Vortex formation and prevention.

D. A. Buratto

University of Windsor

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VORTEX FORMATION AND PREVENTION

A Paper
submitted to the Faculty of Graduate Studies
in partial fulfilment of the requirements
for the degree of

Master of Applied Science
in the Department of Civil Engineering

University of Windsor

by
D. A. Buratto, B.Sc.
Windsor, Ontario
April, 1971
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ABSTRACT

During the design of the West Windsor Sewage Treatment Plant, vortex formation was anticipated in the influent and effluent chambers of the primary settling tanks. The formation of vortices can seriously reduce the hydraulic capacity of conduits because of air entrainment. The resulting reduction in capacity creates difficulties in the hydraulics of the system. Therefore, it is rather important that steps are taken to avoid these problems. A model study was considered to be the most reliable and economical method of investigation. A model was built to a scale of 1:16 and incorporated into the piping system in the hydraulic laboratory at the University of Windsor. The first phase of the testing included water level measurements and flow measurements in the chambers and observations with regard to associated flow patterns. The range of flows studied was from 24 M.I.G.D. to 90 M.I.G.D. which represent the design dry weather flow and the maximum anticipated flow for the prototype. The first phase of testing indicated that
vortices were formed as flows approached 45 M.I.G.D. In addition, air entrainment in the discharge pipes was noted and turbulence on the water surface caused splashing at the higher flows.

On the basis of the observations from the first phase of testing and from a review of literature on the subject, a baffle arrangement was selected and testing on the model including baffles was conducted for the same range of flows used in the first phase of the testing.

The baffle arrangement proved to be very effective in preventing the formation of vortices and reducing the turbulence on the water surface. Air entrainment in the discharge pipes was significantly reduced although still noticeable at the higher flows. It has been noted that air entrainment does not occur in the prototype for the range of flows which have been observed to date. The present average flow in the prototype is approximately 12 M.I.G.D. and has reached a maximum of 60 M.I.G.D. on several occasions. For this range of flows there has been no vortex formation, surging, or air entrainment. Sufficient opportunities have not been available to study the effectiveness of
the baffles for unusual flow conditions.

The elimination of vortices in a chamber after it has been constructed can be very inconvenient, particularly in a sewage treatment plant. Correction of the situation may require full scale testing and shut-down of certain portions of the plant in order to make chamber modifications. By conducting the model study in advance of the construction of the prototype, this inconvenience was avoided.
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1. INTRODUCTION

Webster's New International Dictionary, Second Edition, defines a vortex as a mass of fluid, especially of a liquid, having a whirling or circular motion, tending to form a cavity or vacuum in the centre of the circle; the form assumed by liquids in such motion; a whirlpool; eddy.

Almost everyone has observed vortex formation at one time or other. The most common example is the vortex formed in the vicinity of the drain when a bath tub or sink is being emptied. One can also observe vortex formation in the shape of a tornado; on the surface of a liquid during rapid stirring, which is termed a forced vortex; and in turbulent flowing streams, a particular example being the whirlpool formation at the foot of the Niagara Falls.

Vortex motion was studied in detail as early as 1858 and 1867 by Helmholtz and Kelvin. Since that time, extensive studies have been undertaken on vortex formation in pump sumps, and intakes for hydraulic
Generally, the formation of vortices is accompanied by a substantial loss of energy, air entrainment, and a reduction in the discharge capacity of a system. The formation of vortices in the influent and effluent chambers of a sewage treatment plant was studied to determine a method of preventing the occurrence of these unfavourable conditions.
2. SURVEY OF LITERATURE

2.1 Experimental Work

From the literature studied, there seems to be a difference of opinion as to the effects of the Coriolis force in the formation of vortices.

According to Einstein and Li (1) the earth's rotation is often sufficient to create violent vortices especially near drains of narrow sections through which a fluid flows. In support of this view, Sibulkin (2) in his reference to work by Shapiro states that consistently counter-clockwise rotation independent of initial applied velocity direction is attributable to the action of the Coriolis force in the Northern Hemisphere (3). He goes on to say that the Coriolis force would determine the direction of the vortex when the residual circulation relative to the chamber is less than the circulation due to the normal component of the earth's rotation which varies from zero at the equator to one revolution per day (0.0007 r.p.m.) at the poles (4). Gibson (5) states
that in the Northern Hemisphere the earth's rotation would tend to cause a counter-clockwise rotation.

