Taum Sauk Upper Reservoir Failure

Report

On

Technical Reasons for the Breach

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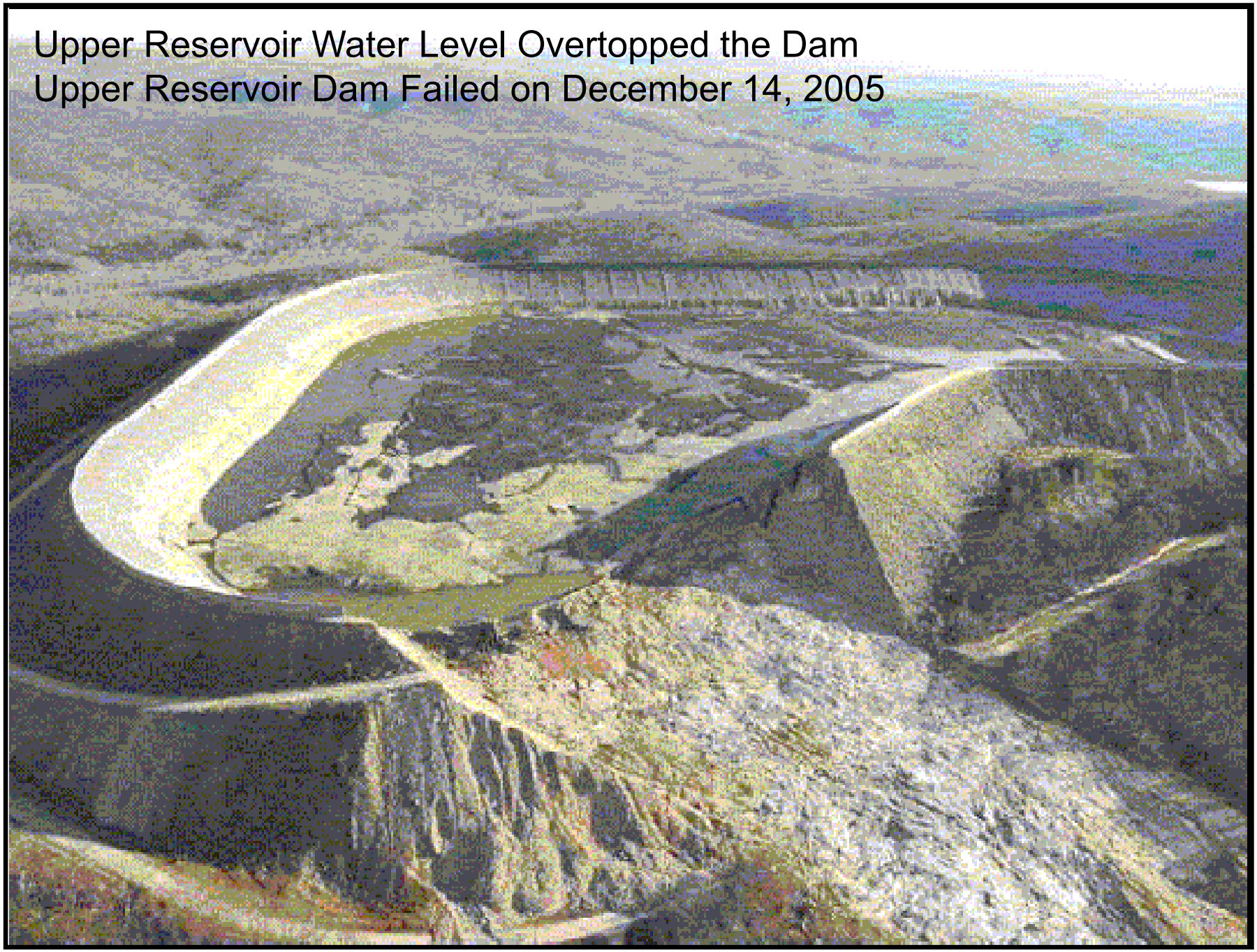
Taum Sauk – Upper Reservoir Full

Project Description

- 450 MW Pumped Storage Project
- Located in Reynolds County, Missouri
- One of the First PSP, Started in 1963
- Licensed by FPC in August 1965
- Owned and Operated by AmerenUE
- Upper Dam is a Continuous Hilltop Dike 6,562 Ft. Long
- Upper Reservoir Water Level Overtopped the Dam
- Upper Reservoir Dam Failed on December 14, 2005

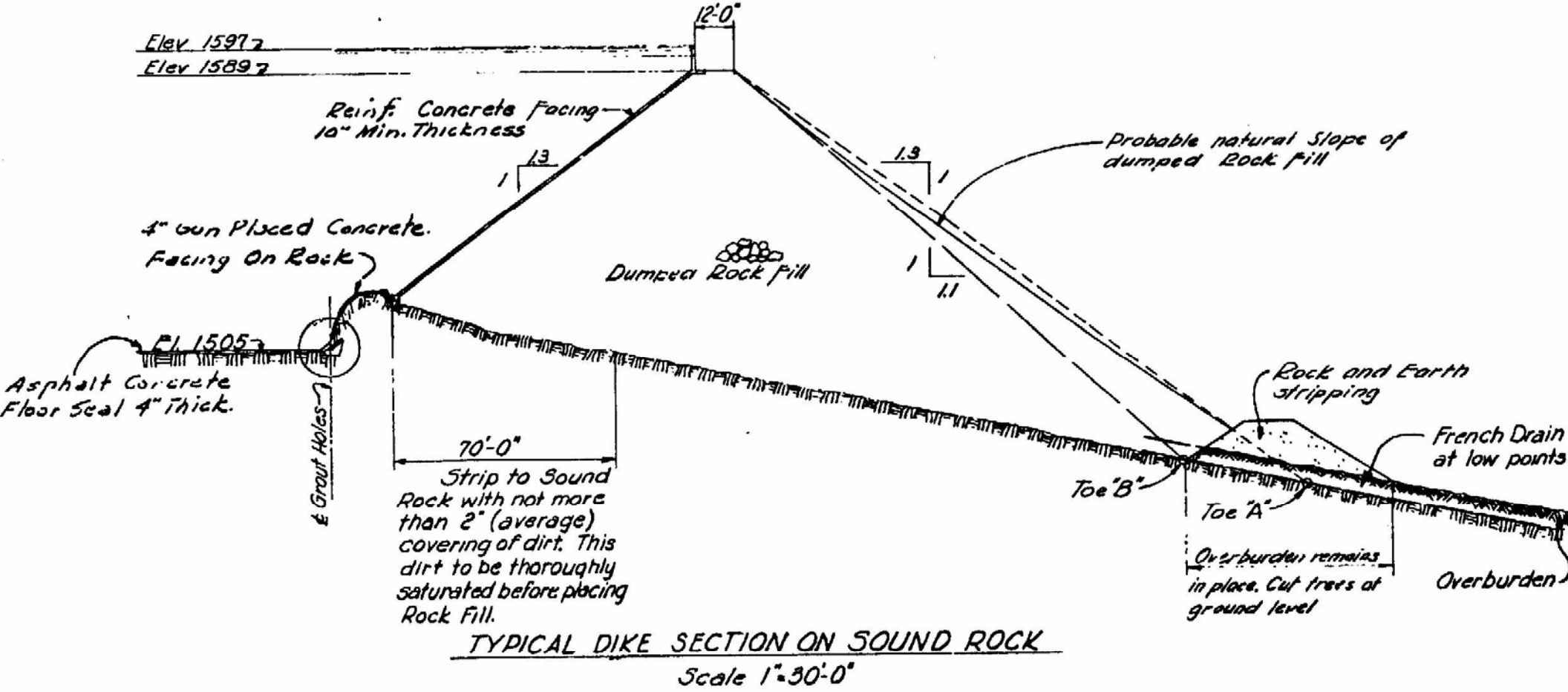


Taum Sauk Upper Reservoir Breached

Scope of Investigations

- Review the operational characteristics of the project including the overpumping protective systems leading up to the breach of the upper reservoir
- Perform a forensic evaluation of the breach of the upper reservoir dam to determine the specific failure mode
- Submit a final report documenting the results of their forensic findings on the cause of the breach of the upper reservoir

