APPENDIX B

“PICKEL REPORT”

May 15, 1964

TAUM SAUK PROJECT
UPPER RESERVOIR
CORRECTIVE WORK - MARCH 14 TO APRIL 17, 1964

General

An outage of five weeks, beginning March 15, was scheduled to permit remedial work in the upper reservoir. During February and early March, a detailed program of contemplated work was developed, which included evaluation and testing of several types of sealing materials.

Dr. F. A. Nickell, consulting geologist, visited the project on February 21. He reviewed and concurred with the proposed plans, and recommended several additional features which were adopted.

The actual work closely followed the proposed plans, except where specific conditions indicated that modifications were in order. In general, these modifications increased the scope of work, and resulted in a more thorough job of sealing.

Various phases of the work are described in detail below.

Reservoir Draining and Inspection

The pool elevation had been lowered to about 1510 by normal plant operation. On March 14 it was lowered to 1503 by low-load generation, to allow time for any water trapped behind the face apron to bleed off. No water was observed to flow from cracks in the face apron, although this condition was common during previous drawdowns.

Extreme caution was observed in lowering level in the vortex basin below 1503, in order to avoid additional ruptures in the asphalt floor seal. The access tunnel gate was lowered on March 15, and pumping out of the depressed area commenced.

Significant observations during and after emptying the reservoir include the following:

1. A large number of cracks in the face apron - particularly at Panels 72 to 77 - were filled with leaves tightly packed. Even hair-line cracks had leaves sucked in.

2. Very few vertical expansion joints showed evidence of leaves being sucked in.

3. Igas caulking in the horizontal toe block joint had been depressed or failed in a number of places.

4. As level in the vortex basin was drawn down below 1500, air was sucked in through the asphalt floor at several places on both sides of the rain dike.

5. A rather rapid drawdown from 1496 to 1492 on March 17 caused a concrete patch in the vortex floor (about 75 feet from the shaft) to blow out.

6. The old crack in the depressed area floor had re-appeared in front of Panels 91 to 93. It was about 150 feet long, 3/4" wide at the maximum and tapering to nothing at the ends.

7. The general condition of the asphalt floor was excellent, except in the vortex basin where it was covered with 8 to 12 inches of sawdust, cinders, Bentonite clay, and leaves, and immediate inspection could not be made.

All toe blocks and face apron berms were covered with cinders, mud, gunite rebound, etc. These were thoroughly washed with fire hoses to permit detailed inspection and sealing of cracks.

Horizontal Expansion Joint and Toe Block

The horizontal joint above the toe block for the entire periphery of the reservoir had been caulked with Igas during the December, 1963 overhaul. In addition, Igas stoppers had been placed in the vertical joints above the toe block to prevent water from following the copper seal and getting behind the Igas of the horizontal joint.

All previous Igas work was carefully inspected and repaired where necessary. Most of the repairs were in areas where the caulking material had not bonded to the concrete properly. In such cases, the old material was removed, the surfaces cleaned and re-primed, and new material applied. The largest areas of this nature were at Panels 43 to 45, 69-70, and 90, where the entire length had not bonded.

At Panels 65 to 68, the test section of Silicone sealant in the toe block joint was removed and replaced with Igas.

After repairs were made, all joints were gone over with hot irons to smooth out the surface and to check bond to the concrete.

Several sections of toe block showed cracks. In chipping out three cracks for repair, large sections of concrete above the copper expansion joint - about four feet in length - broke out. These areas were primed with concrete adhesive and dry-packed with sand-cement mortar before the Igas repair was made.

Three hundred and five gallons of Igas were used in making joint repairs, and for stoppers in vertical joints.

At the toe of Panel 43 there was evidence of leakage between the toe block and the asphalt floor. This had been repaired previously with Igas, but the patch did not hold. The repair made under this program consisted of a concrete block about two feet high poured against the toe block. This construction extended beyond the end of the Panel 43 toe block and along the face apron of Panel 42, for a total length of 80 feet. The block was dowelled to the floor and also horizontally to the toe block or face apron. Twenty cubic yards of concrete were used.

Vertical Expansion Joints to Elevation 1565

The vertical expansion joints between face panels have long been suspected as a big contributor to the leakage, either through ruptures in the copper seal, or porous concrete at the edges of the copper. Evidence to support this supposition was obtained in February, 1964, when dye was injected through plastic tubes into twenty joints selected in areas of leakage. Eleven of these tests showed dye in leakage at the outer toe.

