TURBID DISCHARGE INCIDENT AT CANNONSVILLE DAM

John H. Vickers, P.E. [1]
William H. Hover, P.E. [2]

ABSTRACT

On July 8, 2015, the New York City Dept. of Environmental Protection (DEP) discovered a turbid discharge at the toe of Cannonsville Dam, a 2,800 ft. long, 175 ft. max. height, earthen dam constructed from 1955 – 1965. The Dam impounds the W. Branch Delaware River, has a storage capacity of 96.7 billion gallons and is an important component of the NYC water supply system which supplies 1.1 billion gallons daily to 9 million people (Figures 1 and 2). Reservoir was at full pool level.

The turbid discharge developed during test borings for foundation design of a proposed hydro- electric plant at the toe of the dam under a license issued by the Federal Energy Regulatory Commission (FERC). Turbid discharge resulted from open bore holes penetrating a confining geologic layer into an artesian formation in the dam foundation. DEP notified FERC and NY State Dam Safety officials and responded immediately to the potential dam safety incident. Actions included cessation of drilling at the dam, around the clock monitoring on site including parameters such as potential settlement, contingency planning in case the situation worsened, reservoir drawdown from full pool, public notification and emergency contracting for engineering consultant and construction contractor support. DEP assembled a team of engineering consultants and additional recognized experts and received active assistance from FERC. The team used a collaborative process to develop, decide upon and implement a rapid mitigation strategy consisting of pressure relief wells and a repair strategy to permanently stop the turbid discharge. Seven pressure relief wells with deep well pumps were installed by the end of July to eliminate or neutralize upward flow from the artesian zone. The turbid discharge stopped by August 1, 2015, at which time DEP ceased active reservoir drawdown (up to 15 feet). Permanent closure of the open boreholes were successfully completed using compaction grouting methods, and the relief well pumps were turned off early in the morning of August 28, 2015. As of May 16, 2016 the reservoir returned to normal pool and the repairs continue to hold with no further turbid discharge.

This paper reviews the dam owner's response; monitoring and early warning mechanisms; efforts to warn and inform the public; the collaborative approach to analyze the situation and design mitigation and repairs; repair and test methods; the monitoring plan; and lessons learned. The following questions are explored: How can dam owners assure that prudent research and contractor preparations are taken before subsurface exploration on or around dams? What actions can dam owners take before an incident occurs that will assist them to respond and recover from an incident should one occur ? What actions can dam owners take during an incident response and recovery that will help them achieve an acceptable solution ?

---

[1] Chief, Water Operations Division, NYC Environmental Protection, Bureau of Water Supply, Source Water Operations, Grahamsville, NY 12740 jvickers@dep.nyc.gov
2 Sr. Principal, GZA GeoEnvironmental, Inc., 249 Vanderbilt Ave., Norwood, MA 02062 whover@gza.com

BACKGROUND

Figure 1 – New York City Water Supply System

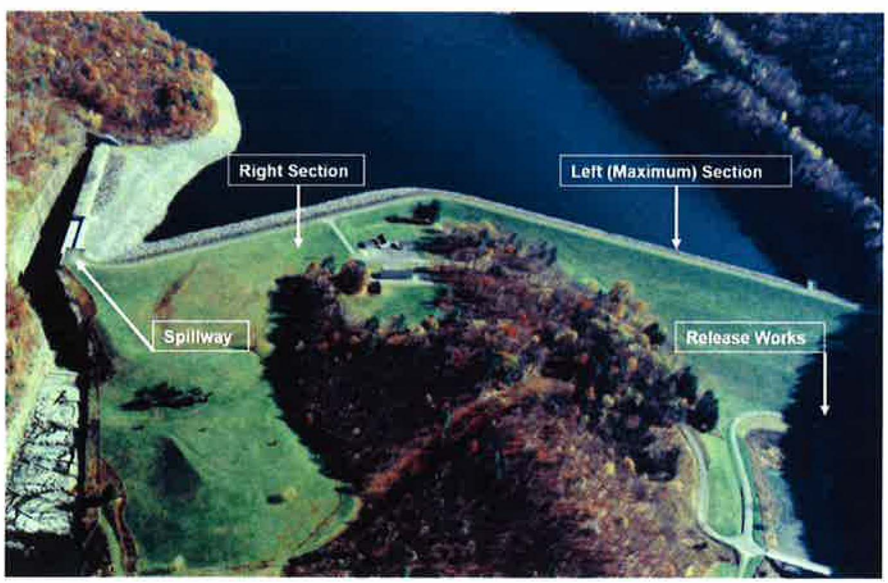


Figure 2 – Aerial View Of Cannonsville Dam – Focus Area At Lower Right

Figure 3 shows stone rip-rap armoring the upstream slope with stone fill below topsoil/turf on the downstream slopes. Benches with catch basins pass surface drainage through the near-surface rock fill. The rock fill toe passes surface drainage and dam seepage to the tailwater..