Upper Reservoir Cross-Section



TYPICAL DIKE SECTION ON SOUND ROCK

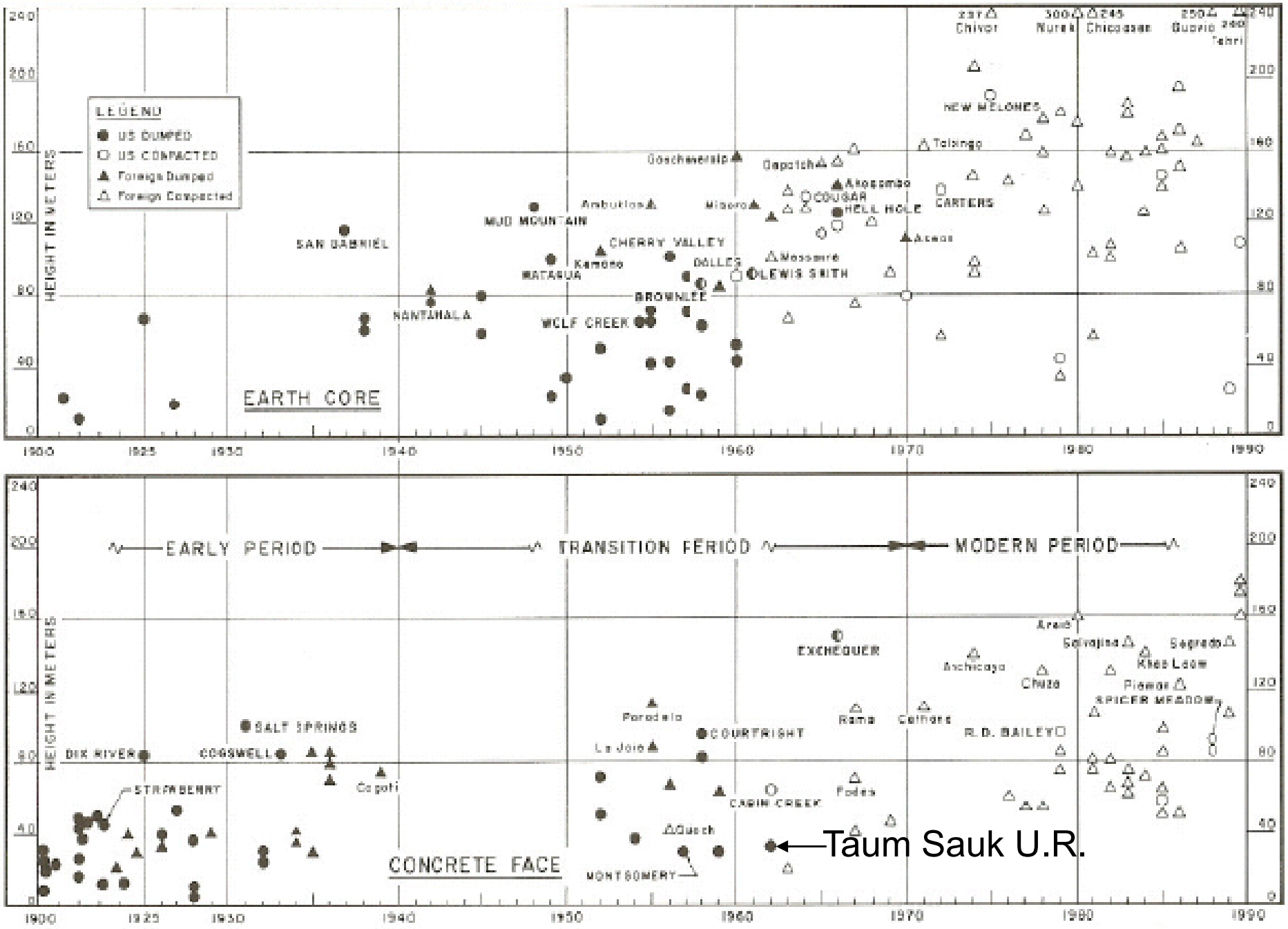
Scale 1"=30'-0"

Upper Reservoir Characteristics

- Dumped and Sluced Rockfill
- Upstream Reinforced Concrete Lining
- Parapet Wall Placed atop the Rockfill Dam
- Underdrainage Concerns Upon First Filling
- Continued High Levels of Leakage Through Dam
- Large Settlements and Movements of Dam and Wall
- Relining in 2004 to Reduce Seepage
- Revised Water Level Instrumentation in 2004

Design and Construction History

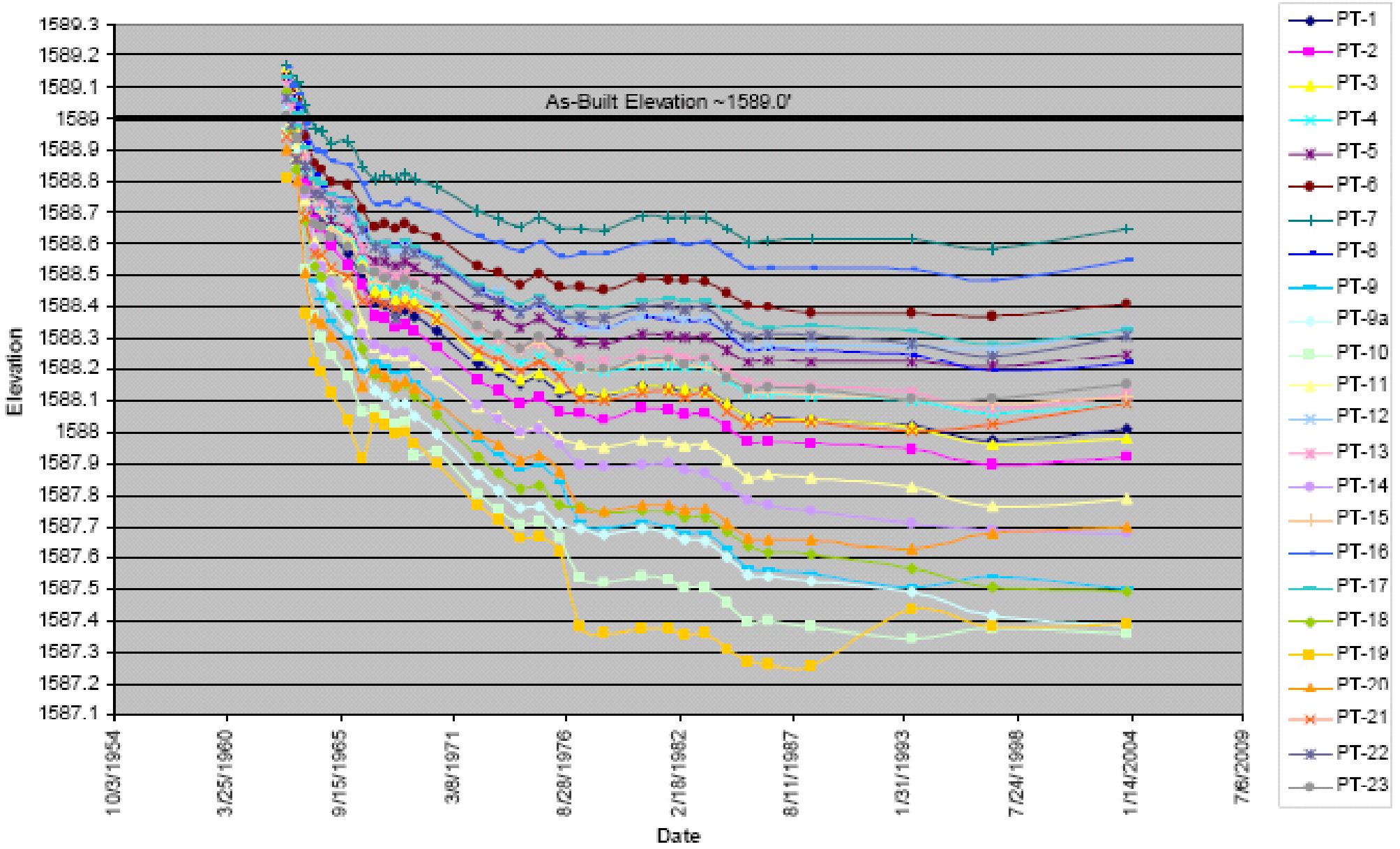
- Comments on Design:
  - Early CFRD Type Dams had Poor Performance
  - Evolution of Design for CFRD Type Dams