The opposite view is held by Posey (6) who in discussing a paper by Einstein and Li (1) states that the Coriolis effect has been widely held but quantitative tests (7) have shown that it is incorrect or grossly exaggerated to say the least. In most cases the moment of momentum resulting from the earth's rotation is so small that vortices resulting from it are barely perceptible and have no measurable effect on discharge. The idea that the vortex once started, may 'feed' upon the head and grow to serious proportions is a fallacy since energy is not convertible into moment of momentum per se. Webb (8) states that the Coriolis effect of the earth's rotation is generally quite negligible for small systems and it is irrelevant which hemisphere we are in.

There is general agreement that vortex formation is dependent on hydraulic conditions and geometry of the structure. Webb (8) declares that the rotation may be in either sense, depending upon the geometrical bias which caused the initial circulation at some distance from the axis. Tests (7) show that the strength of the
vortex and its effect on the discharge depend upon whether the velocity of approach has components which are tangential relative to the outlet. If the approach velocity is strictly radial, no appreciable vortex will form. Berge ( ) agrees that vortex formation depends on numerous parameters, notably hydraulic conditions (depth of water, rate of flow, etc.) and the geometry of the installation. Sibulkin (2) in his tests, noted that for settling periods of a few hours or less the direction of rotation of the vortex coincided with the direction in which the chamber was filled and the strength of the vortex decreased as the settling period increased. For longer settling periods the direction of rotation was consistently counter-clockwise. McCorquodale ( ) also verified these observations using settling times up to seven days.

Regarding model studies of vortices ( ), similitude conditions depend on the criterion considered for the comparison which could be one of the following:

(i) Conditions for the formation of the initial hyperbolic portion of the vortex funnel on the free surface.
(ii) Conditions for initial air entrainment.

(iii) Air-core vortex frequency and duration under given condition.

An experimental method is required whereby the characteristics of a vortex might accurately be determined at any given instant from the moment of initial depression formation to that of air entrainment. Direct methods of determining the vortex funnel profile (point gauges, pressure pick-ups) cannot be considered since a vortex continually changes its position on the free surface and also because of the upsetting effect of such instruments upon the flow, even if in miniaturized form.

Only an optical method is practicable but not conventional photography of the vortex shape because of considerable error when applied to shallow vortices.

The 'refracted ray' method developed at the Chatou Research Center 1960 has been used successfully. This method is based on the optical phenomenon whereby a caustic surface (envelope of rays emanating from a point and reflected or refracted by a curved surface) forms when light rays are diverted in passing through the dieotropic (refractive) air-water surface of revolution of the vortex funnel.
Formation of the hyperbolic upper part of the vortex funnel on the free surface appears to comply with the Froude similitude requirements. Given equal velocities in the model and prototype, the initial air process would also comply with similitude requirements.

2.2 Theoretical Work

For a free (irrotational) vortex with vertical axis the velocity vectors are tangential to the circular stream lines and vary inversely with the radial distance from the axis (11). Under such circumstances the product of the velocity magnitude and the circumference of the stream line will equal a constant, known as the circulation \( c \).

\[
c = 2\pi rv
\]

where

\( v = \text{velocity} \)
\( r = \text{radius} \)

From Figure No. 1, if the velocity head is written in terms of the circulation and radius, and if the sum of the pressure head and elevation is written in terms of the piezometric head, the distance \( H-h \) between the horizontal total-head line and the elevation of the free surface will be

\[
H-h = \frac{1}{2g} \left( \frac{c}{2\pi r} \right)^2
\]

where

\( H = \text{total head} \)
\( h = \text{elevation of free surface} \)
\( g = \text{gravitational acceleration} \)
Since the velocity head varies solely with the radius it follows that the pressure must be hydrostatically distributed in all but the radial directions. Surfaces of constant \( h \) are therefore concentric cylinders, and surfaces of constant pressure intensity have the same form as the free surface.

The central zone of a vortex is generally occupied by fluid following rotational rather than irrotational velocity function, \( v = r\omega \), where \( \omega \) is the angular velocity. The circulation increases from zero at the axis to that of the other zone at the border between the two types of motion.

The free surface of the vortex core will have the form of a paraboloid of revolution thus

\[
h = h_0 = \frac{1}{2g} \left( \frac{cr}{2 \pi r^2} \right)^2
\]

where

\[h_0 = \text{elevation of free surface at vortex core}\]
\[r^2 = \text{Radius of vortex core}\]

and the line of total head will fall accordingly until it coincides with the free surface at the axis.

The free surface of the irrotational vortex will have an elevation equal to the total head at an infinite radius where the velocity is zero, and a
theoretical elevation of negative infinity at the axis.

