Pine Hill Reservoir Dam (State Dam ID# 3-14-134-6) Underwater Inspection and Acoustic Imaging

November 2014

Prepared for:

CDM Smith

50 Hampshire Street
Cambridge, MA 02139

Prepared by:

COLLINS ENGINEERS INC.

650 Islington Street, Suite 1
Portsmouth, New Hampshire 03801
603.766.3342 • www.collinsengr.com

TABLE OF CONTENTS

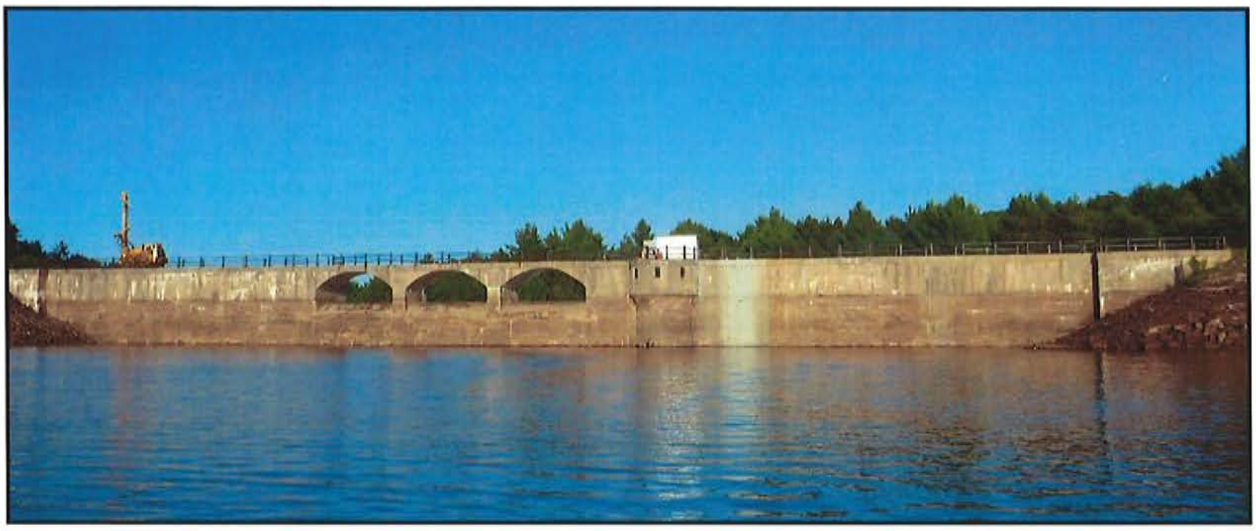
CDM Smith

EXECUTIVE SUMMARY

Project: Pine Hill Reservoir Dam Underwater Inspection

Purpose of Project: Complete a routine condition assessment and acoustic imaging scan on the upstream face of the Pine Hill Reservoir Dam.

Inspection Team: Diver/Team Leader – Daniel O'Connor, P.E. – Collins Engineers, Inc.
Diver Supervisor – Alex Tetreault, P.E. – Collins Engineers, Inc.
Dive Tender – Russell Richards, E.I.T. – Collins Engineers, Inc.



Upstream Face of Dam – Looking East

Inspection Date(s): September 8-9, 2014 and September 15-16, 2014

Summary of Findings:

- 125 square feet of concrete surface degradation typically 2-4 inches deep
- 7 square feet of voids in concrete with a maximum depth of 3 inches
- 85 linear feet of cracks up to 1/8-inch wide
- Four locations of construction joints with failed sealant
- Leaking intake valve

Summary of Recommendations:

- Repair areas of concrete degradation and voids on a low-priority basis
- Investigate and resolve leaking gate valve issue on a low-priority basis
- Complete routine underwater inspection at 60-month interval to monitor cracks and progression of deterioration

1.0 INTRODUCTION

1.1 Purpose and Scope

This report presents the results of an underwater inspection and 3-D acoustic imaging performed on the upstream face of the Pine Hill Reservoir Dam in Holden, Massachusetts. Collins Engineers, Inc. (Collins) conducted the inspection on September 8 and 9, 2014 and imaging on September 15 and 16, 2014. The purpose of the routine investigation was to assess the general condition of upstream face of the concrete dam, from the waterline to mudline (reservoir bottom). No above-water inspections were completed by Collins as part of this scope.

The following report includes a description of the structure, the method of investigation, a description of existing conditions and findings, and an evaluation and recommendations based on the conditions observed.

1.2 General Description of the Structure

The Pine Hill Reservoir Dam is located on the Asnebumskit Brook in the town of Holden, Massachusetts, and is owned and operated by the City of Worcester (See Figure 1 and Figure 2). The dam is a concrete and earth structure built in 1924, measuring approximately 370 feet across the top of the dam, from the south abutment to the north abutment. Wing walls are located at both the north and south abutments, extending approximately 170 feet from the south abutment and 310 feet from the north abutment, for a total length of approximately 850 feet. The top of the dam is located at elevation 920.0 referenced to NGVD 29 datum, with a maximum exposed height of 70 feet on the upstream face (measured from top of dam to mudline) and 73 feet on the downstream face (measured from top of dam to bottom of stilling basin). A 15-ft diameter semicircular gate house is located approximately 100 feet north of the south abutment, on the upstream face of the dam, with gate valves located at three elevations between the mudline and the waterline. An 80-ft long overflow spillway is located approximately 25 feet north of the gate house. The spillway crest is located approximately 10 feet below the top of the dam (Elevation 910.0).

The dam is constructed of mass concrete, with various shotcrete repairs completed on the upstream and downstream faces of the structure. It is unknown when the repairs were completed. A riprap slope is located on both ends of the dam on upstream face, and a soil embankment slope is located on both ends of the downstream face. At the time of inspection, the waterline was located 22.3 feet below the top of the dam (Elevation 897.7).