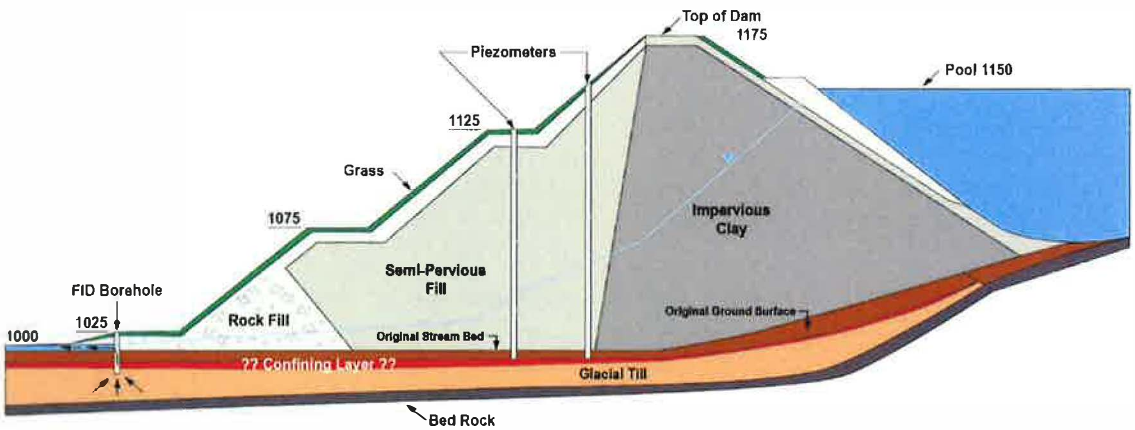


Figure 3. Inferred Dam Section During The Incident

DEP filed for and FERC granted to NYC a license on May 13, 2014 to construct a 14.1 MW hydroelectric plant, with powerhouse located next to the release chamber (Figure 4). A hydropower consultant developed a plan to collect subsurface information and install piezometers to estimate seepage flows and measure pore water pressures in the powerhouse foundation (Figure 5). Eight borings were proposed and three were partially completed.