Physical inspection of the copper seal was attempted by removing short sections of the asphalt impregnated board. A few small holes were observed, but at least some of them were made by chisels during removal of the board. Because of possible additional damage to the copper, further inspection was discontinued.

It was decided to seal these joints at the face slab surface. The material chosen for this work was Silicone Sealant, furnished by General Electric Company. When properly installed and cured, this material develops the required strength and elasticity, and also bonds to the concrete.

The initial phase of this work was carried only to Elevation 1565, so that there would be a reasonable chance of completing and curing all joints within the time allowed.

Procedures for applying this sealant were as follows:

1. Chip out asphalt board in joint to a depth of about 1-1/2 inch. Where board had been cut too deep, it was built up with redwood strips. Some joints had opened up to such an extent that redwood board had to be inserted along the side of the asphalt board.

2. Exposed concrete edges in the joint were cleaned to remove asphalt, and then ground. Grinding was extended about one inch on the face slab surface on either side of the joint to remove loose concrete and rebound.

3. The ground concrete surfaces were painted with Silicone masonry primer.

4. Immediately after priming, the joint was partially filled with "Ethafoam" rope 3/4" or 1" diameter, or with 1/2" thick "Ethafoam" sheet, depending on width of the joint. The purpose of this was to provide a backing under the sealant, and also to prevent a bond between the sealant and the asphalt board.

5. The unfilled portion of the joint was now about 3/8" deep. Silicone sealant material was extruded into this space and worked with paddles to remove air bubbles. During this finishing process material was carried beyond the joint to provide a one inch lap about 1/8" thick on the panel faces.

At the bottom of each Silicone joint, a relief device was installed to reduce hydrostatic pressure behind the Silicone during reservoir drawdown. This consisted of a 3/8" check valve and 1/2" OD copper tube. The tube was worked through the asphalt board to the copper expansion joint, and sealed in place with Igas.

At the top of each Silicone joint (Elevation 1565), a stopper was installed to prevent water from entering along the copper expansion joint from above. A small section of asphalt board was removed and the space was then filled with Igas.

A total of 114 joints were sealed by this method, requiring 480 gallons of Silicone sealant.

Four joints were reserved for a test installation using Carboline caulking compound. These joints are at Panels 35-36, 36-37, 60-61, and 61-62. Preparation and application was essentially the same as for Silicone, except that the materials used were Carboline No. 190 primer, and Carboline No. 704 caulking.

Vertical Expansion Joints Above Elevation 1565

The second phase of joint sealing was to complete all vertical expansion joints from Elevation 1565 up to the horizontal joint below the parapet. Work was planned so that this could be accomplished with water in the reservoir to Elevation 1562.

Procedure was the same as for the initial phase. The stopper at 1565 was removed to a depth of about 1-1/2 inch, and replaced with "Ethafoam", so that any leakage in the upper section would have a connection to the vent valve at the bottom of the joint.

An additional Igas stopper was located at the horizontal joint below the parapet.

Four vertical parapet joints were also sealed with Silicone. These are located at Panels 11-12, 16-17, 30-31, and 32-33, which were observed to be leaking on previous occasions.

A total of 225 gallons of Silicone were used in the second phase, which was completed on April 30, 1964.

Face Apron Repairs

The face apron refers to those areas where original rock extended above the reservoir floor and formed a part of the dike after excavation. The excavated face was sealed by a four inch layer of "Gunall" concrete and wire mesh as part of the original construction.

In practically all of these face apron areas there is at least one major crack, generally horizontal, in some cases as much as 1/2" wide. In addition, there are numerous smaller cracks varying from hair-line to 1/16" wide. These appear in a random horizontal and vertical pattern.

The major cracks had been repaired several times in the past, either by guniting, grouting, or caulking with Igas and other materials. This old material was chipped out and the cracks were thoroughly cleaned. The exposed surfaces were then painted with Carboline No. 192 Adhesive, after which the crack was dry-packed with sand-cement grout. In the larger cracks, a parting-strip of tar paper was inserted in the grout joint above the original fracture to localize any future movement or shrinkage.

The above preparatory work was to provide a back-up for the final sealing membrane which was applied in the following steps:

1. Face apron surface along the grouted joint and several inches on either side was sand blasted to remove dirt and loose concrete.