For a drained vortex, the theoretical discharge
(12) can be defined as

\[
Q = \frac{\pi c^2}{\sqrt{2gH}} \left\{ \left( \frac{r_0}{a_t} \right)^2 - 1 \right\}^{\frac{1}{2}} - \cosh^{-1}\left( \frac{r_0}{a_t} \right)
\]  - - - (4)

where,

- \( c \) = the circulation constant
- \( H \) = the energy head above the orifice
- \( r_0 \) = the radius of the orifice
- \( a_t \) = the theoretical radius of the air core at the orifice

This expression is based on an ideal model having boundaries which are assumed to be axially symmetrical about a sharp edged circular orifice which is placed flush with a horizontal floor. In addition, the working liquid is inviscid and incompressible. The flow is steady and there is a constant tangential velocity being supplied by an axially symmetrical inflow. Surface tension is negligible.

The above equation was found to over-estimate the actual discharge.

If critical flow is assumed to occur at the vena contracta instead of the plane of the orifice, the following expression (12) defines the theoretical discharge
\[ Q = A_o \sqrt{2gH} \left[ C_c \left( \sqrt{1 - \lambda^2} - \lambda^2 \ln \left( \frac{1 + \sqrt{1 - \lambda^2}}{\lambda} \right) \right) \right] \] (5)

where,

- \( A_o \) = the area of the orifice
- \( H \) = the depth measured above the plane of the orifice
- \( C_c \) = the coefficient of contraction
- \( \lambda \) = the vena contracta swirl number

The vena contracta swirl number \( \lambda \) is defined by the following expression:

\[ \lambda = \frac{a}{b} \] (6)

where,

- \( a \) = the radius of the air core
- \( b \) = the radius of the vena contracta

The radius of the vena contracta is:

\[ b = r_o \sqrt{C_c} \] (7)
3. EXPERIMENTAL STUDY

3.1 Purpose of Study

The problem of vortex formation was anticipated in the influent and effluent chambers of the West Windsor Sewage Treatment Plant. In the primary settling phase of treatment, four large circular tanks were incorporated into the design. Sewage is distributed to each of four tanks in equal portions through an influent chamber (Fig. 2). The influent chamber consists of a circular basin at the end of an open channel. In the circular basin are four vertical pipes each discharging downward to a primary settling tank. It was anticipated that numerous flow patterns could be established in the influent chamber, depending on the number of primary settling tanks in service, the combination of same, the quantity of flow and the associated depth of flow. It was assumed that the geometry of the chamber would contribute to the formation of vortices. However, the strength of such vortices, their effect on flow in the discharge pipes, and various other factors associated with the flow could
not be established unless a model study was undertaken. It was considered very probable that vortex formation, if strong enough, could cause air to be trapped in the discharge pipes, reduce the carrying capacity, and cause the water level to increase and back up into the inlet channel. The backwater effect of such a water level increase could presumably extend back to a previous process and affect the efficiency of such process, as well as create submergence of weirs and possible over-topping of channel sides. In addition, the increased depth caused by a vortex formation could reduce the velocity of flow in the inlet channel to a point where organic material could settle in the channel before reaching the settling tanks.

For purposes of maintenance, the influent chamber is provided with an inspection platform on its periphery at the top of the wall. The formation of vortices and the associated turbulence from various flow conditions could cause splashing onto the platform. In cold weather the splashing would lead to dangerous ice accumulation on the platform. It was hoped that a model study would also provide a solution to the problem of splashing.
For reasons of economy and functional desirability the effluent chamber is attached to the periphery of the influent chamber as shown on Figure 2. After the sewage has completed the primary settling phase of treatment, the resulting effluent flows over V-notch weirs into peripheral channels on the primary settling tanks. These peripheral channels collect the effluent and deliver it to the effluent chamber. The arrangement used on this particular design as shown in Figure 2, incorporates an effluent chamber on either side of the influent chamber. Each effluent chamber is fed by two primary settling tanks, and one vertical pipe discharges downward to the next phase of treatment from each effluent chamber. Vortex formation in the effluent chamber was also anticipated, causing similar problems of back water effects, reduction in pipe capacity, and splashing.

Correction of vortex situations in the prototype was not considered practical because of cost and inconvenience resulting from plant shutdowns. A model study was therefore considered essential.
3.2 Model Description

A model scale of 1:16 was chosen to suit the available laboratory space. The model was designed to provide Froude similitude.

