University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 176

COLLECTOR WELL STUDY
FOR THE COOLING WATER INTAKE SYSTEM OF THE JAMES H. CAMPBELL ELECTRIC POWER GENERATING PLANT, UNIT NO. 3

by

Heinz Stefan

and

Alec Fu

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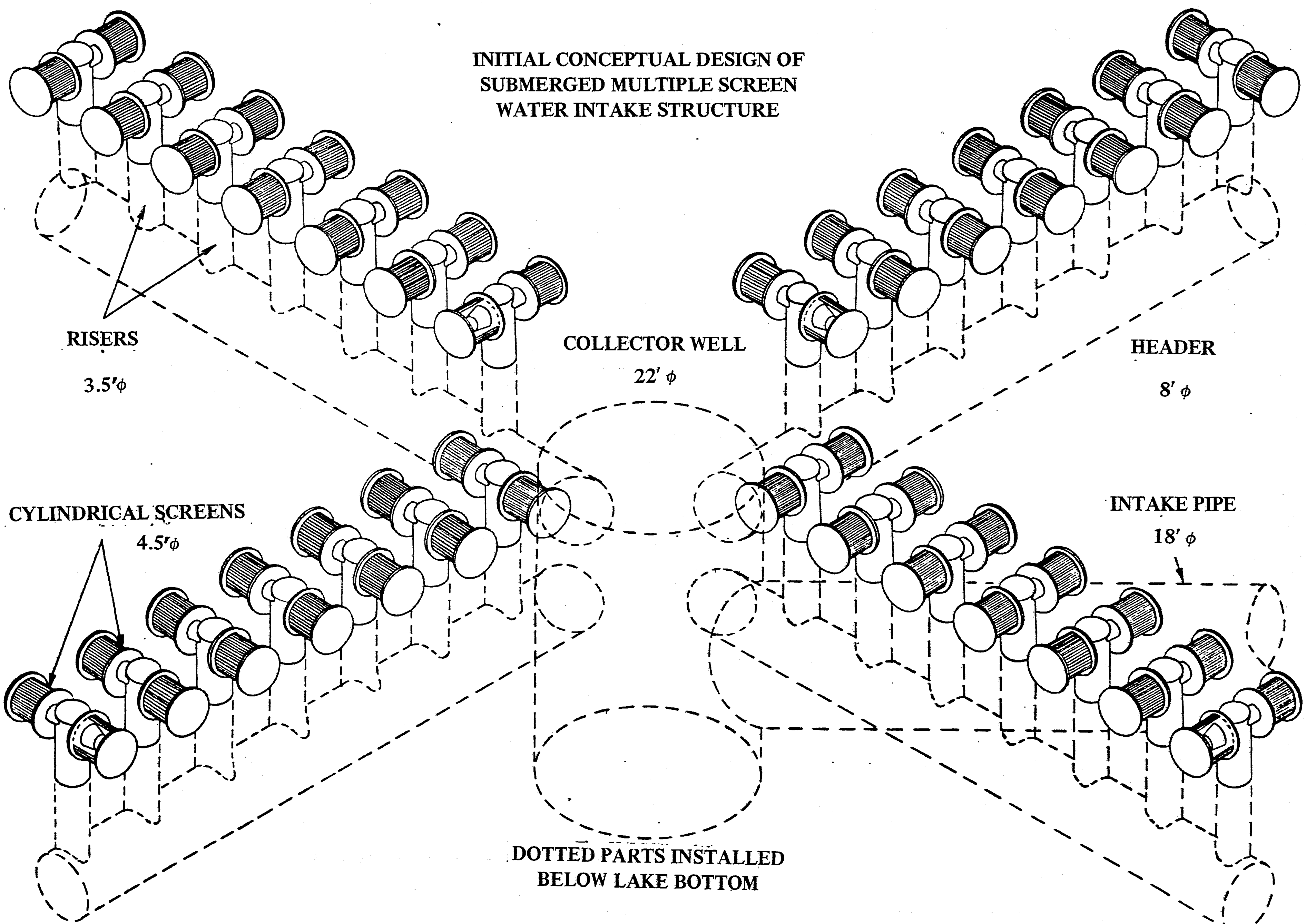
INITIAL CONCEPTUAL DESIGN OF
SUBMERGED MULTIPLE SCREEN
WATER INTAKE STRUCTURE
RISERS
3.5′ϕ
COLLECTOR WELL
22′ ϕ
HEADER
8′ ϕ
CYLINDRICAL SCREENS
4.5′ϕ
INTAKE PIPE
18′ ϕ
DOTTED PARTS INSTALLED
BELOW LAKE BOTTOM

CONTENTS

Abstract

A 1:24 scale model of the collector well, the central structure of the projected cooling water intake for the James H. Campbell Power Generating Plant, Unit No. 3, on the eastshore of Lake Michigan was built and operated to determine the hydraulic characteristics of the structure. Piezometric pressure distributions and total energy headlosses were measured. Flow patterns and air evacuation characteristics were observed. The total headloss in the 22 ft diameter collector well was determined to be on the order of 4.5 in. for the design flow of 824 cfs. The height of the collector well cover above the header axis had to exceed 6 ft in order to avoid formation of a strong vortex in the well. At a height of 11 ft the well performed satisfactorily. Flow rates in the four headers feeding into the collector well deviated by less than 2 per cent from the average. Air entrapped in the dome was evacuated by the flow. Flow from only two headers through the collector was also investigated.

Listing of Studies

for the James H. Campbell

Unit No. 3 Cooling Water Intake

1. H. Stefan and A. Fu, "Headloss Characteristics of Six Profile-Wire Screen Panels," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, Project Report No. 175, September 1978, 71 pages.

2. H. Stefan and A. Fu, "Collector Well Study for the Cooling Water Intake System of the James H. Campbell Electric Power Generating Plant, Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, Project Report No. 176, November 1978, 46 pages.

3. H. Stefan, W. Q. Dahlin, J. F. Ripken, A. Wood. and T. Winterstein, "Experimental Flow Studies with the Dual-Screen Cooling Water Intake Assembly ("Riser") for the James H. Campbell Electric Power Generating Plant Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Project Report No. 177, December 1978, 130 pages.

4. H. Stefan, C. Shanmugham, and S. Dhamotharan, "Cooling Water Manifold Intake (Header) Study for the James H. Campbell Electric Power Generating Plant, Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, Project Report No. 178, January 1979, 59 pages.

5. John M. Killen and H. Stefan, "Hydraulic Analysis of Alternative Cooling Water Intake Designs for the James H. Campbell Electric Power Generating Plant, Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, External Memorandum No. 161, December 1978, 22 pages.

LIST OF TABLES AND FIGURES

I. INTRODUCTION AND OBJECTIVE

The initial conceptual design of the cooling water supply system for the James H. Campbell Power Generating Plant, Unit No. 3 owned by Consumer Power Company, Jackson, Michigan and designed in cooperation between Commonwealth Associates, Inc., Jackson, Michigan and Johnson Division UOP, Inc., St. Paul, Minnesota called for the installation of a collector well as the central structure of the cooling water intake. The structure would have been located in Lake Michigan, about 3500 ft. offshore and in about 35 ft of water.

Several elements of the Campbell Unit No. 3 cooling water intake were studied analytically and experimentally by the authors at the St. Anthony Falls Hydraulic Laboratory in order to provide guidance in the design and to produce anticipated performance data. The Campbell Unit No. 3 intake differs considerably from other intake structures in the Great Lakes. It is designed for a maximum intake velocity of 0.5 ft/sec in the screen opening. It also uses 56 individual, cylindrical screen elements of 4.5 ft diameter, 4.0 ft length and of 3/8 in. square opening.

The initial conceptual design of the Campbell Unit No. 3 intake is shown in Fig. 1. The collector well is in the center. An 18.0 ft diameter intake pipe leads to shore. The lake water enters through 56 screens which are mounted with a horizontal axis on 28 risers. Seven risers are connected to four individual headers of 8.0 ft diameter and arranged in the shape of a cross.[1)] After passing through the screen, the water flows horizontally in a short T assembly, down a riser and horizontally through a header into the well and from there into the intake pipe leading to the plant. The collector well and the headers are buried in the lake bottom. Only the upper portions of the 28 risers carrying the screens protrude through the lake bottom.

Separate studies have been conducted for the risers, the headers and the collector well. Only the collector well study will be described herein.

The headers enter the collector well in a perfectly symmetrical configuration. The withdrawal from the collector well is asymmetrical. An

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1) The final design selected for construction is a branching pipe system. It does not use a collector well. It is described in External Memorandum No. 161 referenced as item number five on page iv.

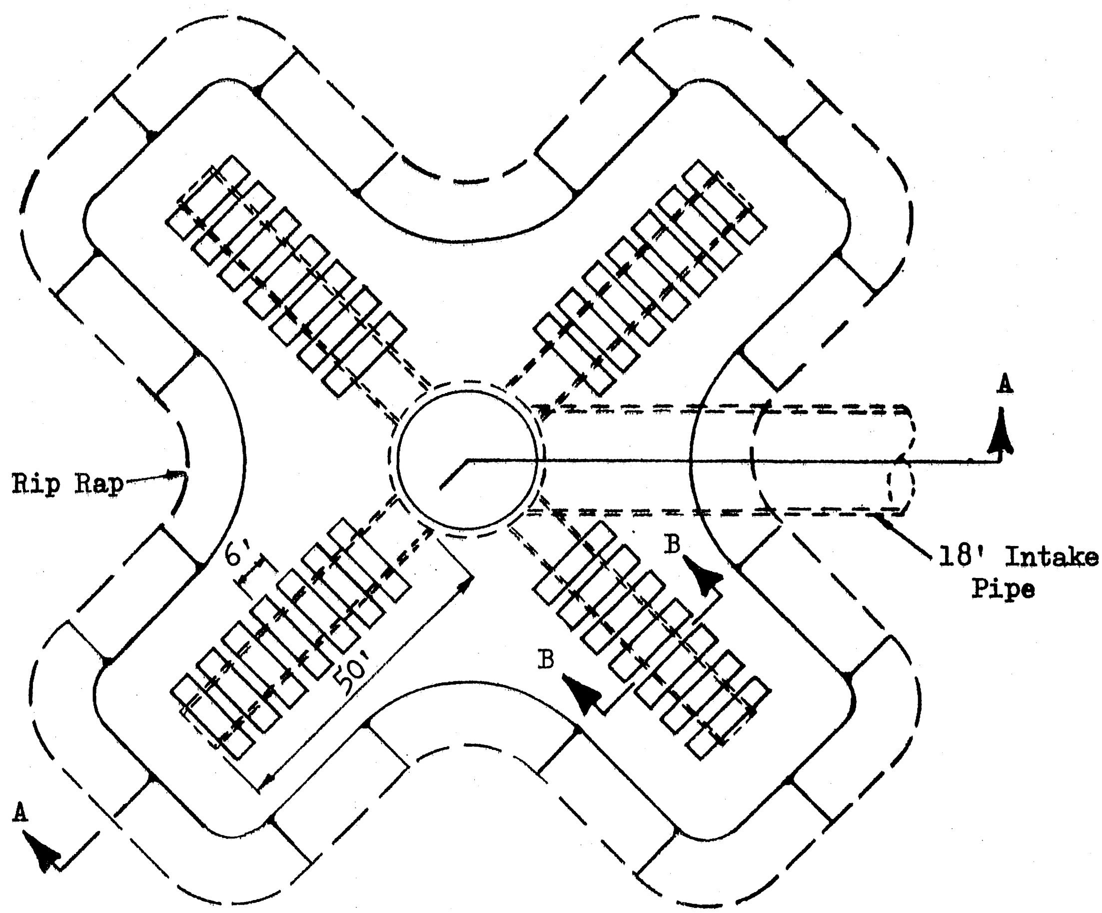
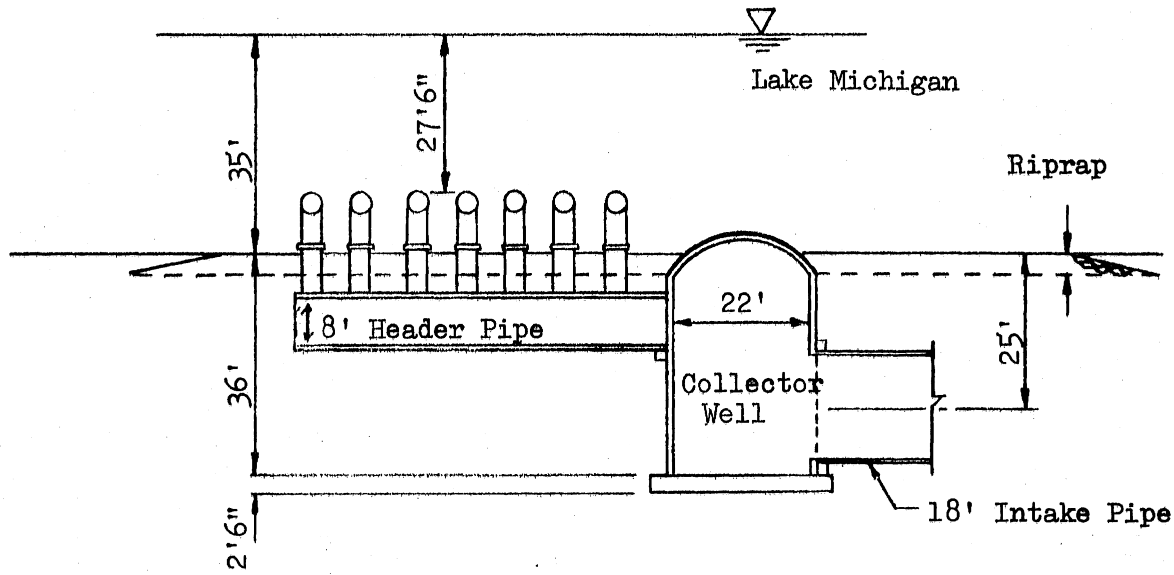
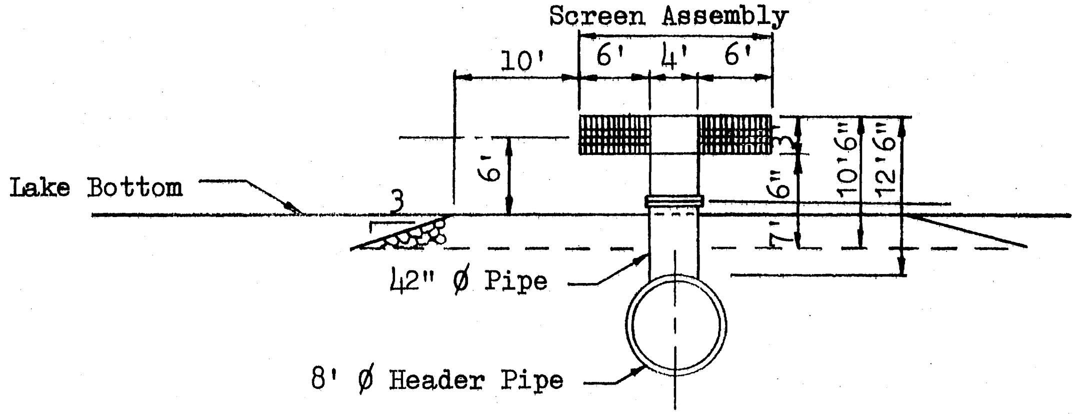