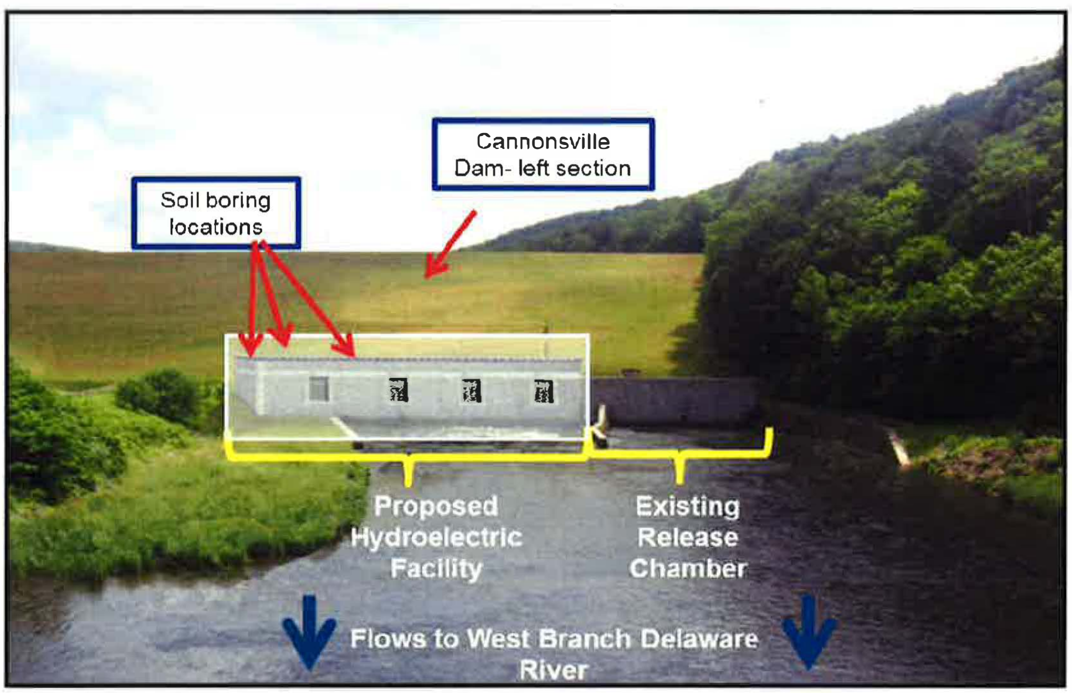


Figure 4. Conceptual Rendering Of Proposed Powerhouse

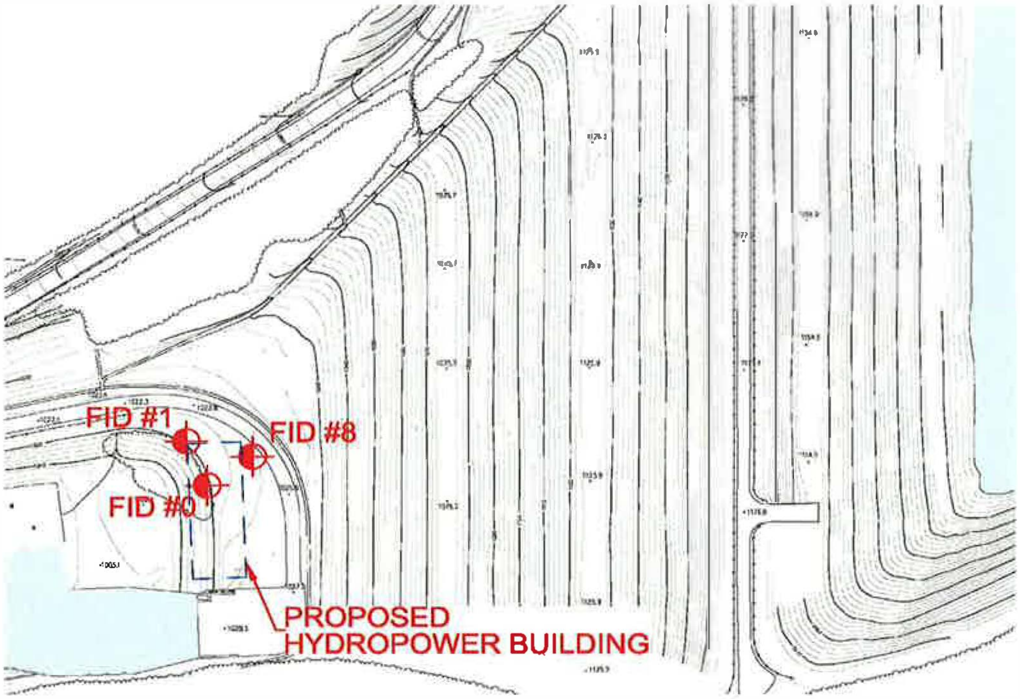


Figure 5. Locations Of Three Borings For Proposed Hydroelectric Plant

INCIDENT

On July 8, 2015, turbid discharge was emanating from the toe into tailwater during the 3rd of 8 boreholes (FID-0) (Figures 5 and 6). FID-8 began on July 1, resuming on July 5 and was drilled through the rock toe via hollow stem augers (HSA) to 52 feet and uncased to about 62 feet by mud rotary methods. The driller had difficulty backfilling FID-8 on July 6 by pouring 9 bags (450 lbs) of bentonite chips, 1 cy of 1 in. stone, 3 cy of sand and 2 bags of bentonite chips into the borehole from ground surface after auger removal. FID-1 was drilled on July 6 and 7 with HSA to 29 feet and uncased to 61 feet by mud rotary methods. FID-1 was backfilled using bentonite mud and cuttings. After HSA removal the hole collapsed to 6 feet below grade and was backfilled with bentonite chips. FID-0 was drilled on July 7 and 8 in the same manner as FID-1. The borehole was filled with 60 gallons of cement grout bentonite grout prior to HSA removal, followed by borehole collapse to 6 feet and backfill with bentonite chips.The belief on July 8 was that drill cuttings, "recirculated mud" and backfill from previous holes were mixing with drainage and seepage causing turbid discharge. DEP stopped the borings to evaluate. After turbidity continued for 2 more days, with significant drops in deep piezometer levels beneath the dam, DEP notified FERC and NY State DEC Dam Safety and mobilized staff to the normally unoccupied site for 24-7 monitoring. DEP notified state, county and town officials and emergency managers. DEP contacted consultants who performed a comprehensive dam safety assessment in the past, to respond. In consult with FERC, DEP initiated reservoir drawdown on July 13 at a rate of 1,000 MGD (max. sustainable release); and increased max.supply diversion to 450 MGD.

RESPONSE

DEP took quick steps to mitigate risk and enable successful resolution. DEP mobilized staff, equipment and materials and, using the Emergency Action Plan as a guide, notified emergency managers, elected officials, regulating agencies and other stakeholders. DEP stockpiled sand, stone, rip-rap, geotextiles and sandbags; and brought in staff, tents, potable water (no amenities available at this remote location), lighting, communications trailers and

Figure 6. Turbid Discharge At Downstream Toe – July 13, 2015

other means to provide 24-7 on site monitoring. DEP surveyors established control points to ensure the dam profile had not changed and erected staff gages in tailwater and on the toe area of turbid discharge to monitor changes in discharge water surface and tailwater elevations with automated pressure transducer (Figure 7). DEP began daily inspections

Figure 7. Staff Gages (Tailwater and Turbid Discharge)

and photo documentation. The Automated Data Acquisition System reading interval of the piezometer array installed in 2000 was changed from daily to hourly, with twice daily analyses. DEP established deviation alarms and SOPs to notify engineers of rapid change of any piezometer. DEP built sediment collection boxes to examine grain size distribution of sediment (Figure 8). DEP installed a constant monitoring turbidimeter and provided data to the Bureau of Water Supply (BWS) control room. BWS requested communications assets from NY State as there is no cellular service at the dam. Verizon and AT&T established satellite voice and data communications until local telephone company upgraded to allow data and voice over internet phones. DEP erected generator powered lights and closed circuit television with camera feed to BWS and deployed satellite telephones. The division chief assimilated daily inspection and meter reading data and issued written situation reports to the project team to document site conditions and any changes.

Figure 8. Sediment Collection Box (36 in. x 12 in.)

Following is a timeline of selected events from the incident.

July 8, 2015	Turbid discharge observed
July 10, "	DEP began 24-7 monitoring on - site
July 13, "	Initiated reservoir drawdown; notified public officials
July 18, "	Selected specialty contractor; First public notification meeting
July 20, "	Submitted relief well design; DEP began 24/7 remote CCTV monitoring. NYSOEM communication trailer arrived - satellite phone, internet service
July 22, "	Verizon communication trailer - 6 phones, internet, improved cell service
July 24 "	Begin drilling Relief Well No. 4; Board of Consultants meeting no. 1
July 28 '	Second larger rig begins drilling Relief Well No. 1
August 2, 2015	Confirmed visually that Relief well pumping eliminated turbidity
August 4-5 "	Board of Consultants meeting no. 2
August 25, "	Compaction grouting of FID Boreholes completed
August 28, "	Termination of relief well pumping

PUBLIC OUTREACH

The dam is key to the safety of 80,000 people in the dam failure inundation area. DEP initiated communications to timely disseminate information to the public. DEP included daily opportunities to ask questions and receive answers about public safety, emergency preparedness, the state of the dam and progress of repairs, preventing rumors and building credibility with downstream neighbors. DEP hosted 12 public meetings, in communities spanning 130 miles of the Delaware River. DEP compiled an email list of officials, business owners, and residents along the Delaware. Updates were sent daily during the height of the incident. Updates and weekly photographs were posted to DEP's Facebook page. To increase the audience for Facebook posts. DEP "tagged" key media outlets, nonprofits and other groups. Updates were designated for community news. Facebook post sharing allowed updates to be seen by tens of thousands of people and provided DEP an opportunity to answer questions. Traditional media shared information about the Dam and repair work. DEP compiled a list of newspapers, radio and TV stations and news websites that covered riverside communities in NY, PA and NJ. Many outlets and towns did not usually receive information from DEP. DEP asked the Associated Press to ensure its story was posted on the wire for all three states. DEP created a central page on its water supply website to post updates, including information on downstream releases, reservoir storage, inundation maps for downstream areas, and other useful information. A cell phone number of DEP's information officer was shared in all updates and at all public meetings. Site tours were provided for elected leaders and emergency response officials, bolstering confidence in the information DEP provided.

