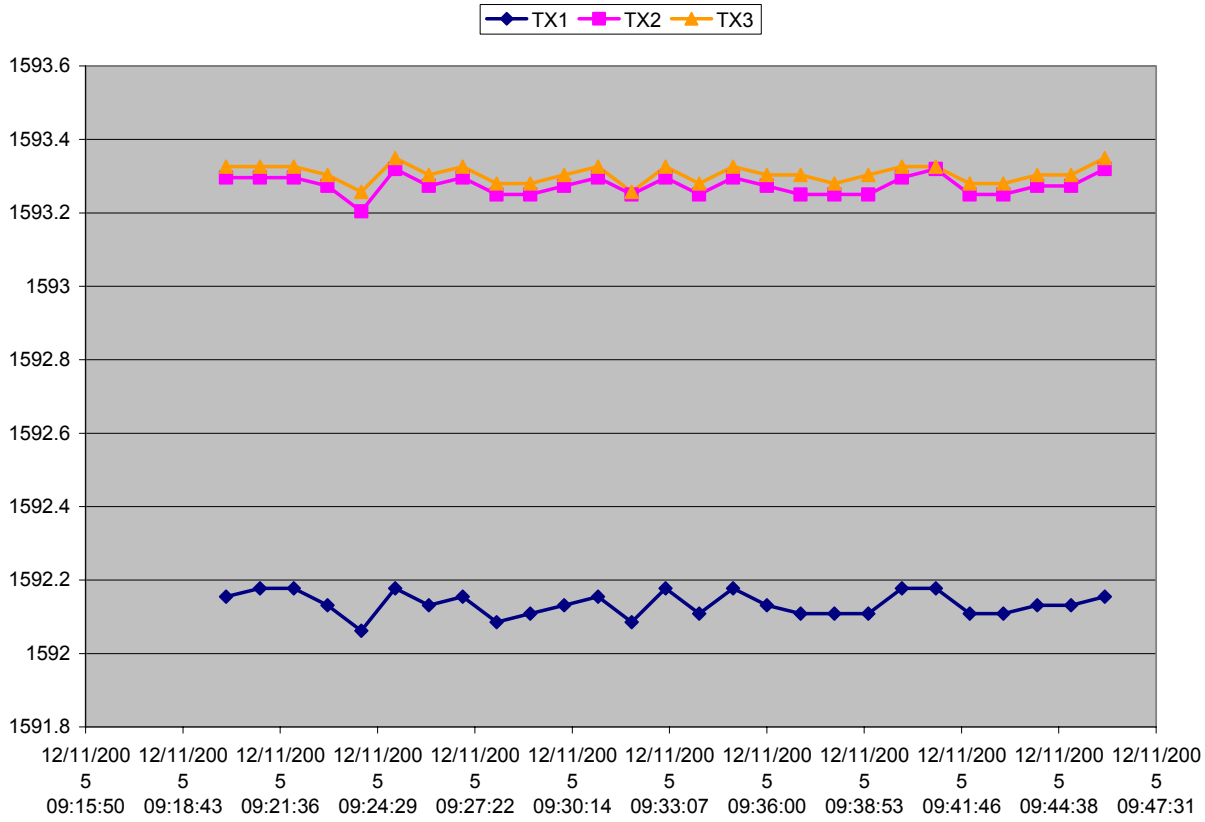


Figure 23: Individual UR Transmitter Reading on 11-Dec-05 between 09:20 and 09:46

This data indicates that all three transmitter readings are moving in parallel. This becomes more evident if the one minute value changes are plotted (here for TX2 and TX3 which were actually used for level control):

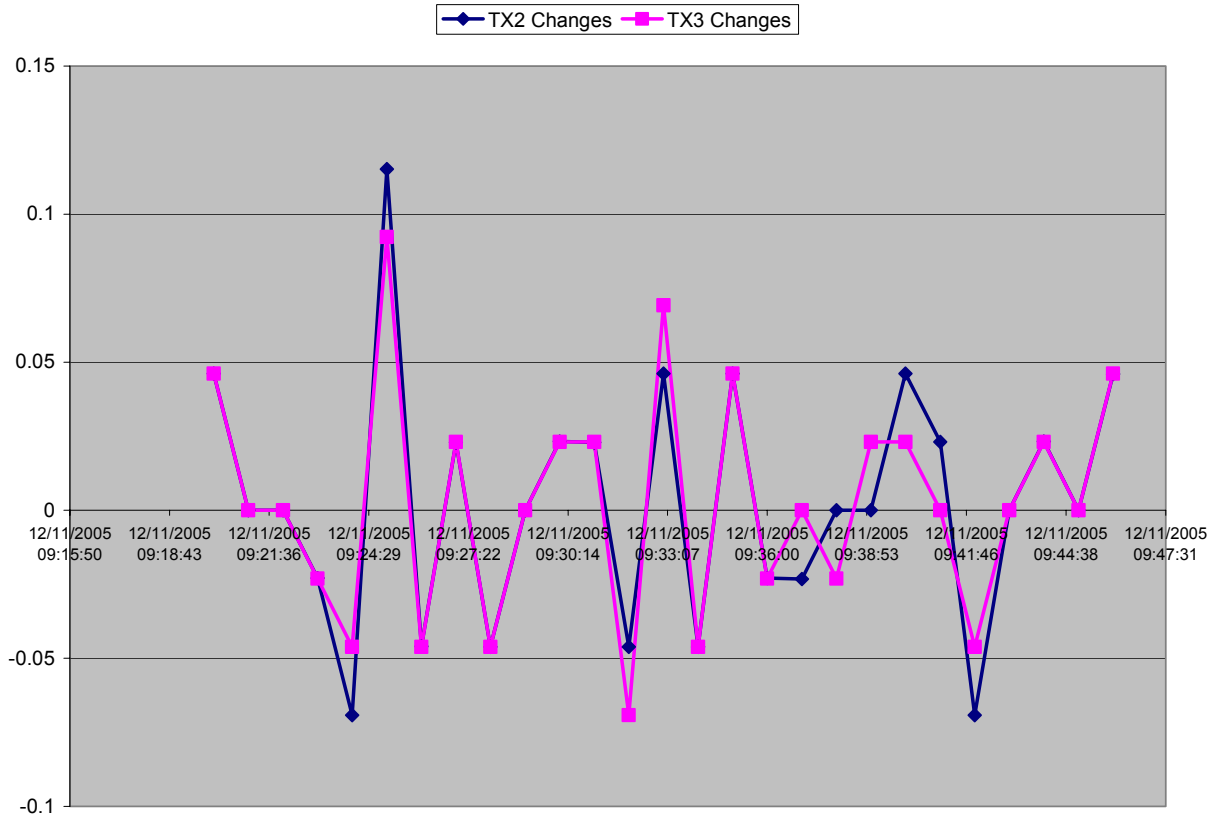


Figure 24: Individual UR Transmitter Reading Changes on 11-Dec-05

Several time intervals with different reservoir levels were reviewed. In all cases, a signal variation of ± 0.1 - 0.15 feet was observed.

Since all three transmitters are moving in parallel, these observations can not be explained with random noise. Siemens assumes that the value changes may have been caused by wave action which either caused actual depth changes sensed by the transmitters or which caused movement of the transmitters generating false noise.

5.2. Comparison between the Upper Reservoir Level and the Penstock Level

The following chart shows the UR level compared to the Penstock head during calm plant conditions (no generation or pumping) for the month of September 2005. The chart indicates that the head measured by the Penstock transmitter is closely correlated to upper reservoir level:

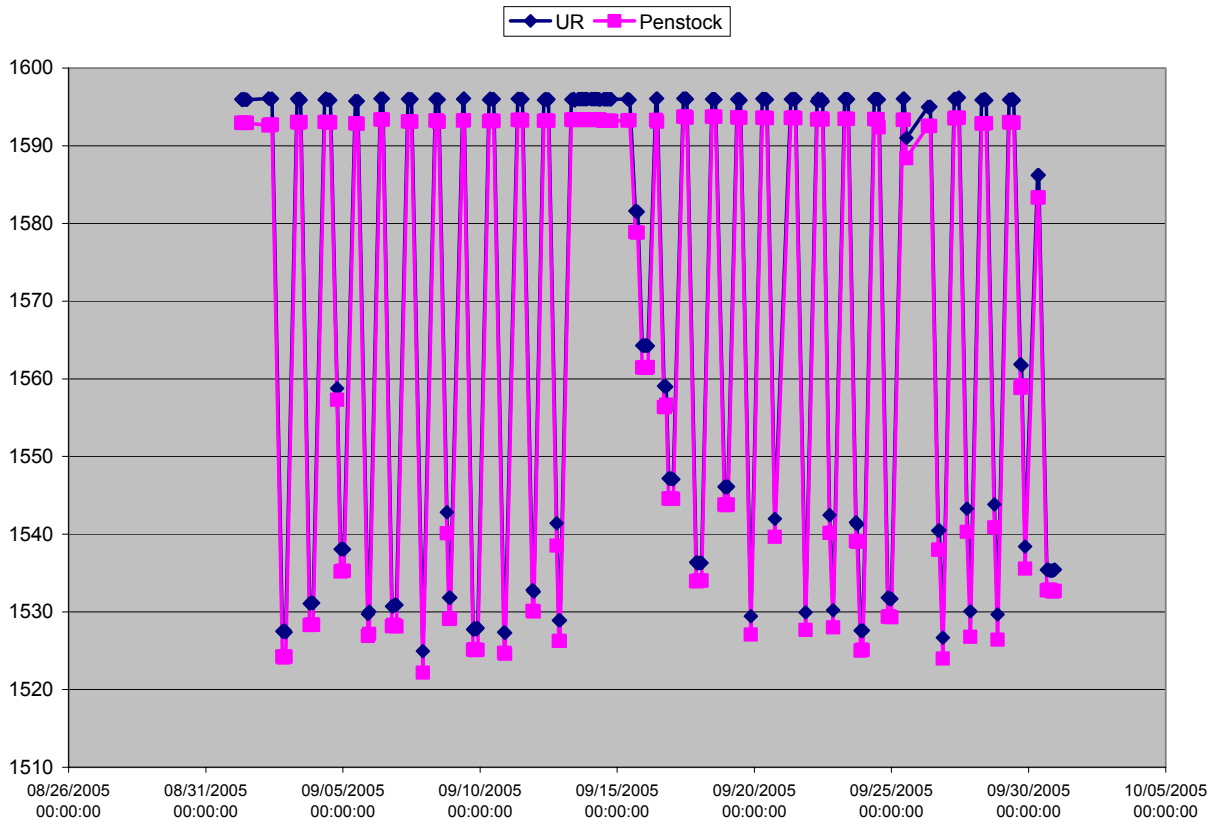


Figure 25: Comparison between UR Average and PS Level Transmitter Readings

The head measured by the penstock transmitter is not suitable for use as a level measurement while the Unit is operating as the measured pressure includes water flow and penstock loss affects that make an upper reservoir level correlation difficult.

