University of Minnesota
ST. ANTHONY FALLS HYDRAULIC LABORATORY

Project Report No. 171

HYDRAULIC MODEL STUDIES
FOR
MODIFICATIONS OF THE COOLING WATER INTAKE
FOR
UNIT NO. 4 - CLAY BOSWELL PLANT
OF THE
MINNESOTA POWER AND LIGHT COMPANY

by

Joseph M. Wetzel and John F. Ripken

Conducted for
EBASCO SERVICES, INC.
Atlanta, Georgia

April 1978
Minneapolis, Minnesota
Introduction

The Minnesota Power and Light Company (MP&L), an investor owned public utility, has an existing steam-electric generating plant located on Blackwater Lake in Itasca County near the City of Cohasset in Northcentral Minnesota. The plant has an intake and pumping station drawing water from the lake. The intake supplies cooling and other water for existing plant Units #1 and #2, each of which is rated at 70 MW. These units employ an open circulating cooling water system and return the heated water to Blackwater Lake. The station also includes service pumps which supply makeup water for plant Unit #3. Unit #3 is rated at 350 MW and employs a closed circulating water system with mechanical draft wet cooling tower. Unit #4 will employ a closed circulating water system with a cooling tower.

The existing intake pumping station, comprised of two intake sumps, is to be modified to provide water for all four steam units. The modifications will necessitate the replacement of some existing pumps with larger pumps and a rearrangement of the service water pumps. The four existing main circulating water pumps and the traveling screens for intake Units 1 and 2 are not to be replaced.

The proposed design modifications of the intake were prepared by Ebasco Services, Inc., Atlanta, Georgia. This report is a brief resume of hydraulic model studies which were carried out at the St. Anthony Falls Hydraulic Laboratory (SAFHL) to clarify and validate the hydraulic performance of the proposed modifications.
The Existing Site Conditions and Proposed Modifications

The existing concrete intake structure to be studied was described by Ebasco drawings Minn 5159 M-1013-0 (dated Preliminary) and Minn G-142881 (dated 6-25-56). The structure is essentially a concrete chamber or sump with inside length of 46'-9", width varying from 11'-2" to 13'-0", and a depth of 27'-6". The 11'-2" wide open end of the sump was originally shown as projecting into the lake 9 feet and the model was so built. Subsequent plans show the entrance as being a modified transition structure.

Fig. 1 delineates the details of the interior of one of the two similar sump units which comprise the intake structure. Only those details considered pertinent to the internal flow processes are shown.

The floor of the sump is located at Elevation 1253.5 as shown and this is also presumed the elevation of the lake bottom in the vicinity of the intake.

The water level in Blackwater Lake varies from a minimum low water elevation of 1270.4 to a maximum high water elevation of 1277.4 with a normal water elevation of 1273.0. It originally was specified that the model studies should be conducted with a water elevation of 1272.0. Later in the program, it was requested that the minimum lower water elevation of 1270.4 be included, as this elevation should create the most severe operating conditions.

In addition to the elements of the sump configuration, Fig. 1 also sketches the main outline and reference position of the three types of pumps (circulating, makeup, and fire) which withdraw water from the sump. The three pipes which feed return water into the sump, i.e. the 10 in. downcomer and the two 6 in. recirculating pipes, are not shown.

The existing circulating pumps, which were built by Westinghouse, have a rated capacity of 27,000 gpm each. These pumps are to remain in their original position as shown. The lower end of these pumps are outlined in Fig. 1 and are shown in more detail in Fig. 2. Figure 2 also shows the arrangement of the suction turning vanes and the concrete blocking and filleting used to set the vanes.

The new makeup water pumps are to have a rated capacity of 8,000 gpm and in sump Unit No. 1 the new pumps will replace both of the existing pumps now
rated at 3,800 gpm. In sump Unit No. 2 only the south pump is to be replaced by a new pump. The new pumps are to be supplied by the Worthington Pump Company as two stage pumps Model 26M 790. The new pumps were originally proposed by Ebasco to be placed at the position upstream of the fire pump as shown in Fig. 1 and Table 1, and hereafter referred to as Alternate A. (Position Alternate B in line with the fire pump was subsequently studied in the SAFHL model tests.) The vertical position of these pumps as originally proposed by Ebasco was established by a bellmouth elevation of 1256.11. Other bellmouth elevations, as shown in Table 1, were alternates subsequently tested at SAFHL. The external configuration of the Worthington pump is shown in Fig. 3.