ANALYZING THE PROBLEM

While DEP mobilized, agency senior leaders used emergency procurement means to hire William Hover, P.E. of GZA GeoEnvironmental Inc., the consultant who had performed a thorough engineering assessment of the dam and was very familiar with it, to assist with the problem. DEP hired 3 additional expert consultants (Joseph Ehasz of AECOM, Frederick Rhyner of Mueser Rutledge and Stephen Whiteside of CDM/ Smith) with the advice and approval of FERC, as the independent Board of Consultants (BOC) to help analyze the situation and provide feedback on DEP plans to mitigate and resolve.

DEP engineers reviewed the piezometer data and discovered that deep piezometers in the dam foundation had 13 to 14 foot drops in head coincident with drilling of boreholes FID#1 on July 7 and FID#0 the next day and then remained relatively steady thereafter (Figure 9). An artesian well located about 200 yards downstream that has historically discharged freely through a 1 inch orifice and approximately 30 inches upward, had dropped to just a few inches above the orifice (Figure 10). The artesian well and the new boreholes were hydraulically connected in some manner.

DEP, its consultants, FERC and DEC performed an abbreviated Potential Failure Mode Analysis on site on July 14, 2015. Of concern was the potential for a piping condition to form and if not halted, leading to dam failure. Larger soil particles could potentially be transported and deposited into the rock fill toe without detection. The rock fill toe, which covers a large area and which propagates into the riverbed, made construction of a measuring weir and filter blanket or other surficial mitigating measures impractical. DEP engineers believed that the 3 boreholes pierced a confining layer under the rock toe into an artesian zone, causing water to flow upward and erode soil from within the boring, creating turbid discharge through the rock toe. (Figure 11 - Sketch by Jeffrey Helmuth, P.E.). The consultant agreed that this was the most plausible theory, while BOC and FERC agreed that this was a plausible theory. To help confirm this theory, DEP collected samples from the borings and the turbid discharge and sent them to a laboratory, the RJ Lee Group, for analysis. RJ Lee's microscopy studies suggested that the material in the turbid discharge was coming from the confining layer of silts and clays located below the rock fill toe and above the artesian zone. Neither bentonite nor Portland cement was observed, confirming that the boring backfill was not the source of turbidity. DEP searched its archives to learn more about dam and foundation construction. Historical photographs helped the project team to understand where the relic riverbed was located; the dense nature of glacial till foundation materials; that higher rates of seepage might occur through seams in the bedrock along either side of the old valley but that overall seepage volumes would be small; and that the downstream artesian well had been used during construction. It was learned that Dr. Arthur Casagrande was a project consultant.