5.2.1. Penstock Transmitter Quality

The following chart shows the readings of the UR level transmitter average vs. the PS head transmitter on 11-Dec-05 between 09:20 and 09:46 (the same time range was used as an example for the UR level transmitter noise discussion above):

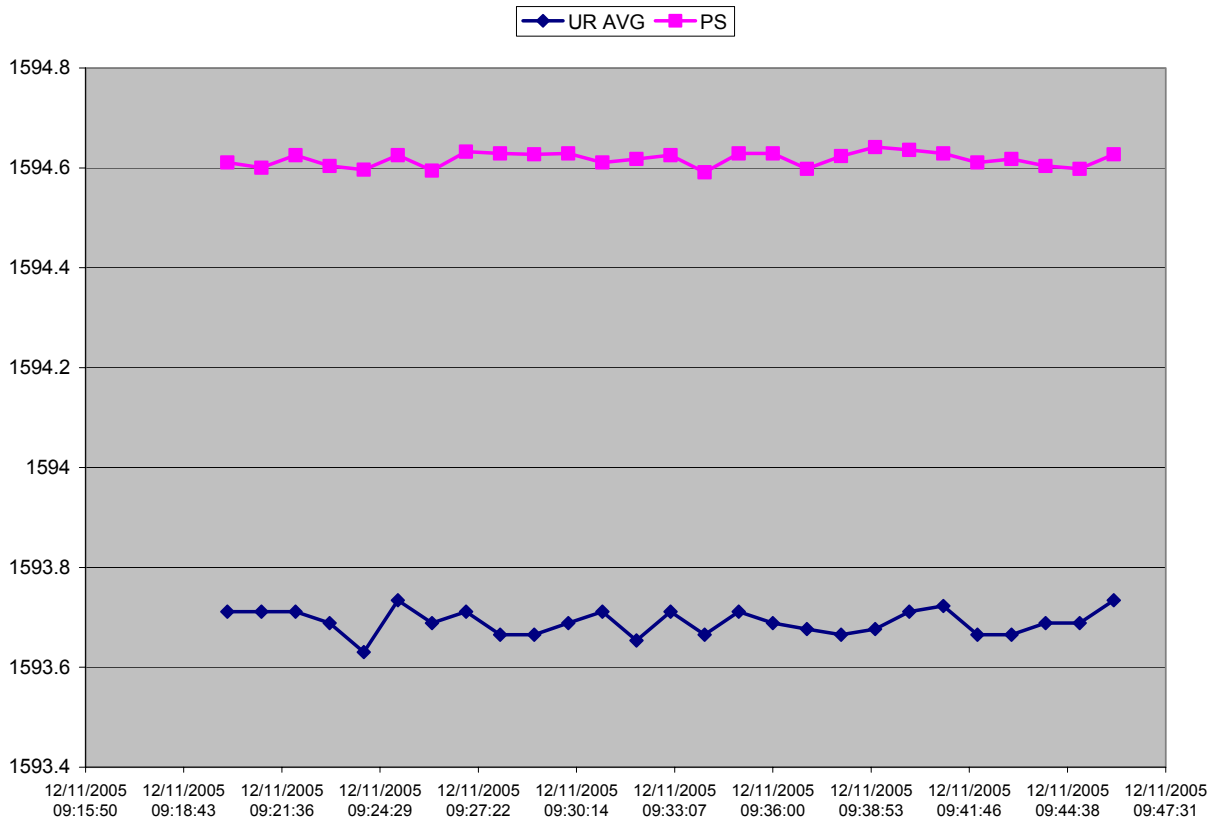


Figure 26: UR Average Transmitter Readings vs. PS Transmitter Readings

This chart indicates again that the levels measured by the UR average transmitters and the levels measured by the PS transmitters correlate and that the PS level transmitter shows less signal noise. Siemens concludes that the installation of the penstock transmitter filters out most wave action affects on level measurement.

The following chart shows the one minute value changes during the same time period for the average UR level average and the PS level:

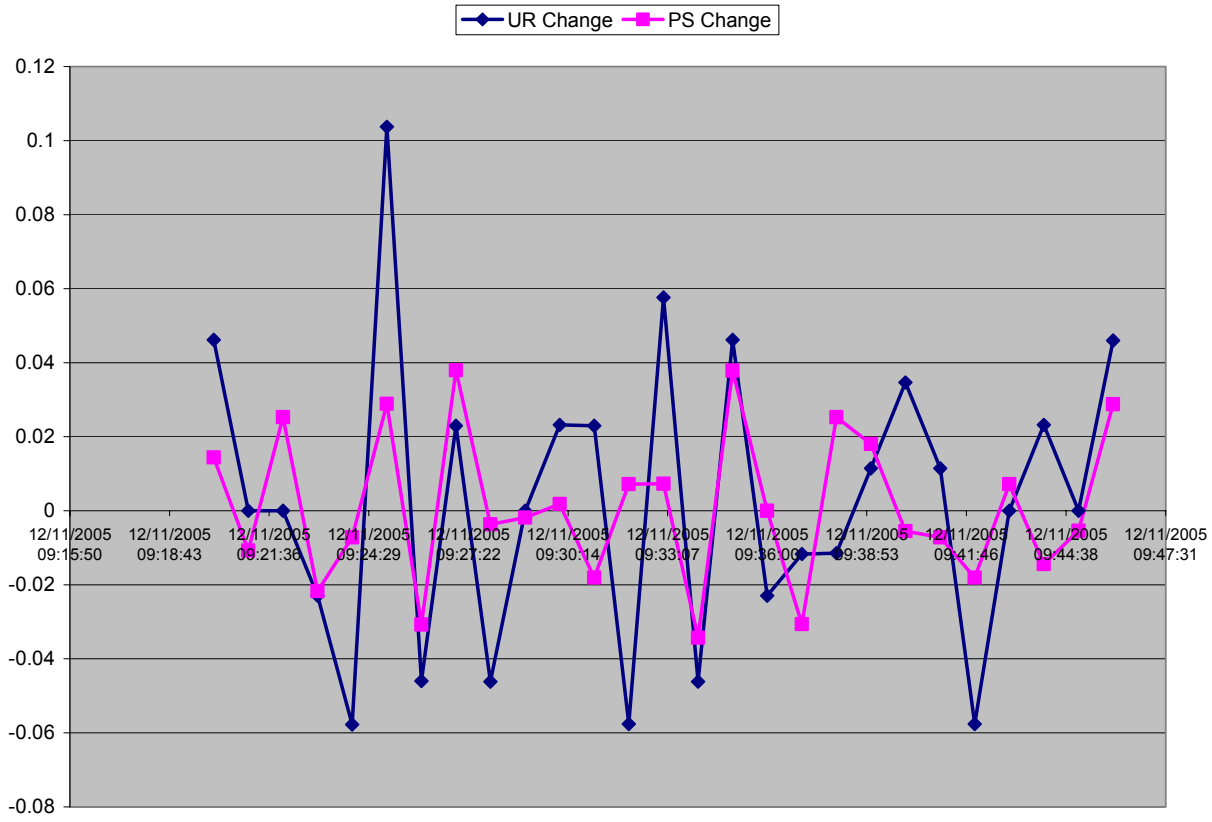


Figure 27: UR vs. PS Transmitter Reading Changes

Again, this chart indicates that the PS level transmitter shows less signal noise than the UR level transmitter average. The standard deviation for the UR series is 0.00399, the standard deviation of the PS series is 0.00204.

Since the PS transmitter shows a smaller standard deviation and its location in a controlled environment makes it less sensitive to mechanical and temperature related changes, it can be used as a reference to gauge the Upper Reservoir level transmitters under static (no flow) conditions.

5.2.2. Differences between the UR Level Transmitters and the PS Level Transmitters

The following chart shows the difference between the measured UR level and the measured penstock level during calm plant conditions from 1-Sep-05 until 14-Dec-05:

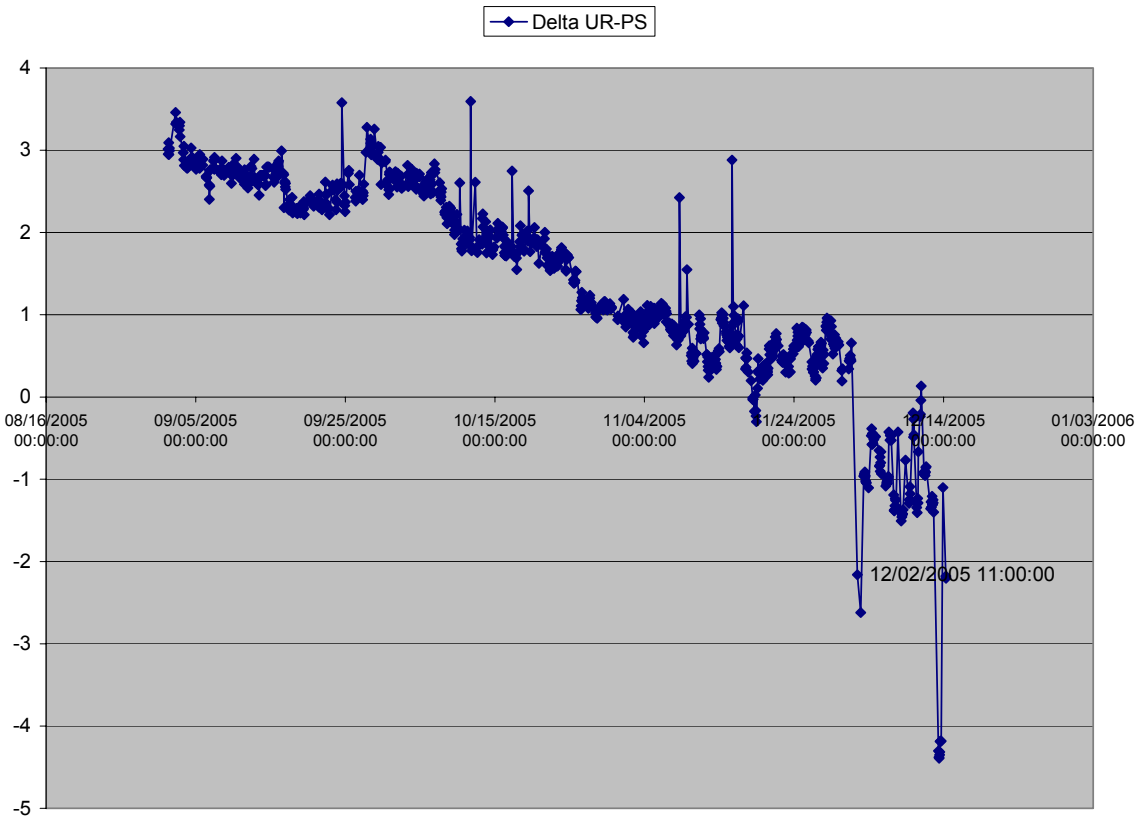


Figure 28: Difference between UR Transmitter Average and PS Transmitter

The gradual decrease of the difference may be explained with a gradual movement of the upper reservoir level transmitter locations. The step changes at the beginning and in the middle of December are discussed below.