Fig. 1. Initial Conceptual Design of the James H. Campbell Unit No. 3 Cooling Water Intake



SECTION A-A



SECTION B-B

Fig. 1 (Cont'd). Initial Conceptual Design of the James H. Campbell Unit No. 3 Cooling Water Intake.

experimental study was therefore proposed to answer several questions related to the internal flow through the header:

a. Will the four headers supply identical rates of flow? If not, what will be the contributions of each individual header?

b. What will be the total headloss of the flows through the collector well?

c. Will undesirable helical vortex flow patterns develop in the collector well?

d. Will major amounts of air, if trapped in the dome during construction, be entrained by the flow after start-up?

It was specified that the above questions should be investigated only for static lake conditions. The results of the study would therefore apply strictly only when lake currents are absent or slow and when lake surface conditions are calm. Frequency distributions of current velocities measured at the site have been analyzed elsewhere. More important, however, is the observation that the problem to be investigated deals with an internal flow and that the pressure drops (headloss) through the risers and the headers are therefore of far more influence than an ambient lake current.

II. HYDRAULIC MODEL DESIGN AND CONSTRUCTION

A hydraulic model of the collector well was designed at a geometrical scale ratio of 1:24. The internal dimensions of the model are shown in Fig. 2. The four headers were modelled without the risers. Instead, each header was fitted with a 90° elbow meter and left open at the end. The 90° elbows served to reduce air entrainment into the headers from the experimental tank in which the model was located. The 9 in. intake pipe was modeled over a distance of 4 diameters.

The entire model was built of lucite to facilitate flow observation. Wall thicknesses varied from 1/4 to 1/2 inch. To measure the pressure drop across the collector well, piezometric pressure taps were installed in each header, 2 in. from the well and also in the 9 in. intake pipe at 1 in., 4.5 in., and 18 in. downstream from the collector well. These latter dimensions correspond to 1/9, 1/2 and 2 times the intake pipe diameter. The locations and tap numbers

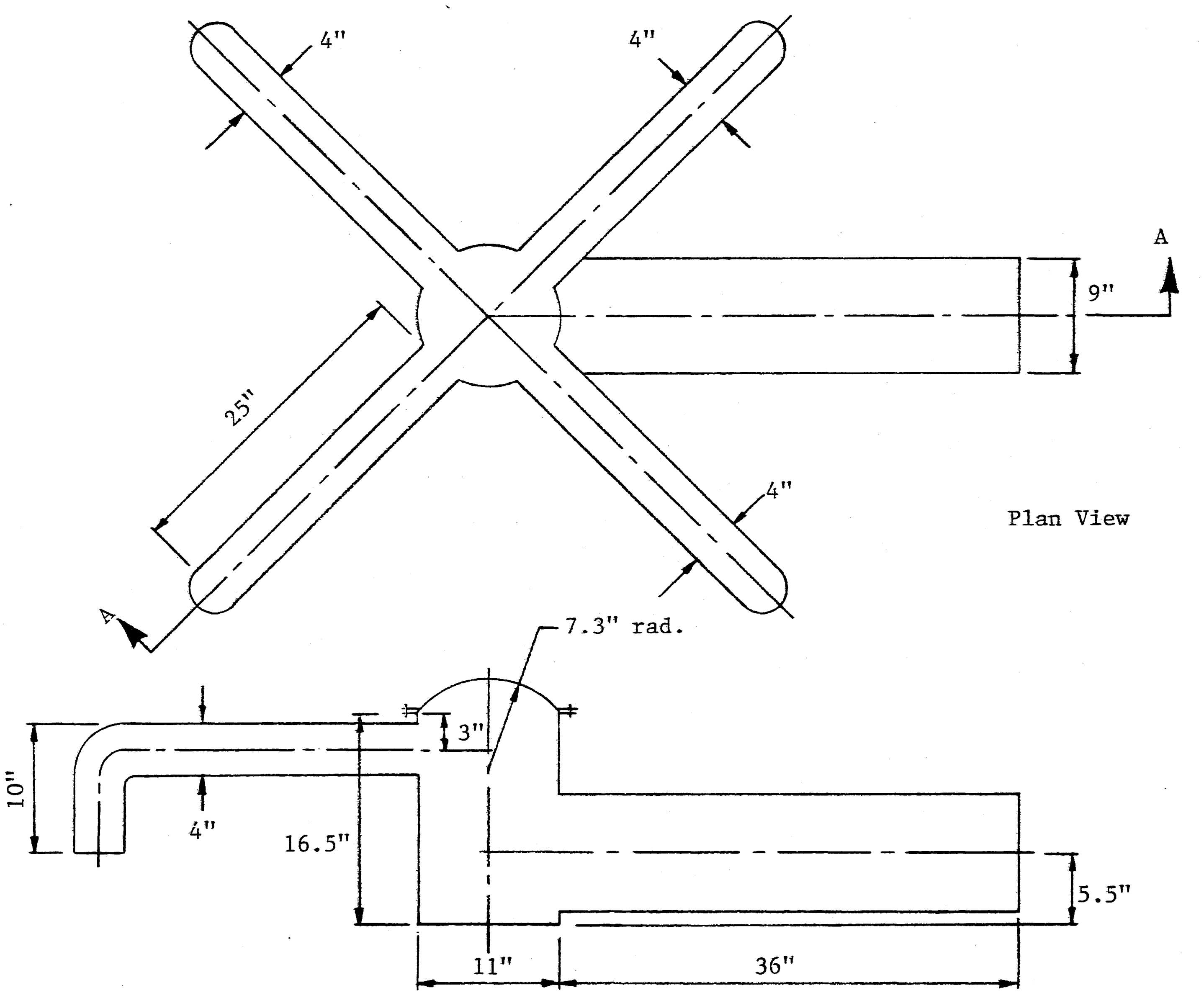


Fig. 2 - Collector Well Model Dimensions (Inside Dimensions in Inches).

are identified in Fig. 3. In each location four pressure holes at 90° intervals around the pipe were interconnected such that a representative mean pressure would be obtained.

Additional pressure taps were located at the four elbow meters as also shown in Fig. 3. One station measured the ambient piezometric pressure in the tank surrounding the model. A total of 16 pressure measuring stations were available. Each was connected to a tube on a piezometer board equipped with a mainfold aspirator for air pressure adjustment. The tubes could be easily read to the nearest 0.1 inch.

The collector well model was installed in a laboratory tank as shown in Fig. 4 before filling and in Fig. 5 after filling. The experimental tank had a surface area of 40 ft by 16.5 ft and was 18 inches deep. A schematic of the complete experimental installation is shown in Fig. 6.

Water withdrawn from the collector well model was recirculated to a distribution box from where it was fed back through a large number of slots into the experimental tank. Baffle blocks were located in front of the slots to minimize any residual circulation in the tank. The recirculation system is shown in Fig. 7. Near the downstream end of the straight section of the 6 inch PVC recirculation pipe a 4 inch orifice flow meter and a flow control valve were installed. The pressure differential induced by the orifice meter was read on two U-tube differential manometers. One was filled with an immiscible liquid with a specific gravity of 2.95 and was used for low flows, the other employed mercury and was used for high flows.

The level in the experimental tank was maintained constant by an overflow weir and a small supply of make-up water to account for losses. The water in the tank did not actually simulate Lake Michigan because the collector well and headers will all be buried in the bottom of the lake and will not be visible as in Fig. 4 or Fig. 5. The sole purpose of the tank was to supply an arbitrary, but constant, ambient reference pressure head relative to which pressure losses in the collector system could be measured. Since water is highly incompressible, all pressure differentials produced by the <u>internal</u> flow inside the pipes were independent of <u>absolute</u> pressures in the system.

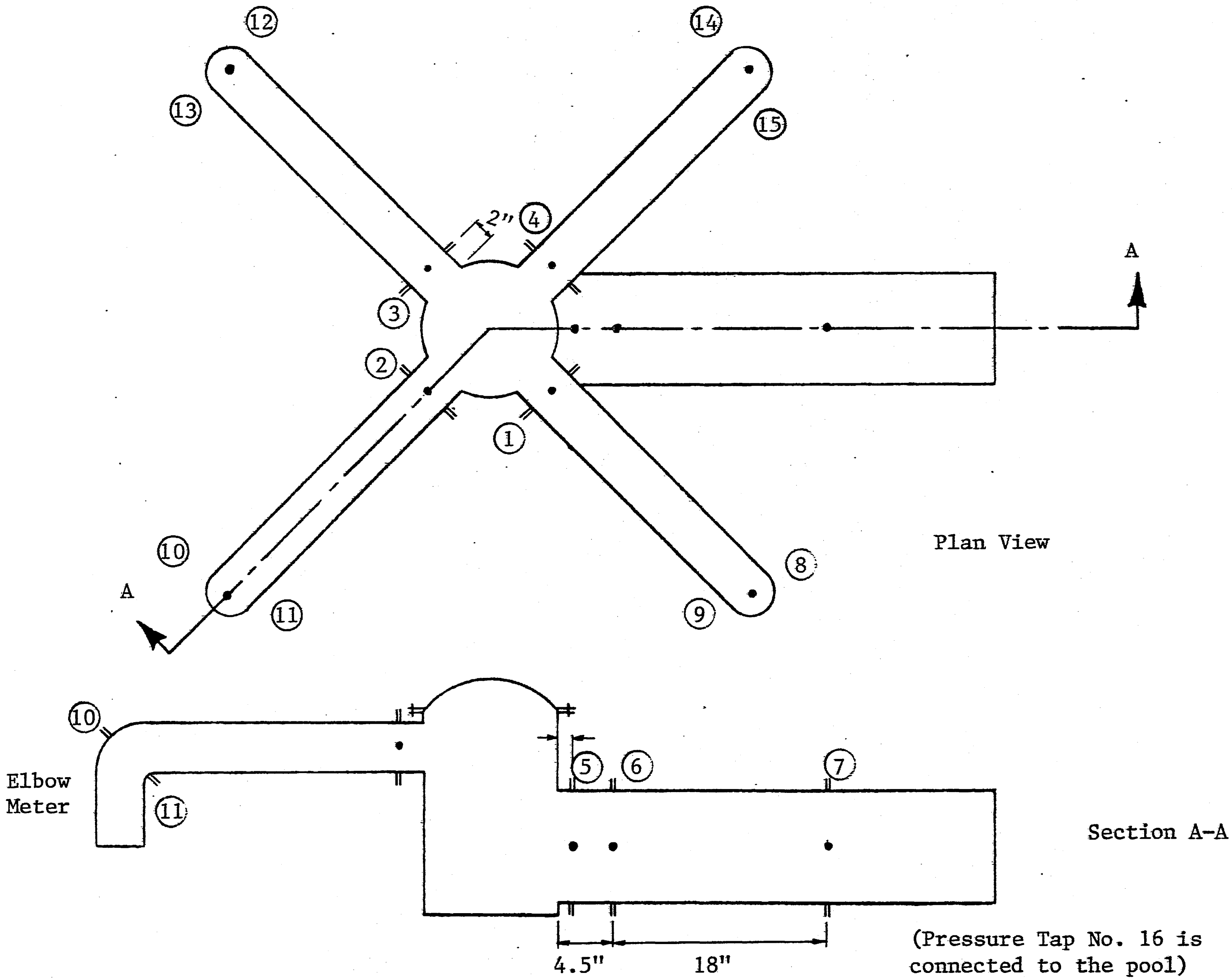
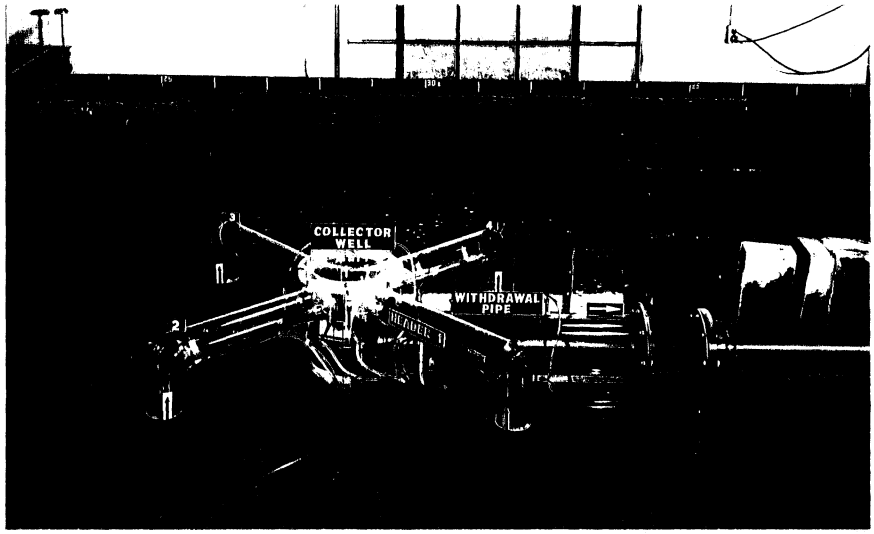