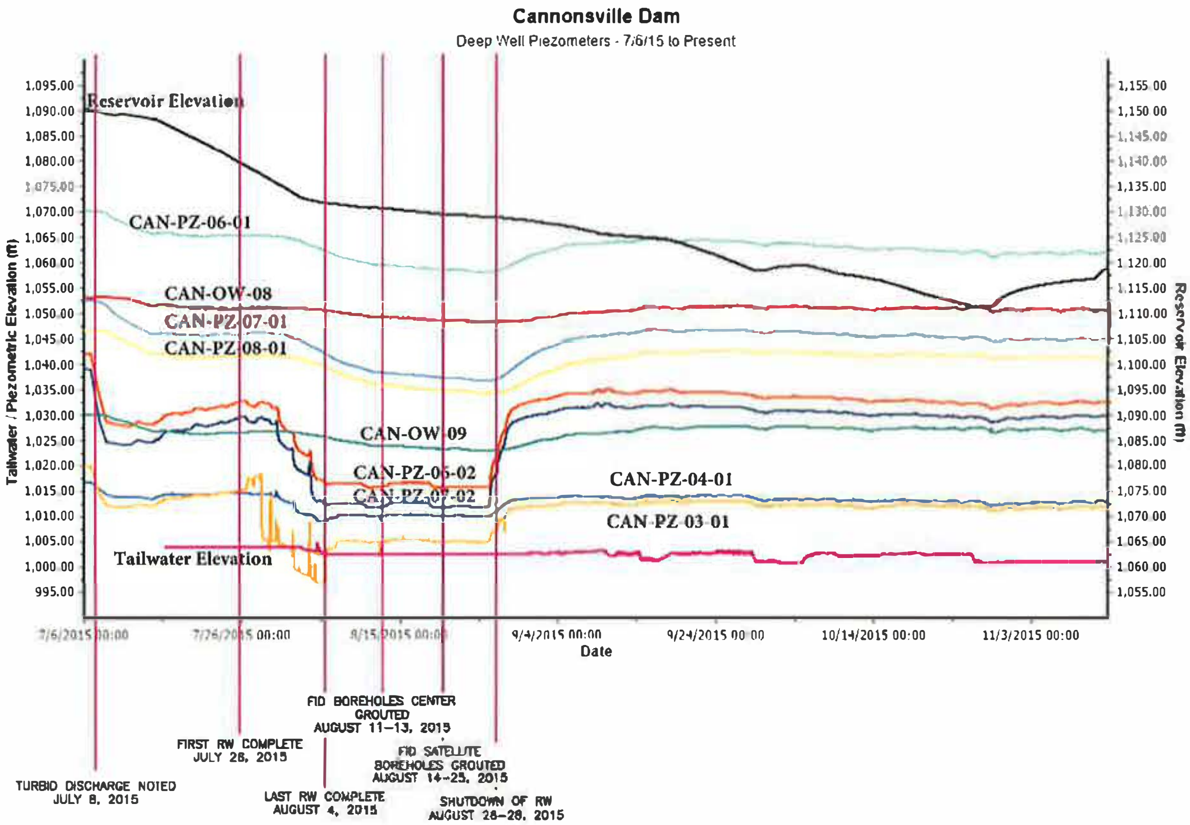


Figure 9. Decreased Piezometer Levels Concurrent With FID Borings

Figure 10. Artesian Well Before (left) and After (Right) New Borings

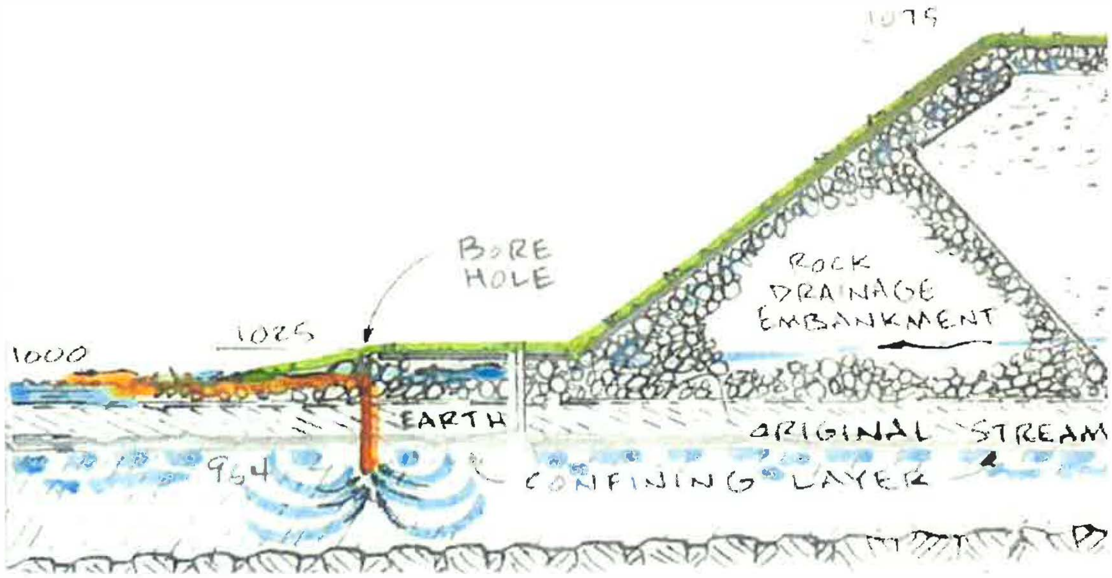


Figure 11 – Sketch by Jeffrey Helmuth, P.E. Illustrating Mechanism Of Artesian Flow

MITIGATION

The project team brainstormed alternatives and all agreed that installation of pressure relief wells would be followed by plugging the boreholes. The relief wells would depressurize the aquifer to halt the turbid discharge and permit the boreholes to be plugged. DEP also tapped the knowledge of four reputable specialty geotechnical contractors. On July 17, 2015 DEP and project team members met with 4 contractors individually and listened to their approach to relief well installation and borehole plugging. Potential remediation measures were discussed to provide a basis for rational selection of a highly qualified contractor with the resources to respond rapidly. Potential solutions discussed included large diameter over-boring the original boreholes, high mobility pressure grouting and low mobility compaction grouting. Three of the four contractors independently felt compaction grouting to be the best solution to plugging the boreholes. DEP entered into an emergency contract with Moretrench to install relief wells and plug boreholes.

Using the experience of the GZA consultant, DEP archives, contractor's recommendations, and a collaborative effort with state and federal regulators and Board of Consultants, the project team settled on 10 temporary relief wells positioned in an arc up-gradient from the boreholes (See Figure 12). The relief wells were designed in a drainage curtain configuration upstream of the proposed powerhouse and along the right abutment at 40 ft. spacing for the 1st stage and 20 ft. spacing for a 2nd stage. Pumps would increase pressure relief, and the wells could be maintained for future use if appropriate. Relief well holes were drilled through permanent steel casings to control artesian pressure. The contractor recommended sonic drilling methods to rapidly advance the larger diameter casing through the rock toe with little or no water or air flushing which could exacerbate the condition The wells were constructed with slotted PVC screen and solid PVC riser. The slotted section was backfilled with filter sand on top of which a bentonite plug was installed. The annular space above the screened zone was backfilled with cement grout. Well screens were set below the silt-clay confining