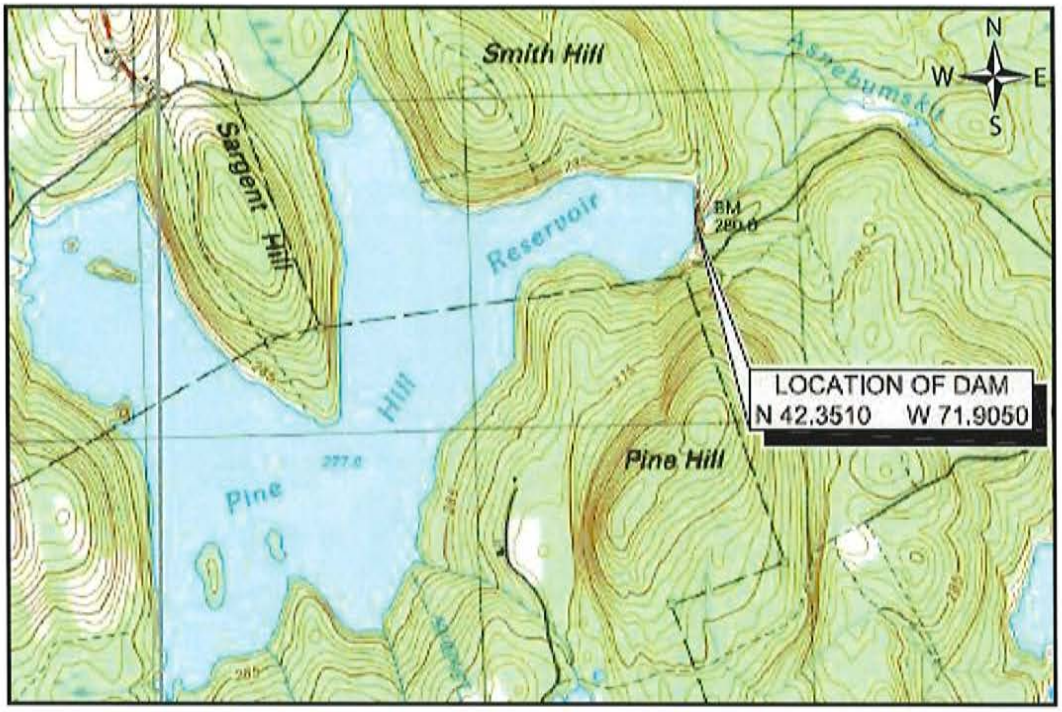


Figure 1 – Location Plan

Figure 2 – Aerial Photo of Site

1.3 Method of Investigation

A three-person dive team consisting of a licensed Professional Engineer/ADCI Diver, dive supervisor, and dive tender completed the underwater inspection in accordance with the "ASCE Manual and Reports on Engineering No. 101: Underwater Investigations, Standard Practice Manual". Dive operations were completed in accordance with Army Corps of Engineers EM-385 dive standards for surface-supplied air diving.

Designating the outboard face of the south abutment as station 0+00 for reference purposes and working from south to north, a Level 1 visual inspection was completed on the underwater portion of the upstream dam face, documenting general conditions, abnormalities, and other observable defects. Underwater visibility was typically 5-10 feet during the inspection, with the exception of the bottom 3-5 feet along the reservoir bottom which had limited visibility due to suspended sediment. Where areas of suspected deterioration were identified, a Level II inspection was completed, consisting of removing marine growth from the area and completing a tactile inspection including hammer soundings and light chipping. Additionally, the diver was equipped with a video/audio system for recording the inspection, which is submitted with this report. Underwater images of typical conditions can be found in Exhibit A.

Following the underwater inspection, 3-D acoustic imaging was completed on the underwater portion of the upstream dam face. Using a three-person team and a small work vessel, a Teledyne Blueview BV5000 3D mechanical sonar scanning tripod was positioned at 10 locations on the reservoir bottom along the face of the dam. Full 360-degree scans were completed at each location, obtaining a 3D point-cloud image of the face of the upstream dam and adjacent reservoir bottom. Control points were positioned at four locations along the top of the dam, which were then located in the above-water survey to provide reference for tying the above-water survey and underwater scan together. The individual scans were then registered together using Leica Cyclone 3D Point Cloud Processing software to create a single 3D image (acoustic scan images included in Exhibit B).

Prior to commencing work, the vessel and all diving/scanning equipment coming in contact with the water was cleaned in accordance with the "Requirements for Boat and Equipment Decontamination for Aquatic Nuisance Species Control and Overall Environmental Protection" document administered by the City of Worcester, Department of Public Works and Parks. A copy of the document is included in Exhibit C.

2.0 EXISTING CONDITIONS

Table 2-1 on the following page provides a summary of the notable defects observed, and an elevation of the wall showing defect locations with tabulated defect information can be found in Exhibit D. A description of the conditions observed are provided below.

2.1 Concrete Dam Structure

The concrete was generally in satisfactory condition, with minor scaling and soft concrete typically 1/8" to 1/4" deep on the surface. Approximately 125-sf of surface concrete degradation was observed, typically with 2-4 inches of soft concrete that could be removed easily by light chipping with a hammer. The areas of concrete degradation were typically located adjacent to construction joints and appear to be due to poor concrete consolidation during original construction. Two small open voids were observed, one located on the dam and one on the gate house. The void on the gatehouse exhibited exposed reinforcing steel; however, no significant section loss was observed in the reinforcing.

Approximately 80-lf of horizontal cracks and 4-lf of vertical cracks up to 1/8-inch wide were observed, typically located 1-2 feet below the water line and 10-12 feet below the waterline.

Minor corner spalling and honeycombing was typically observed around the edges of the construction joints, and failed joint sealant was observed in four construction joints, with joint openings up to 3 inches wide and up to 5 inches of penetration.

2.2 Gate House Intakes

The bottom intake at the gate house was not completely closed at the time of inspection and significant migration of soil and infiltration of water through the intake was apparent. No water movement through the upper two intakes was observed. The intake flanges on the exterior of gate house exhibited marine growth with minor surface corrosion.

2.3 Reservoir Bottom

The reservoir bottom generally consisted of loose silt and suspended gravel, with up to 1 foot of penetration. Riprap was observed along the north and south ends of the dam, with the toe of the riprap located at approximately 0+50 on the south end of the dam and 2+70 at the north end of the dam, where the slope transitioned to the loose silt and gravel profile. Scattered debris was observed adjacent to the dam, consisting of timber branches with diameters up to 3 inches and tree segments with diameters up to 12 inches. No

locations of scour or any indication of soil migration through the dam was observed along the face of the structure, other than a small depression around the gate house, likely due to water movement through the lower gate intake.

A retaining wall was detected in the 3-D acoustic imaging, located at station 1+65 approximately 10 feet from the face of the dam. The retaining wall appears to have originally been installed to retain the northern slope; however, the imaging indicates that the bottom contours have changed such that the wall is no longer required for slope stability.