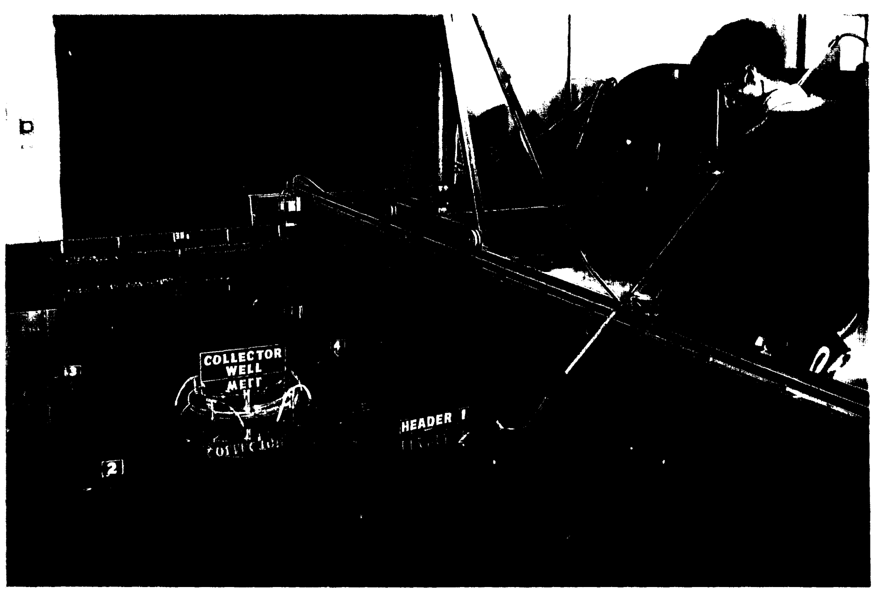
Fig. 3 - Pressure Tap Locations and Numbers on Collector Well Model (All Dimensions in Inches).

Fig. 4. Collector Well Model in Tank Before Filling.

Fig. 5. Collector Well Model in Tank After Filling.


COLLECTOR WELL
WITHDRAWAL PIPE
HEADER 1
2
3
4

b


COLLECTOR WELL
HEADER 1
2
4

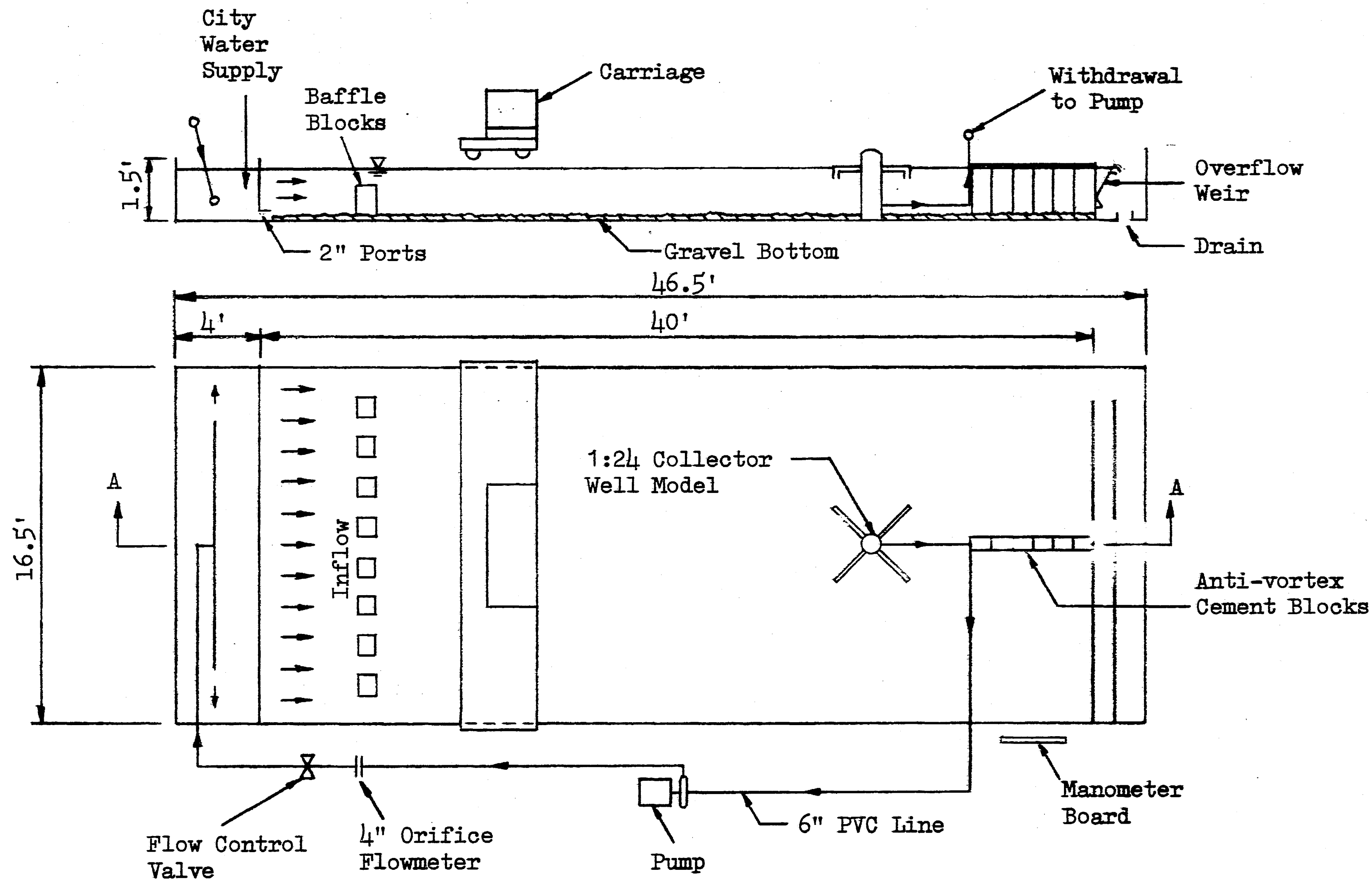
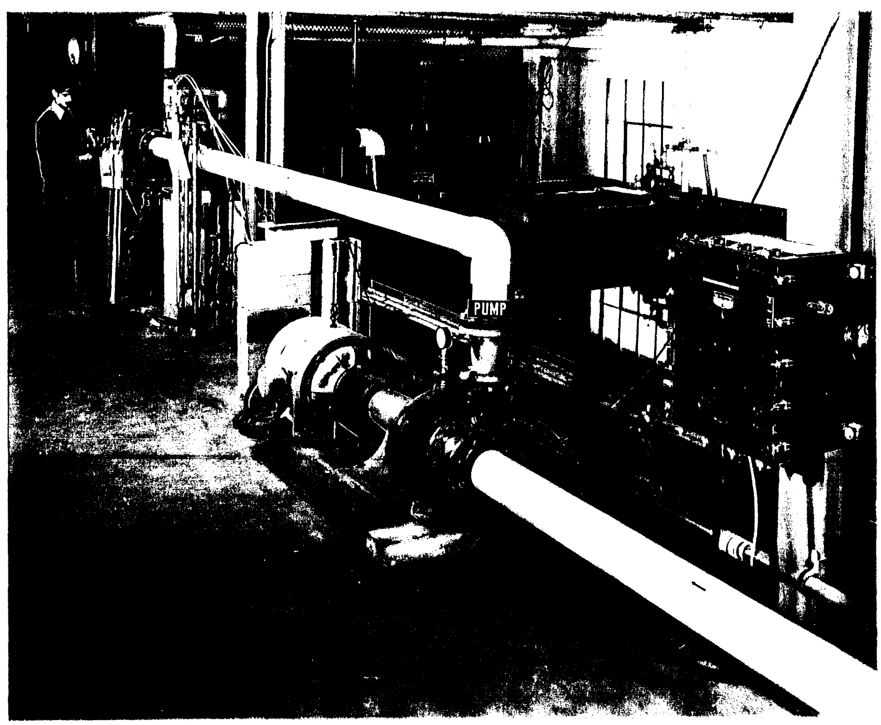


Fig. 6. General Layout of Experimental Tank and Water Circulation System.

Fig. 7. Water Recirculation System for Collector Well Model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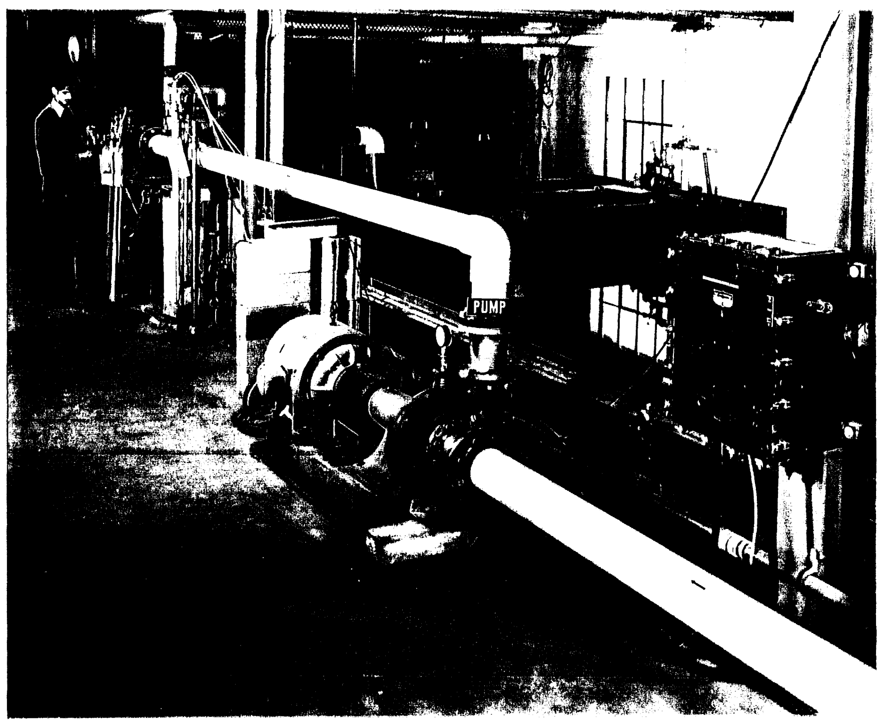
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III. MODEL OPERATION, DATA COLLECTION AND DATA REDUCTION

Achievement of model Reynolds numbers identical to those of the prototype would have been an ideal operational objective. With water as a model fluid this goal could not be attained. Experiments at Reynolds numbers on the order of 1/10 or less of those in the prototype were used. The model flow rates varied from 0.5 to 2.1 cfs and Reynolds numbers $Re = VD/\nu$ based on the mean flow velocity and the diameter of the 9 inch intake pipe (18 ft in the prototype) ranged from 49,000 to 240,000. The flow from the headers into the collector well and the flow from the collector well to the intake pipe is a fully separated flow; this was verified by dye experiments. In such flow fields pressure drops and headlosses are only very weakly Reynolds number dependent, provided that a sufficient level of turbulence is achieved. In other words, if a certain minimum Reynolds number is exceeded, coefficients of piezometric pressure or head differentials are practically constant. These coefficients are defined generally as

$$k_{i-j} = \frac{\gamma \Delta z_{i-j} + \Delta p_{i-j}}{\rho V^2/2} = \frac{\Delta h_{i-j}}{V^2/2g} \qquad (1)$$

where Δp_{i-j}, Δh_{i-j} = the pressure drop and the piezometric headloss between any two stations i and j, respectively.

Δz_{i-j} = difference in elevation between any two stations, i and j.

V = a mean flow velocity in the system; usually, but not necessarily, at i or j.

ρ = density of water

g = acceleration of gravity

γ = specific weight of fluid; in this case water.

Absence of appreciable Reynolds effects was verified by repeating the experiments at several different flow rates. The model results, although obtained at lower than prototype Reynolds numbers, are therefore useful to predict prototype performance.

Commensurate with the study objectives, the following types of experiments were conducted:

A. Measurement of piezometric pressure versus header flow rate.

Steady-state model withdrawal rates in the range from 0.5 to 2.1 cfs were established and piezometric pressure heads were read on the piezometer board. Experiments were usually conducted for seven different flow rates and sometimes repeated on separate days. To detect any imbalance in flow rates between the four headers, the pressure drop across the elbow meter at the entrance to each header, or the head loss along the header could be used.