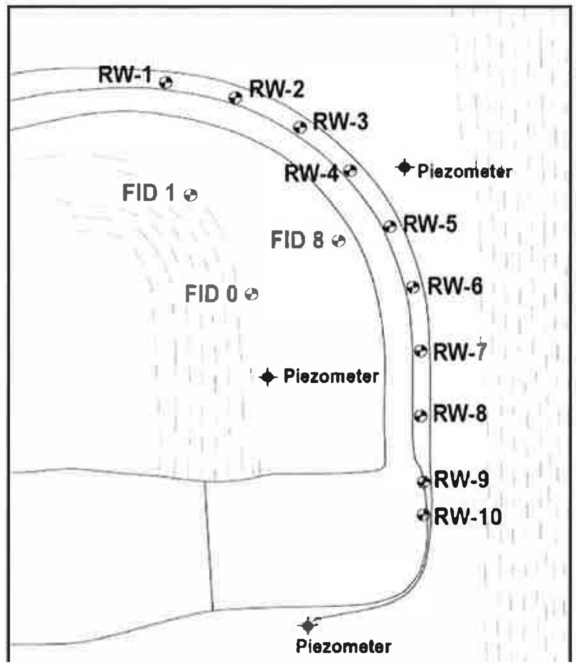


Figure 12 – Relief Well Location Plan

layer to relieve the artesian stratum (Figure 13). Each relief well accommodated an electric submersible pump with a PVC discharge pipe fitted with a sampling port and flow meter and then connected to a collection header discharging into a sedimentation tank and then into an existing catch basin. Ready availability of sonic drill rigs and permanent casing for borehole installation limited screened diameters. Two different sizes of relief wells, with 3-inch and 4-inch diameter finished well screens, were installed. Ten (10) inch sonic drill casing allowed a permanent 8-inch steel casing to be grouted into the confining soil strata below the rockfill before advancing the hole into soils under artesian head. A careful evaluation was essential to provide a casing with adequate seal into the confining layer, before encountering the artesian stratum. During initial drilling, the extent and depth of the artesian zone was unknown.

Sonic drilling allowed continuous soil sampling and custom design of screened zones for each well. RW-1 was screened in clean sands and gravels associated with an ancient buried river bed under artesian pressure, encountered beneath the dam crest and upper downstream berm, deep within the glacial till foundation during 2001 explorations. The old artesian water supply well located downstream of the dam, RW-2 and RW-3 were screened in the same stratum.RW-4 through RW-7 did not encounter the sand-gravel stratum and were screened in the till or till – like material just above bedrock.The first well drilled was RW-4; completed on July 28, 2015. This well was selected based on the proximity of a nearby piezometer and availability of the first sonic drilling rig which was a smaller machine. RW-1, closest to FID-01 (borehole showing 1st piezometer reaction), was designed to intercept the ancient riverbed. RW-1, 2 and 3 awaited the larger sonic rig to allow larger well screens and pumps. RW-7 was the 2nd well established before arrival of the larger drill rig. RW-1 showed 14 gpm artesian flow, RW-7 did not. When RW-4 started pumping at 4 gpm, turbid discharge slightly declined. RW-7 initially yielded 12 gpm but quickly ran dry. On August 1, RW-1, 2 and 3 were pumping 50, 25 and 30 gpm. The toe was depressurized and turbidity was no

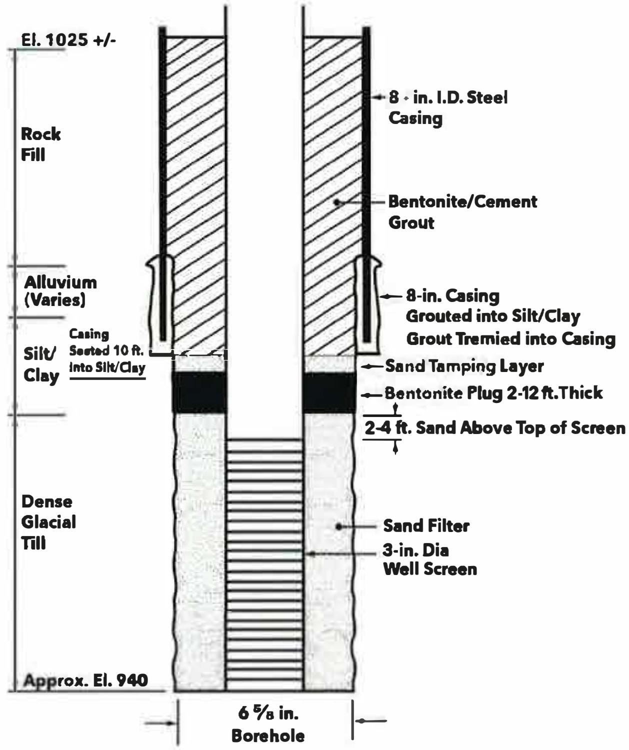


Figure 13. Relief Well Detail

longer observed (Figures 14, 15). The relief wells were declared a success the next morning. Pumping only from the deep artesian stratum using RW-1, 2 and 3 revealed that it was the source of water causing turbid discharge. Further confirmation of the source of the erosive flow was provided when pumping was briefly stopped for electrical re-wiring and turbid seepage re-emerged. The construction photo (Figure 16) indicates the relic river channel corresponding to the stratified sands, silts, gravels and clays above of the silt-clay confining layer and underlying pervious artesian zone, and the location of the higher yielding wells and the piezometers that were highly responsive to pumping.

Figure 14. Staff Gage and Sediment Box Flow Rate, Turbidity Diminished July 31, 2015 – RW-1 at 50 gpm

Figure 15. Tailwater – No Turbid Discharge August 2, 2015

As a result of the successful relief well pumping, authorization to resume normal reservoir operations was granted by FERC. DEP stopped deliberate reservoir drawdown (15 feet in 18 days) by returning both the release and water supply diversion to normal seasonal rates of flow. The reservoir continued to decline more gradually due to normal reservoir operation.

Figure 16. Dam Construction - Note Former Shallow River Channel

REMEDIATION

The FID borehole remediation plan was developed concurrent with relief well installation. The team selected compaction grouting to restore pre-breach hydraulic conditions by sealing the boreholes through the confining layer, replacing eroded ground washed out by artesian flow. The precise location and verticality of the FID boreholes was unknown. The team decided that the grouting should modify the ground within a target area rather than at the precise borehole location. Determination of the outcome of the grouting program would require indicators such as piezometric levels and tailwater turbidity.