2. The cleaned surface was sprayed with Carboline No. 190 primer and allowed to dry for 24 hours.

3. A thin layer of Carboline No. 706 caulking was applied to the grouted portion of the joint, the purpose being to permit the final membrane to adjust to movement without developing high localized stresses.

4. The sealing membrane, Carboline No. 1304, was sprayed over the entire joint to a thickness of about 40 mils. This membrane was bonded to the original gunall surface on either side of the crack.

Minor cracks (1/16 inch and less) were sealed with Carboline membrane in the same manner as the major cracks, except that the chipping and grouting operations were omitted. A layer of Carboline No. 706 caulking placed over the crack serves as backing for the final membrane.

Hair-line cracks were not to be sealed under the scope of work originally planned. However, these cracks were so numerous and extensive that the work was extended to include as many as time and materials permitted. The general procedure involved sandblasting, priming with Carboline No. 190 primer, and spraying with Carboline No. 1304 membrane. In the final stages of the work (Panels 50 to 68) Carboline No. 704 caulking or General Electric Silicone sealant was substituted for the Carboline membrane in some areas.

Face apron sealing required the use of 37 gallons of primer, 72 gallons of Carboline No. 704 and 706 caulking, and 50 gallons of Carboline No. 1304 membrane.

Dr. F. A. Nickell had expressed the opinion that these face apron cracks were caused by hydrostatic pressure behind the gunall during reservoir drawdown. In accordance with his recommendations, a total of 104 relief devices were installed. These consist of 3/4" ball check valves on pipe nipples grouted into the face apron after 2-1/4" holes had been drilled two to three feet into rock. Holes were located by inspection in areas where water was seeping through the gunall, or in cracks. They are three to six feet above the floor, and average about three per panel.

Depressed Area Floor

In accordance with plans, the long crack in the asphalt floor of the depressed area was repaired by covering it with a reinforced concrete slab. Conveyor belting was placed over the actual crack after first

placing a 2" layer of concrete. Another layer of concrete was then placed on top of the belt to seat it and hold it in place. After this concrete had set up, the 10" slab reinforced with 4 x 4 No. 6 mesh was poured. This slab extends from the toe block at Panel 90 to the middle of Panel 94, and is a minimum of ten feet wide. One hundred and ten cubic yards of concrete were used.

Edges of this slab where it rests on the asphalt floor were caulked with Igas.

This crack and slab are located in a low trough which receives the entire initial rush of water when this part of the reservoir is filled. To dissipate the energy and reduce the velocity at the lower end, several one-ton boulders were placed along the edge of the slab.

Prior to pouring the slab, a considerable amount of pressure grouting was done in that general area. A detailed description is given in a subsequent section.

Vortex Basin

Original plans did not contemplate any extensive repairs in this area other than a small amount of pressure grouting.

The blow-out at a previously repaired rupture was cleaned out and patched with concrete. Two 1-1/2" pipes with check valves were installed prior to placing the concrete.

A similar concrete patch in the floor near Panel 49 showed evidence of leakage and having raised up. This was completely removed and replaced with new concrete and a 1-1/2" check valve vent.

Construction equipment working in the area broke off or damaged 15 of the 3/4" check valves installed in November. The nipples were removed and the holes filled with grout.

Two holes showed running water all during this outage. In order to grout these holes it was necessary to install relief pipes, which were then closed with 1-1/2" check valves.

Green, red, and blue dye was inserted in several vent pipes for the purpose of tracing and identifying future leakage. Location of dye and other features described above is shown by Sketch No. 1.

Pressure grouting in the vortex basin area is described in the following section.

Pressure Grouting

Panels 72 to 77 As the major horizontal crack in the face apron in this area was being cleaned out and old patching material removed, some voids and hollow spots were visible below the gunall face. It was then decided to consolidate the rock by pressure grouting, with a line of grout holes below the crack and another line above it.

Two and one-half inch drill holes ten feet deep were drilled on ten foot centers. All holes were diagonal or sloping. The bottom row of holes encountered some discontinuity as compared to solid hard rock at various depths to about eight feet, after which the rock was hard. The upper row was generally more sound. A number of vertical holes were drilled at the top of the berm, but since these had to be hand drilled, and the rock was hard, this row was not completed.