Experiments were conducted for four fully open headers or for combinations of two open and two closed headers. Seal caps were placed over the inlet ends of the headers to close them. Referring to the header numbers shown in Fig. 4, the following combinations of open headers were tested:

1 & 3 or 2 & 4
1 & 2 or 3 & 4
2 & 3
1 & 4

B. Experiments to observe vortex formation in collector well.

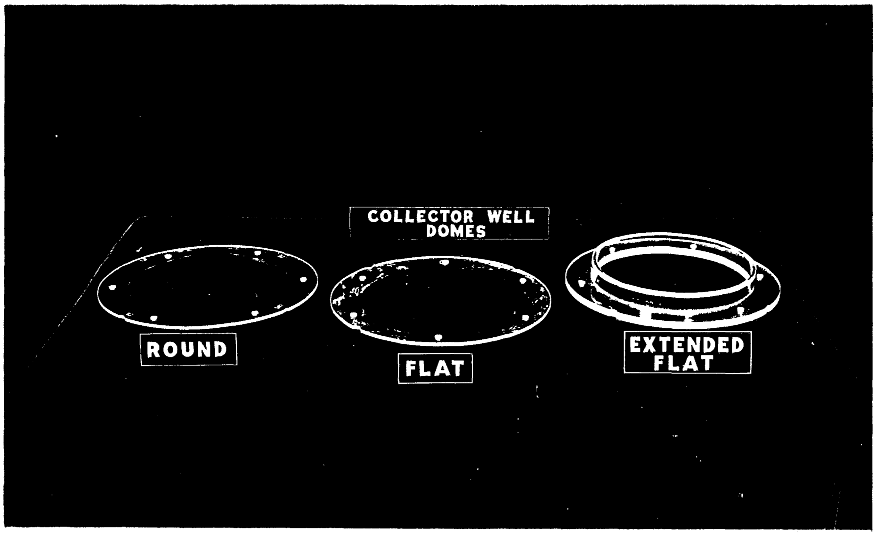
To observe the nature of the flow field inside the collector well, dye was injected into individual headers as shown in Fig. 5 and its flow path and dissipation in the collector well were observed from above (through the lucite dome). Three different dome configurations were tested: 1) a rounded dome with a model radius of 7.3 inches as shown in Fig. 2, 2) a flat cover in place of the dome and 3) an elevated flat dome. The three model domes are shown in Fig. 8.

Overhead photographs were taken to record the dye behavior as it passed through the model.

C. Experiments to observe air evacuation from collector well dome.

After construction and placement of the collector well in the lake, it is (remotely) possible that the dome of the collector well will be partially filled with air. This might affect the collector well flow pattern. The entrainment and evacuation of an air pocket by the water flowing through the collector well were observed in the model. No quantitative similarity criteria were established.

Fig. 8. The Three Model Dome Configurations


COLLECTOR WELL
DOMES
ROUND
FLAT
EXTENDED
FLAT

In the experiment the air pocket could be produced by inserting one end of a tube into the header elbow and leaving the other end open to the atmosphere. The low pressure in the elbow would entrain air that would accumulate in the dome. The tube was removed after the air pocket had formed.

Readings of piezometric pressure heads on a manometer board and associated volumetric withdrawal rates and water temperatures were recorded. Using Eq. 1 the data were reduced to give the coefficients for piezometric pressure head differentials between the following stations (see Fig. 3):

Station 16 (ambient) & Station 1 16 & Station 2 16 & Station 3 16 & Station 4	Set 1 Piezometric headloss along individual, simplified headers
Station 1 & Station 7 2 & Station 7 3 & Station 7 4 & Station 7	Set 2 Piezometric headloss across collector well
Station 16 & Station 7	Total model piezometric headloss between ambient & Station 7

Station 7 was chosen over Station 5 or Station 6, because preliminary experiments indicated that piezometric pressure at Station 5 and Station 6, just inside the intake pipe were always lower than those at Station 7, suggesting that a separated flow region or otherwise higher velocities existed in the entrance of the 9 inch intake pipe.

The Set 1 coefficients give piezometric headloss along each simplified header.

The Set 2 coefficients give piezometric headloss across the collector well.

The velocity at Station 7 was calculated from the total measured withdrawal rate and the cross-sectional area of the 9 inch withdrawal pipe $V_7 = Q/A_7$. The velocity V_7 was used as reference velocity in Eq. 1 and also to calculate the Reynolds number

$$Re_7 = V_7 D_7/\nu \qquad (2)$$

which is reported in the tables of the next section.

IV. EXPERIMENTAL RESULTS

1. Piezometric Headlosses

A summary of measured piezometric head or pressure loss coefficients is presented in Tables 1 through 5. Each table identifies (a) the collector well design to which it applies (rounded dome top or flat top or elevated flat top), (b) the number of headers which carry a flow, (c) the Reynolds number at Station 7, (d) the average piezometric headloss in each header, (e) the mean model flow velocity (model withdrawal velocity) in the 9 inch intake pipe, (f) piezometric headloss coefficients in headers (a plus sign between stations means that the stations have been averaged), (g) piezometric headloss coefficients across collector well, total average piezometric headloss coefficient between the ambient tank and Station 7, and (h) total energy headloss coefficient between the ambient lake and Station 7.

The value given under (h) is equal to that under (g) minus 1.0. The total energy headloss coefficient K_L measures the energy head lost irreversibly due to viscous effects. It is given by the relationship

$$h_{16} = h_7 + V_7^2/2g + K_L \cdot V_7^2/2g$$

$$K_L = \frac{h_{16} - h_7}{V_7^2/2g} - 1 \qquad (3)$$

where h = piezometric pressure head

V_7 = mean flow velocity

Subscripts refer to station numbers shown in Fig. 3.

It was observed that the piezometric pressure loss coefficients at Reynolds numbers $Re_7 < 100{,}000$ were sometimes slightly higher than those for $Re_7 > 100{,}000$. The higher values were ignored in computing averages because results will be applied to prototype conditions with Re-numbers much larger than 100,000.

Tables 1, 2, and 3 give piezometric pressure drop coefficients for three different collector well configurations when all four headers are running full. For each set of data, the headloss in each of the four headers is nearly equal. However, the flat top on the collector well produces a much larger piezometric head drop across the collector well than the rounded or flat dome. The increase in loss is accompanied by a strong vortex formation in the well as will be shown later.

TABLE 1

Summary of Pressure Measurements
in Collector Well Model
(Rounded Dome Top)

(All headers running full)

Re*	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station: (Average)	1+4	2+3	1+2+3+4	1+4	2+3	1+2+3+4		(energy loss)
49.4	1.34	1.13		5.6	5.6	5.6	1.7	1.7	1.7	7.3	6.3
58.1	1.36	1.13		5.8	5.55	5.7	1.6	1.8	1.7	7.4	6.4
73.0	2.35	1.68		4.45	4.55	4.5	1.85	1.8	1.85	6.35	5.35
83.8	2.28	1.68		4.45	4.3	4.4	2.4	2.6	2.5	6.9	5.9
86.0	2.97	1.68		5.75	5.6	5.7	1.25	1.4	1.35	7.05	6.05
95.8	3.71	2.20		4.1	4.15	4.15	1.85	1.85	1.85	6.0	5.0
112.7	3.64	2.20		4.1	4.0	4.05	1.7	1.8	1.75	5.8	4.8
136.2	7.42	3.12		4.05	4.1	4.1	1.85	1.9	1.9	5.9	4.9
152.4	6.55	3.12		3.6	3.6	3.6	1.8	1.8	1.8	5.4	4.4
156.2	7.18	3.12		4.0	3.9	3.95	1.8	1.85	1.85	5.8	4.8
167.8	10.90	3.85		3.9	4.0	4.0	1.85	1.9	1.85	5.85	4.85
187.8	11.95	3.85		4.35	4.3	4.35	1.65	1.7	1.7	6.05	5.05
202.3	16.05	4.64		4.0	4.0	4.0	1.8	1.8	1.8	5.8	4.8
226.4	14.96	4.64		3.75	3.7	3.75	1.65	1.7	1.7	5.45	4.45
Average for last nine measurements:				4.0	4.0	4.0	1.75	1.8	1.8	5.8	4.8

Note: All coefficients rounded off to the nearest 0.05.
All Reynolds numbers are at Station 7.

TABLE 2

Summary of Pressure Measurements
in Collector Well Model
(Flat Top)

(All headers running full)

Re*	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station: (Average)	1+4	2+3	1+2+3+4	1+4	2+3	1+2+3+4		(energy loss)
52.6	0.95	1.13		4.0	3.95	4.0	1.8	1.9	1.85	5.85	4.85
77.9	2.08	1.68		3.9	4.0	3.95	2.95	2.9	2.95	6.9	5.9
102.1	3.61	2.20		3.95	4.05	4.0	3.9	3.75	3.85	7.85	6.85
140.8	7.35	3.12		4.0	4.05	4.05	3.9	3.85	3.9	7.95	6.95
173.4	10.63	3.85		3.8	3.9	3.85	3.75	3.7	3.75	7.65	6.65
210.7	15.04	4.64		3.7	3.8	3.75	3.85	3.7	3.8	7.6	6.6
Average for last four measurements:				3.8	3.95	3.9	3.85	3.75	3.8	7.75	6.75

Note: All coefficients rounded off to the nearest 0.05.
All Reynolds numbers are at Station 7.

TABLE 3

Summary of Pressure Measurements
in Collector Well Model
(Elevated Flat Top)

(All headers running full)

Re*	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station: (Average)	1+4	2+3	1+2+3+4	1+4	2+3	1+2+3+4		(energy loss)
52.6	0.94	1.13		4.1	3.8	3.95	1.4	1.7	1.55	5.5	4.5
58.1	1.73	1.46		4.45	4.25	4.35	1.6	1.85	1.75	6.1	5.1
77.9	2.09	1.68		4.15	3.8	4.0	1.4	1.8	1.60	5.6	4.6
86.0	2.08	1.68		4.1	3.8	3.95	1.4	1.8	1.6	5.55	4.55
102.1	3.59	2.20		4.1	3.85	4.0	1.5	1.8	1.65	5.65	4.65
112.7	3.59	2.20		4.1	3.9	4.0	1.55	1.8	1.65	5.65	4.65
145.2	7.36	3.12		4.2	3.9	4.05	1.5	1.8	1.65	5.7	4.7
160.4	7.26	3.12		4.15	3.8	4.0	1.45	1.8	1.65	5.65	4.65
178.9	10.75	3.85		4.0	3.75	3.9	1.45	1.7	1.6	5.5	4.5
197.5	10.75	3.85		4.05	3.75	3.9	1.45	1.75	1.6	5.5	4.5
215.7	16.25	4.64		4.15	3.9	4.05	1.45	1.75	1.6	5.65	4.65
238.2	16.05	4.64		4.1	3.85	4.0	1.55	1.8	1.7	5.7	4.7
Average for last eight measurements:				4.1	3.85	4.0	1.5	1.75	1.65	5.65	4.65

Note: All coefficients rounded off to the nearest 0.05.
All Reynolds numbers are at Station 7.

When only two of the four headers are working in the model, the coefficients increase substantially because velocities at Station 7 decrease. The experimentally determined piezometric pressure loss coefficients are given in Tables 4 and 5. The change in terms of actual head drop for prototype conditions will be given in Section V.

2. Flow Balance

The piezometric head differentials for each of the four elbow meters, i.e. between Stations 8 and 9, Stations 10 and 11, Stations 12 and 13, and Stations 14 and 15 were calculated to determine differences in flow rates in the flow headers. The flows in the four headers are fully turbulent and very similar. Ratios of flow rates in individual headers are therefore proportional to the square root of the measured pressure differentials across the respective elbow meters. Similarly the piezometric pressure headloss in each header can be used to determine flow rate ratios. The ratio of maximum to average flow rate is calculated from the relationship

$$\frac{Q_{max}}{Q_{ave}} = \frac{1}{2}\,\frac{h_{max}}{h_{ave}} + \frac{1}{2} \qquad (4)$$

The results are given in Table 6 and 7 for the collector well with a rounded and an elevated flat top, respectively. An imbalance of less than 2 per cent existed for the elevated flat top collector.

3. Vorticity of Collector Well Flow

Vorticity of the flow in the collector could be readily detected when dye was injected into any one of the headers.

During the experiments with the rounded dome no vorticity was observed, regardless of Reynolds number of the flow. Dye was injected into each of the four headers. No vorticity was observed. Figs. 9 through 12 give instantaneous overhead views of the jet flows from individual headers into the well. The dye patterns changed from one instant to another because of the turbulent nature of the flow.

Following the request for installation of a flat top in place of the rounded dome, flow visualization experiments were repeated. A strong and persistent vortex flow in the collector well, not previously observed with

TABLE 4

Summary of Pressure Measurements
in Collector Well Model
(Rounded Dome Top)

Headers 1 & 3 open (or) 2 & 4 open

Re	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Head Head Loss Coefficient
(10^3)	(in)	(fps)	Station: or Station	1 4	3 2	1+3 4+2	1 4	3 2	1+3 4+2		
56.6	3.73	1.13	(Headers 1&3 open)	14.8	14.8	14.8	3.8	3.8	3.8	18.6	17.6
83.8	8.26	1.68		16.3	15.9	16.1	3.3	3.7	3.5	19.6	18.6
91.7	9.80	1.83		16.2	16.2	16.2	3.7	3.6	3.65	19.85	18.85
130.2	19.78	2.60		16.0	15.6	15.8	3.1	3.4	3.25	19.05	18.05
156.2	28.48	3.12		15.7	15.4	15.55	3.4	3.7	3.55	19.1	18.1
56.6	3.98	1.13	(Headers 2&4 open)	21.4	22.2	21.8	1.7	0.8	1.25	23.05	22.05
83.8	8.81	1.68		16.8	17.7	17.25	2.5	1.6	2.05	19.3	18.3
91.7	10.45	1.83		15.4	15.1	15.25	2.6	2.9	2.75	18.0	17.0
130.2	21.10	2.60		14.9	14.3	14.6	2.2	2.8	2.5	17.1	16.1
156.2	30.38	3.12		15.0	14.6	14.8	2.0	2.4	2.2	17.0	16.0
Average for 1&3 open (or) 2&4 open				16.3	16.15	16.2	2.85	2.85	2.85	19.05	18.05

TABLE 4 (cont'd)

Summary of Pressure Measurements
in Collector Well Model
(Rounded Dome Top)