TABLE 2-1: SUMMARY OF OBSERVED DEFECTS

Defect Type	Defect Center	Distance Below Top of Dam (ft)	Length (ft)	Height (ft)	Crack Width (in)	Depth (in)	Comments
Horizontal Crack	0+70	35	30	1/8	1/8		
Concrete Void	1+22	24	4	1		2	1 exposed bar
Surface Degradation	1+22	45	4	2.5		2	
Leaking Intake Valve	1+10	52					Intake not completely sealed
Open Constr. Joint	1+28	50	30		3/4	3	Failed sealant
Horizontal Crack	1+33	25	12		1/8		
Surface Degradation	1+40	60	6	6		1	
Surface Degradation	1+50	43	6	4		4	
Horizontal Crack	1+50	33	12		1/16		
Open Constr. Joint	1+65	41	15		3	5	Failed sealant
Horizontal Crack	1+85	33	20		1/8		
Surface Degradation	1+90	38	3	1		4	
Open Constr. Joint	1+95	45	20		2	3	Failed sealant
Surface Degradation	2+15	40	6	1		4	
Vertical Crack	2+15	25	4		1/8		Continues above waterline
Horizontal Crack	2+35	25	10		1/16		
Open Constr. Joint	2+35	23	15		1		Failed sealant
Concrete Void	2+40	33	2	1		3	
Surface Degradation	2+52	40	15	2		2	
Surface Degradation	2+60	35	8	2		1	Prior Repair

Note: Surface Degradation typically consisted of honeycombing and soft concrete 2-4 inches deep.

3.0 EVALUATION AND RECOMMENDATIONS

Soft concrete 1/8 inch to 1/4 inch deep was typically observed on the concrete surface, with deeper degradation and isolated voids up to 4 inches deep identified on approximately 132-sf of the dam face (approximately 3% of the underwater dam face). Approximately 85-lf of cracks were observed; however, the concrete was generally sound around the cracks. The deterioration observed does not indicate advanced deterioration or any reduction in structural capacity, and as a result the structure is in Satisfactory condition.

Recommended repairs include repairing the areas of deteriorated concrete and voids to maintain the integrity of the structure; however, the repairs can be completed on a low-priority basis. Repairs would consist of removal of soft and deteriorated concrete down to sound concrete, forming around the limits of the repair area, and placement of new concrete. All concrete repair work can be completed underwater by using a form-and-pump method with a marine grade concrete or a polymer-modified mortar such as Octocrete U. Concrete repairs may also be completed in the dry using temporary cofferdams, however this approach is far more expensive and generally used where more critical structural repairs are required; therefore this repair method is not warranted for this project. Additionally, the leaking intake valve should be investigated to determine the cause and the issue resolved on a low-priority basis.

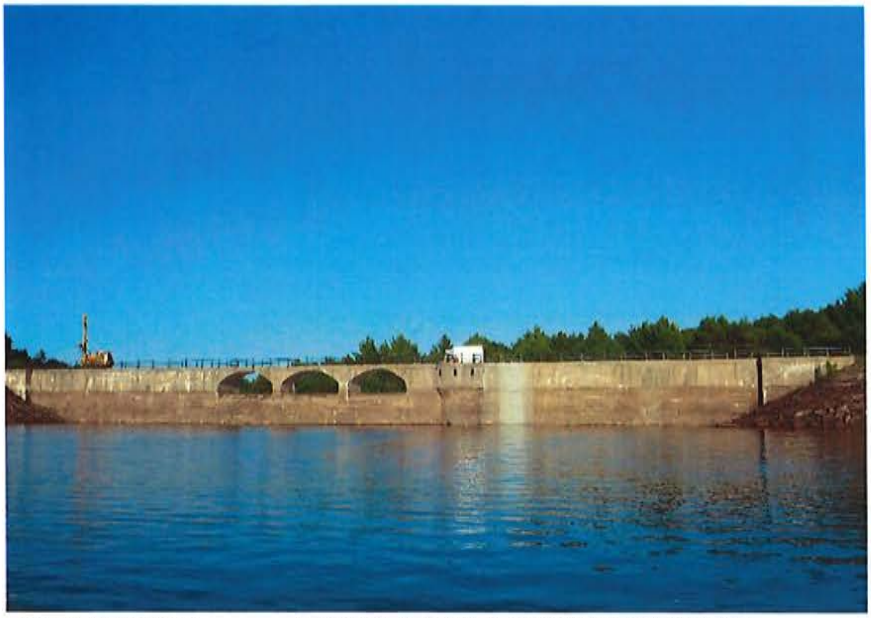
Typically, crack repairs are completed on concrete structures to limit water intrusion and corrosion of embedded reinforcing steel. However, the dam is a mass-concrete structure with minimal to no reinforcing steel, and due to the age of the observed cracks, water infiltration has already occurred. Therefore, sealing the cracks and open construction joints is not warranted at this time.

Based on the inspection findings, it is recommended that the submerged portions of the structure be routinely inspected at an interval not to exceed 60 months to monitor crack propagation and progression of deterioration.

Respectfully Submitted,
COLLINS ENGINEERS, INC.

Daniel W. O'Connor, P.E.
Regional Manager

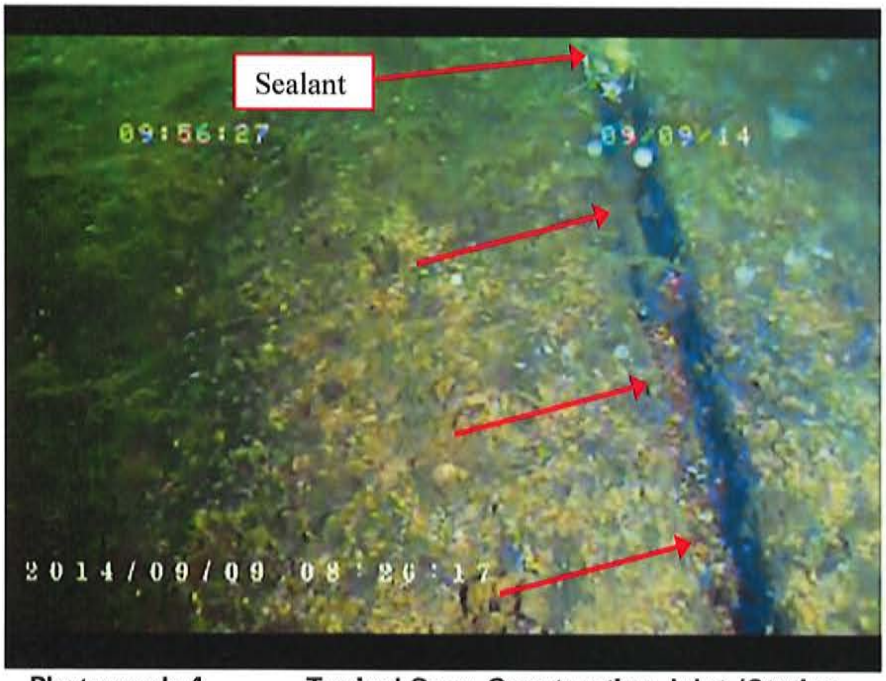
EXHIBIT A – INSPECTION PHOTOS



Photograph 1. Overall View of the West Elevation, Looking East.