A total of 100 holes were drilled in this area and required 1,108 cubic feet of cement grout to fill. Grout requirement varied from a minimum of one to a maximum of 155 cubic feet per hole. In most cases the holes held a pressure of 50 to 60 psi after filling, although in one case the gunall face was cracked with a pressure of 30 psi.

Location of holes and distribution of grout is shown by Sketch No. 2.

Depressed Area Additional grout holes were drilled in the depressed area in front of Panels 90 to 95. These were on a line parallel to and about four feet from the original grout curtain placed in November, and were spotted between the original holes. Additional holes along the toe block and across the depression were also drilled, as shown on Sketch No. 3.

Holes were drilled 10 and 20 feet deep. Generally the drill encountered several feet of clay and soft or broken rock, with hard rock consistently below seven feet.

A total of 97 holes were drilled, and required 2,739 cubic feet of grout. In some cases the grout pressure held at 40 to 60 psi, but as a general rule grouting had to be stopped when the asphalt floor started to raise. In several cases grout appeared in adjacent holes. Maximum take for one hole was 278 cubic feet.

See attached Sketch No. 3 for grout distribution.

Vortex Basin In this area, grout holes were drilled in three separate locations.

Along the rain dike a row of ten foot holes on ten foot centers was drilled, and also several random holes where air had been sucked in during emptying of the reservoir. Rock in this area is shattered for several feet, with some voids, then generally hard. After the initial holes had been grouted, six additional holes were drilled near one which had taken 37 cubic feet. These were drilled diagonally to a depth of 30 feet. When grouted, the average requirement was five cubic feet. The total requirement was 185 cubic feet for 29 holes.

At the toe in front of Panels 53 to 56, sixteen holes 20 feet deep were drilled between old grout holes. As in the previous grouting program, considerable trouble with water was encountered. The total requirement for these holes was 169 cubic feet.

Along the slope between the shaft and the rain dike, a series of ten foot holes on 10 foot centers was drilled. After grouting, intermediate holes 20 feet and 30 feet deep were drilled. The drilling process was very difficult because of broken rock up to six feet below the surface. Below six feet the rock was generally sound and hard, but many cavities were encountered. Three of the ten foot holes were redrilled to a depth of 20 feet after initial grouting. Although one of these holes had taken 123 cubic feet initially, none took more than four cubic feet when redrilled. A total of 77 holes required 2,828 cubic feet of grout.

Location of grout holes and distribution of grout in the vortex area is shown by Sketch No. 4.

Vertical Shaft Inspection

On April 11, a Union Electric engineer inspected the vertical shaft to a depth of about 200 feet suspended from a crane cable. Portable radio sets were used for communication.

The gunite lining to a depth of 130 feet was generally in good condition. A 2" hole about 100 feet down had been observed before the plant went into operation, and was in essentially the same condition at this time. Four small holes about 1/2" in diameter were noted, with evidence of previous leakage, but were not leaking at this time.

Two areas about 18 inches in diameter have a top layer of gunite spalled off, about 1/2" deep.

Just below the gunite collar at the clay seam 130 feet down there was a small hole from which water was pouring - about the equivalent of a garden hose.

Granite surfaces below the gunite collar were generally in original condition, with most surfaces showing a build-up of calcium deposits.

No holes or channels which could contribute appreciably to reservoir leakage were observed.

Inspection below the 200 foot level was not possible because of water in the shaft.

Summary of Results

The door of the access tunnel was closed on April 17, 1964. Refilling commenced on April 19, at which time the vortex basin and depressed area were filled to approximately Elevation 1505. During vortex basin filling, air was observed being forced through the asphalt floor.

Within four hours, leakage was observed at Panel 54, generally in the vicinity of the vortex basin. Green dye flowed from this leak for about two days. (After pool was raised to Elevation 1515, green dye showed up in leaks at Panels 42 and 49.)