The length ratio, \( L_x \), can be expressed as follows:

\[
L_x = \frac{L_m}{L_p}
\]  

(8)

where,

\( L_m \) = model length

\( L_p \) = prototype length

Assuming gravity and inertia as the only influences, the time ratio was determined as follows:

Gravity:

\[
\frac{F_m}{F_p} = \frac{W_m}{W_p}
\]

\[
= \frac{w_m}{w_p} \cdot \frac{L_m^3}{L_p^3}
\]

\[
= w_r L_x L_p^3
\]  

(9)

where

\( F_m \) = force in model

\( F_p \) = force in prototype

\( W_m \) = weight in model

\( W_p \) = weight in prototype

\( w_m \) = unit weight in model

\( w_p \) = unit weight in prototype

\( w_r \) = unit weight ratio

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Inertias:

\[
\frac{F_m}{F_p} = \frac{M_m a_m}{M_p a_p} = \frac{\rho_m L_m^3}{\rho_p L_p^3} \cdot \frac{L_r}{T_r^2} = \rho_r L_r^3 \cdot \frac{L_r}{T_r^2}
\]

(10)

where

- \( M_m \) = mass in model
- \( M_p \) = mass in prototype
- \( a_m \) = acceleration in model
- \( a_p \) = acceleration in prototype
- \( \rho_m \) = density in model
- \( \rho_p \) = density in prototype
- \( \rho_r \) = density ratio
- \( T_r \) = time ratio

Equate Gravitational and Inertial Forces Ratios as follows:

\[
\frac{w_r L_r^3}{\rho_r L_r^3} = \frac{L_r}{T_r^2}
\]

Solve for \( T_r \)

\[
T_r^2 = L_r \cdot \frac{\rho_r}{w_r}
\]

\[
= \frac{L_r}{g_r}
\]

where \( g_r \) = gravitational acceleration ratio
Since \( g_r = 1 \)
Therefore \( T_r = L_r^{1/3} \) - - - - - - - - - - - - - - (11)

The flow ratio, \( Q_r \), is expressed as follows:

\[
Q_r = \frac{Q_m}{Q_p} = \frac{L_r^{3/2}}{T_m} = \frac{L_r^{3/2}}{L_p^3/T_p} = \frac{L_r^{3/2}}{T_r}
\]

Substituting Equation (11)

\[
Q_r = \frac{L_r^{3/2}}{T_r} = L_r^{5/2} - - - - - - - - - - - - - - (12)
\]

The velocity ratio, \( V_r \), is expressed as follows:

\[
V_r = \frac{L}{T_r}
\]

Substituting Equation (11)

\[
V_r = \frac{L_r}{L_r^{3/2}} = L_r^{1/2} - - - - - - - - - - - - - - (13)
\]
Water for the model study was supplied from a constant head tank located above the hydraulics laboratory at the University of Windsor. The constant head tank supply was replenished by a variable speed pump which returned the used water from a channel in the floor through a piping system up to the constant head tank.

The flow was measured with a Venturi meter located in the piping between the constant head tank and the model. Flow was indicated on a mercury monometer graduated in U.S. gallons per minute. The schematic arrangement shown in Figure 3, illustrates the piping system used to conduct the model study. Flow through the model was controlled manually by a six inch gate valve mounted on the inlet pipe to the model and head box. The water level in the model could be varied by adjusting a four inch gate valve on the discharge pipe from the model. In addition, separate valves were mounted on each discharge pipe from the influent chamber so that various combinations of discharge could be simulated.

The model was constructed of plywood and finished with marine type paint especially manufactured for use on underwater applications. The model discharge
piping from the influent and effluent chambers was Schedule 80 PVC pipe sized to suit the model scale. Steel piping connected the constant head tank to the model head box.

The baffle arrangement used in the model study is shown in Figure 18.

3.3 Procedure

The dry weather flow (DWF) for the sewage treatment plant is 44.6 cubic feet per second (c.f.s.). The interceptor sewers leading to the sewage treatment plant are designed to deliver 2.5 DWF to the treatment plant, which is equivalent to a flow of 111.5 c.f.s. However, if the interceptor sewers are surcharged, larger flows are expected and the hydraulic design was based on a maximum flow of 167 c.f.s., which is equivalent to 3.75 DWF. It is reasonable to assume that the problem of vortex formation will be greater as the flow increases. However, vortex formation at lower flows is also considered undesirable. For this reason, the model study was conducted on the basis of the flows shown in Table 1.
TABLE 1
CONDITIONS OF FLOW