The same data between 1-Dec-05 10:00am and 3-Dec-05 10:00am:

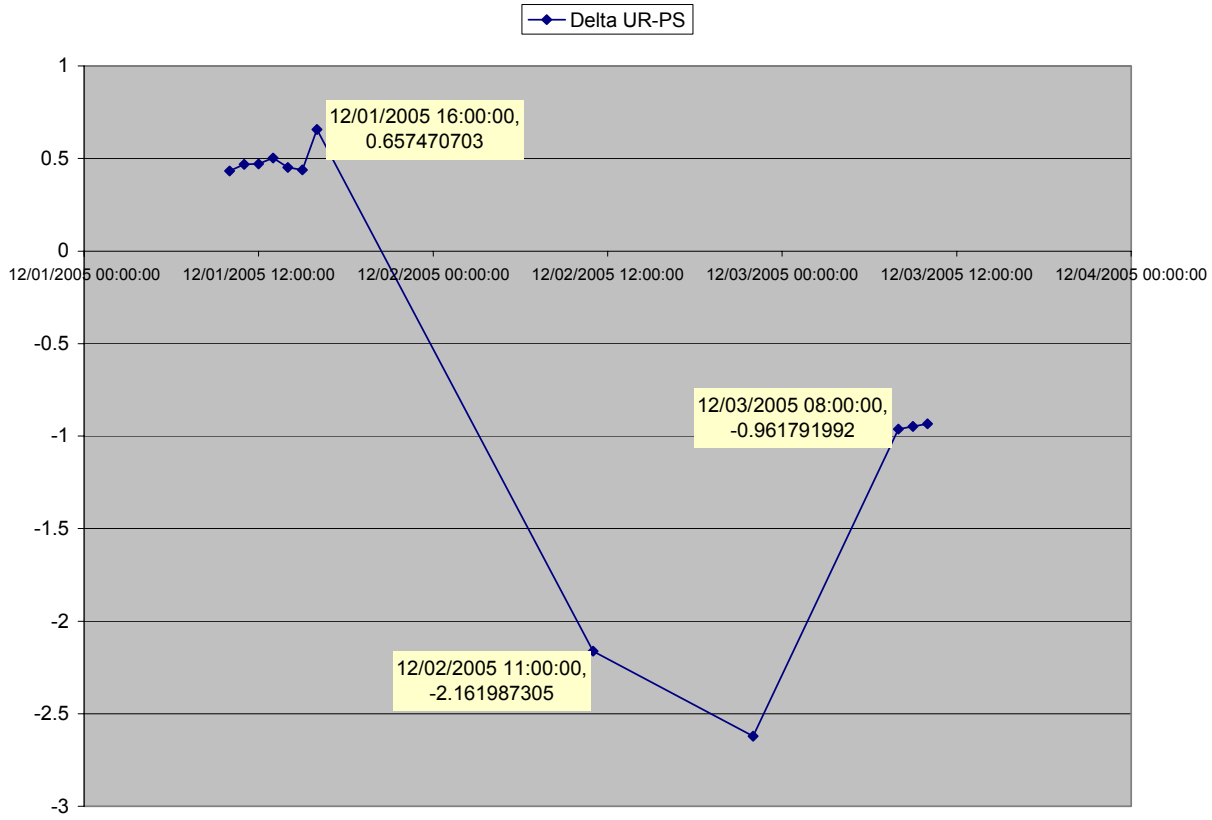


Figure 29: Difference between UR Transmitter Average and PS Transmitter between 1-Dec-05 and 3-Dec-05

Note the change in between 1-Dec-05 16:00, 2-Dec-05 11:00 and 3-Dec-05 08:00. This sudden change can not be explained by a change of environmental conditions. One assumption could be that the location of the UR level transmitters may have shifted during that time period.

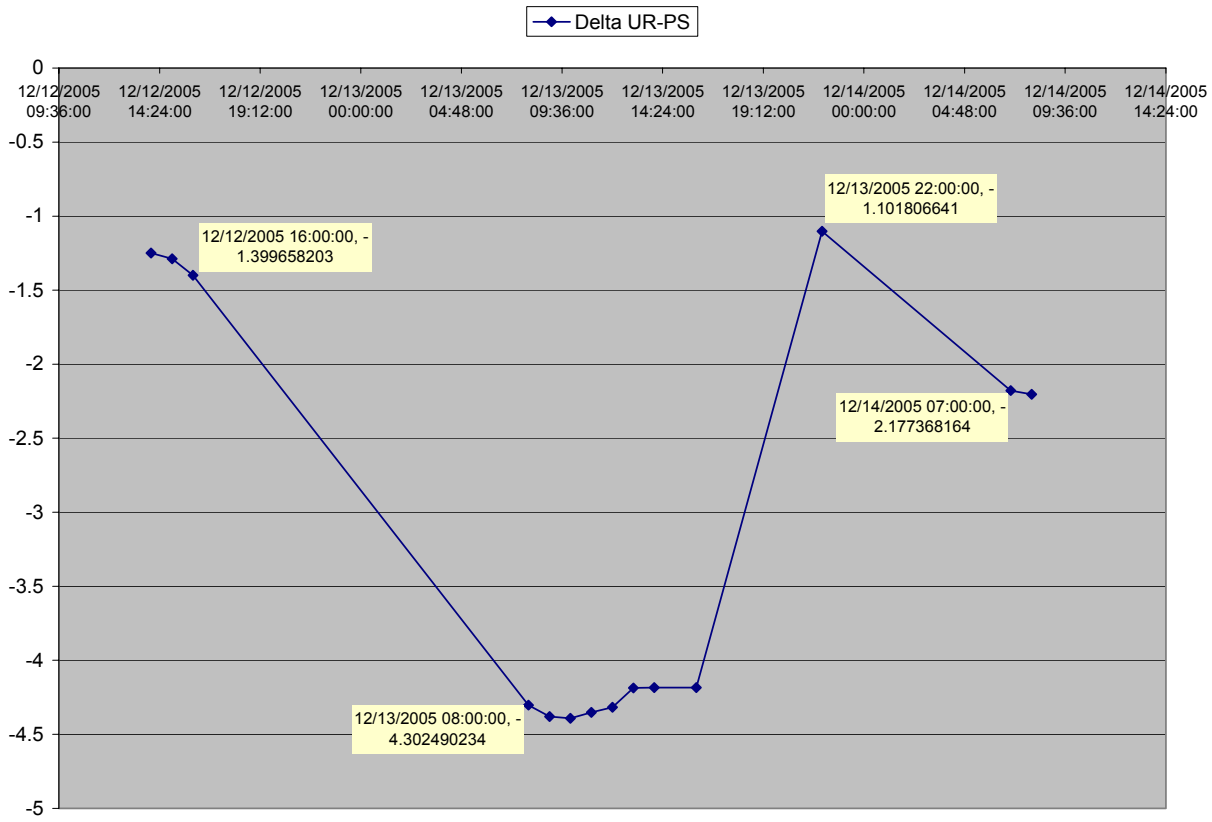


Figure 32: Difference between UR Transmitter Average and PS Transmitter between 12-Dec-05 and 13-Dec-05

A similar sudden change of the transmitter readings can be observed between 12-Dec-05 and 13-Dec-05. This change is also likely to be caused by a shift of the instrument elevation.

5.2.3. Upper Reservoir Level Transmitter Variance at the Time of the Incident

The maximum UR Level transmitter reading was 1593.72 at 5:15:00 AM. Since the lowest point elevation of the parapet wall was surveyed as 1597 feet, the actual water level must have been above that level.

In addition, the parapet wall was also overtopped at panels 44 – 53.

Here are the elevations of the panels 44 through 53 (each panel has two measurements – see IMG059025):

Panel	Elevation
44.1	1597.54
44.9	1597.46
45.1	1597.42
45.9	1597.33
46.1	1597.37
46.9	1597.26
47.1	1597.28
47.9	1597.34
48.1	1597.18
48.9	1597.35
49.1	1597.20
49.9	1597.35
50.1	1597.40
50.9	1597.33
51.1	1597.30
51.9	1597.55
52.1	1597.52
52.9	1597.46
53.1	1597.36
53.9	1597.43

The average elevation in this area is 1597.37 feet.

Figure 33: Surveyed Wall Elevations between Panel 44 and 53

Based on this information, it can be assumed that the upper reservoir level measurement which was used to control the automatic stop of the last pump was reading at least 3.65 feet (1597.37 – 1593.72) too low.

If one applies this constant to all UR transmitter readings as shown in the table below, then overtopping at the lowest point of the wall may have occurred between 05:05 and 05:16.

Date	UR Level	UR Level +3.65
12/14/2005 5:02	1593.077	1596.727
12/14/2005 5:03	1593.008	1596.658
12/14/2005 5:04	1593.181	1596.831
12/14/2005 5:05	1593.388	1597.038
12/14/2005 5:06	1593.204	1596.854
12/14/2005 5:07	1593.342	1596.992
12/14/2005 5:08	1593.434	1597.084
12/14/2005 5:09	1593.319	1596.969
12/14/2005 5:10	1593.619	1597.269
12/14/2005 5:11	1593.538	1597.188
12/14/2005 5:12	1593.573	1597.223
12/14/2005 5:13	1593.688	1597.338
12/14/2005 5:14	1593.619	1597.269
12/14/2005 5:15	1593.723	1597.373
12/14/2005 5:16	1593.388	1597.038
12/14/2005 5:17	1592.743	1596.393
12/14/2005 5:18	1590.355	1594.005
12/14/2005 5:19	1585.961	1589.611
12/14/2005 5:20	1581.590	1585.240

5.2.4. Upper Reservoir Level Transmitter Accuracy Discussion

As discussed in chapter 5.2.3, the average upper reservoir level reading was off by at least 3.65 feet low. The estimated minimum instrument lift was at least 2.54 feet. The difference of 1.11 feet (3.65 – 2.54) is most likely attributable to additional lift. As indicated in chapter 4.6.2.3 temperature affects are unlikely.