Low mobility grouting (LMG) was selected for borehole closure. LMG employs low slump mortar-like grout injected under pressure through an open-ended steel casing to displace and densify the surrounding soil. The grout forms a bulbous mass. Strategically placed grout bulb "columns" within the target zone displace and densify the surrounding soil, as well as fills larger voids. The technique inherently results in ground displacement and movements.

The Phase 1 LMG grouting plan included an attempt to re-trace each exploratory hole and also three holes surrounding each FID borehole location on a triangular pattern (Figure 17). The re-traced holes were to clean out and backfill the FID boreholes and the surrounding three holes were to squeeze the FID boreholes closed if they could not be found and re-traced. The grouting plan included stand by time for dissipation of locally elevated pore-pressures. The LMG casing was advanced by internal flush duplex drilling to the target depth. The casing was then retracted in 2-ft (0.6-m) lifts as the grout was injected. For each lift, injection continued until pressure refusal, a pre-determined target grout volume was reached, or surface heave was observed. The team agreed that borehole re-tracing, cleaning out and grouting would be the most reliable closure expected. Special measures were taken to give this approach the greatest success. Relatively flexible, specially selected 2.5 inch drill casing with a lost point tri-cone 3.5-inch diameter bit was advanced first with positive water flush so as to follow the existing FID borehole as closely as possible. The approach worked very well at each FID borehole location. Minimal resistance to the advancement of the drill string and an abrupt increase in density at termination depth of each FID holes was a conclusive indicator that the boreholes were re-traced to full depth.

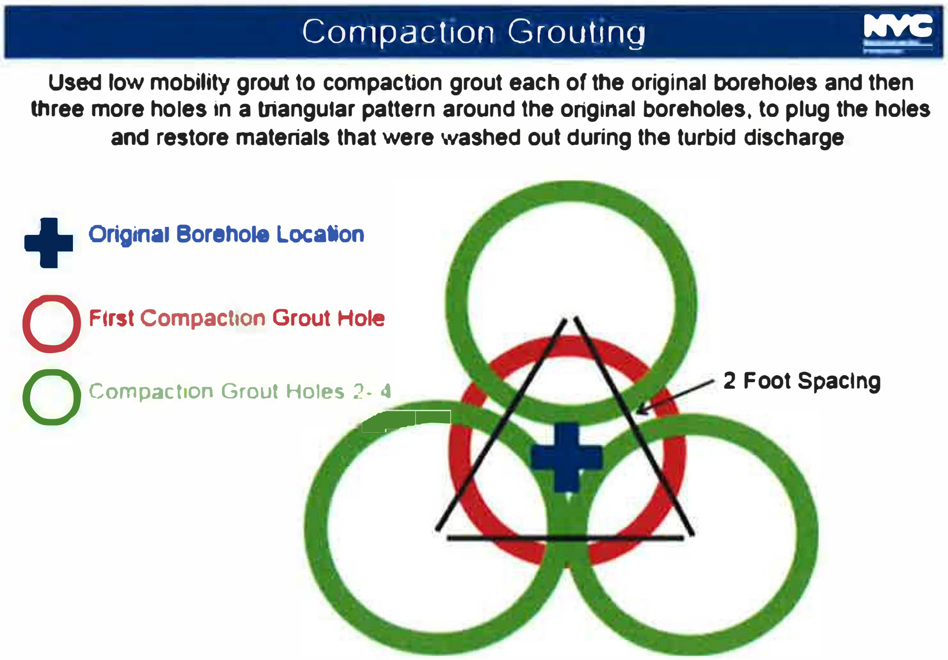
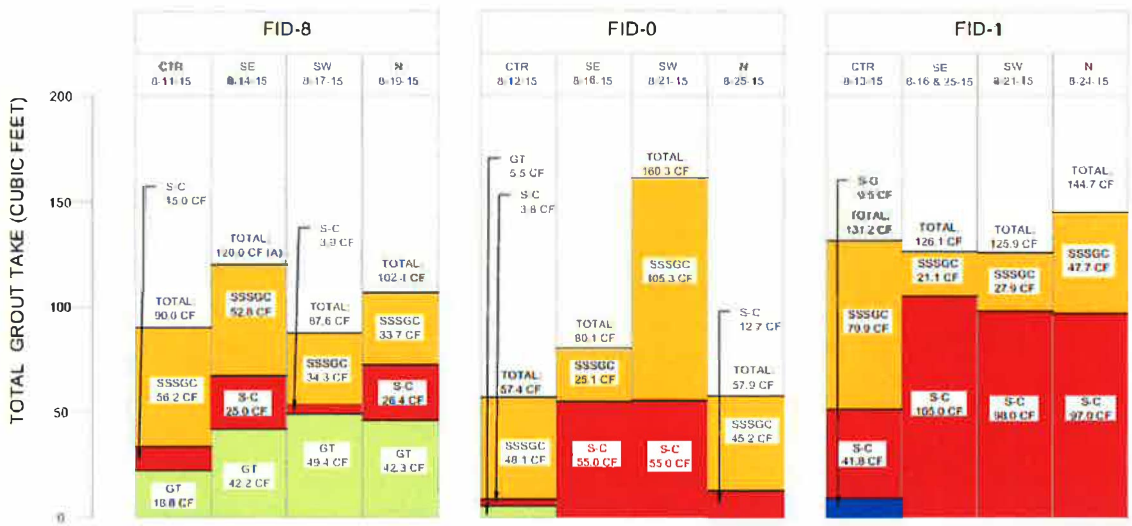


Figure 17. LMG Borehole Closure Pattern

The lost-point bit was dropped at the bottom of each of the 3 boreholes and the hole flushed with water and pressure grouted with a stiff mortar-like material. The high pressure grouting began 3 -5 feet below the bottom of FID boreholes. This assisted in densifying soils which may have been lifted or loosened as a result of upflow. Higher grout pressures, up to 500 psi, were utilized beneath the confining stratum of hard silt-clay and underlying glacial till to replace eroded ground and compact loosened soils. Lower pressure grouting, at 50 to 300 psi, was performed with an LMG grout of greater slump [4 to 6 inches] in the "erodible zone" of soils comprised of the stratified sands, silts, gravels, and clays above the silt-clay confining layer and below the rockfill and the foundation interface at the bottom of the rockfill. Pressures were lowered to reduce the potential for damaging the erodible and confining layers due to the high forces that accompany LMG grouting.