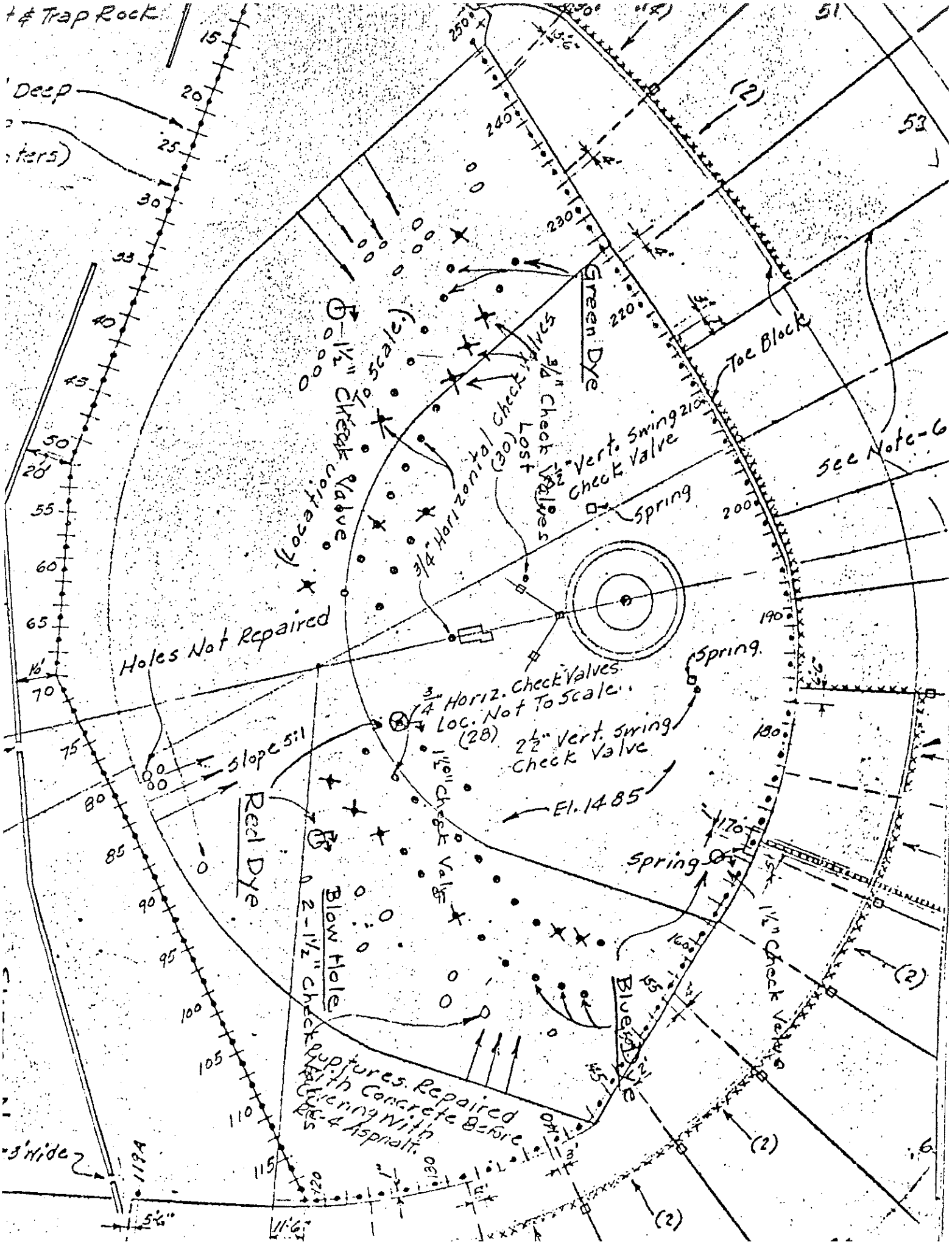
Reservoir filling above this level was carried out on a controlled basis so that leakage could be observed. In general, the level was increased 10 feet each day, and leakage was determined by change in reservoir level. The following tabulation represents the results of these observations.

Date	Reservoir Level	Duration	Calculated Leakage
4-19-64	1505.7	10 hours	2 cfs (est.)
4-20-64	1515.95	19 hours	2.02 cfs
4-21-64	1529.85	55 hours	4.75 cfs
4-23-64	1539.85	16 hours	7.25 cfs
4-24-64	1550.48	16 hours	9.20 cfs
4-25-64	1549.83	10 hours	8.53 cfs
4-26-64	1560.64	23 hours	11.10 cfs