Headers 2 & 3 open

Re	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station:	2	3	2+3	2	3	2+3		
56.6	3.66	1.13		15.1	15.6	15.35	1.7	1.1	1.4	16.75	15.75
83.8	8.10	1.68		15.0	15.6	15.3	1.7	1.1	1.4	16.7	15.7
91.7	9.61	1.83		15.6	16.1	15.85	1.5	1.0	1.25	17.1	16.1
130.2	19.4	2.60		15.2	15.3	15.25	1.3	1.2	1.25	16.5	15.5
156.2	27.9	3.12		15.2	15.5	15.35	1.4	1.2	1.3	16.65	15.65
Average				15.2	15.6	15.4	1.5	1.1	1.3	16.7	15.7

TABLE 4 (cont'd)

Summary of Pressure Measurements
in Collector Well Model
(Rounded Dome Top)

Headers 1 & 2 open

Re	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station:	1	2	1+2	1	2	1+2		
56.6	3.73	1.13		15.9	16.6	16.25	1.8	1.1	1.45	17.7	16.7
83.8	8.26	1.68		15.6	16.0	15.8	1.7	1.3	1.5	17.3	16.3
91.7	9.80	1.83		15.9	16.3	16.1	1.7	1.2	1.45	17.55	16.55
130.2	19.78	2.60		15.4	16.2	15.8	1.9	1.1	1.5	17.3	16.3
156.2	28.48	3.12		14.0	15.0	14.5	2.0	1.0	1.5	16.0	15.0
Average				15.4	16.0	15.7	1.8	1.15	1.5	17.2	16.2

TABLE 4(cont'd)

Summary of Pressure Measurements
in Collector Well Model
(Rounded Dome Top)

Headers 1 & 4 open

Re	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station:	1	4	1+4	1	4	1+4		
58.1	3.88	1.13		18.6	17.9	18.25	0.1	0.8	0.45	18.7	17.7
86.0	8.57	1.68		16.3	15.9	16.1	0.3	0.6	0.45	16.55	15.55
94.1	10.17	1.83		16.8	16.4	16.6	0.5	1.0	0.75	16.35	15.35
133.6	20.53	2.60		15.6	15.0	15.3	0.5	1.1	0.8	16.1	15.1
156.2	29.56	3.12		15.3	15.0	15.15	0.5	0.8	0.65	15.8	14.8
Average				16.5	16.0	16.3	0.4	0.85	0.6	16.7	15.7

TABLE 5

Summary of Pressure Measurements
in Collector Well Model
(Elevated Flat Top)

Headers 1 & 3 open (or) 2 & 4 open

Re	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station:	1	3	1+3	1	3	1+3		
			or Station:	4	2	4+2	4	2	4+2		
52.6	3.55	1.13	(Headers	14.7	14.2	14.45	1.5	1.9	1.70	16.15	15.15
54.8	3.55	1.13	1&3 open)	14.9	14.8	14.85	2.8	2.9	2.85	17.70	16.70
77.9	7.76	1.68		14.7	14.3	14.5	2.1	2.4	2.25	16.75	15.75
81.1	8.05	1.68		15.40	15.40	15.40	2.2	2.2	2.20	17.60	16.60
85.2	9.30	1.83		14.5	14.4	14.45	1.9	2.1	2.0	16.45	15.45
88.7	10.11	1.83		16.30	16.0	16.15	2.0	2.3	2.15	18.3	17.30
121.0	18.80	2.60		16.0	15.7	15.85	2.0	2.3	2.15	18.0	17.0
126.0	19.44	2.60		15.60	15.20	15.40	2.1	2.4	2.25	17.65	16.65
148.2	27.0	3.12		15.2	14.9	15.05	2.0	2.3	2.15	17.2	16.20
151.2	28.28	3.12		15.70	15.40	15.55	1.9	2.2	2.05	17.60	16.0
50.0	3.77	1.13	(Headers	16.2	16.2	16.2	2.3	2.3	2.3	18.5	17.5
54.8	3.65	1.13	2&4 open)	15.2	15.4	15.3	2.5	2.4	2.45	17.75	16.75
74.0	8.26	1.68		15.4	15.6	15.5	2.0	1.8	1.90	17.40	16.4
81.0	9.90	1.83		15.7	16.1	15.9	2.4	2.1	2.25	18.15	17.15
81.1	7.76	1.68		14.9	14.8	14.85	2.5	2.6	2.55	17.40	16.40
88.7	9.73	1.83		15.4	15.7	15.55	2.9	2.6	2.75	18.30	17.30
117.3	19.90	2.60		16.1	16.3	16.2	2.6	2.3	2.45	18.65	17.65
126.0	19.25	2.60		15.3	15.2	15.25	2.8	2.9	2.85	18.10	17.10
140.8	28.70	3.12		15.2	15.3	15.25	2.0	1.9	1.95	17.95	16.95
151.2	26.64	3.12		14.5	14.8	14.65	2.8	2.5	2.65	17.30	16.30
Average for 1&3 open (or) 2&4 open				15.35	15.3	15.35	2.30	2.30	2.3	17.6	16.6

TABLE 5 (cont'd)

Summary of Pressure Measurements
in Collector Well Model
(Elevated Flat Top)

Headers 1 & 2 open (or) 3 & 4 open

Re	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station:	1	2	1+2	1	2	1+2		
			or Station:	4	3	4+3	4	3	4+3		
51.0	3.71	1.13	(Headers	15.8	15.6	15.7	1.8	2.0	1.9	17.6	16.6
75.5	8.13	1.68	1&2 open)	15.7	16.1	15.9	2.1	1.7	1.9	17.8	16.8
82.6	9.74	1.83		16.0	16.2	16.1	1.8	1.7	1.75	17.85	16.85
117.3	19.63	2.60		15.2	15.2	15.2	1.7	1.6	1.65	16.85	15.85
140.8	28.3	3.12		14.9	15.0	14.95	1.9	1.7	1.8	16.75	15.75
51.8	3.74	1.13	(Headers	14.4	16.3	15.35	3.8	1.9	2.85	18.2	17.2
54.8	3.70	1.13	3&4 open)	15.5	15.5	15.5	2.2	2.2	2.2	17.7	16.7
76.6	8.18	1.68		15.4	15.5	15.45	2.3	2.2	2.25	17.7	16.7
81.1	8.18	1.68		15.6	15.7	15.65	2.2	2.1	2.15	17.8	16.8
83.9	9.80	1.83		16.1	16.1	16.1	2.4	2.3	2.35	18.45	17.45
88.9	9.83	1.83		15.7	15.7	15.70	2.2	2.1	2.15	17.85	16.85
119.1	19.76	2.60		15.8	15.8	15 8	2.1	2.1	2.1	17.9	16.9
126.0	19.95	2.60		15.8	15.8	15.8	2.2	2.1	2.15	17.95	16.95
143.0	28.5	3.12		15.5	15.4	15.45	2.2	2.4	2.3	17.75	16.75
151.2	28.55	3.12		15.7	15.7	15.7	1.7	1.6	1.65	17.35	16.35
Average for 1&2 open (or) 3&4 open				15.7	15.5	15.65	2.0	2.2	2.10	17.70	16.70

TABLE 5 (cont'd)

Summary of Pressure Measurements
in Collector Well Model
(Elevated Flat Top)

Headers 2 & 3 open

Re (10^3)	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
			Station:	2	3	2+3	2	3	2+3		
52.6	3.75	1.13		17.2	17.0	17.1	1.7	1.9	1.8	18.9	17.9
77.9	8.21	1.68		15.0	14.9	14.95	1.4	1.5	1.45	16.4	15.4
85.2	9.83	1.83		15.3	15.3	15.3	1.4	1.4	1.4	16.7	15.7
121.0	19.8	2.60		15.9	15.8	15.85	1.5	1.6	1.55	17.4	16.4
145.3	28.5	3 12		15.4	15.4	15.4	1.5	1.4	1.45	16.85	15.85
Average				15.75	15.7	15.7	1.5	1.55	1.55	17.25	16.25

TABLE 5 (cont'd)

Summary of Pressure Measurements
in Collector Well Model
(Elevated Flat Top)

Headers 1 & 4 open

Re	Average Piezometric Head Loss in Header	Velocity at Station 7		Average Piezometric Head Loss Coefficients in Headers			Average Piezometric Head Loss Coefficients Across Collector Well			Total Piezometric Head Loss Coefficient	Total Head Loss Coefficient
(10^3)	(in)	(fps)	Station:	1	4	1+4	1	4	1+4		
51.0	3.82	1.13		15.9	15.9	15.9	0.9	1.3	1.1	17.0	16.0
75.5	8.36	1.68		15.2	15.3	15.25	0.9	0.8	0.85	16.1	15.1
82.6	10.0	1.83		17.1	17.0	17.05	1.0	1.1	1.05	18.1	17.1
117.3	20.2	2.60		16.2	16.1	16.15	0.9	1.0	0.95	17.1	16.1
140.8	29.1	3.12		15.7	15.5	15.6	0.9	1.1	1.0	16.6	15.6
Average				16.0	16.0	16.0	0.9	1.05	1.0	17.0	16.0

TABLE 6

Imbalance of Flow in Individual Headers
Induced by Collector Well
(Rounded Dome)

(All four headers running full)

Re (10^3)	Max/average flow rate based on headloss in headers	Max/average flow rate based on elbows meters
49.4	1.000	1.017
58.1	1.018	1.023
73.0	1.011	1.018
83.8	1.011	1.002
86.0	1.009	1.030
95.8	1.008	1.021
112.7	1.006	1.005
136.2	1.002	1.011
152.4	1.000	1.017
156.2	1.006	1.024
167.8	1.006	1.013
187.8	1.008	1.017
202.3	1.000	1.021
226.4	1.009	1.017
Average of last eight measurements	1.005	1.016

(Re > 100,000)

All Reynolds numbers are at Station 7

TABLE 7

Imbalance of Flow in Individual Headers
Induced by Collector Well
(Elevated Flat Top)
(All four headers running full)

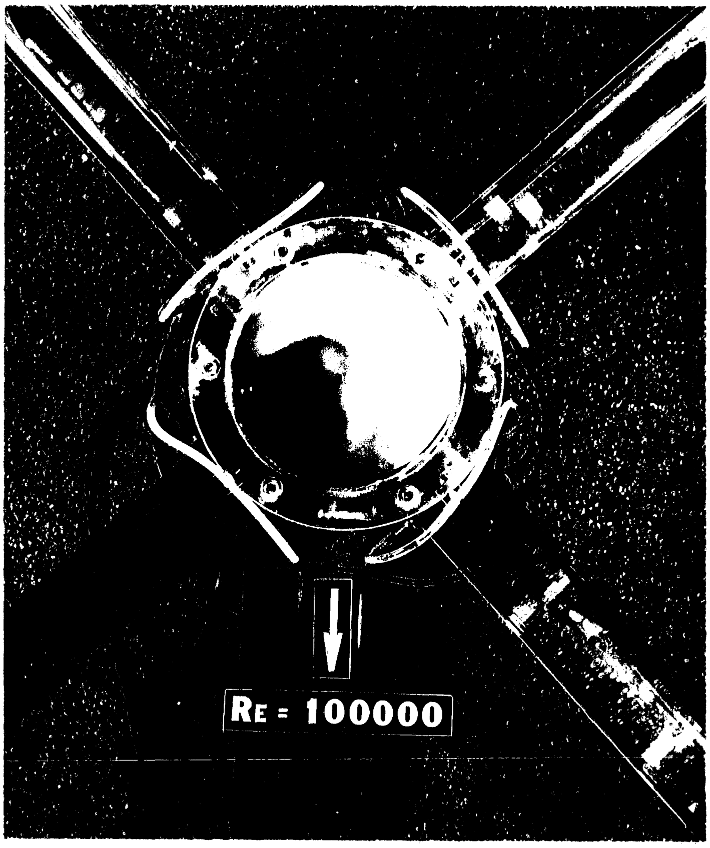
Re (10^3)	Max/average flow rate based on headloss in headers	Max/average flow rate based on elbows meters
52.6	1.031	1.013
58.1	1.017	1.000
77.9	1.015	1.016
86.0	1.019	1.014
102.1	1.015	1.013
112.7	1.012	1.024
145.3	1.018	1.013
160.4	1.028	1.008
178.9	1.015	1.011
197.5	1.025	1.022
215.7	1.021	1.018
238.2	1.016	1.008
Average of last eight measurements	1.019	1.015

(Re > 100,000)

All Reynolds numbers are at Station 7

Fig. 9. Overhead view of dyed flow from header No. 1 into rounded dome collector well. All four headers running full.