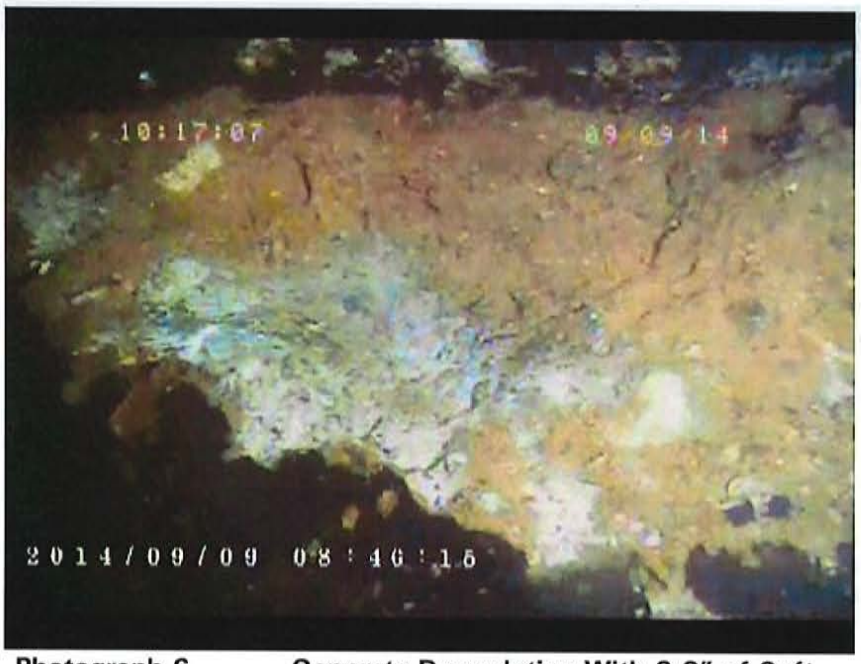
Photograph 2. Overall of the West Elevation, Looking Northeast.

Photograph 3. Typical Horizontal Crack (Station 1+80 shown).

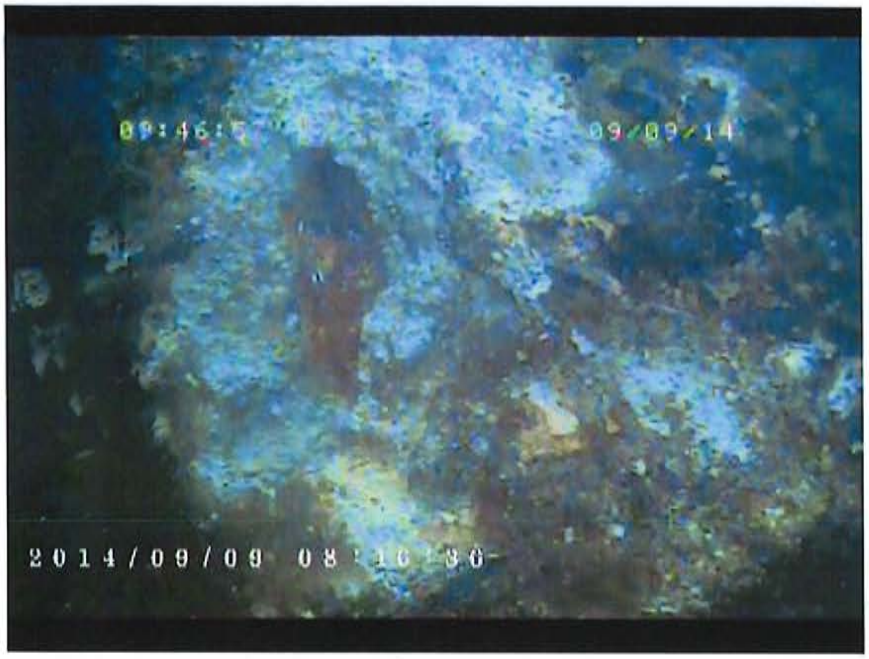


Photograph 4. Typical Open Construction Joint (Station 1+28 Shown. Note Sealant Intact at Top)

Photograph 5. Typical Concrete Condition with 1/8" to 1/4" Soft Concrete (Station 1+15 Shown)

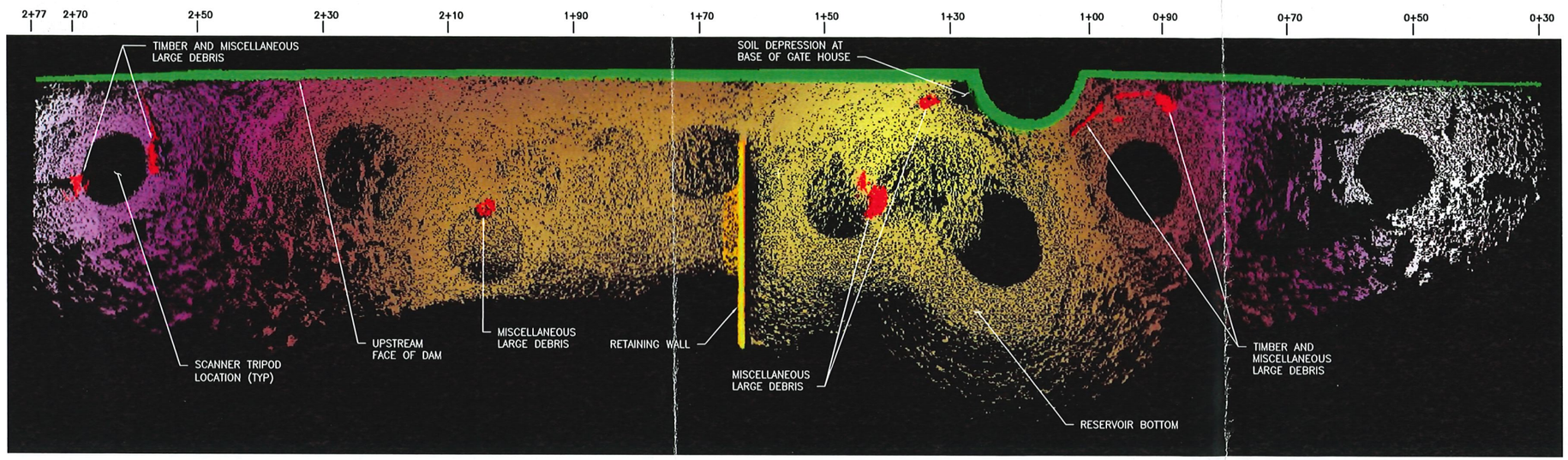


Photograph 6. Concrete Degradation With 2-3" of Soft Concrete (Station 1+50 shown).