The new fire pumps of capacity 2000 gpm are to replace existing units. The new units are to be supplied by Peerless Pump Company as Model 16 MCF with 4 stages. The new pumps are to be located in the same position as the existing fire pumps as shown in Fig. 1 and with their bellmouth position at Elev. 1266.0. The external configuration of the Peerless pump is approximated as shown in Fig. 4. The bellmouth strainer was not modeled due to the difficulty of modeling screen structures.

Flows which may be returned to the sumps and which can be a disturbing factor are provided by the recirculating or relief flows which are bled back from the makeup pumps and the overflow from the Unit #3 ash sluice tank. The two relief lines are each of 6" pipe size and have flows of 1250 gpm. The nozzled discharges of these lines are positioned in line with the alternate makeup pump positions shown in Fig. 1 and the nozzles are located at Elev. 1274.5. The overflow return line or downcomer is a 10" pipe positioned near the north wall in line with the upstream fine screen groove in Fig. 1 and it discharges 4000 gpm. The exit of this line is located at Elev. 1268.0.

Sources of flow disturbances apart from the basic sump and the pumps and return lines are found in the screening auxiliaries. At the intake entrance is a coarse bar trash rack for removal of large debris. This consists of 3" x 3/8" bars on 3" centers. Downstream of this is a conventional traveling screen unit as made by Rex Chainbelt. The screen units consist of 2' x 7' baskets covered with screen cloth of 12 W&M galvanized material having a 3/8" square mesh. The main structural framing members of the screen, which may serve as significant flow disturbers, are shown in Fig. 1. The sump also provides insertion grooves for fine screens but these screens are reported as unused.
Stop log guides are provided behind the coarse screens and ahead of the circulating water pumps. All guides and grooves were modeled but the 1" sill projections at the bottom of the stop log grooves were considered not contributing to disturbance and were not modeled.

The Test Program

The principal objective of the model test is to determine whether the proposed sump arrangement provides satisfactory flow conditions at the entrances to the pumps. Satisfactory flow is judged to be that which is largely free of non-uniformities entering the suction bell or evidences of strong discrete vortices entering the bell. In the present state of the art of mating pumps with pumping sumps there appears to be no rigorous specification of what levels of non-uniformities or local vorticity are acceptable. Wholly unacceptable are flows which permit a near-steady, air-sucking vortex to enter the pump. Non-uniformity and vortices in the pump supply can contribute to rough and noisy pump operation, degradation in pump performance, cavitation damage, fatigue failures of metal, increased maintenance problems, and shortened life.

The model and its test program were designed to permit ready simulation, observation, and evaluation of all anticipated operating conditions which might produce unacceptable or critical performance. A determination of critical performance was to be followed by a determination of feasible remedial measures.

The expected source of flow abnormalities entering the pump was believed to spring from separation eddies which regroup or otherwise gain strength as the general flow in the bay accelerates in its approach to the pump. Prior art has sought flow cures by reducing general velocities, better unifying approach velocity distributions, improving flow alignment, and eliminating or streamlining sharp or bluff structures in the upstream flow.

For the existing intake design of Fig. 1, flow abnormalities were expected to have origin in the following features:

1. The complete intake consists of an earth channel from Blackwater Lake which terminates in a flared steel sheet pile transition wall on each side of the channel. The arrangement is somewhat different on each Unit, but, in general, each pile wall angles out at about 60° from the
centerline of the channel. On Unit #1 there is a return flow channel between the sheet pile wall and the Unit and between the Units there is a recessed vertical sheet pile wall. The sheet pile wall on Unit #2 ends in a short section parallel to the channel centerline. The section is difficult to model, the velocities of water are low, and the presence of the trash rack just inside the entrance will partially damp such irregularities. Since trash racks are difficult to scale properly in a model, a model without trash racks is considered a worst case or conservative way to examine the problem. Therefore, trash racks were omitted in the model study.

2. The entrance opening to the sump rises 15.5 feet above the floor of the sump or to El. 1269.0 where a concrete barrier or skimmer wall restricts flow into the sump. Pump operations which are at river stages above El. 1269.0 will produce flows with a strong separation eddy generated downstream of the skimmer wall and flow in the bay above El. 1269.0 will be retarded.