The following chart shows the difference between the UR and PS transmitter readings in calm conditions (after an auto pump stop), the ambient air temperature and the water temperature between 3-Sep-05 and 12-Dec-05:

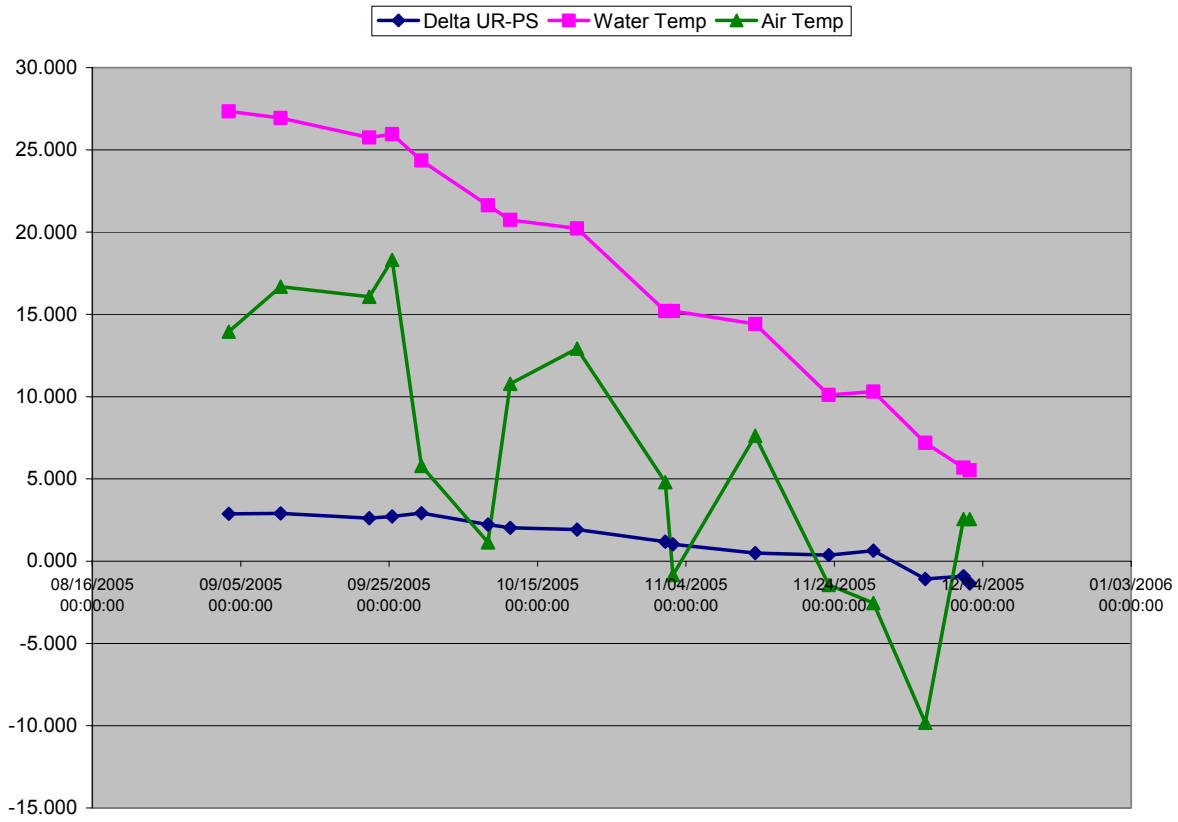


Figure 30: Transmitter Difference and Temperatures

6. Upper Reservoir Level Probe Alarm Analysis

The two level probes installed for overtopping protection generate binary signals. If both signals are active at the same time for more than 60 seconds, the Unit 1 Main PLC logic is to trip pump 1.

The following table summarizes the as-designed and as-found probe elevations as presented by Ameren on 13-Jan-06:

Probe	As-designed Elevation	As-found Elevation[5]
HI Probe	1595.9	1597.3
HI-HI Probe	1596.2	1597.7

Events generated by the HI-HI probe are displayed as an alarm on the operator screen and logged in the process data archive.

Ameren presented the following HI-HI alarm history between 1-Sep-05 and the incident date:

Number	Date	Source	Duration	UR Level
1	27-Sep-05 10:11	Osage Operator Log	Unknown	1596.062866
2	28-Sep-05 18:18:19	Process Data Archive	1 second	1543.345459
3	2-Nov-05 12:49:14	Process Data Archive	9 seconds	1578.452759

First HI-HI Alarm (on 27-Sep-05)

HI-HI Alarm number 1 could have been caused by a high level in the upper reservoir. According to the operator log, the last pumping cycle before this alarm ended on 27-Sep-05 at 05:57 with a pump auto stop[6].

The operator logs states that "*the HPT's (hydro plant technicians) are working on something @ Sauk*". In addition, the process data archive did not record values at 10:04 and 10:05. This is an indication that there could have been maintenance activities at the PLC which may have caused the alarm.

[5] Siemens calculation.
[6] The process data archive entry supports the operator log entry. During one interview, Ameren voiced the concern that all process archive data may be off by 2 hours due to a set-up problem with the historian. However the operator log entries times correlate closely with the process data archive time stamps, which suggests that the process data archive time may have been correct at least since 1-Sep-05. Another Ameren document stated that the process archive time stamping was corrected in June 2005.

Second HI-HI Alarm (on 28-Sep-05)

The reservoir level was reported as too low to support that this alarm was caused by a high water level. The operator states that Jeff Scott (Production Supervisor at the Taum Sauk plant) called the Osage control room on 17:55. It is possible that he or other people were still at work when the alarm was recorded. Ameren's report to FERC states that this alarm may haven been caused by a lightning storm which moved through the area at that time. The short duration of the alarm is consistent with this assumption. If someone would have worked on the level probes, more alarms and longer alarm durations could be expected. This HI-HI alarm is not mentioned in the operator log.

Third 3 HI-HI Alarm (on 2-Nov-05)

Again, the reservoir level was reported to be too low to support that this alarm was caused by a high water level. The operator log states that the units were taken offline to support a diver. According to Ameren personnel the diver was working on the lower reservoir, not the upper reservoir. As of this writing, Siemens has no explanation for this alarm.

This HI-HI alarm is not mentioned in the operator log.

7. Fault Tree Analysis

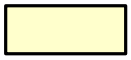
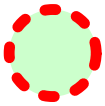
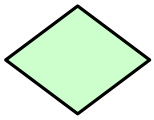
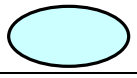
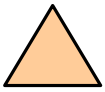
The fault tree analysis tool was used to perform the potential cause investigation. This tool allows a top down approach to find possible root causes for the incident. The root event is the fact that the dam was breached. As a first refinement step, a possible weakness of the dam structure and the possibility of an overspill are considered. Then possible causes for a weakness of the structure and the overspill are considered.

This process of finding possible causes for events stops when one of the following criteria is met:

- The possible cause analysis is covered in a different report (e.g. the dam structure analysis is covered in a report submitted by Paul C. Rizzo Associates)
- The possible cause would not contribute to the event analyzed (e.g. a transmitter malfunction of the tailrace level transmitter would not cause the pumps to stop)
- There is insufficient information to determine whether the possible cause was contributing to the event or not (e.g. events generated by the HI level probe were not stored in the process data archive)
- It is known that the possible cause did not contribute to the event (e.g. it is known that all three upper reservoir transmitters were powered and communicating since they continued to transmit data throughout the event)
- The search for possible causes becomes trivial (e.g. was water in the reservoir when the dam breached).

7.1. Fault Tree Symbols

The following symbols were used in the fault trees:

Fault Tree Analysis Symbol	Explanation
	Intermediate Event: Used to specify a failure event that occurs due to one or more causes acting through logic gates below it in the fault tree.
	Basic Initiating Event: Used to specify a failure event that does not require any further development i.e. it is a “leaf” of the fault tree and has no gates or events below it in the tree.
	Basic initiating Event which may have contributed to the failure with a high likelihood > 50%.
	Basic initiating Event which may have contributed to the failure with a lower likelihood ≤ 50%.
	Undeveloped Event: Used to specify a failure event that is not developed as far as it could be, either because the event is of no importance in this fault tree, or because there is not enough information available.
	Conditioning Event: Used to specify certain conditions upon any logic gate.
	And Gate: Used to show that the output fault will only happen if all of the inputs occur.
	Or Gate: Used to show that the output fault will only occur if one or more of the input faults take place.
	Not Gate: The output is true if the input is false and vice versa.
	Transfer symbol: Link to another fault tree diagram.

7.2. Fault Trees

7.2.1. Fault tree 1: Potential Causes for the Dam Breach

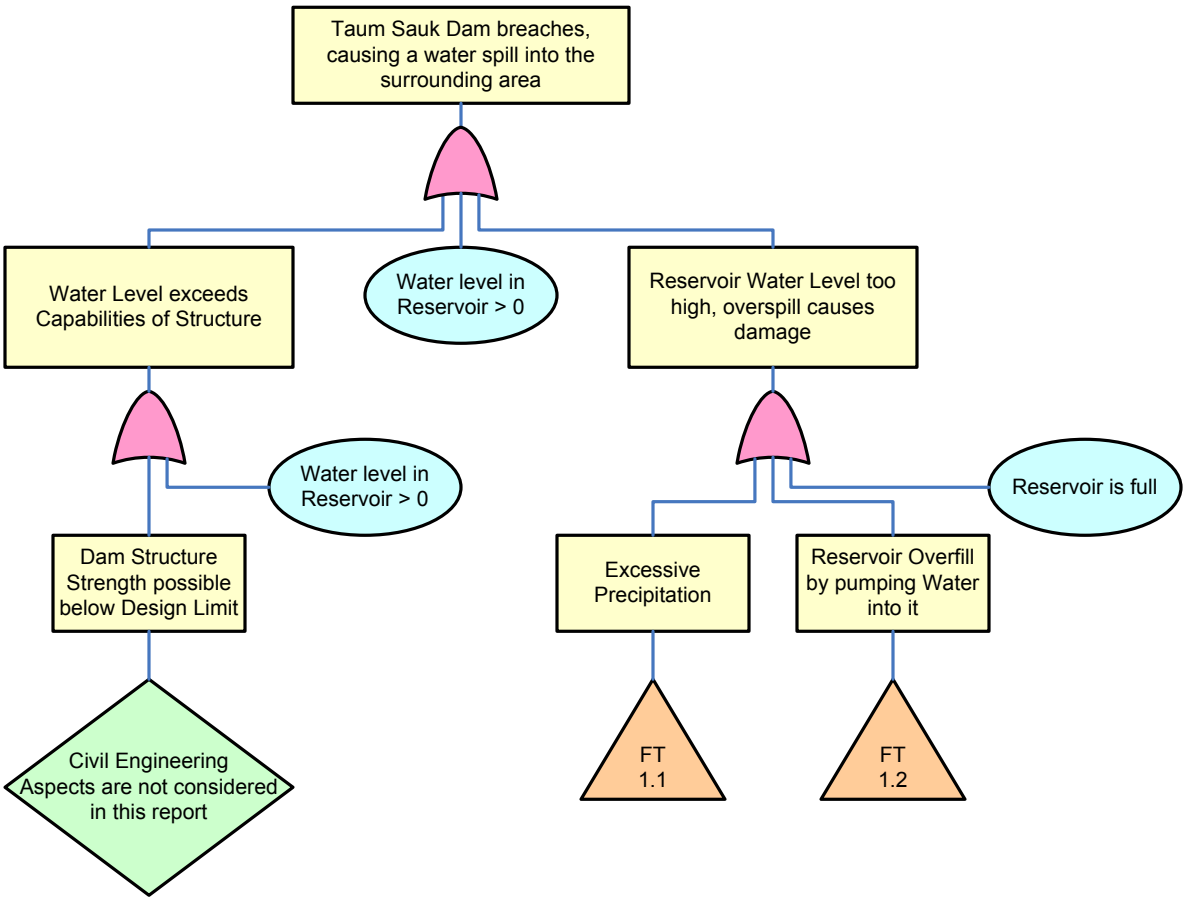


Figure 31: Fault Tree 1: Possible Causes for Dam Breach

The dam breach could have been caused either by a normal water level and a weakened dam structure or by water overspill which subsequently caused damage to the dam structure. The overspill could have been caused by precipitation or by pumping water into the reservoir. Since the dam structure analysis is covered by a separate report, this possibility is not explored further.