Fig. 10. Overhead view of dyed flow from header No. 2 into rounded dome collector well. All four headers running full.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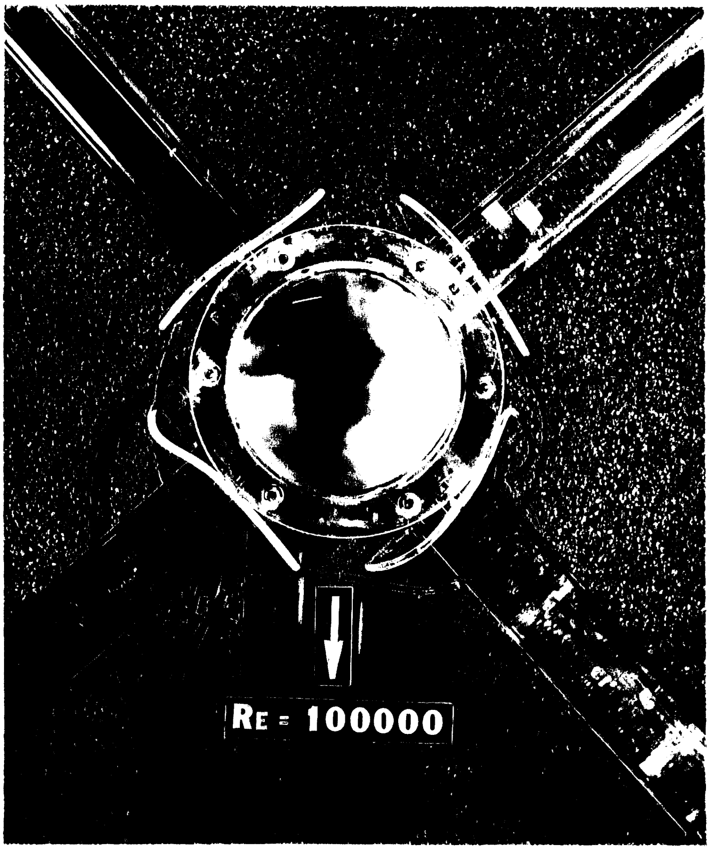
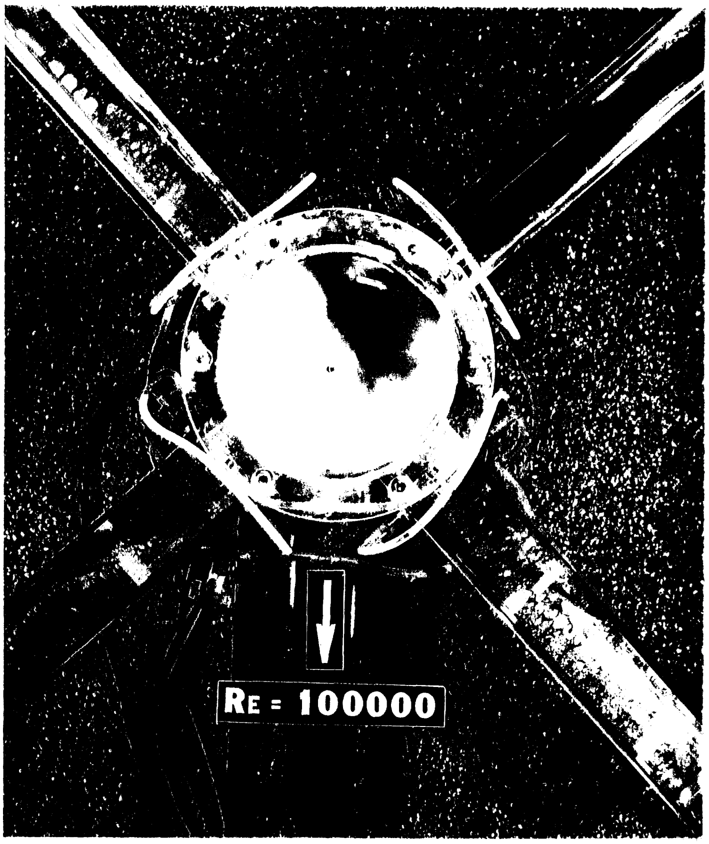

RE = 100000

Fig. 11. Overhead view of dyed flow from header No. 3 into <u>rounded dome</u> collector well. All four headers running full.

Fig. 12. Overhead view of dyed flow from header No. 4 into <u>rounded dome</u> collector well. All four headers running full.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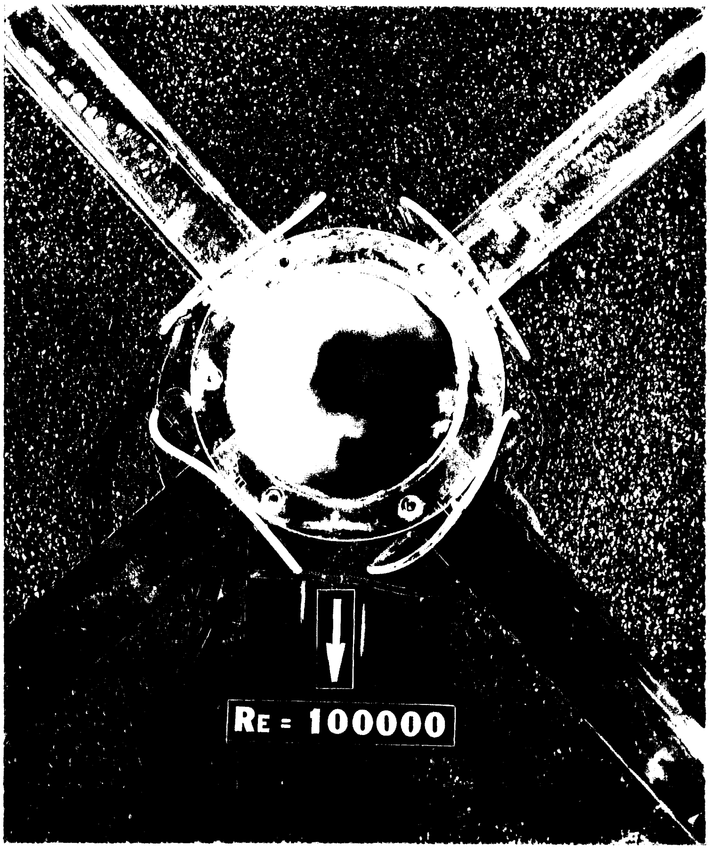

RE = 100000

the rounded dome version of the structure, was very apparent. Figs. 13 through 16 show overhead views of the flow inside the collector well.

The flow rates in each of the four headers were still nearly identical, but the piezometric pressure drop coefficient across the collector well had increased from an average value of about 1.8 to about 3.8. Correspondingly, the headloss (energy loss) in the collector well at Q = 794 cfs had increased by 3.6 inches, from 4.4 inches to 8.0 inches. Table 2 gives the piezometric pressure loss coefficients associated with Figs. 13 through 16.

A vortex flow in the collector well not only increases the headloss in the intake structure but is undesirable because the high flow velocities in the vortex may cause increased abrasion by solid particles moving along the bottom and wall of the structure.

As a result of the undesirable findings with the flat top structure, a request was made to experiment with an <u>elevated flat top</u> with a height approximately equal to the rounded dome. The model was modified accordingly and visualization experiments were repeated. The vorticity in the previous experiments was most likely related to the constraint of the jets (coming from the headers) on the flat top. It was expected that an elevated flat top would provide sufficient space for the incoming jets to spread vertically.

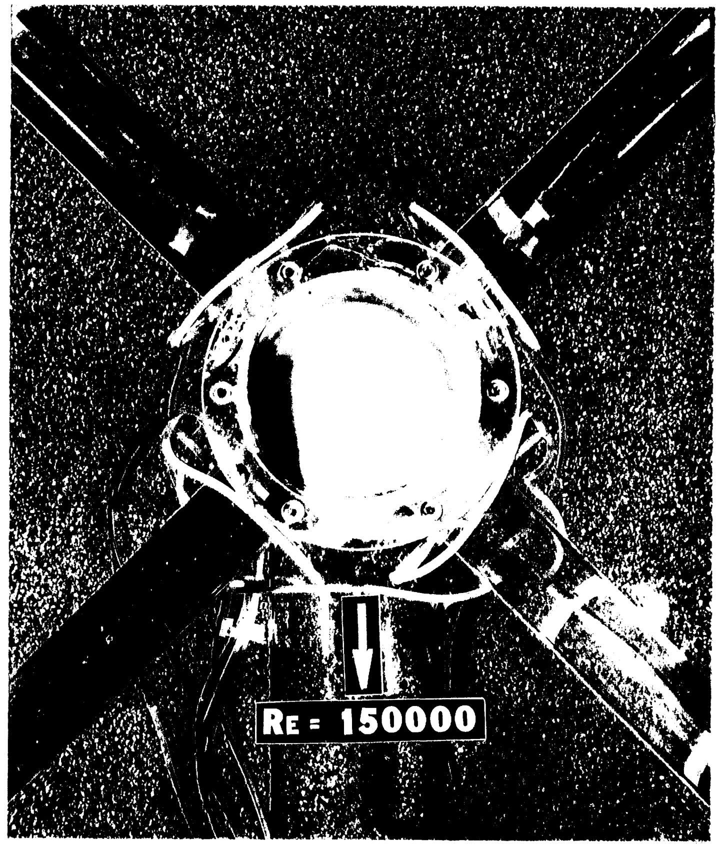
Experiments with the elevated flat top showed the vortex had disappeared. Figs. 17 through 20 show typical flow patterns. When headers 2 and 4 were closed and headers 1 and 3 running full, the flow configuration changed somewhat, but no vortex formed in the well. Figs. 21 and 22 illustrate this situation. The disappearance of the vortex is accompanied by a significant drop in headloss as shown in Tables 2 and 3.

4. Evacuation of Entrapped Air

It was observed in the model that air entrapped under all three dome configurations was readily entrained by the flow. The amount of time required was the shortest for the rounded dome and the longest for the low flat top dome. The similitude of air entrainment depends on Froude number, Reynolds number, and Weber number.

Fig. 13. Overhead view of dyed flow from header No. 1 into <u>flat top</u> collector well. All four headers running full.

Fig. 14. Overhead view of dyed flow from header No. 2 into <u>flat top</u> collector well. All four headers running full.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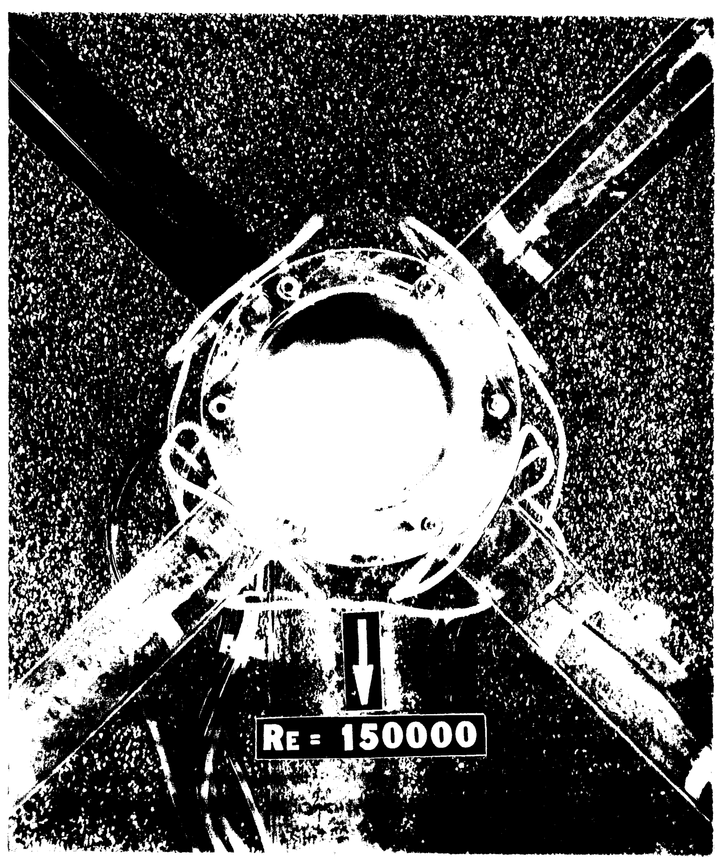
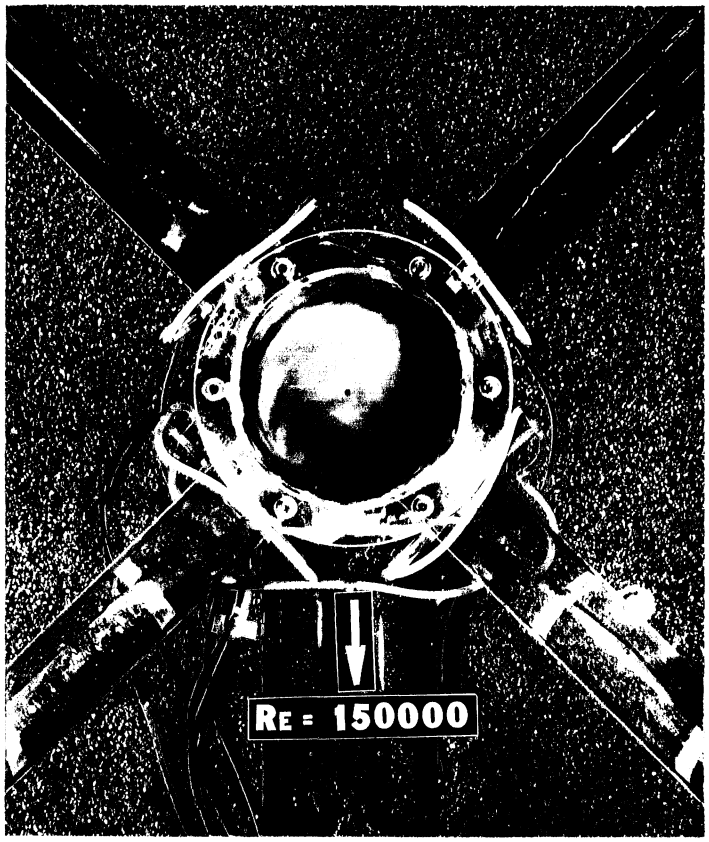

RE = 150000

Fig. 15. Overhead view of dyed flow from header No. 3 into flat top collector well. All four headers running full.