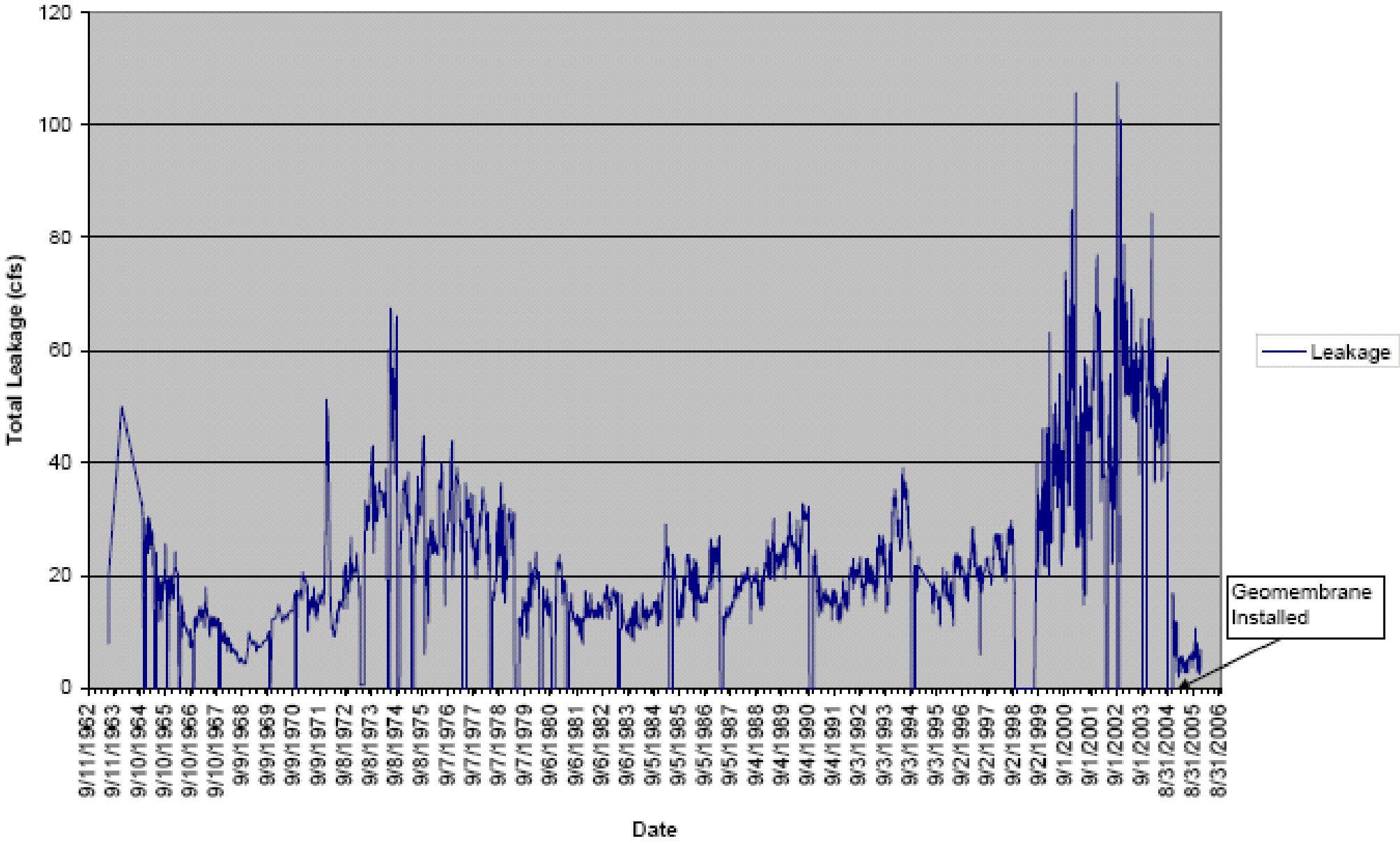
Trends in Type and Height of Rockfill Dams

Design and Construction History

- Comments on Performance
  - Early Indications of High Leakage and Settlement
  - Emergency Repairs Along NW Side in 1963-64
  - Long History of Leakage and Deformation