3. The traveling screens are mounted on large concrete projections from the sump walls. These locally serve to substantially restrict the width of the sump channel and increase the mean flow speed. Subsequent expansion of this central jet into the wider sump passage downstream of the screen will produce large and strong separation eddys along the sump walls. This flow is additionally altered and worsened by the presence of the large structural screen framing members which are shown in Fig. 1. The traveling screen itself will in general tend to provide some improvement in the flow approaching the screen in that the screen resistance and character will tend to reduce and homogenize the eddies and turbulence of the approach flow. Since screens like trash racks are difficult to model effectively, a model without screens is considered a worse case or conservative way in which to examine the pumping problem. Therefore, screens were omitted in the model study.

4. The four very large structural tie beams which span the sump chamber as shown in Fig. 1 are sharp cornered and will generate large and strong separation eddies in the flow downstream of the beams. These
eddies may be expected to be especially influential in producing eddies in the intake of the makeup pumps because of the close proximity of the pumps to the eddy source.

5. The makeup pumps are to be mounted in a chamber with flaring side walls. Such walls inherently produce reverse wall flows, separation eddies, and flow stability. These eddies may also be expected to strongly influence the makeup pumps because of their close proximity.

6. The bulk of the flow entering the main circulating pumps passes through a metal turning vane system with filleted corners. This configuration provides a well organized approach into these pumps for most of the flow. However, some of the flow entering the pumps approaches from above the pump bell through the stippled area shown in the plan view of Fig. 2. This flow turns about 180° upon entering the pump bellmouth and has a varying width of stream around the periphery of the bellmouth.

7. Withdrawal via the various pumps generates flow patterns in the sump which varies with the pattern of pumps operating at any particular time. This mutual effect between pumps necessitates that test observations for critical pump conditions shall include all possible combinations of pump operating arrangements. Since the feed lines which return flow to the sump also influence sump flow patterns, their actions must also be programmed into the pump test operations.

The specific tests which were conducted to evaluate the influence of the above disturbance sources are separately detailed under "Test Results" which follows the next succeeding section describing the test model.

The Test Model

The objective of the test model design was to provide a set-up which would reasonably simulate the actions of the pumps in the eventual full scale installation. The model was to permit operational programming of all the flow variables which might be pertinent to the pump performance and was to permit observation and evaluation of these flow effects at reasonable cost.
In this instance the model was adapted to existing Laboratory water supply and space constraints which lead to the selection of a 1 to 8.4 model scale ratio. The resulting model is shown in the photos of Fig. 5.

A free surface model of the type described is generally considered to be motivated primarily by gravity and the model occurrences will then have a relation to the full scale in accord with the Froude law. This requires that all length values be in accord with the length ratio \( L_m / L_{fs} = 1/8.4 \), all velocity values in accord with \( V_m / V_{fs} = \left( L_m / L_{fs} \right)^{1/2} \) or \( = 1/2.9 \), and all discharges in accord with \( Q_m / Q_{fs} = \left( L_m / L_{fs} \right)^{5/2} = 1/204.5 \). Many experimentalists when working with hydraulic machinery models run tests at Froude scaled velocities and in addition either full scale velocities or the highest velocity practically attainable in the model. The tests under discussion were run this way.

The model consists of a 4' x 8' rectangular box reservoir representing Blackwater Lake together with the intake structure involving one fully detailed pump test sump.

Test runs were largely confined to the low water stage simulating El. 1270.4. The water employed in the model was drawn from the Mississippi River by way of a large flume and a 6 inch supply pipe. Water temperature varied from 48°F to 56°F during the tests.

Only one pump bay was modelled in scaled detail with stop log wall slots, traveling screen, and model pumps. The traveling screen was modelled only in regard to the bulk dimensions of the edge mounting angles. Other details were omitted.

The model makeup pumps simulated the lower elements of Worthington pump 26M790 with pertinent full scale dimensions as shown in Fig. 3 and model dimensions as shown in Fig. 6. External dimensions of the pump above the bellmouth were roughly approximated by a 2-stage pump bowl assembly followed by a riser pipe of \( 1\frac{1}{4} \) inch (16 inch full scale) outside diameter. Internal dimensions of the pump above the suction eye of the first stage were not modelled but were replaced instead in one pump with an assembly supporting four small vortex indicators as shown in Fig. 6. The vortex indicators consisted of lightweight, two bladed, axially aligned rotors centrally mounted above the four between-strut openings in the bell assembly. The rotors served as sensitive indicators.
of the presence of flow rotation. The dimensions shown for the pump bell, bearing hub and hub support struts are not in rigorous agreement with the actual dimensions proposed by Worthington. The Worthington drawings for the pump were received too late to accommodate the specified model construction and testing program. The dimensional differences are not considered significant to the eventual model observations.