Photograph 7. Spall with Exposed Reinforcing Steel at Gate House (Station 1 + 22).

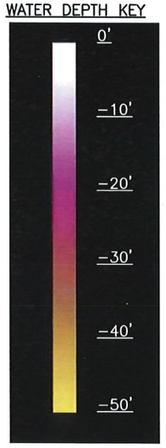
EXHIBIT B – ACOUSTIC SCAN IMAGES

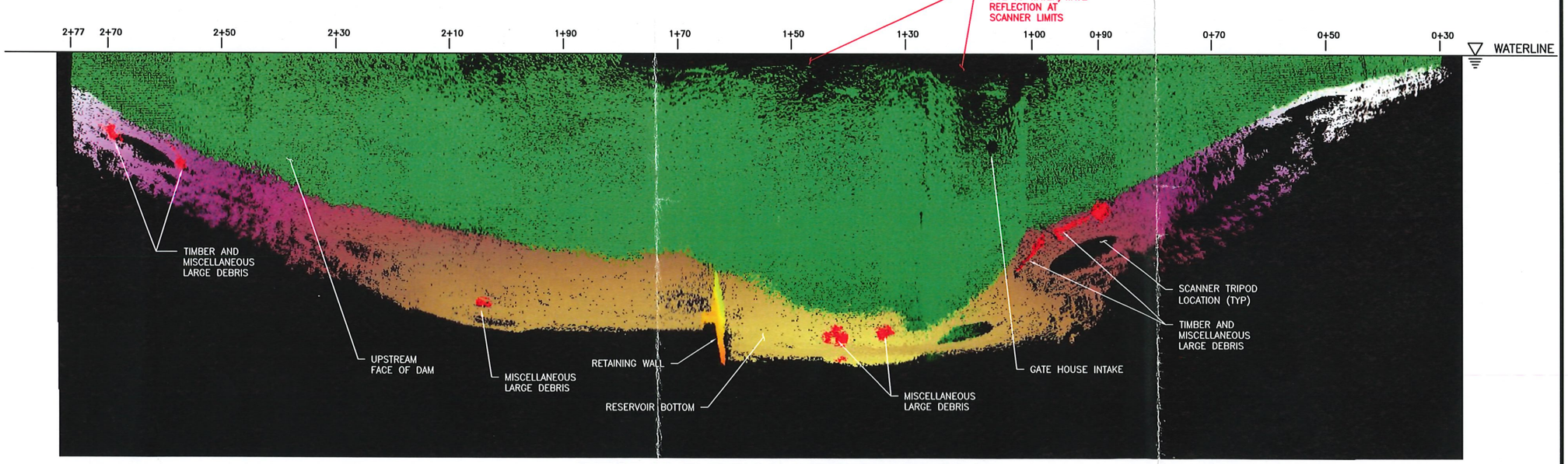


PLAN VIEW OF DAM

SCALE: 1"=20'-0"

WATER DEPTH KEY

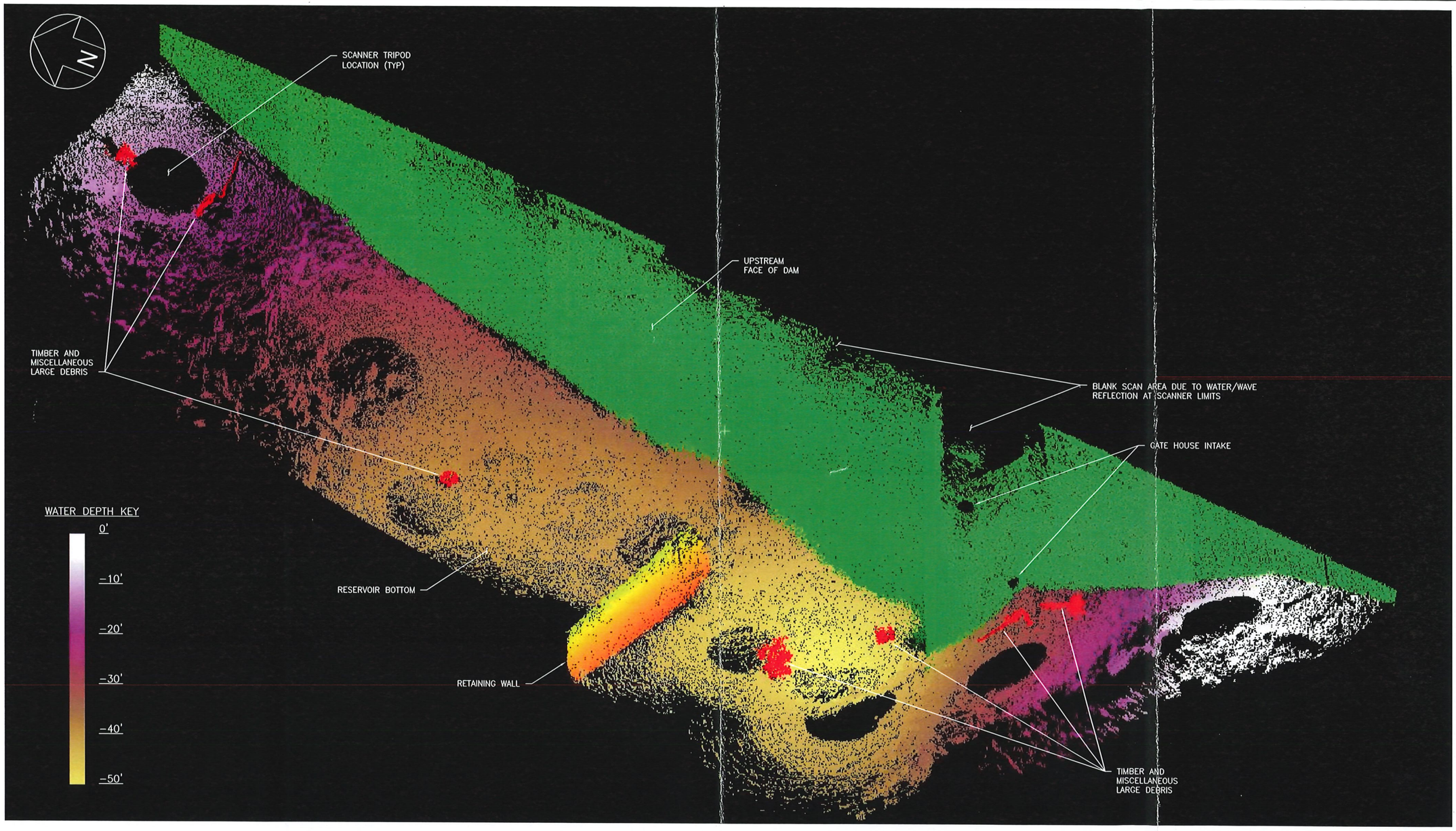




WEST ELEVATION (UPSTREAM FACE)