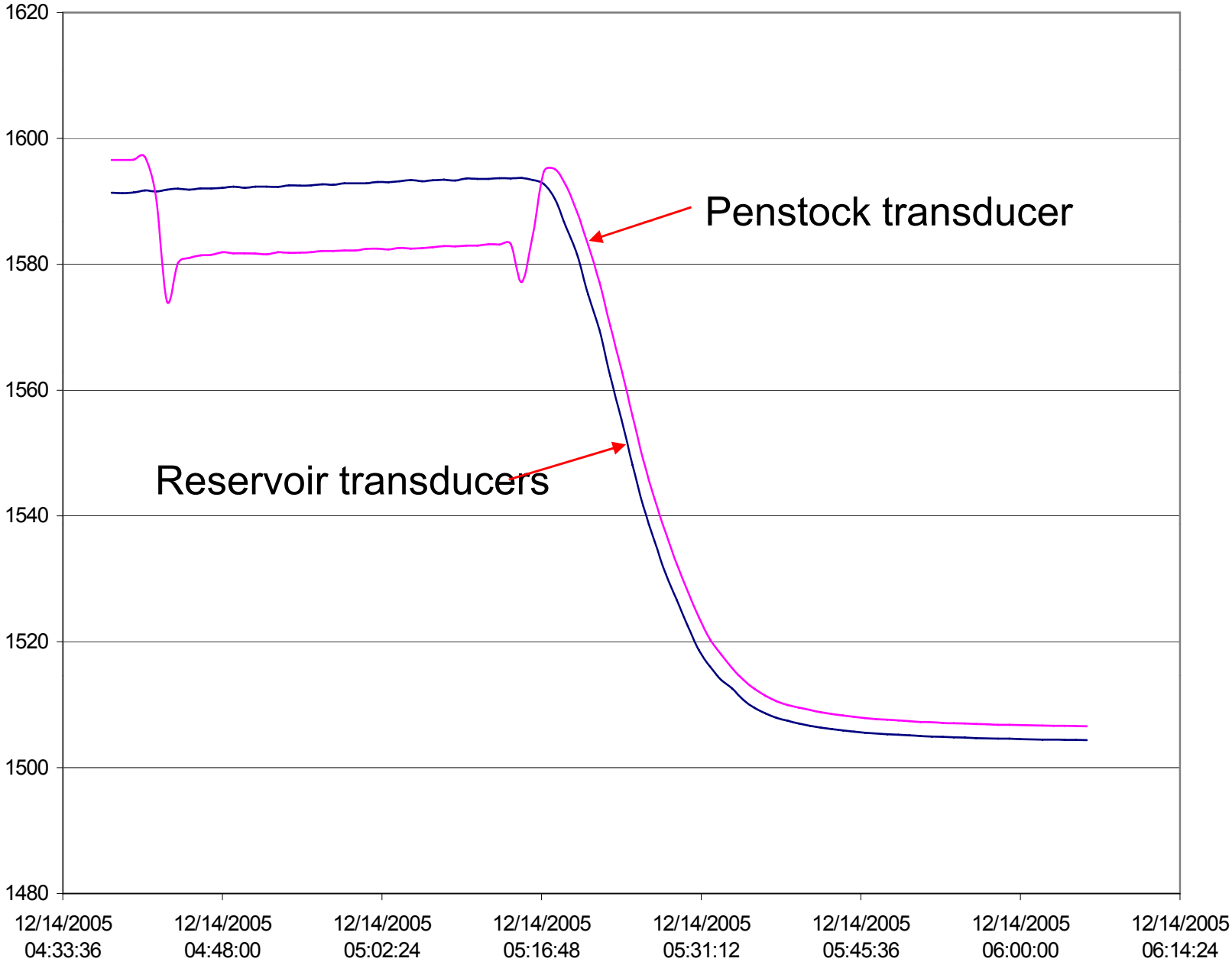
Total Settlement History



Total Leakage (cfs) vs Time

Forensic Investigation

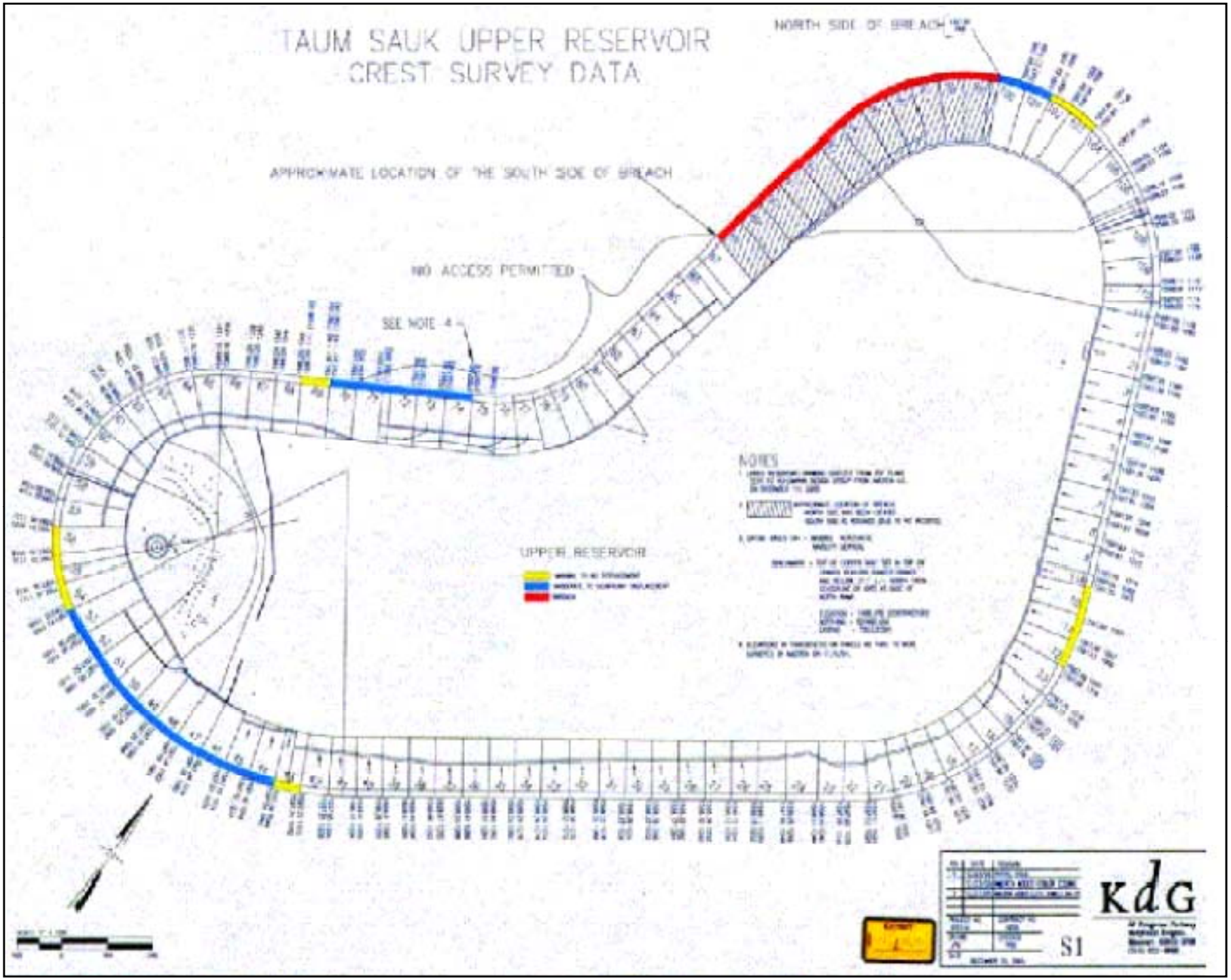
- **Why did the Reservoir Breach?**

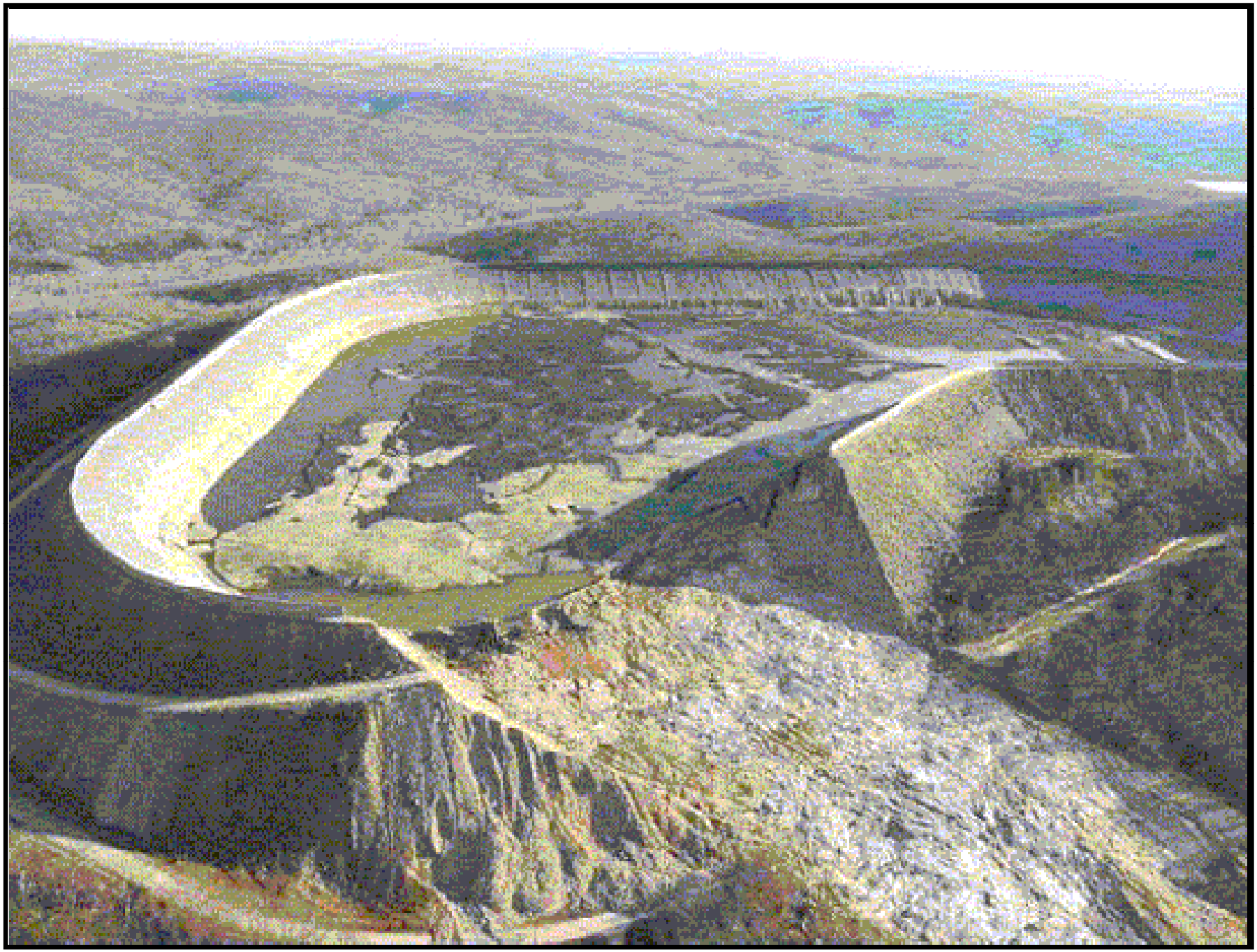


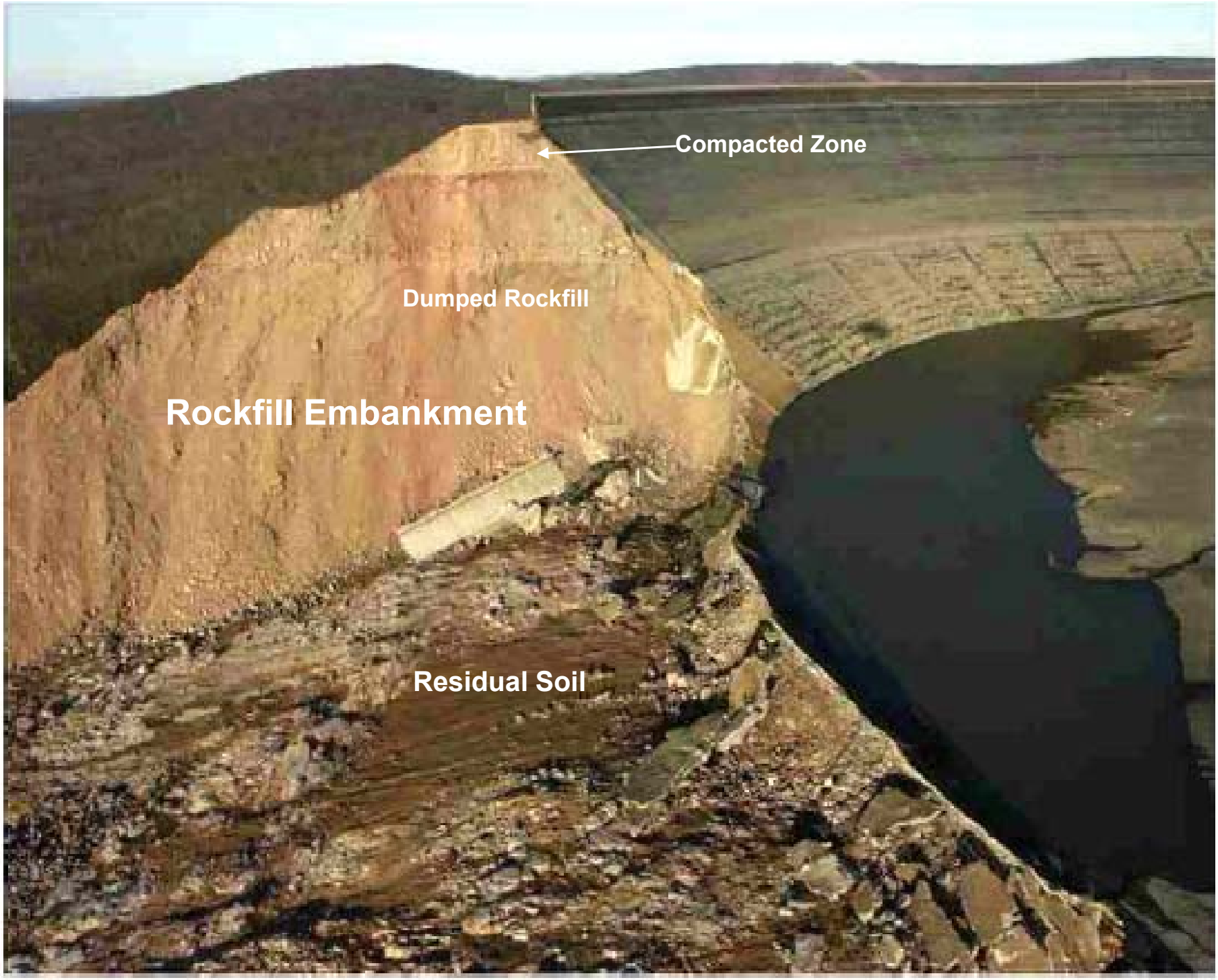
Dec. 14th breach.