The model pumps were fitted with a suction withdrawal system including a flow meter and control valve. The withdrawal piping readily permitted changes in the position and elevation of the suction bell of the pumps. Tests with either Froude scaled velocities or larger values could readily be made. For tests simulating the low water stage of EL 1270.4, these larger velocity values approximated about two times the Froude scaled velocity.

The fire pump was tested in only the one position shown in Fig. 1 and the model pump had the dimensions shown in Fig. 4. The model pump was fitted with metered withdrawal piping. The fire pump, which is operated only on rare occasions, was not observed in any detail in the model study. It was included in the model only for the effect that its withdrawal might have on the circulating or makeup pumps.

The circulating water pumps shown in Fig. 2 were fitted with a modelled version of the contraction and suction vaning as shown in Fig. 5(a). The modelled pump was as shown in Fig. 7. The modelled pumps were fitted with metered water withdrawal piping. One of the modelled pumps was fitted with a row of five vortex indicators as shown in Fig. 7. The indicators consisted of lightweight, two bladed, axially aligned rotors mounted on a support rake. The support rake was attached to a rotatable central shaft which could be turned by an external handle above the turning elbow. The rotors served as sensitive indicators of the presence of flow rotation in the pump intake. By slow rotary traversing of the indicator rake, the entire pump intake cross section could be sampled for the presence of vortices.

The Unit #3 ash sluice overflow return line downcomer was attached to a calibrated water supply and was fabricated to permit easy movement to other positions and elevations. The downcomer in the model terminated in a straight length of 1 in. diameter pipe.
The two recirculating or relief pipes were connected to a high pressure, calibrated water supply. These pipes were terminated with a nozzle which provided essentially the scaled velocity head for the jet at the design flow conditions.

Test Results

A. General Flow Pattern in Sump.

With the circulating water and the makeup pumps operating at their design discharges, the general flow patterns into the pump pit were observed using woolen yarn attached to a vertical rod, dye injection, and confetti on the water surface. These observations led to the conclusion that the obstructions upstream of the makeup pumps created considerable flow disturbances which may result in poor approach conditions to the pump intakes. A series of photos were taken to document the surface flow patterns. For these photos the makeup pumps were located on a transverse line with the new fire pump and the bells were at Elev. 1264.07. Although photos were taken for several water levels, only the results for the minimum low water level of 1270.4 have been included here as they should represent the worst flow conditions.

Photo 8a is a view looking from the reservoir into the entrance of the pump pit. The streaks are caused by confetti on the water surface and a time exposure of 1 sec. The length of the streak is a measure of particle or surface velocity. Thus, both velocity and flow pattern can be inferred from the photos. Two vortices can be noted in the corners in the vicinity of the cutoff or skimmer wall, although they were not of sufficient strength to create a dimple in the water surface.

Photo 8b shows the area downstream of the cutoff wall and include the framework for the traveling screen, the downcomer pipe, and the column of one makeup pump. The confetti traces clearly show the contraction occurring in the region of the traveling screen supports and frame. Some large eddies are also evident in this area. A large eddy is visible just upstream of the makeup pump column in the region where the sump sidewalls diverge. The reverse flow associated with this eddy will be observed in photographs of yarn filaments near the surface. Surface flow patterns were essentially the same for other water surface elevations.
From the above typical observations, it was felt that it would prove beneficial to improve the uniformity of the flow downstream of the traveling screen and other support members. A perforated plate with hole diameters of \( \frac{1}{4} \) in. (model size) and a solidity ratio of 42 percent was placed in the wall slots originally designed for fine screens. It was found that the screen greatly improved the flow uniformity and further evidence will be provided in the following section. It was not possible to take photos of the confetti patterns with the screen in place due to the overhead plumbing of the pump suction lines.

B. Makeup Pumps.

The flow quality into the bell of the pump was evaluated by observation of the activity of the vortex indicators shown in Fig. 6. These evaluations were made for a variety of pump locations and bell elevations as listed in Table 1. The alternate locations have been separated into series A and B, where A is the position originally proposed and B is the position in line with the fire pump. The lateral spacing of the pumps with respect to the structure centerline, a and b, is related to that shown in Fig. 1. Note that the elevations are referenced to the bottom of the pump bell.