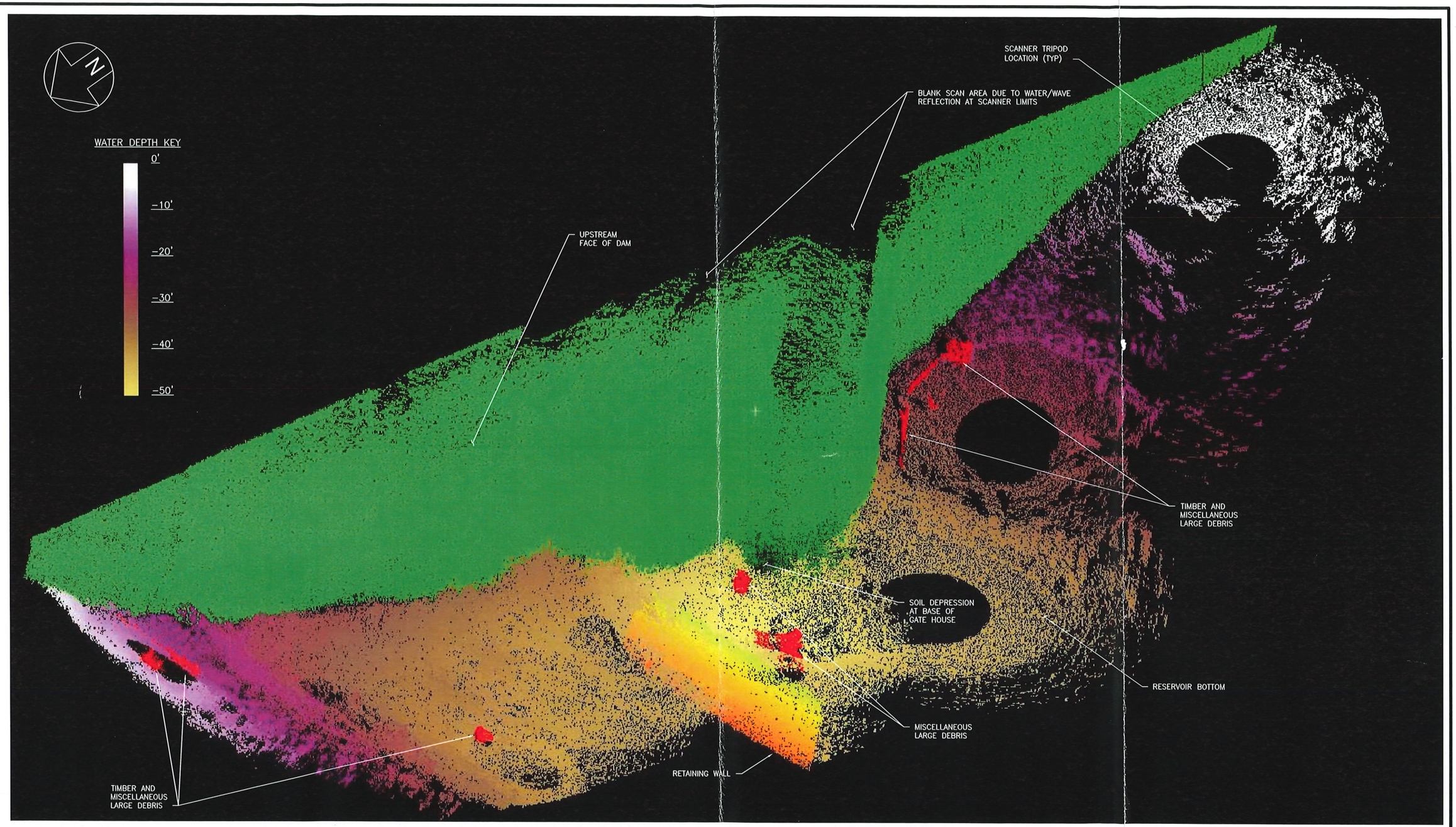
SCALE: 1"=20'-0"
NOTE: VERTICAL SCALE SKEWED DUE TO ISOMETRIC VIEW

GRAPHIC SCALE (FEET)	DATE		
0 10' 20' 40'	NOVEMBER 2014	COLLINS ENGINEERS, INC. 650 ISLINGTON STREET, SUITE 1 PORTSMOUTH, NH 03801 COLLINS ENGINEERS SUBCONTRACTOR FOR: CDM Smith	CITY OF WORCESTER, MA PINE HILL RESERVOIR DAM STATE DAM ID# 3-14-134-6 HOLDEN, MA PINE HILL RESERVOIR DAM ACOUSTIC IMAGING FIG. NO. B1



NORTHEAST ISOMETRIC VIEW OF DAM

GRAPHIC SCALE (FEET) **NOT TO SCALE**	DATE NOVEMBER 2014	COLLINS ENGINEERS, INC. 650 ISLINGTON STREET, SUITE 1 PORTSMOUTH, NH 03801 SUBCONTRACTOR FOR: CDM Smith	CITY OF WORCESTER, MA PINE HILL RESERVOIR DAM STATE DAM ID# 3-14-134-6 HOLDEN, MA PINE HILL RESERVOIR DAM ACOUSTIC IMAGING FIG. NO. B2



SOUTHEAST ISOMETRIC VIEW OF DAM

GRAPHIC SCALE (FEET) **NOT TO SCALE**	DATE NOVEMBER 2014	COLLINS ENGINEERS, INC. 650 ISLINGTON STREET, SUITE 1 PORTSMOUTH, NH 03801 COLLINS ENGINEERS SUBCONTRACTOR FOR: CDM Smith	CITY OF WORCESTER, MA PINE HILL RESERVOIR DAM STATE DAM ID# 3-14-134-6 HOLDEN, MA PINE HILL RESERVOIR DAM ACOUSTIC IMAGING FIG. NO. B3

TTL CADD DWG \\COLLINSENGR.COM\IL\DATA-NH\REGULAR PROJECTS\15-08612.00 - PINE HILL RESEVOIL RESEVOIR DAM UW INSPECTION\REPORT\DRAWINGS\DEFECT PLAN.DWG Nov 10, 2014 - 3:34pm
ZJENKINS

EXHIBIT C – REQUIREMENTS FOR BOAT AND EQUIPMENT DECONTAMINATION

City of Worcester – Department of Public Works and Parks
Pine Hill Reservoir Dam Inspection

Requirements for Boat and Equipment Decontamination for Aquatic Nuisance Species Control and Overall Environmental Protection

A. Boat/Motor/Trailer/Equipment – Inspection and Cleaning

All inspection/cleaning/rinsing/drying should take place offsite at a facility that supplies potable water in a location that will not impact the water body to be protected.