Upper Reservoir
Wall Break

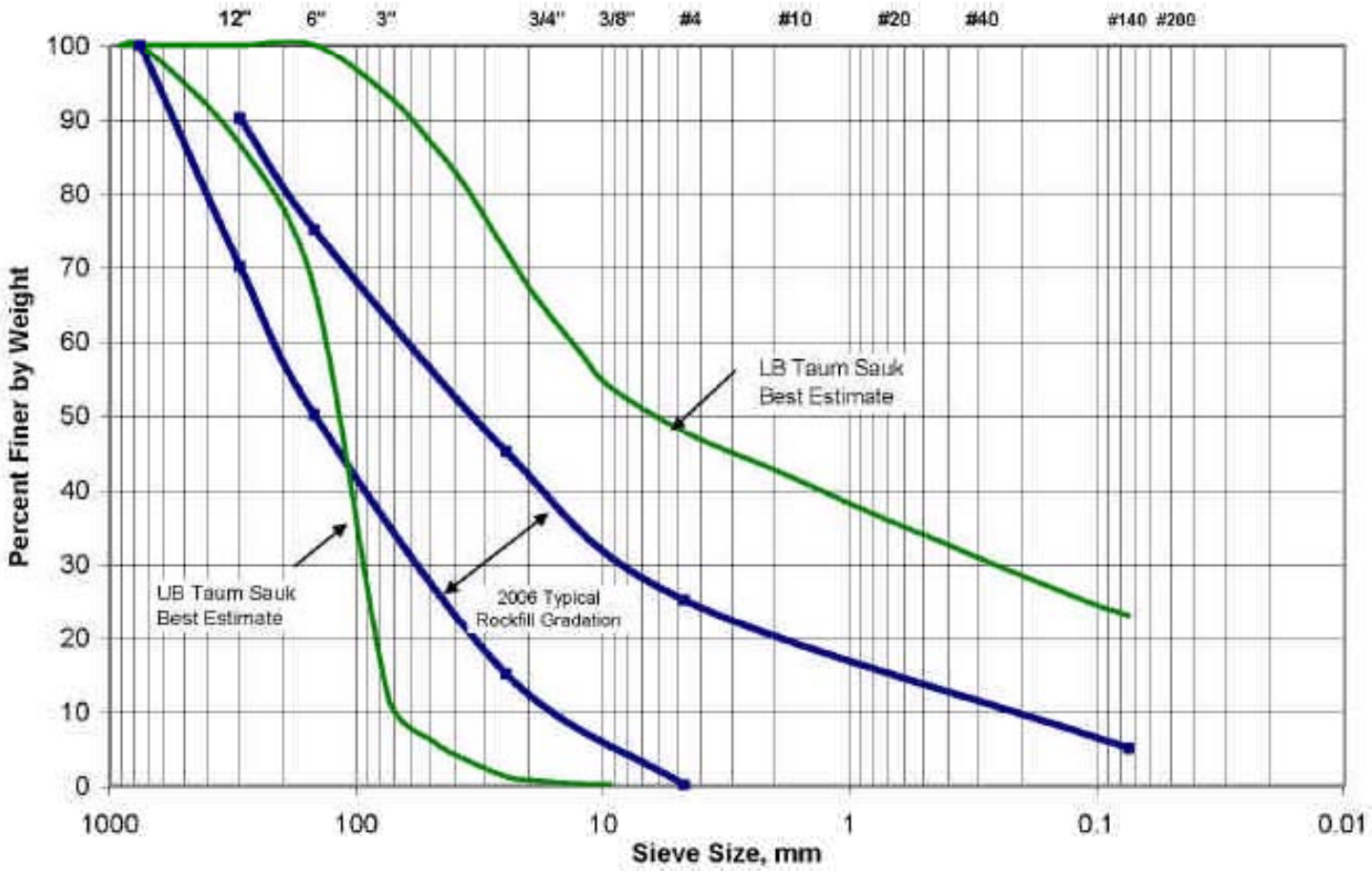
TAUM SAUK UPPER RESERVOIR
CREST SURVEY DATA







North Side of Breach Face



BEST ESTIMATE OF ROCKFILL GRADATION

Eroded foundation, note rock jointing and overlying clay materials

Rockfill between top of rock and base of plinth,
note reddish grout in rockfill beneath the plinth

Rockfill between top of rock and base of plinth,
note reddish grout in rockfill beneath the plinth

Modes of Failure

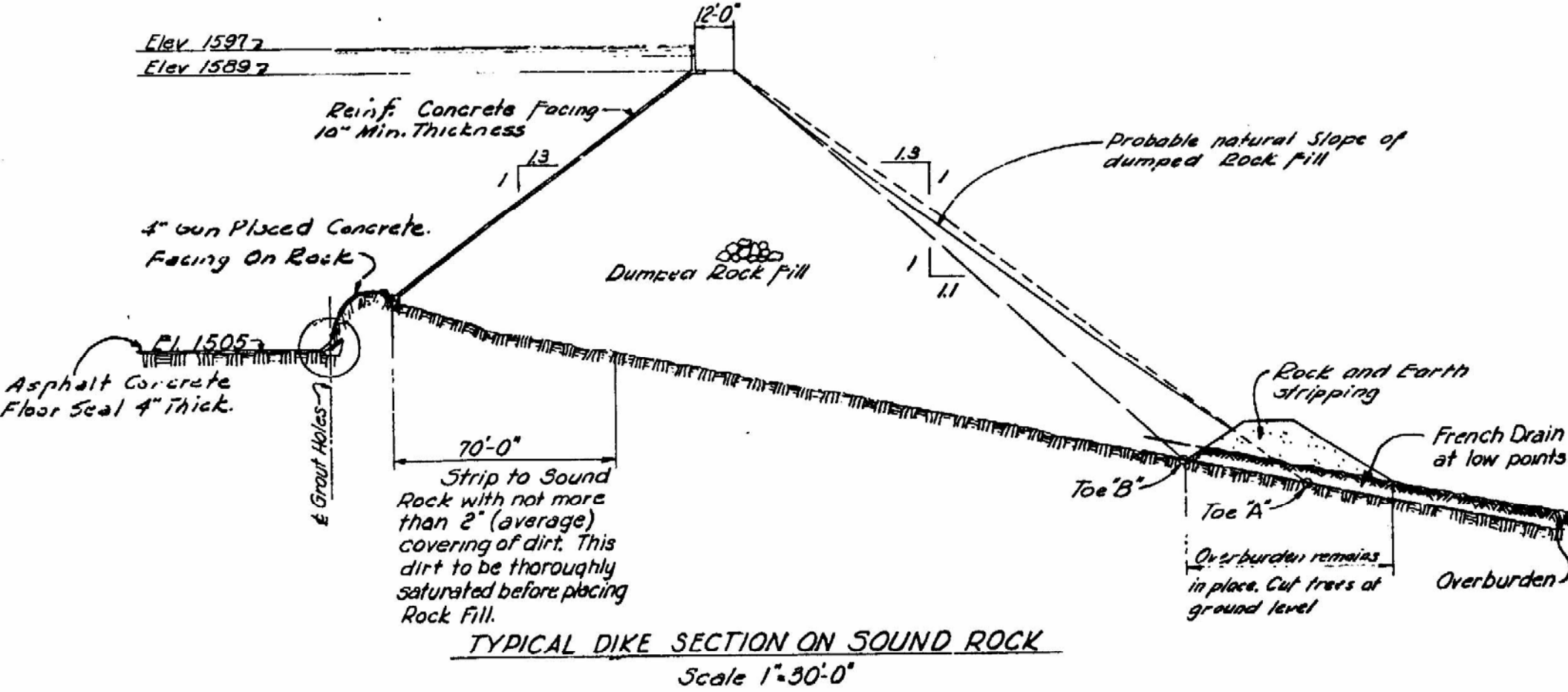
Mode a) Erosion on Steep Slopes Leading to Sliding and Panel Sliding