Fig. 16. Overhead view of dyed flow from header No. 4 into flat top collector well. All four headers running full.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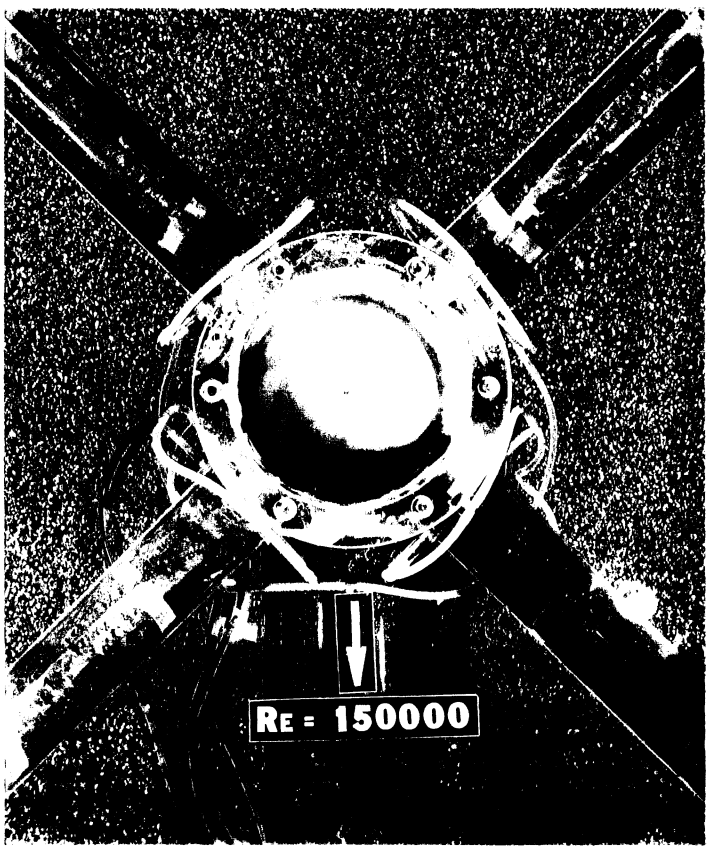
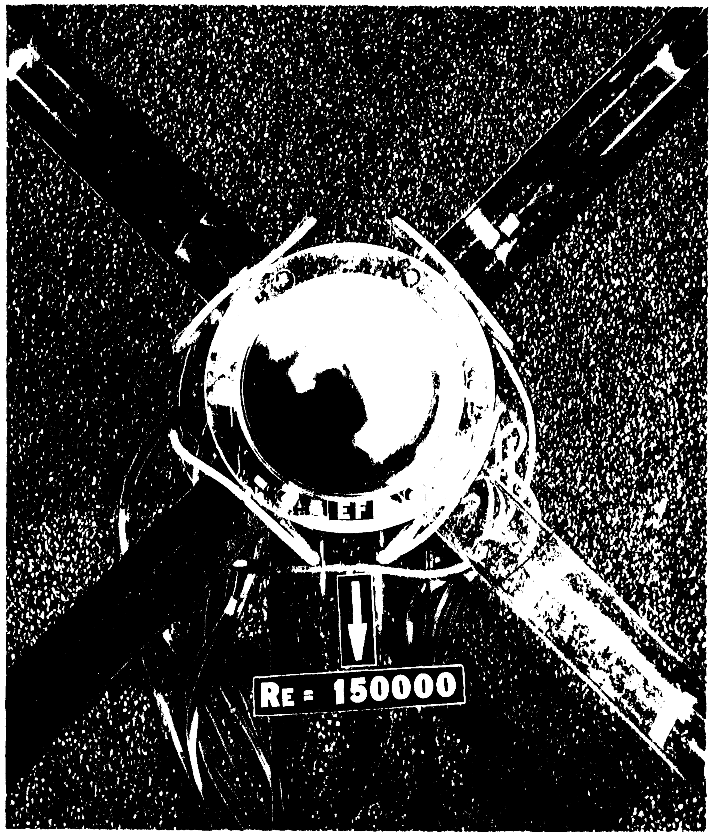

RE = 150000

Fig. 17. Overhead view of dyed flow from header No. 1 into elevated flat top collector well. All four headers running full.

Fig. 18. Overhead view of dyed flow from header No. 2 into elevated flat top collector well. All four headers running full.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RE = 150000

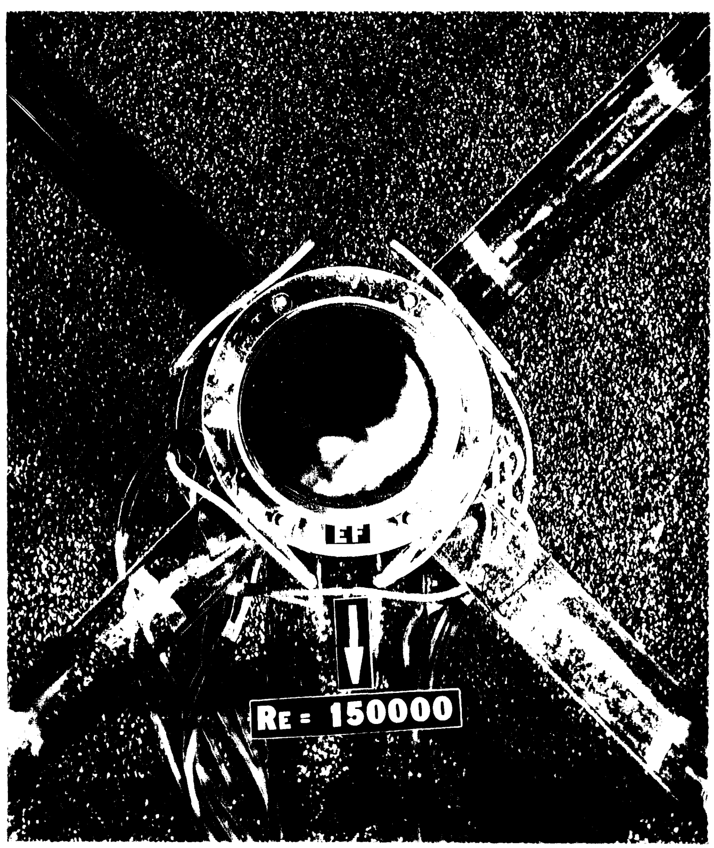

EF
RE = 150000

Fig. 19. Overhead view of dyed flow from header No. 3 into elevated flat top collector well. All four headers running full.

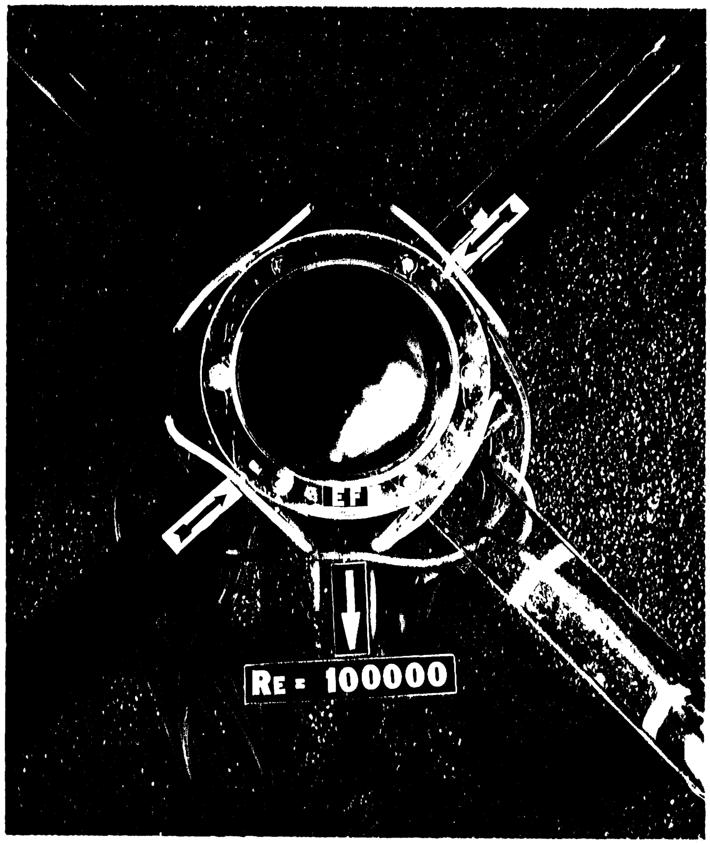
Fig. 20. Overhead view of dyed flow from header No. 4 into elevated flat top collector well. All four headers running full.


EF
RE = 150000


EF
RE = 150000

Fig. 21. Overhead view of dyed flow from header No. 1 into elevated flat top collector well. Headers 1 and 3 are running full; headers 2 and 4 are closed.

Fig. 22. Overhead view of dyed flow from header No. 3 into elevated flat top collector well. Headers 1 and 3 are running full; headers 2 and 4 are closed.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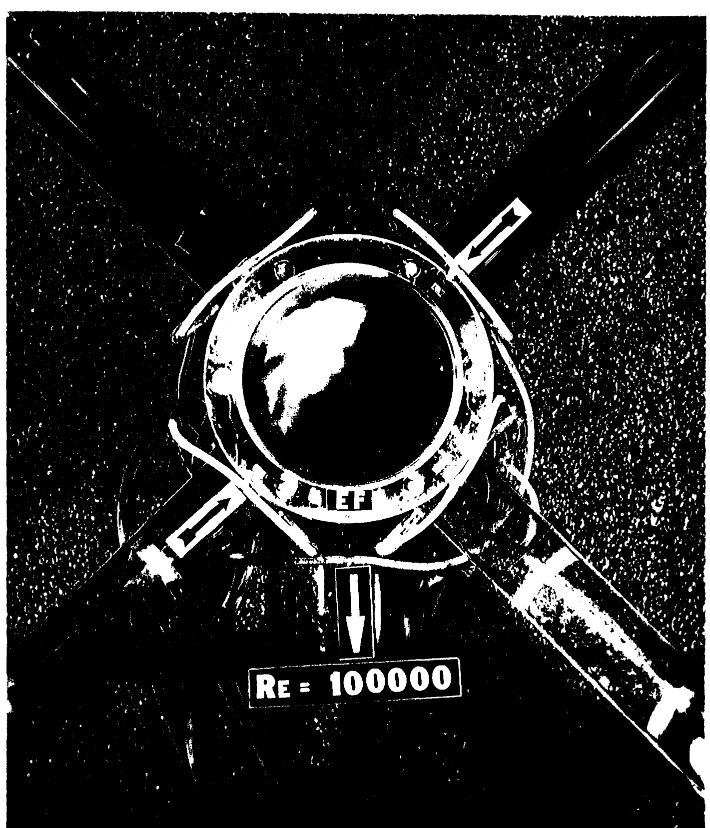

RE = 100000

V. PREDICTIONS FOR PROTOTYPE

Two of three collector well configurations studied in the model performed satisfactorily. The respective prototype dimensions of those two model wells are shown in Fig. 23 and 24. The piezometric head changes and the total energy head losses across the two prototype wells were calculated using the dimensionless coefficients derived from the model results and presented in several tables in the preceding section.

The piezometric head change between, for example, Station 2 and Station 7, was calculated from the relationship

$$h_2 - h_7 = K_{2-7} \cdot \frac{V_7^2}{2g} \qquad (5)$$

where $h_2 = Z_2 + P_2/\gamma$ = piezometric head at Station 2

and $h_7 = Z_7 + P_7/\gamma$ = piezometric head at Station 7

Z_2, Z_7 = elevations of pipe axis of Station 2 and 7, respectively

P_2, P_7 = pressures at Stations 2 & 7, respectively

V_7 = mean flow velocity at Station 7

g = acceleration of gravity

γ = specific weight of water

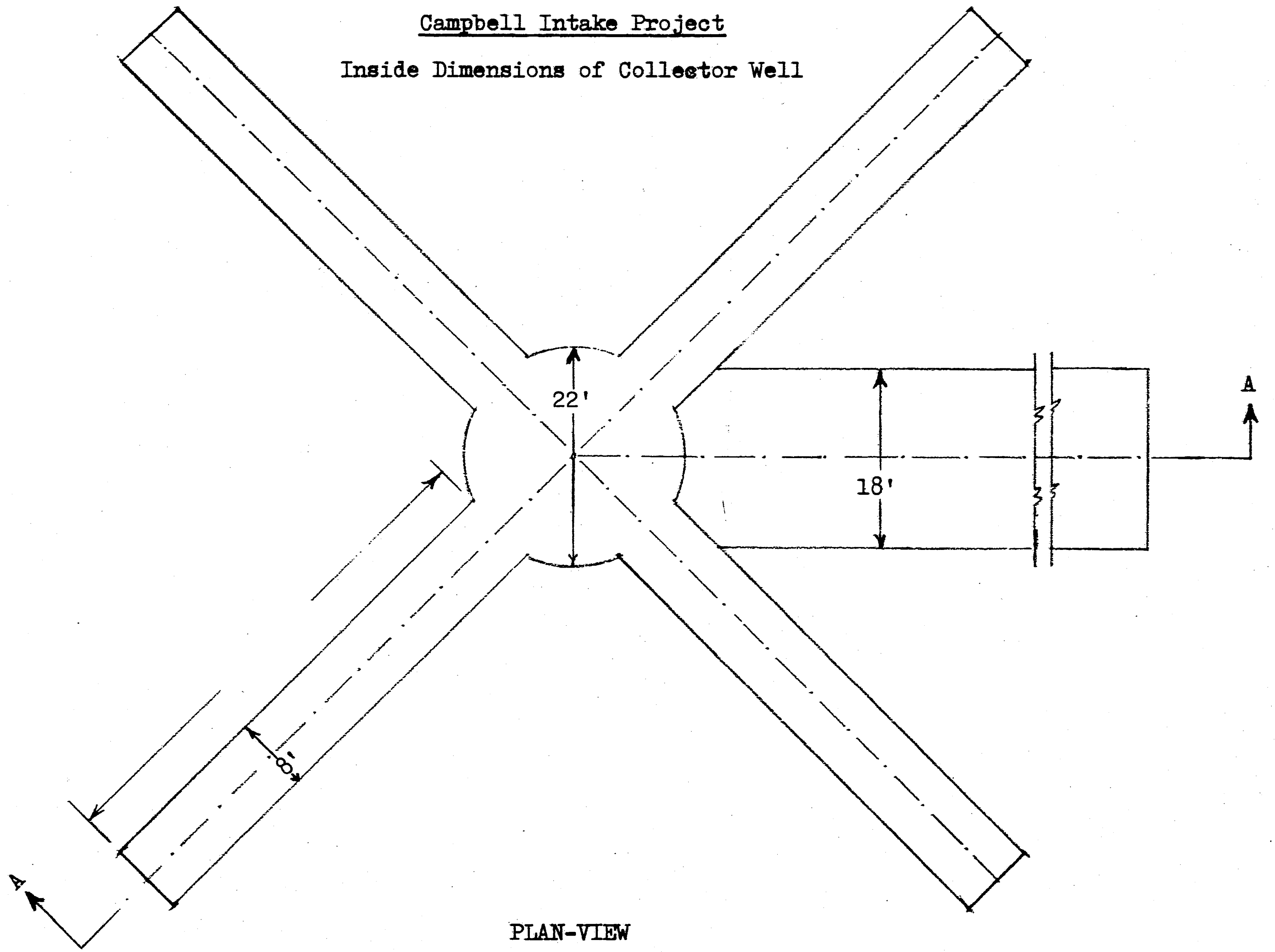
K_{2-7} = piezometric pressure change coefficient given in Table 1, Column 8 for the rounded dome and in Table 3, Colume 8 for the elevated flat dome

Using a design flow of 824.4 cfs with all four headers running full and 464.0 cfs for two headers running full, the piezometric headloss across the collector was calculated. The results are given in columns 5 through 8 in Table 8 for the rounded dome and in Table 9 for the elevated flat top.