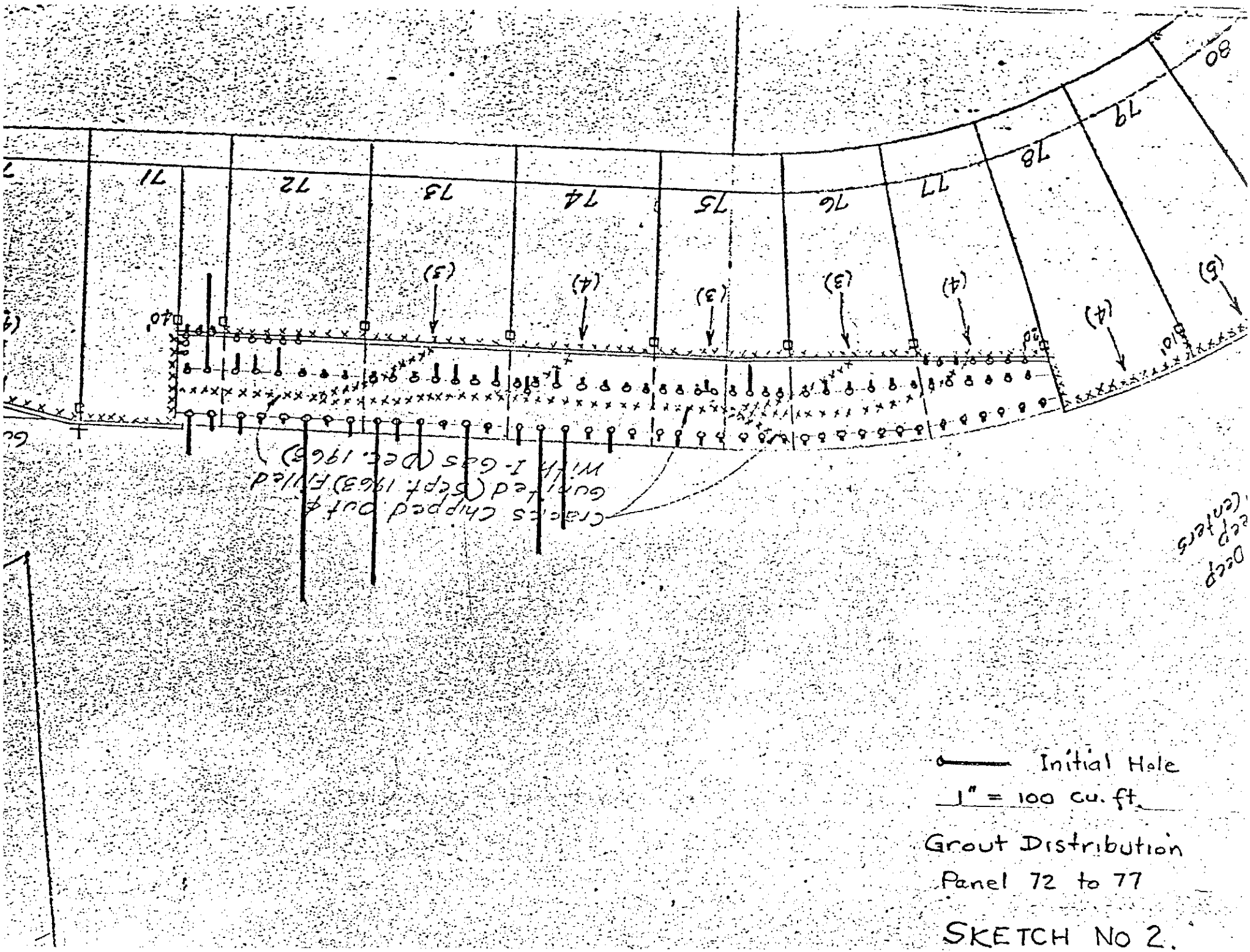
Location of leaks is generally the same as observed prior to this work, but are considerably reduced in volume. One of the larger leaks had been at Panels 71 and 79. This area was dry for two days, but leakage showed up on April 22. On April 23, red dye was observed in the flor from Panel 71, but not from 79.