Mode b) Mode a) Followed by Overtopping Water Eroding Wall Foundation Causing Wall Overturning and Rapid Rockfill Movements

Mode c) Creation of Local Wedge Beneath Wall from jet Impingement and Raising Phreatic Surface Resulting in Rockfill Movements

Mode d) Creation of Deep Seated Wedges Driven by High Phreatic Pressures Resulting in Mass Rockfill Movements

Upper Reservoir Cross-Section



TYPICAL DIKE SECTION ON SOUND ROCK

Scale 1"=30'-0"

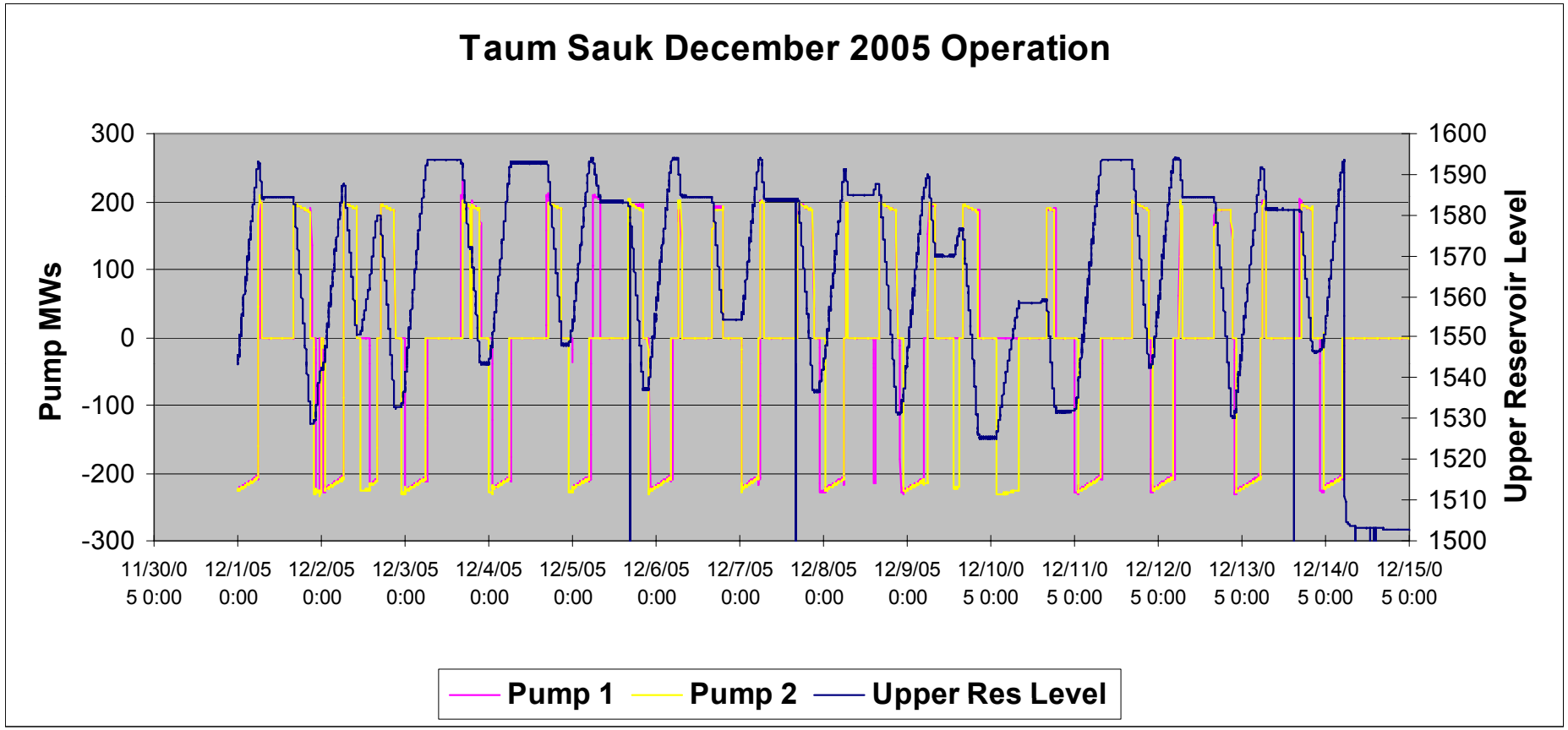
Forensic Investigation

- **Why did neither pressure transducers nor conductivity probes shut down the pumps?**

Typical Project Operation

- Generating and pumping decisions made at St. Louis based on economics, MISO and NERC requirements.
- MISO = Mid-West Independent System Operator.
- NERC = Northeast Electric Reliability Council.

Operational Characteristics



Over-Pumping Protection

- Automatic computer initiated pump shut down at pre-set upper reservoir levels based on averaged level indications from three pressure transducers.
- Back-up emergency pump shut down based on signals from two conductivity probes at fixed elevations.
- Installed in fall of 2004 replacing older systems.

Water Level Monitoring/Control System (1)

- Three 0-100 psi pressure transducers enclosed in one protective plastic pipe.
- Water level and volumes derived from average reading of three pressure transducers.
- Level and volume displays at Taum Sauk, Bagnell control center (Osage) and St. Louis control center.

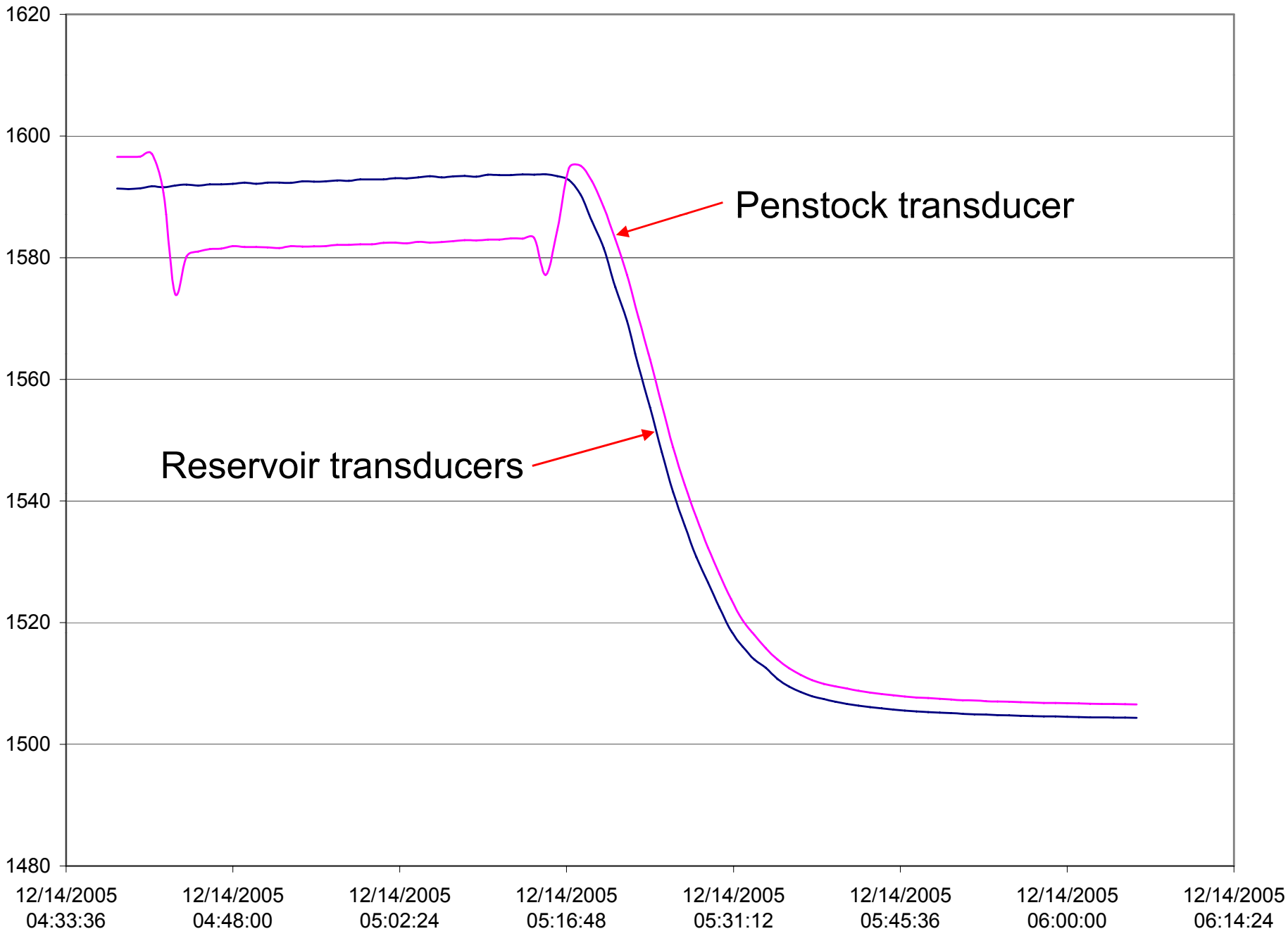
Water Level Monitoring/Control System (2)