7.2.2. Fault Tree 1.1: Excessive Precipitation

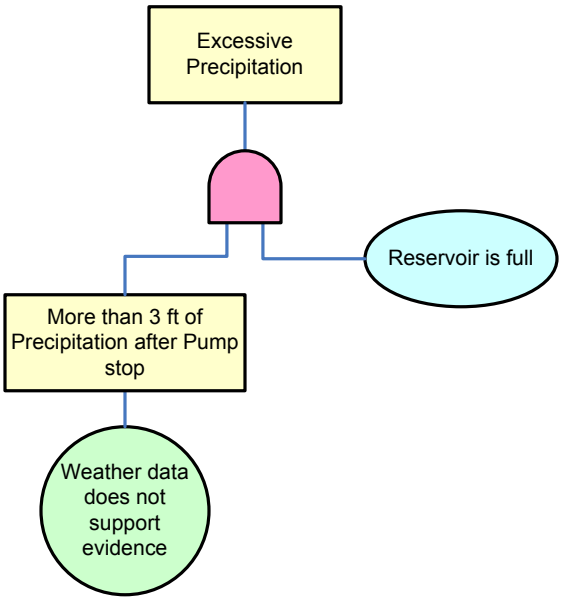


Figure 32: Fault Tree 1.1: Excessive Precipitation

Excessive precipitation may cause an overspill if it amounts to 3 feet after the auto-stop of the last pump which occurs at 1594[7] feet (the lowest wall elevation is 1597 feet). However, the weather data reviewed by Siemens does not support this possible cause.

[7] This was the auto-stop setpoint at 14-Dec-05.

7.2.3. Fault Tree 1.2: Reservoir Overfill by Pumping Water

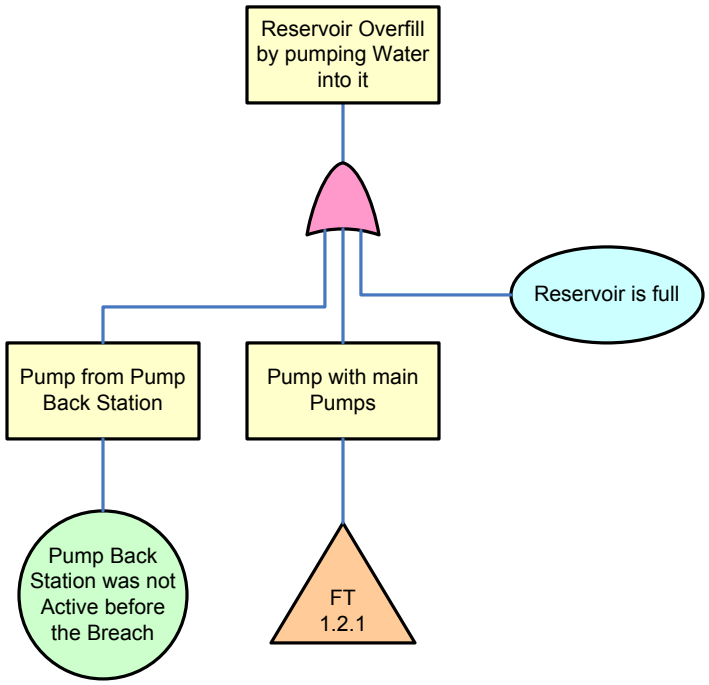


Figure 33: Fault Tree 1.2: Reservoir Overfill by Pumping Water

The reservoir can be filled by two independent pumping systems: The main pumps and a small pump-back pump. The main pumps are used to pump the water from the lower reservoir into the upper reservoir.

Since the upper reservoir was reported by Ameren to be leaking water at a small rate, the leakage water was collected in a small pond close to the UR. If the water level in that pond rises to a predefined level, it is to trigger a limit switch which causes the pump-back pump to start. The small size of the pump and the fact that it does not appear to have been running during the incident suggests that it did not contribute to the overfilling.

7.2.4. Fault Tree 1.2.1: Pump with main Pumps

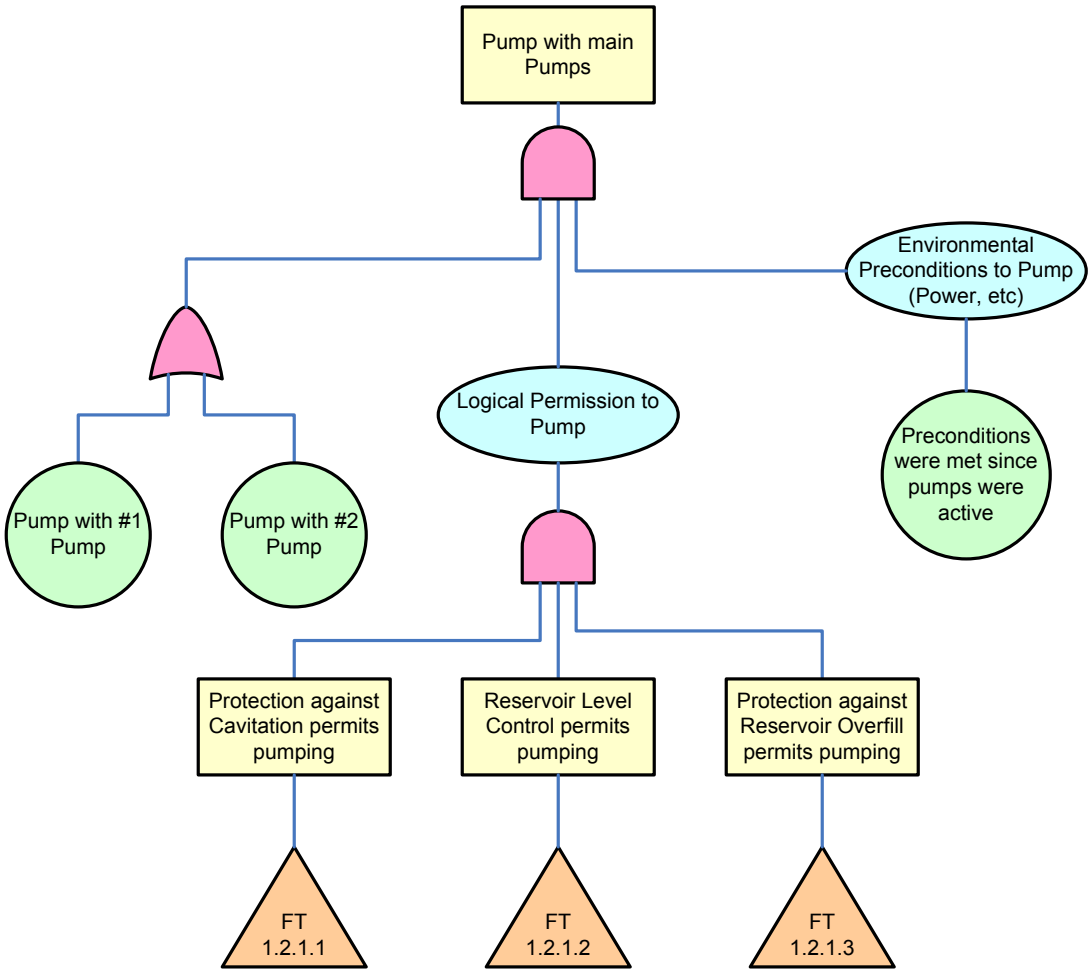


Figure 34: Fault Tree 1.2.1: Pump with Main Pumps

Certain environmental preconditions and permissions need to be met to enable the pumps to continue to operate. Start permissions for the pumps are not considered further since the data reviewed by Siemens suggests that the pumps were running throughout the incident.

To enhance readability, the permissions for the two pumps are analyzed in parallel. It has been discussed in this report that the pump trip logic for pump 2 may have been disabled due a programming issue. However, Siemens believes that this programming issue did not contribute adversely to the incident since pump 2 was to be stopped automatically by level control.

7.2.5. Fault Tree 1.2.1.1: Protection against Cavitation

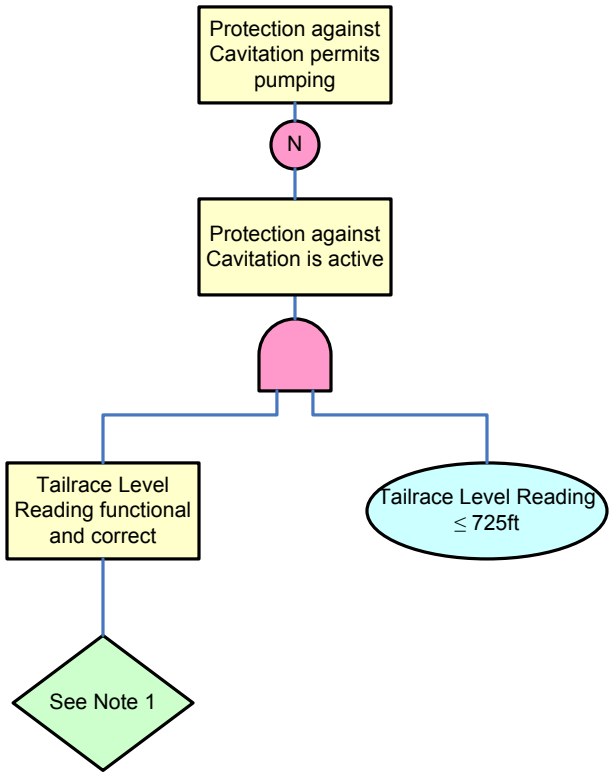


Figure 35: Fault Tree 1.2.1.1: Protection against Cavitation

Notes:

1	An incorrect tailrace reading by itself should not *cause* an overspill. An incorrect tailrace reading should only prevent an overspill if it fails low (≤ 725). The process data archive suggests a functional transmitter during the incident. A correct tailrace reading should not prevent an overspill if there is sufficient water in the tailrace.

Since Siemens believes that a wrong tail race reading would not be the root cause for an overspill, it is not considered any further.

7.2.6. Fault Tree 1.2.1.2: Level Control

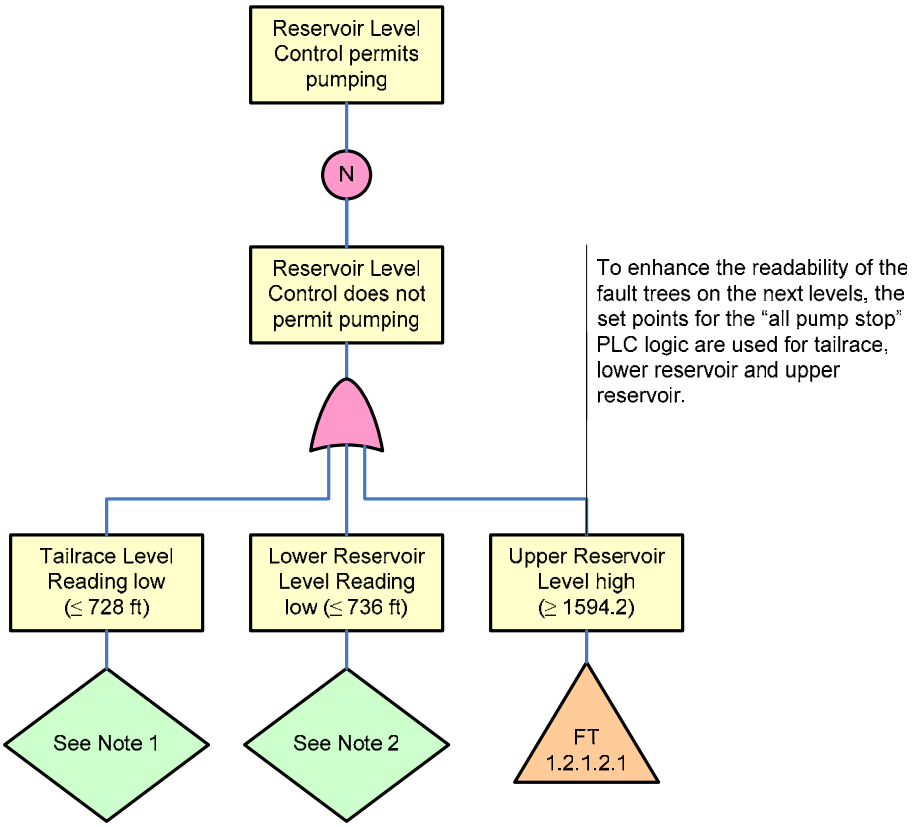


Figure 36: Fault Tree 1.2.1.2: Level Control

Notes

1	An incorrect tailrace reading by itself should not *cause* an overspill. An incorrect tailrace reading should only prevent an overspill if it fails low (≤ 725). The process data archive suggests a functional transmitter during the incident. A correct tailrace reading should not prevent an overspill if there is sufficient water in the tailrace
2	See tailrace transmitter discussion above. The same applies to the lower reservoir transmitters

Since Siemens believes that a wrong tail race or lower reservoir level reading would not be the root cause for an overspill, it is not considered any further.