P A Pickel

Prepared by: P. A. Pickel

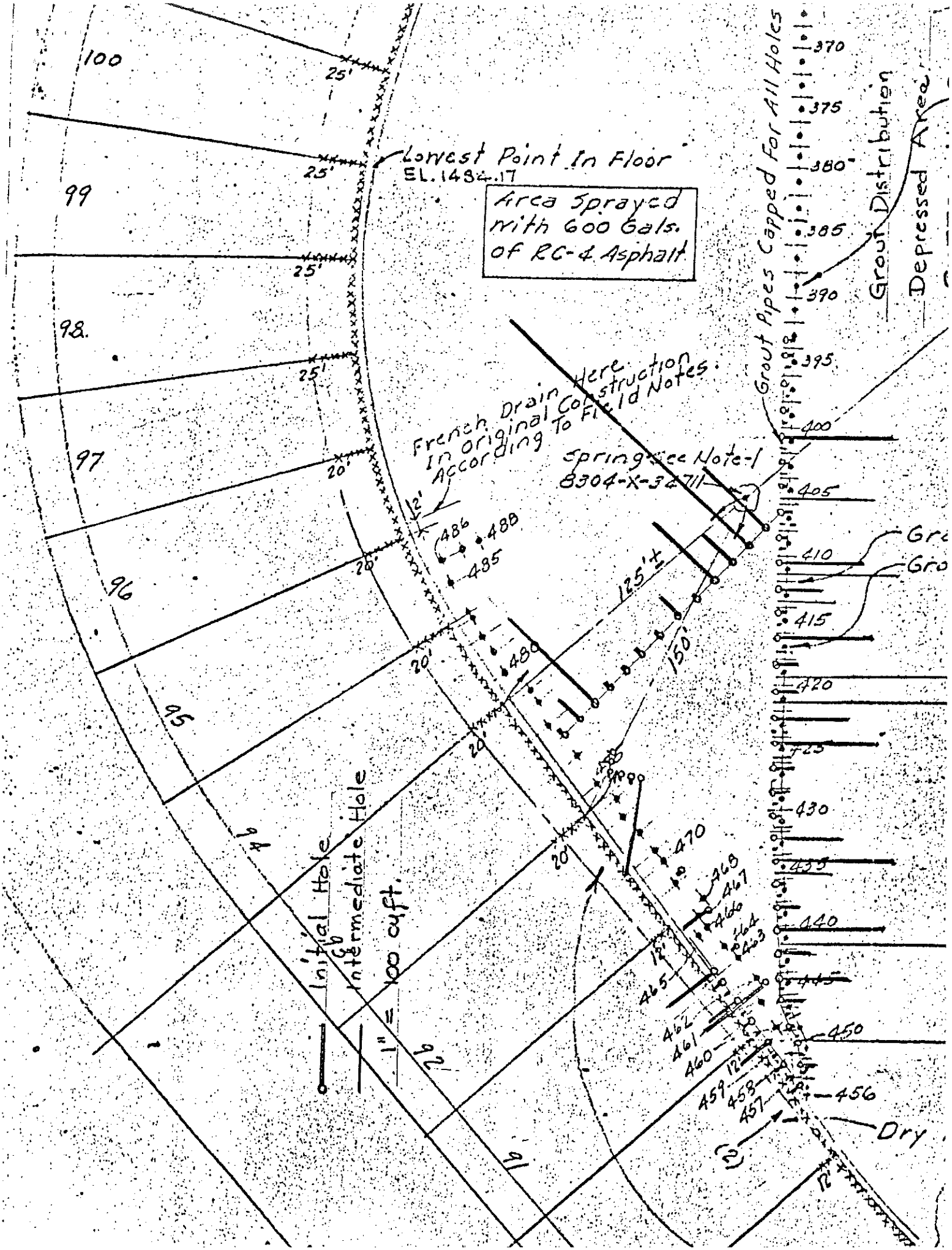


t & Trap Rock
Deep
ters)
Green Dye
Toe Block
See Note-6
1½" Check Valve
(Location To Scale)
3/4" Horizontal Check Valves
(30)
3/4" Check Valves Lost
1½" Vert. Swing Check Valve
Spring
Holes Not Repaired
Spring
3/4" Horiz. Check Valves Loc. Not To Scale
(28)
2½" Vert. Swing Check Valve
Slope 5:1
Red Dye
1½" Check Valve
El. 1485
Spring
Blow Hole
2-1½" Check Valves
Blue Dye
1½" Check Valve
Ruptures Repaired With Concrete Before Covering With RC-4 Asphalt.
3' Wide



Grout Distribution
Panel 72 to 77

SKETCH No 2.