<table>
<thead>
<tr>
<th>Alternate</th>
<th>a</th>
<th>b</th>
<th>Bell Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4'-3&quot;</td>
<td></td>
<td>1256.11</td>
</tr>
<tr>
<td>A1</td>
<td>4'-3&quot;</td>
<td></td>
<td>1255.17</td>
</tr>
<tr>
<td>A2</td>
<td>4'-3&quot;</td>
<td></td>
<td>1254.44</td>
</tr>
<tr>
<td>A3</td>
<td>3'-3&quot;</td>
<td></td>
<td>1255.17</td>
</tr>
<tr>
<td>A4</td>
<td>4'-3&quot;</td>
<td></td>
<td>1264.07</td>
</tr>
<tr>
<td>B</td>
<td>4'-6&quot;</td>
<td></td>
<td>1264.07</td>
</tr>
<tr>
<td>B1</td>
<td>4'-6&quot;</td>
<td></td>
<td>1263.07</td>
</tr>
<tr>
<td>B2</td>
<td>4'-6&quot;</td>
<td></td>
<td>1255.17</td>
</tr>
<tr>
<td>B3</td>
<td>4'-3&quot;</td>
<td></td>
<td>1255.17</td>
</tr>
<tr>
<td>B4</td>
<td>3'-3&quot;</td>
<td></td>
<td>1255.17</td>
</tr>
</tbody>
</table>

The first evaluation was made with the makeup pumps at the position Alternate A, and the circulating water and makeup pumps operating at their
design discharges. The vortex sensors rotated rapidly and consistently, particularly the two sensors on the back side facing the circulating water pump. This behavior was probably to be expected as the pump bell was subjected to the cross flow created by the circulating water pump. It was felt that the vorticity was excessive and other locations were sought, such as those described in Alternates A1, A2, and A3. No significant improvement was noted in these alternate positions. In an attempt to provide more uniformity to the approach flow, several devices were briefly tried. A grillage of vertical, $\frac{1}{4}$ in. dia. pipes (model size) extending from the sump bottom to about Elev. 1262 was attached to the lower downstream crossbeam support. This grillage was not effective, and was abandoned. The pump intakes were next enclosed in a cage made of perforated plate with $\frac{1}{4}$ in. dia. holes (model size). This screen covered the bells and extended across the entire width of the pump pit. The flow into the makeup pump intake was greatly improved, as the vortex indicators remained essentially stationary. It was felt that the possibility of trash in the water in the full-scale structure may eventually lead to clogging of the screens, and these screens would be difficult to remove. Therefore, the cage was removed and a vertical screen of the same material was placed in the fine screen groove as described earlier. Comparison of the activity of the vortex sensors with and without the screen in place indicated some improvement in the flow was obtained, although not as much as with the cage surrounding the bell.

It was anticipated that raising the bells of the makeup pumps would reduce the influence of the flow into the circulating water pumps and thus be beneficial. Hence, the pumps were raised to an elevation that still satisfied the minimum submergence requirement of the pump manufacturer at the minimum low water level. This position is referred to as Alternate A4 in Table 1. Flow into the bell was observed, and the improvement was not as much as originally expected. However, flow quality was further improved with the perforated screen in place.

These findings suggested that the pumps be moved closer to the circulating water pumps, in line with the fire pump. First tests were made with Alternate B and the pumps at their minimum submergence. Flow quality was better than at the other locations examined up to this point provided that the perforated
screen was in place. With the pumps in this elevated position, the possibility of not extending the screen the entire distance to the bottom of the pit was examined. Observations indicated that no deterioration of the flow quality was noted until the bottom of the screen was raised above Elev. 1260.

A series of documentary photographs were taken with the pumps in the Alternate B position. Woolen yarn was attached to a rod at 1 ft full-scale intervals, and this rod was positioned on the pump centerline about one bell diameter up and then downstream of the pump column. Typical photographs with a time exposure of 1 sec. are shown in Figs. 9, 10, and 11. Figure 9 shows the flow with no screen in place. The flow upstream of the pump is quite unsteady as indicated by the yarn movement. The previously mentioned reverse flow at the surface is also apparent. In Fig. 9b, the direction of the yarn filaments shows the flow pattern into both the circulating water and makeup pumps.