7.2.7. Fault Tree 1.2.1.2.1: Upper Reservoir Level Control

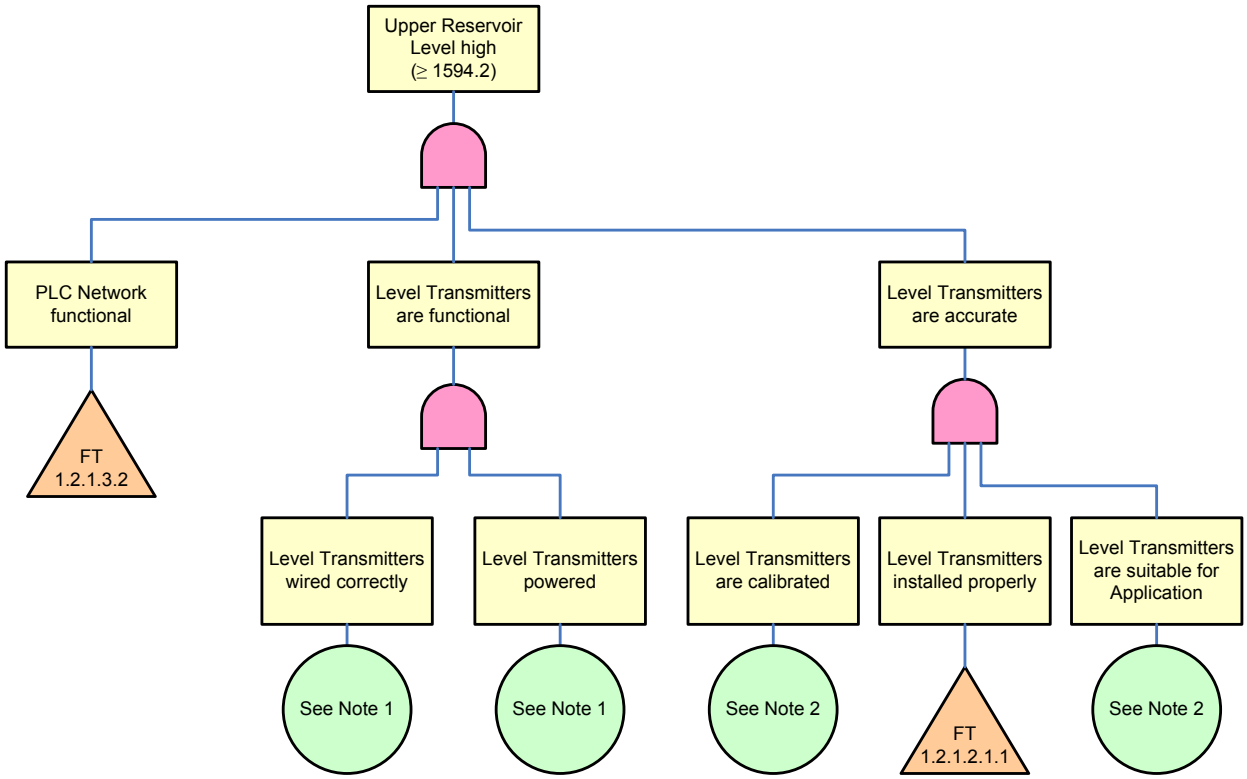


Figure 37: Fault Tree 1.2.1.2.1: Upper Reservoir Level Control

Notes

1	The transmitters were apparently accessible from the PLC system throughout the incident and the readings correlate with the physical events observed.
2	Testing of the transmitters at the manufacturer's facility demonstrated that the transmitters were sufficiently calibrated and suitable for this application (see chapter 4.6.2.3). The temperature sensitivity of TX2 did not contribute adversely to the event.

7.2.8. Fault Tree 1.2.1.2.1.1 Level Transmitters Installation

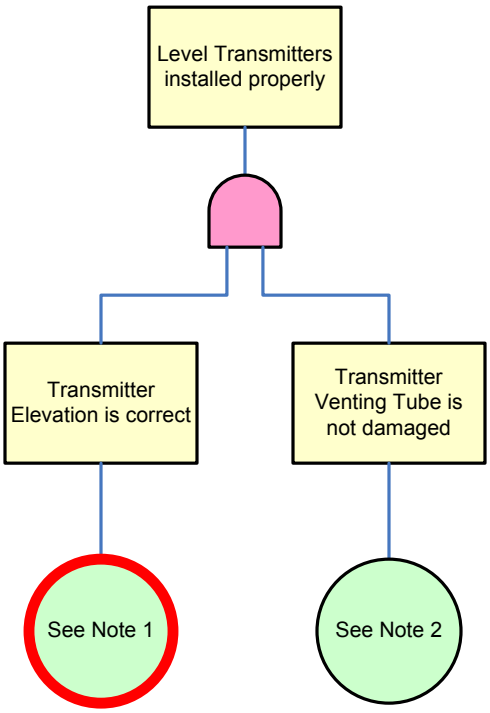


Figure 38: Fault Tree 1.2.1.2.1.1: Level Transmitter Installation

Notes:

1	The bow in the instrument pipe caused a shift in the elevation of the level transmitters. The transmitters were moved up, causing a reduction of the water level above them. Therefore the measured water level was likely too low. See also the pipe bow discussion in chapter 4.6.2.2.
2	The barometric air pressure was compared with level transmitter measurements. At stable plant conditions changes of the barometric pressure did not affect the level measurement of the upper reservoir. Therefore, Siemens assumes that the venting tube was not damaged.

7.2.9. Fault Tree 1.2.1.3: Level Protection

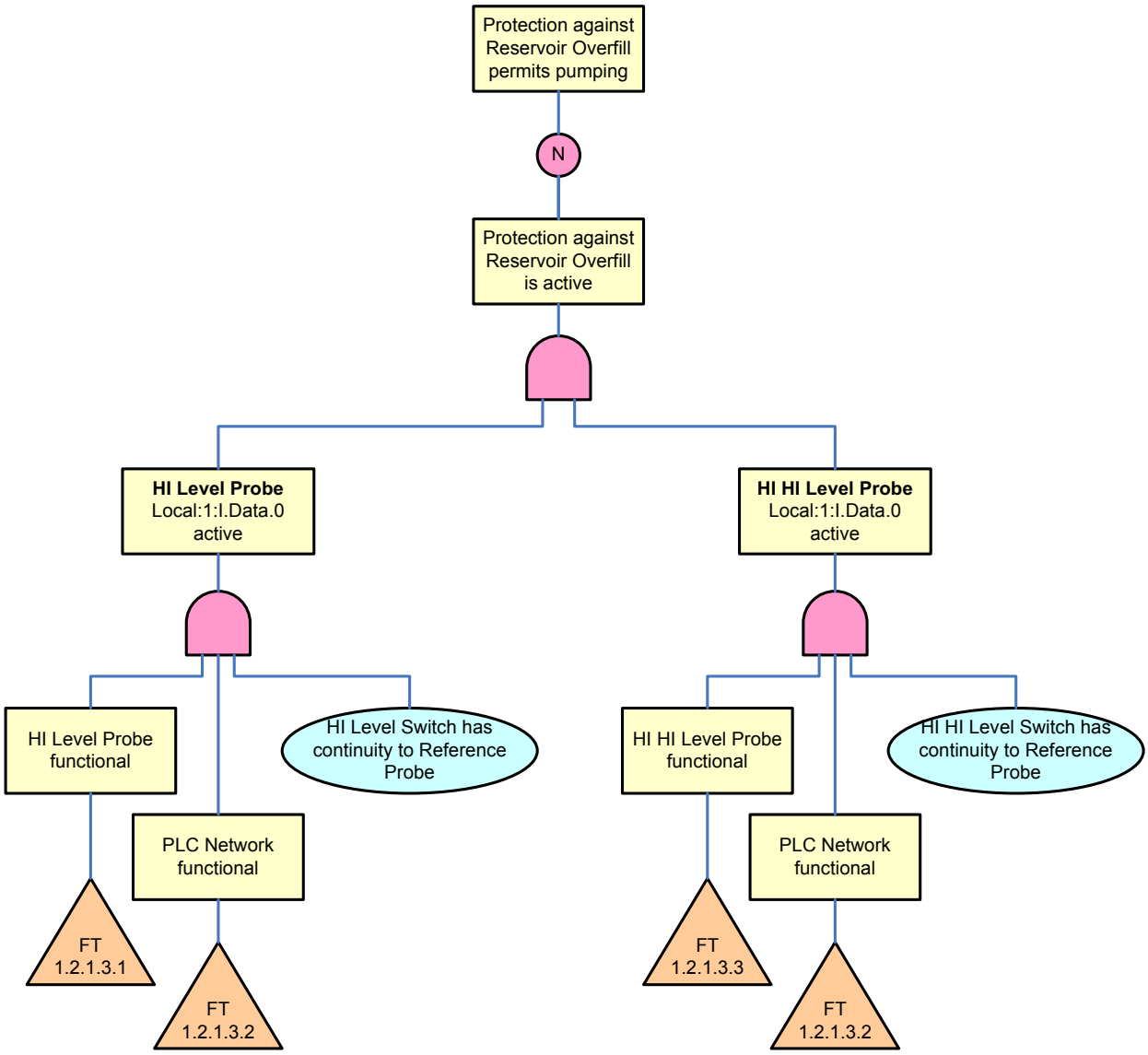


Figure 39: Fault Tree 1.2.1.3: Level Protection

In the as-found logic, the protection against overfill requires the HI and the HI-HI probe to become active. The probes can only become active if they are functional. In addition, the probe signals are processed properly only if the PLCs and the network are operational.