Lowest Point In Floor
EL. 1484.17
Area Sprayed with 600 Gals. of RC-4 Asphalt
French Drain Here In original Construction According To Field Notes.
Spring See Note-1
8304-X-34711
Grout Pipes Capped For All Holes
Grout Distribution
Depressed Area
Initial Hole
Intermediate Hole
1" = 100 cu ft.
125'±
150'
Dry
100
99
98
97
96
95
94
92
91
25'
20'
12'
370
375
380
385
390
395
400
405
410
415
420
425
430
435
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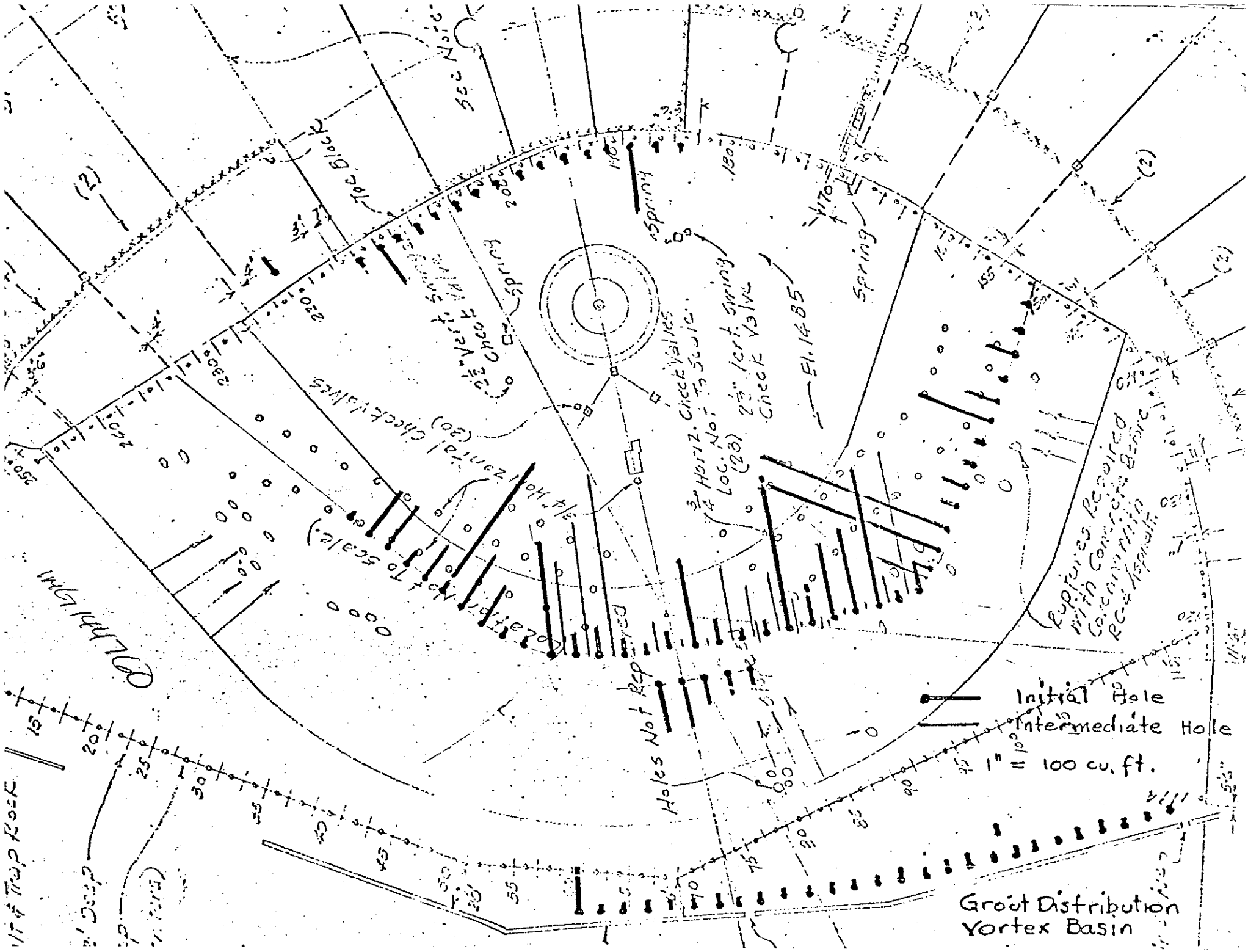
Initial Hole
Intermediate Hole
1" = 100 cu. ft.
Grout Distribution
Vortex Basin
Holes Not Repaired
Spring
Toe Block
El. 1485
Ruptures Repaired with Concrete Before Covering with RC-4 Asphalt
Horizontal Check Valves
Vert. Swing Check Valve
Horiz. Check Valves Loc. Not To Scale
Vert. Swing Check Valve
Trap Rock