Potential hydro-fracturing of the confining layer required careful selection of the grout mix and the grouting pressure. The grout mix was relatively dry to keep the grout from acting too "liquid." The grouting pressure needed to be high enough to close the borehole, but not cause hydraulic fracturing, nor lift the strata grouted, potentially causing new groundwater flow paths. A value of 500 psi was several times lower than the undrained shear strength of the silt-clay confining layer, and lower than the shear strength of the underlying soils and was selected for trial use based on these considerations and engineering judgment. Based on successful trial use, including vertical surveys which demonstrated that lifting was not occurring, the 500 psi value was adopted.

Following grouting of the 3 FID boreholes, grouting was performed on a triangular pattern around each FID borehole, based on the volumes of grout injected and concern about radial voids or loosened zones beneath the confining layer. Figure 18 shows the grout volumes injected vs depth at each FID borehole. The highest grout volume was observed at FID-1, which was suspected by the project team to be the most problematic based on its hydraulic connection to the artesian layer (Figure 18).



SSSGC = Stratified Sand, Silt, Gravel, and Clay; S-C = Silt-Clay;
GT = Glacial Till; S-G = Sand and Gravel

Figure 18. Grout Volumes Vs. Depth at Each FID Borehole Repair Location

Observations during drilling of the FID boreholes provided confidence that the boreholes had been retraced. Observations during grouting indicated that the ground had been tightened. After 24 hours grout cure time, the relief wells were deactivated one at a time. Immediate piezometer response (Figure 9) suggested that pre-breach conditions had been restored. On August 30, 2015, after all relief wells were turned off, the project team determined that the grouting had been successful, but long-term verification of recharge of the piezometer levels as the pool returned to historic levels would be more conclusive.

RECOVERY

DEP developed a phased monitoring program to check the success of the borehole remediation. The first phase continued the same level of 24/7 on site monitoring and lasted two weeks after the borehole repairs were completed, ending on September 11, 2015, at which time DEP partially demobilized from the site. The second phase lasted approximately 10 weeks and included daily inspections, remote visual monitoring, turbidimeter and enhanced piezometer reading frequency and analysis (which had been changed to 5 minute intervals to support relief well installation and LMG processes). DEP continued weekly

Situation Reports, without issues. Following submission of the Forensic Report on November 25, 2015, monitoring entered the third phase. DEP decreased inspections to twice weekly and issued reports monthly. Throughout the third phase, piezometer readings rose towards pre-incident levels as the reservoir level returned to full pool. On May 16, 2016, the project team met on site to reassess the incident and plan for disposition of the relief wells. The team agreed that DEP could return to pre-incident levels of monitoring and to maintain the relief wells in a stand-by status pending decisions on the future hydro-electric project.

LESSONS LEARNED

The root cause of the incident was the improper preparation for and execution of the FID boreholes, using uncased drilling techniques which led to unsuccessful borehole closure. Contributing factors included lack of understanding of subsurface conditions at the toe of the dam, selection of an inexperienced lead field geotechnical engineer for the boring operation, and lack of contingency planning and preparations in case of artesian conditions. Successes included prior engineering assessments and installation of piezometers, periodic data collection and addition of the ADAS which enabled quick determination of areas of the dam reacting to the turbid discharge. Routinely conducted dam safety training programs prepared DEP to quickly react with confidence and mobilize staff, materials and equipment. Successes included the existence of a well laid out Emergency Action Plan which helped to guide public notifications and contingency planning. The multi-point public information and awareness push informed local elected leaders, businesses and residents, while preventing anxiety and instilling confidence with downstream stakeholders. The collaborative decision making process with regulators, consultants and the contractor led to good decisions and resulted in mutual trust and confidence that supported timely field changes.

The hydro-electric project is on hold pending further feasibility analysis in light of the artesian conditions below the proposed power house. DEP has taken steps to prevent recurrence of a similar incident at Cannonsville Dam and other locations. DEP has updated its Drilling and Boring checklist to ensure open hole methods are not used in areas subject to artesian conditions. This includes the base of all dams, dikes and aqueducts.

CONCLUSIONS

The turbid discharge incident at Cannonsville Dam was a hard fought skirmish which required quick, informed and collaborative decision making. The success of the project team prevented the risk from developing into something much worse. DEP was quick to respond and, with the help and support of FERC and NYS Dam Safety and other local and state officials, gathered a team of experts that used their diverse knowledge, skills and abilities to respond, analyze the problem, mitigate and remediate the problem, and develop and implement plans for long term success. It is our hope that the lessons learned will assist other dam owners and dam safety professionals.

CONTRIBUTING AUTHORS

NYCDEP - Thomas DeJohn, BWS Dam Safety Engineer, Paul Costa, P.E. BEDC Portfolio Manager Anthony Garagliano BWS Instrumentation Engineer
GZANY – Chad Cox, P.E. Associate Principal, Laurie Gibeau, P.E. Assistant Project Manager, James Guarente, P.E. Sr. Project Manager