7.2.10. Fault Tree 1.2.1.3.1-3 Level Probe functional

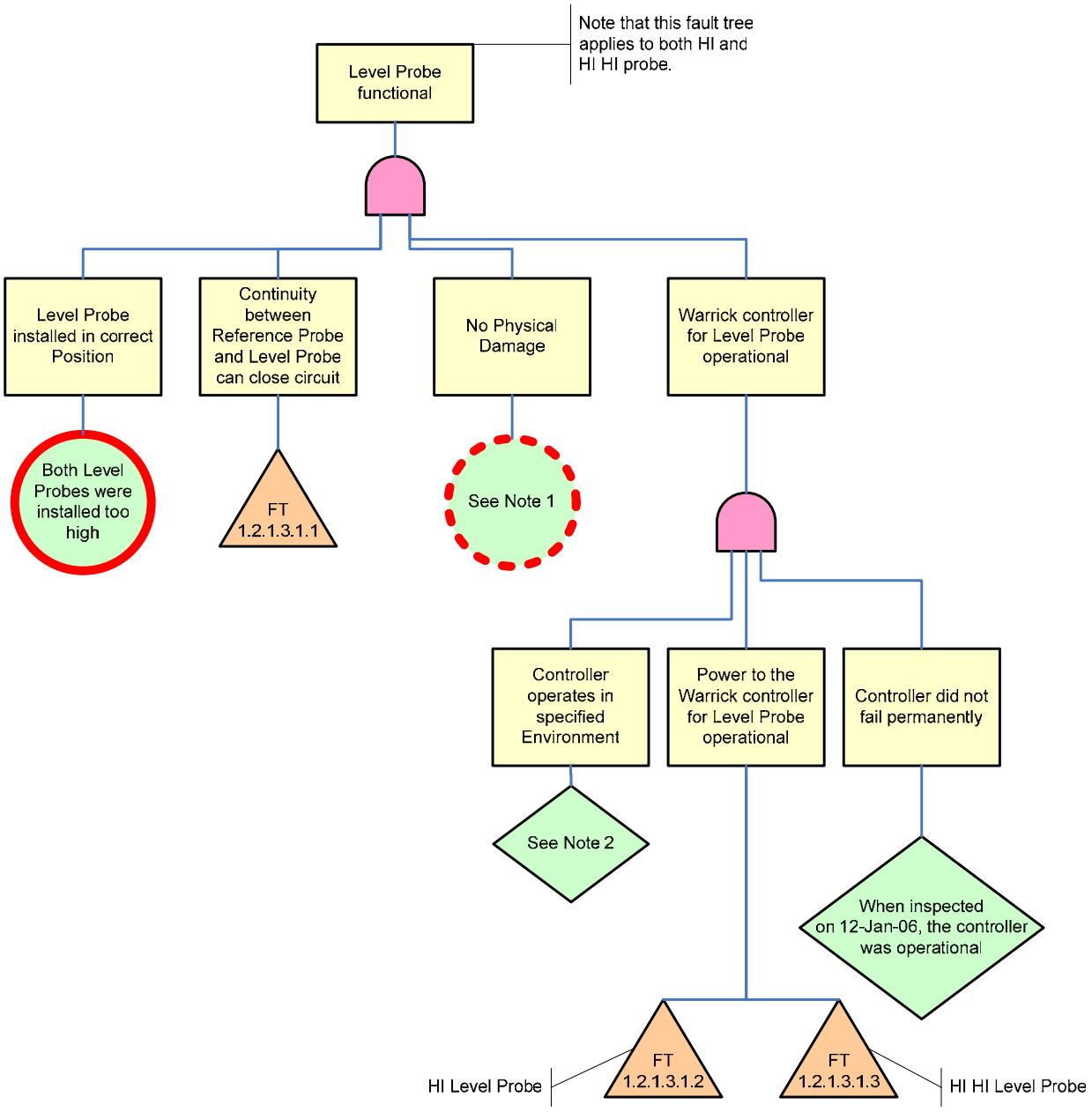


Figure 40: Fault Tree 1.2.1.3.1-3 Level Probe functional

Notes

1	Although the probes did not show substantial physical damage when inspected on 12-Jan-06, minor rust observed on the reference probe may have affected continuity. However, when tested on 2-Feb-06, the probes were operational.
2	Controller was installed in a controlled but unmonitored environment. No PLC components were believed by Siemens to have failed in the UR gauge house during the event

This fault tree applies to both the HI and the HI-HI level probes since they are of the same design. It is known that the level probes were installed too high which effectively disabled them.

7.2.11. Fault Tree 1.2.1.3.1.1: Continuity between the Signal Probe and the Reference Probe

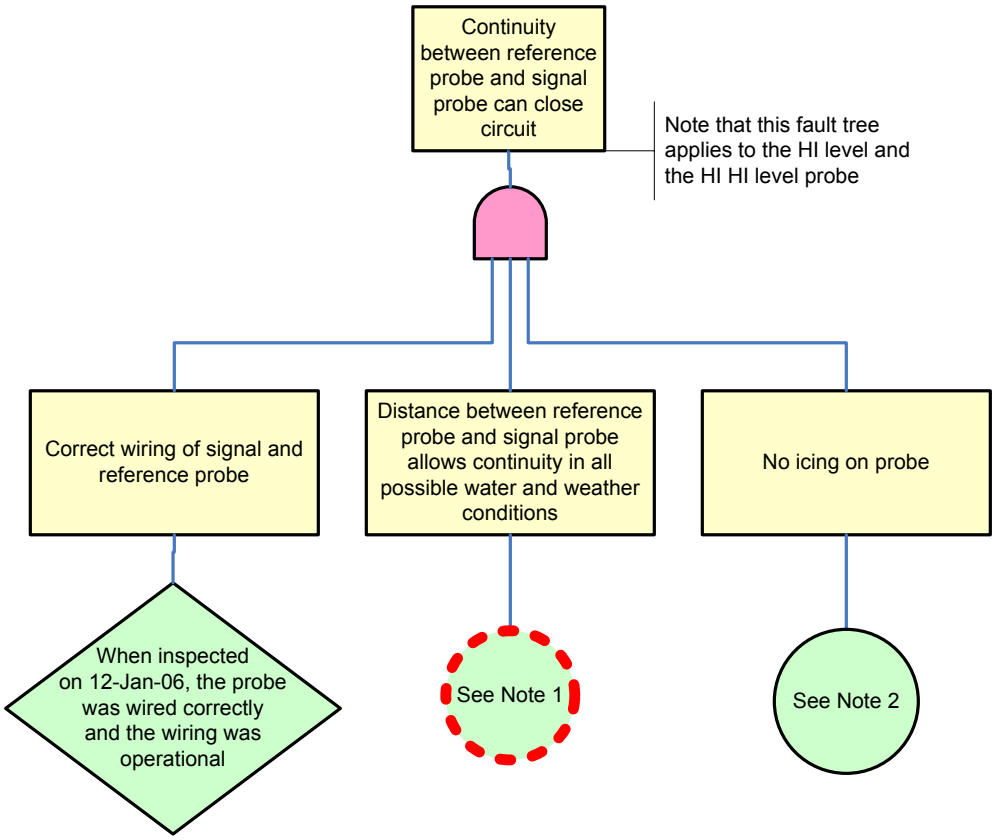


Figure 41: Fault Tree 1.2.1.3.1.1: Continuity between the Signal Probe and the Reference Probe

Notes:

1	The manufacturer (Tom James on 1/27/06) stated that the recommended maximum distance between the reference and the signal probe is 4 feet. However, when tested by Siemens and Ameren on 2-Feb-06, probes had continuity of up to 200 feet As installed, the probes were not only depending on the continuity of the water. The stainless steel cable and the ladder provided additional continuity.
2	The weather data suggests that icing may have occurred with a very small likelihood.

This fault tree applies to the HI and HI-HI level probes since they are of the same design. There is a very small likelihood of icing due to weather conditions[8] before the event. However, it is unlikely that the icing may have built up due to pumping activity and contributed adversely to the continuity.

[8] Reported arial temperatures below the freezing point at the power house between 03:00am and 05:00am at the day of the incident.

7.2.12. Fault Tree 1.2.1.3.1.2: Power to HI Level Probe operational

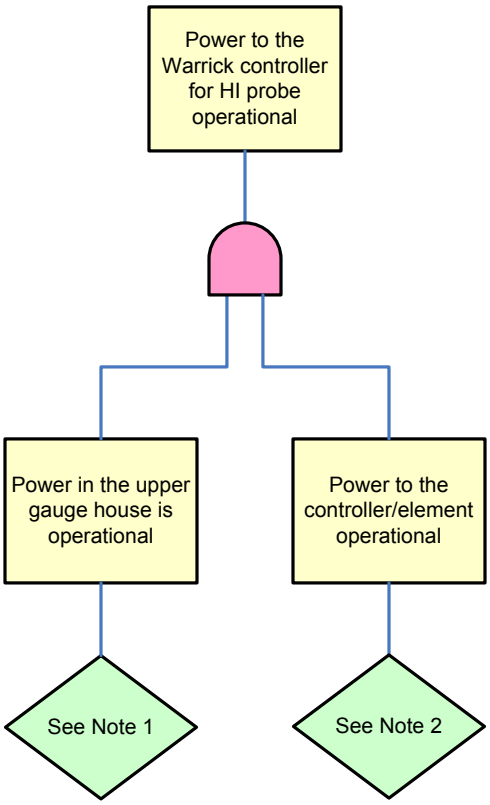


Figure 42: Fault Tree 1.2.1.3.1.2: Power to HI Level Probe operational

Notes

1	There was no UPS alarm and the PLC appears to have been operational during the event. Therefore Siemens assumes that the power in the upper gauge house was operational.
2	A failure of power would not be detected by the system or the operators. However, Ameren checked the circuit after the event and determined that the circuit was operational.

7.2.13. Fault Tree 1.2.1.3.1.3: Power to HI-HI Level Probe operational

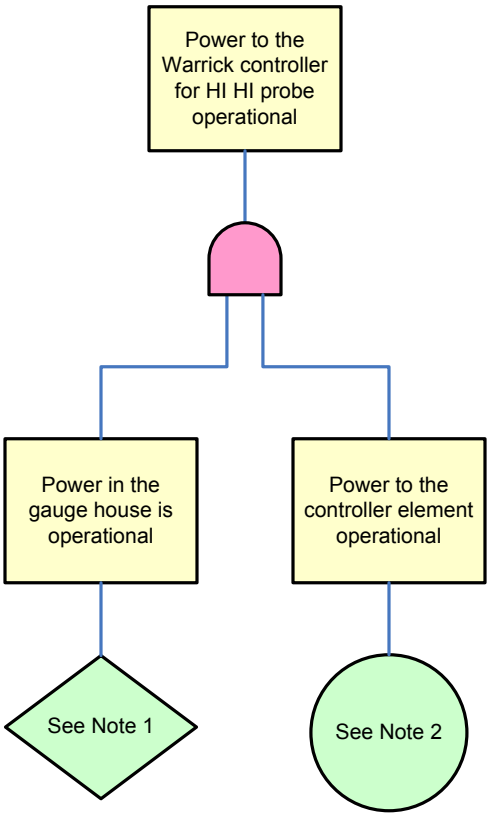


Figure 43: Fault Tree 1.2.1.3.1.3: Power to HI-HI Level Probe operational

Notes:

1	There was no UPS alarm and the PLC was operational during the event. Therefore, Siemens assumes that the power in the upper gauge house was operational.
2	A failure of power should cause a LO-LO alarm since both contacts are supplied by the same power source. That LO-LO alarm was not observed.