1. Check and clean all of the systems and components that ***apply specifically to the craft and gear*** from among the following:

    a. Boat Exterior: Entire hull, floor, transom wall, ballast tanks, ropes and lines, anchors, lights, pitot tube, depth sounders, trim tabs, cavitation plates, thru-hull fittings, depth transducers, water intakes and outlets.

    b. Motor: Entire exterior housing, propeller, propeller shaft, propeller shaft support, propeller guards, propulsion units, lower unit, gimbal area, water intakes and outlets.

    c. Boat Equipment and Contents: All lines and ropes, float belts, life jackets, float cushions, gloves, equipment lockers, clothing and footwear, floats, fenders, dock guards inner tubes and other inflatable items, buckets, and internal ballast tanks.

    d. Trailer: Trailer frame, axles, license plate and holders, lights and wiring, fenders, hangers, trailer tires and wheels, rollers and bunks, wiring, springs, pockets and hollow spaces

2. Thoroughly inspect all exposed surfaces on vessel and trailer. Scrape off any mussels and kill them by crushing them. Dispose of all material in the trash.

3. Remove all plants and mud from boat, motor, trailer, and all equipment. Dispose of all material in the trash.

4. Start and run engine for 5 minutes using a freshwater hose to flush the engine. The engine should be flushed every time the boat is moved from one body of water to another.

    a. The flushing can utilize the backwash port if the engine is so equipped.

    b. If the engine is not equipped with a backwash port, the flushing earmuffs can be used.

c. If the engine cannot be run and flushed for five minutes, it cannot be used.

5. Stop the engine and remove all plants, mud, and other contaminants from the steering nozzle and the rest of the hull.

6. Carefully feel the boat's hull for any rough or gritty spots, which may be young mussels that have settled on the vessel and cannot be seen. Microscopic mussels will feel like sandpaper.

7. Wash the boat's hull, trailer, equipment, bilge, and any other exposed surfaces with high-pressure, hot water. When possible use water at a temperature of 140° F (60° C) at the hull – or about 155°F (68° C) at the nozzle. Factors for effective power washing include:

   a. Use water that is 140 degrees Fahrenheit (at the point of contact) to achieve the adequate kill.

   b. Allow at least 10 seconds to elapse from the leading edge of the spray to the tailing edge when moving the wand across the surface to maintain sufficient "lethal" contact time.

   c. Use a power wash unit capable of spraying at least 4 gallons/minute with a nozzle pressure of 3,000 psi or greater (not to exceed 3,500 psi) on all exposed surfaces of the watercraft, equipment, trailer and engine.

   d. A brush may also be used in conjunction with flushing for hard-to-access areas.

   e. Maintain a contact time of 60 seconds for hard to reach and sensitive areas to assure kill.

   f. Clean the boat hull systematic fashion and all solids removed from the vessel need to be disposed of in a proper fashion.

   g. Use the appropriate attachment connected to the power wash unit or other hot water source, start the vessel's engine and run for 1-2 minutes to kill mussels in the engine cooling system.

8. Drain all water from the boat (pull all plugs) and dry all areas, including the motor, motor cooling system, live wells, ballast tanks, bladders, bilges, and lower outboard units. Dry any pockets that may be wet or holding water.

9. Make sure that all items that have been in the water, including life jackets, anchors, ropes, etc., are inspected, cleaned, and dried.

10. Clean and dry personal belongings, clothing, and footwear that have come in contact with the water.

11. If possible, keep the watercraft dry for at least five days in warm, dry weather and up to 30 days in cool, moist weather before launching.

B. Dive Gear – Inspection and Cleaning

1. Check/inspect all gear that could potentially hide any water (potentially containing veligers). This should include regulators, buoyancy compensation device (BCD), wetsuits, masks, gloves, boots, snorkels, and any other dive gear. Veligers are the larvae produced by nuisance mussels and they are too small to see with the naked eye.

2. Thoroughly clean all regulators, BCDs, wetsuits, masks, snorkels, and any other dive gear, making sure to clean both the inside and outside of the BCD to ensure that no mud or organic matter is present – use a brush to scrub if necessary.

3. After cleaning, soak gear used in freshwater dives in 3.5% salt solution (1/2 cup salt per gallon of water). Can also use potassium at 100mg/liter at a temperature of >30° C, or using commercially available dive equipment cleaning compound that contains ammonia, vinegar, or chlorine. Dispose of cleaning solution properly.

4. Rinse inside and outside of gear with hot water.

5. Drain all water from all equipment.

6. Allow gear, suit, and other equipment to dry before diving. Veligers can survive on a wetsuit if left damp. Dry everything at least five days (in warm temperatures; longer in colder weather) to kill small species not easily seen OR wipe with a towel before reuse.

7. Wipe all areas down with a towel before reuse. Completely dry all equipment before reusing.

8. If feasible, consider freezing equipment overnight to kill any veligers.

C. Environmental Protection

1. Four stroke engines are mandatory. Two stroke engines are not allowed.

2. No more than 10 gallons of fuel are allowed on board the boat.

3. A spill containment boom shall be maintained on site at all times.

4. No equipment or gear shall be serviced, repaired, lubricated, or refueled within 100 feet of the reservoir or downstream channel, and shall be done in an area that does not drain into the reservoir or downstream channel.

5. No fishing, hunting, swimming, wading, dogs or other animals, feeding wildlife, fires, or alcoholic beverages are allowed.