The flow uniformity and steadiness is considerably improved with the perforated screen installed full depth as shown in Fig. 10. The yarn filaments are much steadier than without the screen. With the bottom of the screen at Elev. 1260 as in Fig. 11, the unsteadiness of the flow is increased at the lower elevations but this does not have a significant influence on the flow into the makeup pump.

As some uncertainty apparently exists concerning the minimum low water level in the full-scale installation, it was suggested that the pumps be evaluated at a greater submergence at a position in line with the fire pump. The pumps were lowered one foot (Alternate B1) and a slight increase in vorticity in the intake was noted. Finally, the pumps were lowered so that the bell was a distance of 1 ft 8 in. from the floor and the lateral spacing of the pumps was varied (Alternates B2, B3, and B4). Observations of the rotation of the vortex indicators were made, and although more rotation was observed than with the pump at the highest elevation B, the performance as compared to other pump locations was relatively good. With the pumps moved further away from the wall, as in Alternates B3 and B4, some minor improvement in flow quality was observed. Photos of the yarn filaments with and without the screen in place are shown in Fig. 12. Some movement of the filaments can be noted even with the screens installed, although observation of the flow over a long period of time indicates that the screen does improve the overall flow quality.
It may be possible that the screen does not have to extend to the water surface with the pumps near the bottom of the pit. However, this condition was not examined.

In summary, it should be mentioned that in all pump positions tested, no ideal location was found. Some rotation of the vortex sensors was observed for all locations of the pumps, although some positions were better than others. Placement of the pump bell in the approach flow to the circulating water pump requires that the flow on the downstream side of the makeup pump must reverse direction in the vicinity of the bell. This change in direction can excite vorticity, and in all cases the action of the vortex sensors consistently was greatest in the downstream half of the bell intake.

C. Circulating Water Pumps.

As described previously, a set of vortex sensors was installed in one of the circulating water pump bells. These sensors were used to detect any excessive vorticity that may be associated with operation of the makeup pumps. The sensors were monitored for all flow conditions and locations of the makeup pumps. It was observed that some vorticity existed in the corners of the essentially square opening into which the bell was placed. Injection of dye into the region above the curved beam entrance to the vaned elbow showed that some flow was entering the bell from above, as well as through the vaned elbow. A thin sheet metal plate was fabricated to cover this opening and thereby greatly reduce the flow from entering the pump from above the bell. The area covered is shown in Fig. 2. With the cover plate installed, the action of the vortex sensors in the corners was virtually zero.

For all conditions tested, no significant influence of the makeup pumps on the performance of the large circulating water pumps could be noted. Apparently the vaned elbow works very well in unifying the flow to the suction bell.

D. Ten Inch Unit #3 Ash Sluice Overflow Return Downcomer.

The downcomer was positioned with its centerline 10 in. from the north pit wall and on the centerline of the first fine screen groove. The outlet of the straight pipe was set at Elev. 1268.0. Tests were conducted to determine the influence of the 4,000 gpm maximum downcomer discharge on the flow pattern into the makeup pumps. These tests have indicated that the downcomer jet creates considerable disturbance and increases the vorticity in the
intake of the makeup pump. However, if the perforated screen is placed down­stream of the downcomer discharge, the influence of the downcomer jet is greatly reduced and may be tolerable.

E. Two Six Inch Relief or Recirculating Water Pipes.

These pipes as originally proposed were terminated in a nozzle to provide a velocity head of about 50 ft at the full-scale design discharge of 1250 gpm. The nozzle was set at an elevation of 1274.5, and was attached to an elbow so that the jet impinged on the water surface at about a $45^\circ$ angle. In the model, a nozzle area was selected to establish essentially the scaled velocity head of the jet, and the nozzle could be rotated to allow determination of the location which resulted in least influence on pump performance.

The original scheme was with the nozzles pointed upstream away from the makeup pumps. The tests with the makeup pumps indicated that best performance was achieved when a perforated screen was placed in the fine screen groove. With such a screen in place, the high velocity jets would impinge directly on the screen. This situation is felt to be undesirable and the nozzles were rotated $180^\circ$ so that the jet would be directed to the back wall of the sump above the circulating water pumps. The tests have shown that the jet penetrates deeply into the water, entrains a large quantity of air, and sets up a recirculation of the water in the area. Vorticity was increased in the makeup pumps, and if the previously mentioned cover plate was not installed over the bell of the circulating pumps, some of the entrained air was drawn into the circulating pump. These conditions were considered unsatisfactory.