The loss in total energy head across the collector well was also determined. For example, the energy loss, $h_{L,2-7}$, across the collector well between Stations 2 and 7 was determined from the relationship

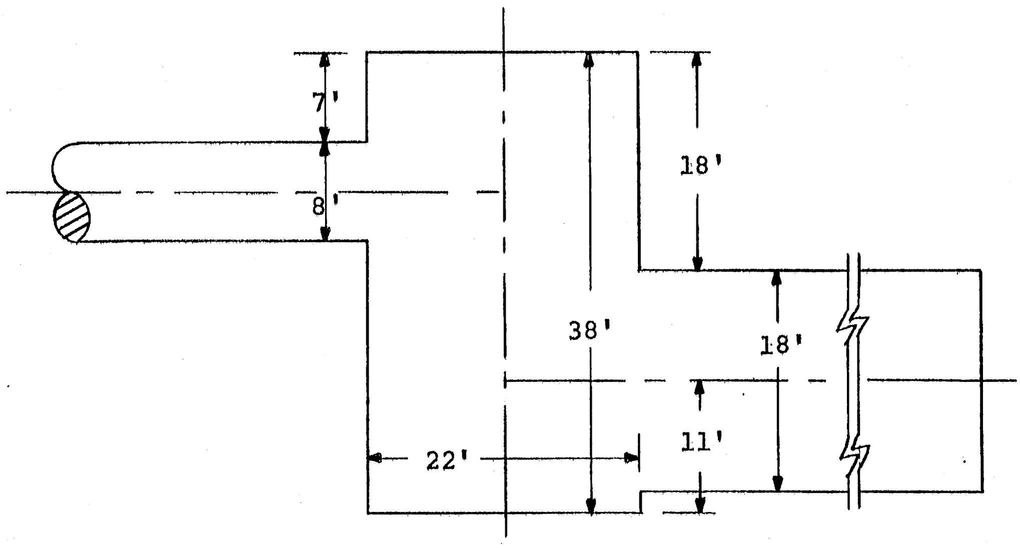
Campbell Intake Project

Inside Dimensions of Collector Well

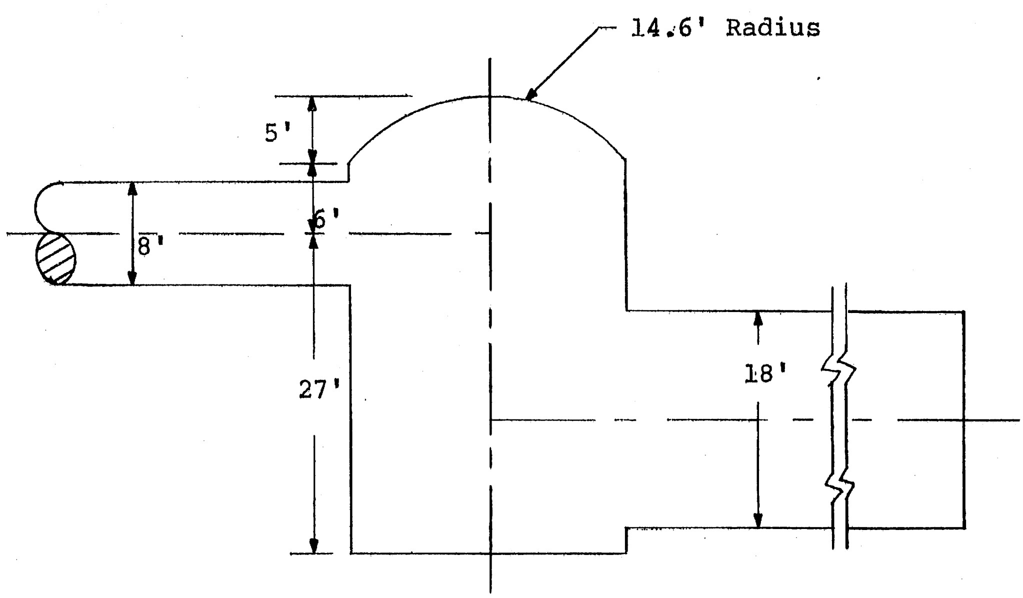


PLAN-VIEW

Fig. 23. Inside Dimensions of Collector Well Configuration



Section AA - Elevated Flat Dome



Section AA - Rounded Dome

Fig. 24. Inside Dimensions of Two Prototype Collector Well Configurations with Satisfactory performance characteristics in the model. (Vertical Sections)

$$h_{L,\,2-7} = h_2 - h_7 + \frac{V_2^{\,2}}{2g} - \frac{V_7^{\,2}}{2g} \qquad (6)$$

where $h_{L,\,2-7}$ = the total energy head loss

h_2, h_7 = piezometric pressure head at Stations 2 and 7, respectively

V_2, V_7 = mean flow velocities at Stations 2 and 7, respectively

The above relationship was developed further, using the continuity equation

$$V_2 = \frac{V_7\ A_7}{4A_2} = V_7 (\frac{18}{8})^2\ \frac{1}{4} = 1.2656\ V_7 \qquad (7)$$

and the piezometric head change coefficient defined by Eq. (1). The final result is

$$h_{L,\,2-7} = (K_{2-7} + 0.60) \cdot \frac{V_7^{\,2}}{2g}\ . \qquad (8)$$

With only two headers running full the continuity relationship is

$$V_2 = \frac{V_7\ A_7}{2A_2} = V_7\ (\frac{18}{8})^2 \cdot \frac{1}{2} = 2.531\ V_7 \qquad (9)$$

and

$$h_{L,\,2-7} = (K_{2-7} + 5.41)\ \frac{V_7^{\,2}}{2g} \qquad (10)$$

Total headloss values across the collector well are given in columns 8 through 10 of Tables 8 and 9.

Sample computations are given in the Appendix.

TABLE 8

Summary of Computed Headloss Across Prototype

Collector Well (Rounded Dome Top)

Flow Condition	Total Design (Prototype): Flow Rate	Total Design (Prototype): Velocity at Stn. 7	Total Design (Prototype): Vel. Head at Stn. 7		Head loss across collector well: Between Station 7 and respective header stations — Pieozometric Head Loss in ft.			Energy Head Loss in ft.		
	cfs	fps	ft.	Sta.	(1 or 4) and 7	(2 or 3) and 7	(1,2, 3 or 4) and 7	(1 or 4) and 7	(2 or 3) and 7	(1,2,3, or 4) and 7
All headers 1,2,3 and 4 pen	824.4	3.24	0.163		0.285	0.293	0.289	0.383	0.391	0.387
				Sta.	(1 or 4) and 7	(3 or 2) and 7	(1&3 or 2&4) and 7	(1 or 4) and 7	(3 or 2) and 7	(1&3 or 2&4) and 7
Diagonal headers 1&3 open or 2&4 open	464.0	1.82	0.0516		0.147	0.147	0.147	0.426	0.426	0.426
				Sta.	(1) and 7	(2) and 7	(1 & 2) and 7	(1) and 7	(2) and 7	(1 & 2) and 7
Adjacent headers 1&2 open	464.0	1.82	0.0516		0.093	0.059	0.076	0.372	0.339	0.356
				Sta.	(2) and 7	(3) and 7	(2 & 3) and 7	(2) and 7	(3) and 7	(2 & 3) and 7
Adjacent headers 2&3 open	464.0	1.82	0.0516		0.067	0.067	0.067	0.347	0.347	0.347
				Sta.	(1) and 7	(4) and 7	(1 & 4) and 7	(1) and 7	(4) and 7	(1 & 4) and 7
Adjacent headers 1&4 open	464.0	1.82	0.0516		0.033	0.033	0.033	0.312	0.312	0.312

TABLE 9

Summary of Computed Headloss Across Prototype
Collector Well (Elevated Flat Top)

Flow Condition	Total Design (Prototype): Flow Rate	Total Design (Prototype): Velocity at Stn. 7	Total Design (Prototype): Vel. Head at Stn. 7		Head loss across collector well: Between Station 7 and respective header stations — Piezometric Head Loss in ft.			Energy Head Loss in ft.		
	cfs	fps	ft.	Sta.	(1 or 4) and 7	(2 or 3) and 7	(1,2,3, or 4) and 7	(1 or 4) and 7	(2 or 3) and 7	(1,2,3, or 4) and 7
All headers 1,2,3, and 4 open	824.4	3.24	0.163		0.245	0.285	0.265	0.342	0.383	0.363
				Sta.	(1 or 4) and 7	(3 or 2) and 7	(1&3 or 2&4) and 7	(1 or 4) and 7	(3 or 2) and 7	(1&3 or 2&4) and 7
Diagonal headers 1&3 open or 2&4 open	464.0	1.82	0.0516		0.119	0.119	0.119	0.40	0.40	0.398
				Sta.	(1 or 4) and 7	(2 or 3) and 7	(1&2 or 3&4) and 7	(1 or 4) and 7	(2 or 3) and 7	(1&2 or 3&4) and 7
Adjacent headers 1&2 open or 3&4 open	464.0	1.82	0.0516		0.113	0.103	0.108	0.39	0.38	0.385
				Sta.	(2) and 7	(3) and 7	(2 & 3) and 7	(2) and 7	(3) and 7	(2 & 3) and 7
Adjacent headers 2&3 open	464.0	1.82	0.0516		0.079	0.079	0.079	0.358	0.358	0.358
				Sta.	(1) and 7	(4) and 7	(1 &4) and 7	(1) and 7	(4) and 7	(1 & 4) and 7
Adjacent headers 1&4 open	464.0	1.82	0.0516		0.050	0.050	0.050	0.330	0.330	0.330

VI. SUMMARY

A collector well with a rounded dome top or an elevated flat top, as shown in Fig. 24, performed satisfactorily from a hydraulic point of view. A low flat top gave a strong vortex flow inside the cover.

All measurements of piezometric head were reduced to piezometric pressure change coefficients. Specifically, sets of coefficients for pressure changes across the collector well were developed.

The total energy headloss across the prototype or full-scale collector well was also determined. With all four headers running full its value was 4.6 inches for the rounded dome collector well and 4.4 inches for the elevated flat top collector well.

A slight imbalance in flow rates from the four headers into the collector well existed due to the non-symmetrical location of the withdrawal pipe. The imbalance value was determined to be less than 2 per cent deviation from the average (if all four headers were contributing equal amounts).

Finally, it was observed that air entrapped in the dome of the collector well was entrained by the flow.

APPENDIX

Computation of Headlosses Across the Collector Well

Refer to the sketch showing the locations of the pressure taps. Find Station 7. Calculate mean flow velocity V_7 at Station 7. The headloss is equal to the piezometric headloss coefficient given in the table multiplied by the velocity head $V_7^2/2g$.

Example 1

All four headers running full, total flow rate = 824.4 cfs. Area at Station 7 = $\frac{18^2 \pi}{4}$ = 254.5 ft^2 .

$$V_7 = \frac{824.4}{254.5} = 3.24 \text{ ft/sec}$$

$$\frac{V_7^2}{2g} = 0.163 \text{ ft.}$$

Piezometric headloss across collector well between Stations 1 & 7.

$$\frac{P_1 - P_7}{\gamma} = 1.5 * 0.163 = 0.245 \text{ ft.}$$

Piezometric headloss across collector well between Stations 2 & 7.

$$\frac{P_2 - P_7}{\gamma} = 1.75 * 0.163 = 0.285 \text{ ft.}$$

Energy headloss across collector well between Stations 1 & 7.

$$h_{L,1-7} = (1.5 + 0.6) * 0.163 = 0.342 \text{ ft.}$$

Energy headloss across collector well between Stations 2 & 7.

$$h_{L,2-7} = (1.75 + 0.6) * 0.163 = 0.383 \text{ ft.}$$

Example 2

Headers 1 & 3 running full, total flow rate = 464.0 cfs,

$$V_7 = \frac{464.0}{254.5} = 1.82 \text{ ft/sec.}$$

$$\frac{V_7^2}{2g} = 0.0516 \text{ ft}$$

Piezometric headloss across collector well between Station 1 & 7.

$$\frac{P_1 - P_7}{\gamma} = 2.3 * 0.0516 = 0.119 \text{ ft.}$$

Piezometric headloss across collector well between Station 3 and 7.

$$\frac{P_3 - P_7}{\gamma} = 2.3 * 0.0516 = 0.119 \text{ ft.}$$

Energy headloss across collector well between Stations 1 & 7.

$$h_{L,1-7} = (2.3 + 5.41) * 0.0516 = 0.40 \text{ ft.}$$

Energy headloss across collector well between Stations 3 and 7.

$$h_{L,3-7} = (2.3 + 5.41) * 0.0516 = 0.40 \text{ ft.}$$