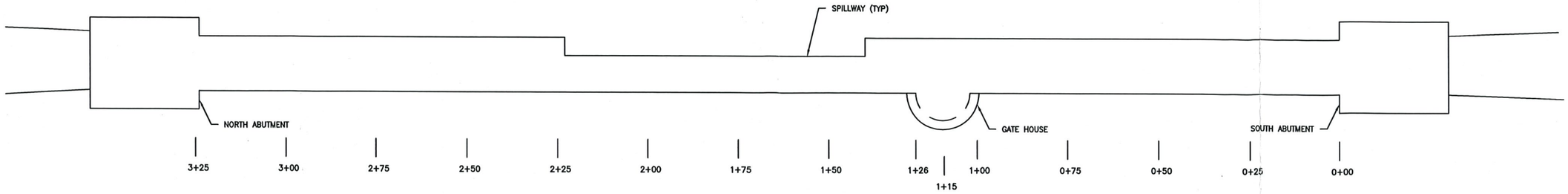
6. No disposal of materials in the reservoir or watershed area is allowed.

7. No acts that pollute the water supply are allowed.

8. All daily work activities must be completed such that all visitors are off-site before dusk.

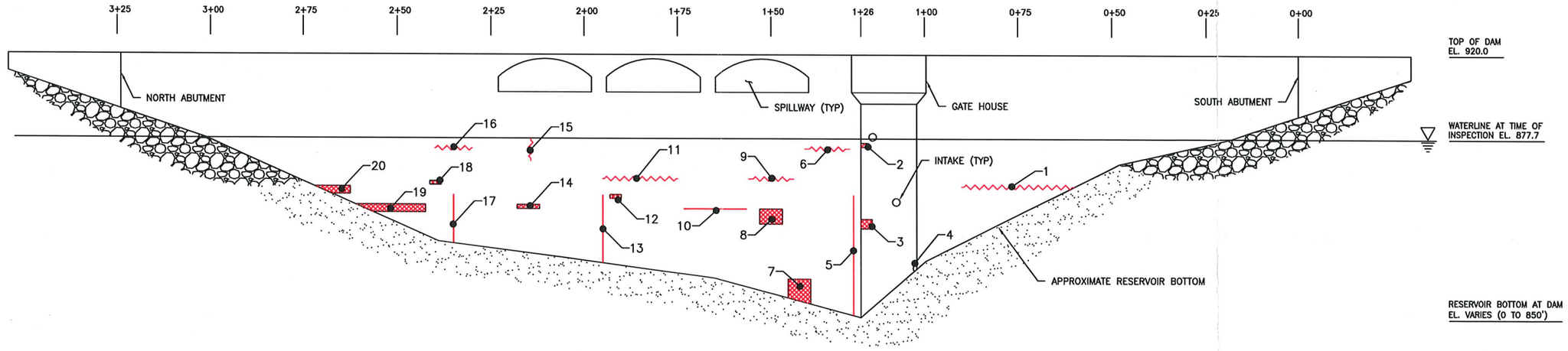
9. The two sets of gates at the Kendall Road entrance shall be closed behind all entering and exiting vehicles. During normal working hours, the gates can remain unlocked (but closed at all times). The last vehicle to leave the site each day shall lock all gates.

EXHIBIT D – DEFECT DRAWINGS



PLAN VIEW OF DAM

SCALE: 1"=30'-0"



ELEVATION VIEW OF UNDERWATER DEFECTS

SCALE: 1"=30'-0"

LEGEND

0+00 STATION

CONCRETE VOID OR SURFACE DEGRADATION

CONCRETE CRACK

OPEN CONSTRUCTION JOINT

1 DEFECT ID (SEE SHEET D2 FOR CORRESPONDING TABLE OF OBSERVED DEFECTS)

NOTE: ELEVATIONS REFERENCED TO NGVD 29 DATUM

GRAPHIC SCALE (FEET)

0 30' 60'

DATE

NOVEMBER 2014

COLLINS ENGINEERS, INC.
650 ISLINGTON STREET, SUITE 1
PORTSMOUTH, NH 03801
COLLINS ENGINEERS
SUBCONTRACTOR FOR:
CDM Smith

CITY OF WORCESTER, MA

PINE HILL RESERVOIR DAM

STATE DAM ID# 3-14-134-6 HOLDEN, MA

PINE HILL RESERVOIR DAM
UNDERWATER INSPECTION

FIG. NO. D1

TABLE D-1: SUMMARY OF OBSERVED DEFECTS

Defect ID#	Defect Type	Defect Center	Distance Below Top of Dam (ft)	Length (ft)	Height (ft)	Crack Width (in)	Depth (in)	Comments	Photo (See Exhibit A)
1	Horizontal Crack	0+70	35	30	1/8	1/8			
2	Concrete Void	1+22	24	4	1		2	1 exposed bar	Photo No. 7
3	Surface Degradation	1+22	45	4	2.5		2		
4	Leaking Intake Valve	1+10	52					Intake not completely sealed	
5	Open Constr. Joint	1+28	50	30		3/4	3	Failed sealant	Photo No. 4
6	Horizontal Crack	1+33	25	12		1/8			
7	Surface Degradation	1+40	60	6	6		1		
8	Surface Degradation	1+50	43	6	4		4		Photo No. 6
9	Horizontal Crack	1+50	33	12		1/16			
10	Open Constr. Joint	1+65	41	15		3	5	Failed sealant	
11	Horizontal Crack	1+85	33	20		1/8			Photo No. 3
12	Surface Degradation	1+90	38	3	1		4		
13	Open Constr. Joint	1+95	45	20		2	3	Failed sealant	
14	Surface Degradation	2+15	40	6	1		4		
15	Vertical Crack	2+15	25	4		1/8		Continues above waterline	
16	Horizontal Crack	2+35	25	10		1/16			
17	Open Constr. Joint	2+35	23	15		1		Failed sealant	
18	Concrete Void	2+40	33	2	1		3		
19	Surface Degradation	2+52	40	15	2		2		
20	Surface Degradation	2+60	35	8	2		1	Prior Repair	

NOTE:
1. SURFACE DEGRADATION TYPICALLY CONSISTS OF HONEYCOMBING AND SOFT CONCRETE 2–4 INCHES DEEP.
2. SEE FIGURE D1 FOR CORRESPONDING DEFECT LOCATIONS

GRAPHIC SCALE (FEET)	DATE	COLLINS ENGINEERS, INC. 650 ISLINGTON STREET, SUITE 1 PORTSMOUTH, NH 03801 COLLINS ENGINEERS SUBCONTRACTOR FOR: CDM Smith	CITY OF WORCESTER, MA PINE HILL RESERVOIR DAM	
NOT TO SCALE	NOVEMBER 2014		STATE DAM ID# 3-14-134-6 HOLDEN, MA PINE HILL RESERVOIR DAM UNDERWATER INSPECTION	FIG. NO. D2