It was then decided to dissipate some of the energy of the jet by terminating the recirculating water pipes with a multiorifice manifold submerged below the water surface. A small manifold was constructed which spanned the distance from the pit wall to the interior dividing wall. This manifold greatly reduced the disturbances and proved to be acceptable. No attempt was made in the model studies to optimize the manifold design, although it is suggested that a submerged manifold located in the region above the circulating water pumps be used in the final design.

F. Fire Pump.

The fire pump was originally modelled only in accordance with its external dimensions to permit evaluation of flow around the pump. It was later requested
that the unit be modified so that the pump could also withdraw water at its
design discharge and thus the influence of the fire pump on the other pumps
could be assessed. The fire pump was operated in conjunction with the other
pumps and no significant influence was noted.

G. Conclusions and Recommendations.

Based on the observations made during the test program, the following
conclusions and recommendations are offered:

1. The flow pattern into the existing sump is disturbed by the traveling
screen frame, supports, and structural beams. Uniformity of the flow
can be improved by placing a perforated screen in the downstream
fine screen groove. This screen should have holes of about 2 in.
dia. and a solidity ratio of about 42 percent.

2. No ideal location and elevation of the makeup pumps was found. How­
ever, some positions were judged better than others. In all cases,
the screen of item 1 improved the flow conditions and is therefore
recommended. The best location was Alternate B with the pumps in
line with the fire pump and a bell elevation of 1264.07. It should be
noted that this elevation provides only the minimum submergence
required by the pump manufacturer for a minimum low water level of
1270.4. Some additional submergence may be desirable in the event
the water level is lower than 1270.4. The next best location was
Alternates B2, B3, and B4 with the pump bell at Elev. 1255.17. Some
improvement in flow quality was noted as the spacing between pumps
was decreased. The spacing finally adapted may be dependent on
installation of the equipment in the available space.
No strong vortices capable of drawing air from the surface or even
dimpling the water surface were observed in the tests.

3. The flow into the circulating water pumps was not significantly in­
fluenced by the makeup pumps. Some vorticity was observed in the
corners of the square approach to the bell, and this could be
significantly reduced by covering the existing opening between the
bell and the vaned elbow. However, since the existing pumps have been
operating satisfactorily for a long period of time, the additional
construction costs may not be justified.
4. The originally proposed location of the downcomer is generally satisfactory if the screen of item 1 is utilized. Terminating the downcomer in a multi-orifice manifold to dissipate the energy of the jet would also be additionally beneficial.

5. The two relief or recirculating water pipes should be terminated in a submerged, multi-orifice manifold to reduce the velocity of the jets. The manifolds should be located in a region removed from the immediate vicinity of the pump intakes.
Sectional Plan View of Pump Sump

Sectional Elevation of Pump Sump

Fig. 1 - Arrangement of Intake Sump Chambers.
Fig. 2 - Details of the Circulating Pump Suction Arrangement.
Fig. 3. External Form of the Worthington Makeup Pump
(after Worthington Drawing 0L 45721)
Fig. 4. External Form of the Fire Pump

Note: Form shown is a simplified model version of the full-scale Peerless pump. Dimensions shown in parentheses are approximate full-scale values.
Fig. 5 - The 1:8.4 Model - Clay Boswell Cooling Water Intake.
Fig. 6. Section of Model Makeup Pump Assembly with Vortex Indicators (Model approximates Worthington 26M-790 and full-scale dimensions are shown in parentheses.)
Fig. 7. Sectional Model Circulating Pump Assembly with Vortex Indicators (full scale dimensions are shown in parentheses)
(a) View from Reservoir. Exposure Time = 1 sec.

(b) View of Pump Pit. Exposure Time = 1 sec.

Fig. 8 - Surface Flow Patterns.
Min. LW Elev. 1270.4
Fig. 9 - Makeup Pump Flow Lines, Alternate B. No Screen.
Fig. 10 - Makeup Pump Flow Lines, Alternate B. Screen Full Depth.
Fig. 11 - Makeup Pump Flow Lines, Alternate B. Partial Screen.
Fig. 12 - Makeup Pump Flow Lines, Alternate B3.