- Operators can enter different water levels into computer to initiate shutdown of pump/turbine 1 and pump/turbine 2.

- Automatic shut down of both units was normally set at Elev. 1596, but after Oct. 2005, was set to Elev. 1594.

Level Protection Backup System

- Commercial conductivity probe and relay system.
- Requires current flow through water.
- Logic requires both Hi and Hi-Hi probe “wet” for 60 seconds to initiate pump shutdown.
- Tested OK during installation in fall 2004.



Dec. 14th breach.

Breach Sequence of Events (1)

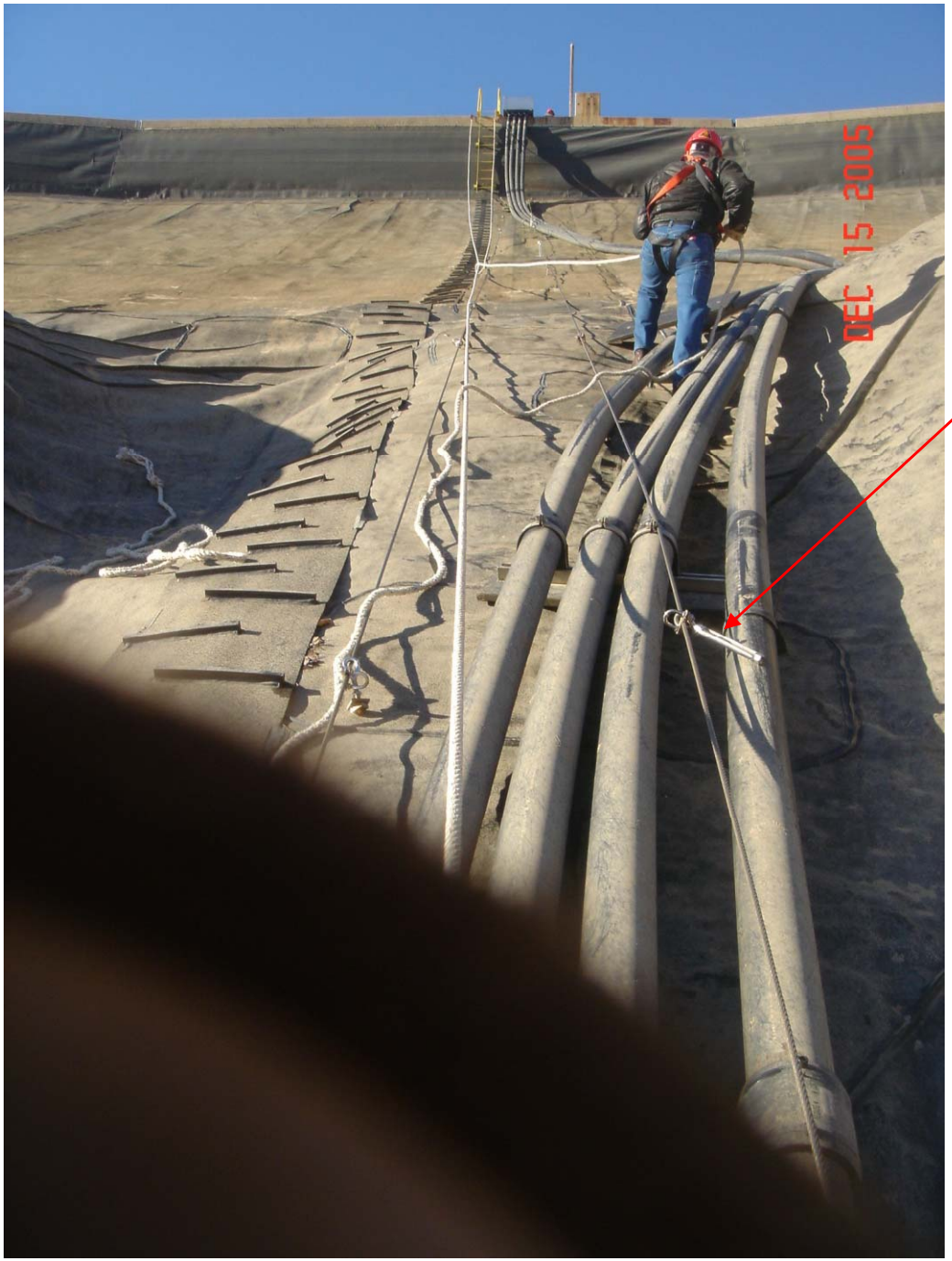
- Pump #1 start at 22:14 Dec. 13th. UR level indicated 1546.6 ft.
- Pump #2 start at 22:55. UR level indicated 1547.8 ft.
- Pump #2 auto stop at 04:39 Dec. 14th. UR level indicated 1591.6 ft.
- Pump #1 stopped by Bagnell per St. Louis instruction at 05:15. UR level indicated 1593.8 ft.

Breach Sequence of Events (2)

- Bagnell notes UR level, tailwater and generate permissives are not normal at 05:38.
- Notifications and EAP initiated.

Oct. 6, 2005

- “A week or so ago we noticed that the reservoir was fuller than normal after pumpback was completed”.
- Also observed that pressure transducer and conductivity probe protective pipes had “come loose from their mooring and have a bend in them down about 50 feet”.
- “We are lowering the pumpback setpoint to 1594, down from 1596.”



Note turnbuckle unthreaded from lower bolt.


DEC 15 2005

Note separation of guy cable eye bolts from base plates and movement of one pipe over another.

Note, straightening of protective pipes between dates of above photos.

Protective pipe base plates are not anchored to reservoir. Left guy cable has come loose from base plate in right photo.