7.2.14. Fault Tree 1.2.1.3.2: PLC Network Functional

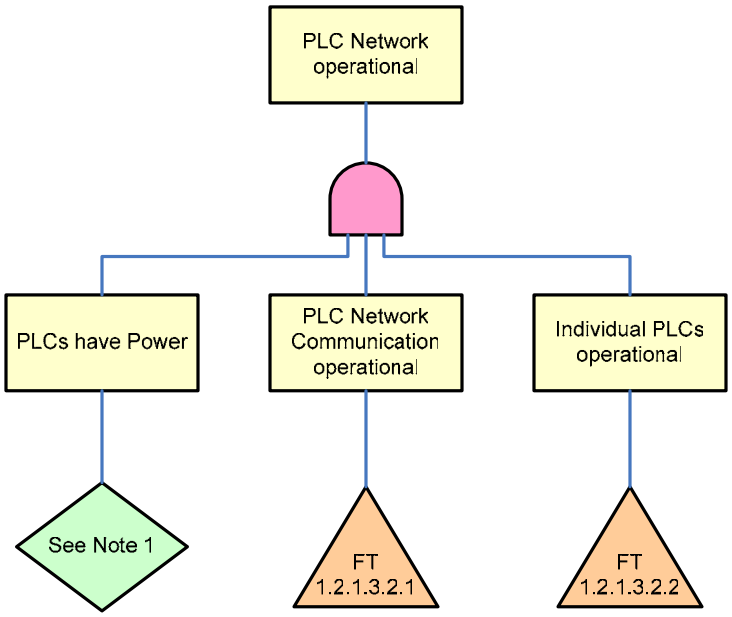


Figure 44: Fault Tree: 1.2.1.3.2 PLC Network Functional

Notes

1	Since all PLCs appear to have been communicating with WonderWare throughout the incident, it can be assumed that they had power.

The availability of power, network communication and the operational status of the individual PLCs are preconditions for the PLC network operation.

7.2.15. Fault Tree 1.2.1.3.2.1: PLC Network Communication

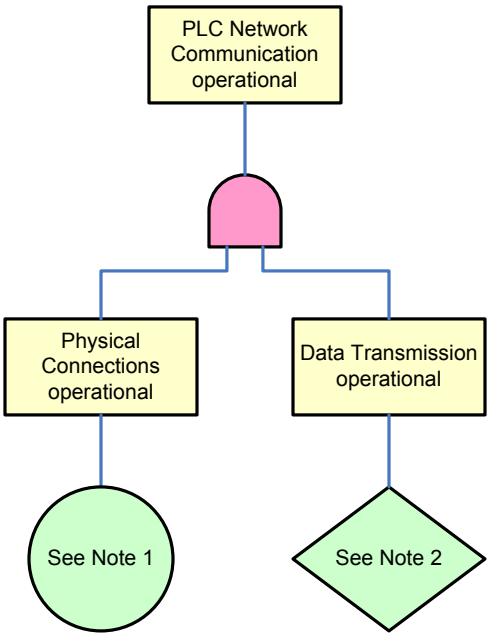


Figure 45: Fault Tree 1.2.1.3.2.1: PLC Network Communication

Notes

1	Physical Network errors are to be detected and generate an alarm. No such alarms were reviewed by Siemens as recorded at the day of the incident.
2	According to Ameren, the last PLC program change before the incident was performed on 7-Dec-05. Since that date, several auto pump stops were performed by the system. This suggests that the PLCs were transmitting data between each other. Since there were no active physical network alarms reported on the data historian at the day of the incident, Siemens assumes that the PLCs were transmitting data throughout the incident. The communication with the Wonderware data process archive also appears to have been operational throughout the day of the incident.

7.2.16. Fault tree 1.2.1.3.2.2: Individual PLC Status

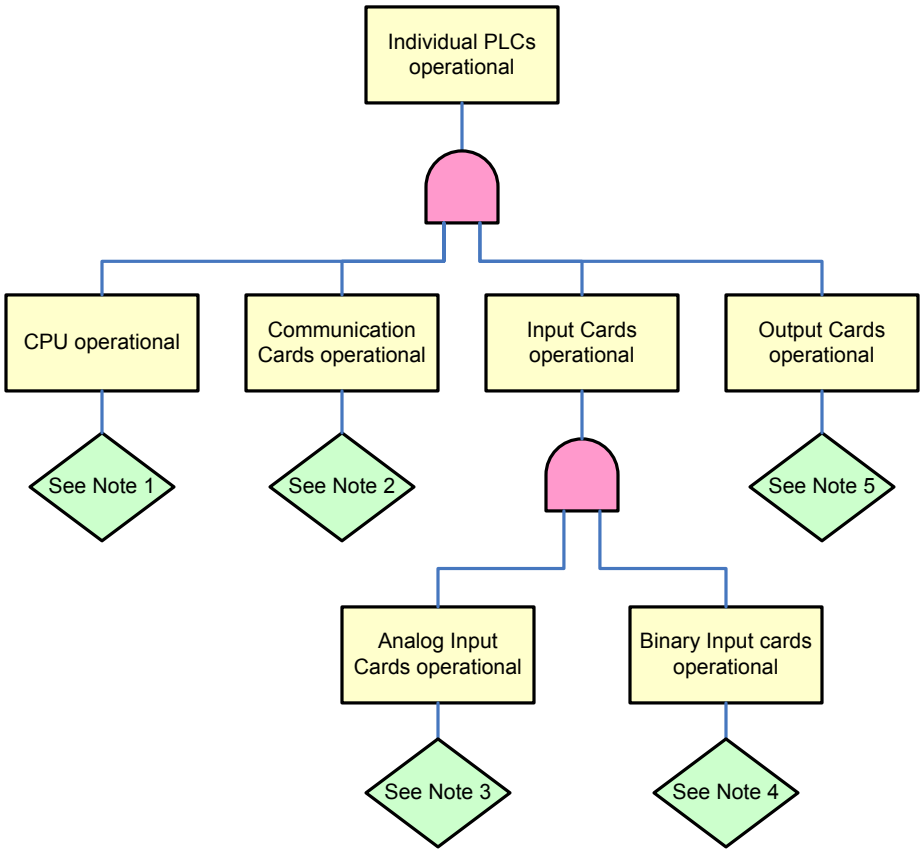


Figure 46: Fault tree 1.2.1.3.2.2: Individual PLC Status

Notes

1	The PLCs appear to have been in communication with the Wonderware process data archive throughout the event. Therefore, Siemens assumes that the CPUs were functional.
2	The PLCs appear to have been in communication with the Wonderware process data archive throughout the event. Therefore Siemens assumes that the communication cards were functional.
3	There is small likelihood that the analog input cards may have contributed to the level transmitter inaccuracy. However, according to the manufacturer's documentation and the fact that the building was thermostatically heated, and calculations performed by Siemens based upon the information reviewed, analog input inaccuracy may cause a variation of 1"-3" of water level.
4	Results of the testing of the level probes after the incident suggest that the binary input cards were operational.
5	It can not be determined whether the output cards on all PLCs were operational at the time of the incident. When tested on 2-Feb-06, the output cards appeared to be operational.

The active communication link to the Wonderware process data archive is consistent with the main PLC components (CPU & communication cards) being operational.

The analog input cards appeared to be transmitting data at the time of the event, which suggests those were operational.

The binary input cards were tested after the incident and the testing suggests that these were operational.

Analyzing the output cards would not contribute to this root cause analysis since the PLC logic would not have attempted to activate the necessary outputs to stop the pumps. Testing performed after the event suggests that the cards were operational on 2-Feb-06.

8. High Level Failure Mode Effects Analysis

The following table shows a high level failure mode effects analysis for the level control and level protection system for the upper reservoir.

Failure	Operator Alarm	Operator Indication	Loss of UR Level Protection	Loss of UR Level Control
PLC Network				
UR PLC Failure	Yes	Yes	Yes	Yes
Common PLC Failure	Yes	Yes	Yes	Yes
Unit 1 PLC Failure[9]	Yes	Yes	Yes	Yes
Unit 2 PLC Failure	Yes	Yes	Yes	Yes
Network Failure between PLCs	Yes	Yes	Yes	Yes
Network Failure to HMI	Yes	Yes	No	No
Power				
Power Failure in UR Gauge House for more than 8 hours.	Yes	Yes	Yes	Yes
Power failure in LR PLC House	Yes	Yes	No	No
Instrumentation				
Complete Loss of one Level Transmitter	No	No	No	No
Complete Loss of two Level Transmitters	No	Yes[10]	No	Yes[11]
Complete Loss of all three Level Transmitters	No	Yes	No	Yes
Complete loss of one Level Probe (HI or HI-HI)	No	No	Yes	No
Complete loss of both Level Probes	No	No	Yes	No
Loss of accuracy and repeatability of level transmitters	No	No	No	Yes
Elevation of Level Probes too high	No	No	Yes	No

[9] The Unit 1 and Unit 2 Main PLCs are redundant.
[10] If the two transmitters used in level control failed.
[11] Only two of the three installed level transmitters were used, the signal of the third transmitter was disabled in the PLC logic.

9. Conclusion

The evidence reviewed by Siemens between 9-Jan-06 and 24-Mar-06 is consistent with a conclusion that the reservoir overspill was caused by failure of the upper reservoir level protection system and inaccurate readings within the level control system.

The level protection system was effectively disabled because the level probes were located in a position too high to sense water during the event (see chapter 4.6.3.2).

The level control system lost accuracy because of the shift of the instrumentation pipes causing a change of the instrument elevation.

No evidence of a hardware failure in the PLC network system or in the wide area network was observed.

There was also no evidence of an operator error observed. The pumping cycles vary greatly depending on the initial reservoir water level, equipment availability and energy demand. The operators had no visual contact with the upper reservoir and had to rely on the information presented by the control system and its control and protection features.

10. References

No	Title
1	Process data archive
2	Ameren's report to FERC submitted on 27-Jan-06
3	IMG013196 - Side Slope Relining Details III drawing 8304-X-155099 r5
4	IMG059025 – Taum Sauk Upper Reservoir Crest Survey Data
5	IMG059220- Interconnection Diagram Level Controls Upper Reservoir & Lower Dam drawing 8303-X-26348 r8
6	IMG069851 - 15-Dec-05 photos of the instrumentation pipes
7	IMG069852 - 16-Dec-05 photos of the instrumentation pipes
8	IMG082735 - Schematic Diagram Upper Reservoir level drawing 8303-P-26648 r15
9	IMG089629.01 – Level Instrument information
10	IMG089630-089631 & other GE Druck cutsheets
11	IMG121866 - Sketch SB1306-3 Gage Pipe Supports As Constructed
12	photo 15-Nov-04 of the as-installed pipe installation
13	photo 16-Dec-2005 of cable hanging technique in upper reservoir instrument box
14	photo 15-Dec-05 of transmitter cable air tube ends
15	Compact I/O Analog Module User Manual, Allen Bradley Publication 1769-UM002B-EN-P - July 2005