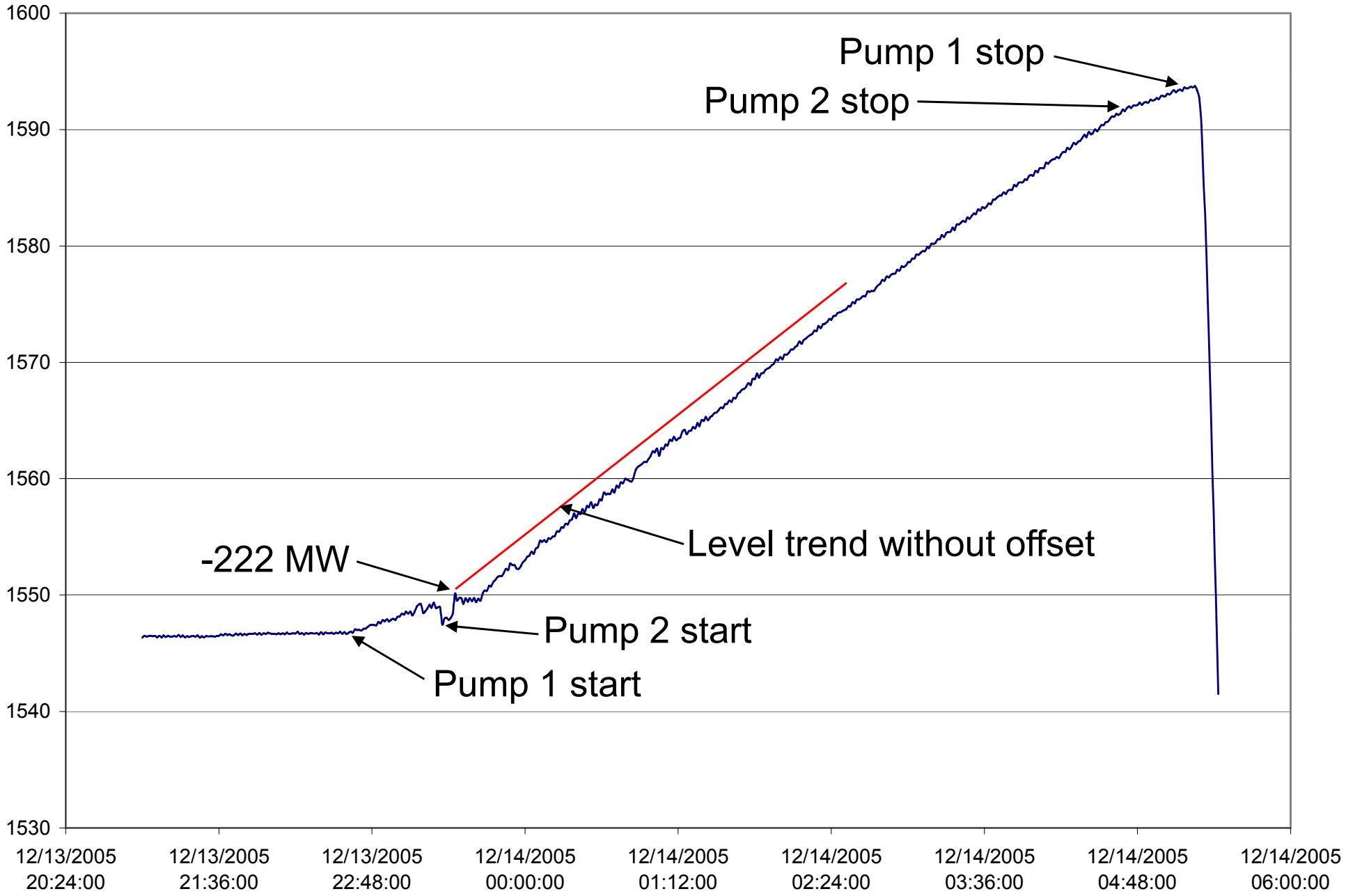
Protective pipe support system as found. Note eye bolt unthreaded from turnbuckle. Also note lock washer in place at connection to U channel but lack of lock washer at turnbuckle.

Pressure Transducer Failure (1)

- Level errors known as early as Sept, 2005.
- Physical evidence of protective pipe movement with transducers inside.
- Transducer movement produces level indications lower than actual level.
- Sept. 2005 removal of one transducer and adjustment of level indications downward by 0.4 ft.

Pressure Transducer Failure (2)

- Movement of protective pipes and cables may have resulted from flow turbulence, Von Karman vortices or both.
- New runner max. pump discharge is 3,000 cfs compared to 2,450 cfs for old runner.
- Exit losses into reservoir (turbulence) varies as flow squared (50% greater).



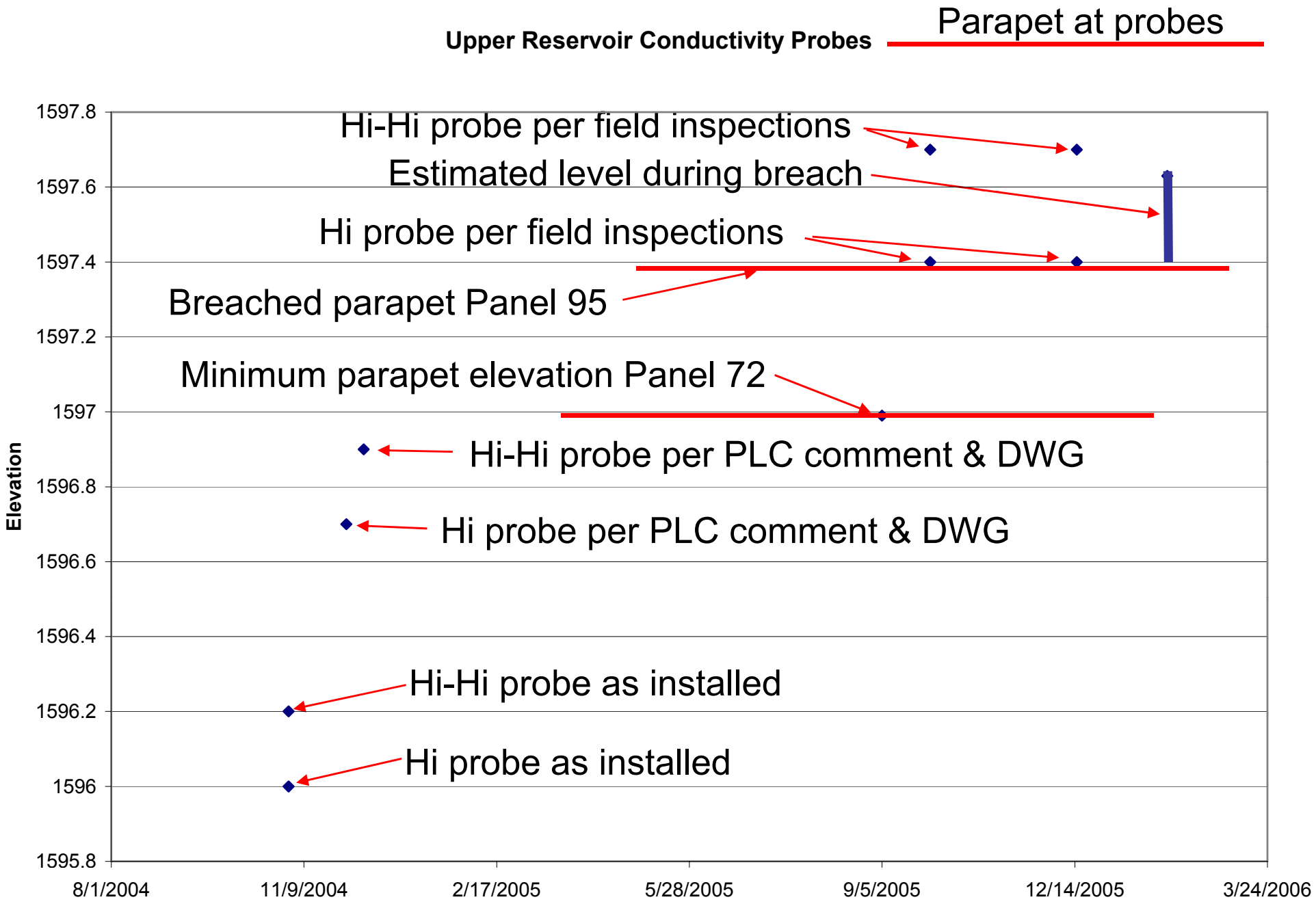
Level indications after pump 2 start shows an offset.
-222 MW = Completion of pump 2 start sequence.

Pressure Transducer Failure Conclusion

- Movement of protective pipe raised transducers resulting in water level indication that was lower than actual level.
- Twelve minutes of two unit pumping on Dec. 14th without reporting water level increase resulted in additional two feet of water level compared to other Dec. days.

Conductivity Probe Response

- No Hi or Hi-Hi pump shut down inputs or alarms came into plant on Dec.14th.


Upper Reservoir Conductivity Probes
Parapet at probes
Hi-Hi probe per field inspections
Estimated level during breach
Hi probe per field inspections
Breached parapet Panel 95
Minimum parapet elevation Panel 72
Hi-Hi probe per PLC comment & DWG
Hi probe per PLC comment & DWG
Hi-Hi probe as installed
Hi probe as installed
Elevation
1597.8
1597.6
1597.4
1597.2
1597
1596.8
1596.6
1596.4
1596.2
1596
1595.8
8/1/2004
11/9/2004
2/17/2005
5/28/2005
9/5/2005
12/14/2005
3/24/2006

Conclusions

- The pressure transducers that monitored reservoir water levels became unattached from their supports causing erroneous water level readings.
- The emergency backup level probes were set too high to shut down the pumps before overtopping.
- The normal operating high water levels of 1 ft. below the top of the parapet wall did not allow adequate operational margin.
- The omission of a spillway from the design was a most important root cause of this failure.

Related Actions Taken (1)

- FERC reviews over pumping protection methods used by other pumped storage projects.
- FERC directs that licensed pumped storage projects be staffed and monitored 24/7.
- FERC convenes meeting of pumped storage owners, FERC staff, consultants and interested parties in Washington.

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Related Actions Taken (2)

- Final draft of guidelines is completed.
- New design of Taum Sauk over-pumping protection system is based on fail-safe direct acting principles
- Attendees organize to develop guidelines for water level control and management.

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Taum Sauk – Upper Reservoir Full