<table>
<thead>
<tr>
<th>FLOW (c.f.s.)</th>
<th>TOP WATER LEVEL (TWL)</th>
<th>ARRANGEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>44.6</td>
<td>591.83</td>
<td>All discharge pipes open.</td>
</tr>
<tr>
<td>83.5</td>
<td>592.33</td>
<td>Nos. 1, 2, 3, and 4 discharge pipes alternately closed.</td>
</tr>
<tr>
<td>111.5</td>
<td>592.33</td>
<td>All discharge pipes open.</td>
</tr>
<tr>
<td>125.00</td>
<td>593.05</td>
<td>Nos. 1, 2, 3, and 4 discharge pipes alternately closed.</td>
</tr>
<tr>
<td>167.00</td>
<td>593.05</td>
<td>All discharge pipes open.</td>
</tr>
</tbody>
</table>

In addition to the above arrangements, vortex formation and flow patterns were studied for a flow of 83.5 c.f.s. with two discharge pipes simultaneously closed in all the possible variations. It was observed however, that the desired TWL could not be achieved in the model because of slight variation in head loss in the model piping with that in the prototype. Although measurements were taken for all the combinations of two discharge pipes simultaneously closed, at a flow of...
83.5 c.f.s., the results are not presented herein.

For a particular flow in the model, a specific water level was created in the influent chamber by adjusting the gate valve on the discharge pipe, to coincide with the water levels in the prototype as determined by hydraulic calculations. The construction of the six inch gate valve used to adjust the flow through the model did not allow rapid and accurate flow adjustment. This valve characteristic required lengthy flow adjustment periods and continual checking of flow to maintain constant flow through the model throughout the test. Once the desired flow had been established, the model was allowed to operate at that flow for approximately 30 minutes to stabilize the flow and establish definite patterns which were unaffected by previous valve adjustments.

Having adjusted the flow through the model and allowing the flow pattern to become established, the next adjustment required was the establishing of the top water level (TML) in the influent chamber as dictated by the hydraulic calculation for the prototype. The gate valve on the discharge line to adjust the water level was of a similar construction to the gate valve on the supply line to the model head box and
presented similar problems of adjustment. However, after several trials the required water level was established and the model was allowed to operate at the required flow with the required water level for another 30 minutes to stabilize the flow pattern. To best illustrate the formation and prevention of vortices and the associated turbulence, it was decided to take measurements of water levels at various pre-selected locations in the chamber. To facilitate the recording of water level measurements, a copper wire grid was mounted on the model and water level measurements were taken at each grid point and recorded on a plan of the model with the grid system incorporated. Water level measurements were taken from the water surface up to the wire grid. Water level measurements were recorded at 37 locations in the influent chamber for each condition of flow, and at 21 locations in the effluent chamber. After baffles were installed, additional water level measurements were recorded at strategic points near the baffles in addition to the normal locations.

The water level for a particular flow at a particular location, was obtained by taking the average of several readings. This was necessary because
of a fluctuating water surface. At each location, ten water level readings were recorded at approximately 30 second intervals. The average of these ten readings was calculated and used to prepare the water surface contours.

To further illustrate the flow patterns for the various flows, photographs were taken of white polystyrene float indicators which were introduced into the head box and allowed to flow through the model.

However, the photographs were not successful, and do not clearly illustrate the flow pattern resulting from the various flow conditions. Several of the photographs are included in the Appendix.

The results of movies were more successful, and the flow patterns are indicated on the contour drawings of the water surface for the various flows. Movies were not taken of all flow patterns or all flow conditions. The movies were projected on a drawing of the chamber to the proper scale and run frame by frame. The float positions were marked on the drawing for each frame.

The procedure used to obtain data for the effluent chamber is similar to that described above except that hydraulic calculations for the prototype indicates that the discharge from the effluent chamber
is a free discharge, i.e. the upstream water level is below the invert elevation of the effluent chamber. Therefore, it was not necessary to adjust the discharge valve to establish a water level in the effluent chamber. The water levels recorded for the effluent chamber at the various flows are those levels established simply by the hydraulics of the model.
4. RESULTS AND DISCUSSION

The object of the study was to observe vortex formation at various flow conditions in the model, and then devise a system of baffles to prevent the formation of the vortices. For this reason, it was necessary to study the flow patterns in the model at the various flow conditions without baffles. Observations of the flow patterns established under these conditions helped to determine the type, size, location, arrangement, and number of baffles required to prevent vortex formation.

4.1 Observations Without Baffles

4.1.1 $Q = 44.6$ c.f.s., all valves open

The TML for these conditions as determined from hydraulic calculations was 591.80. Flow in the influent chamber was characterized by a relatively calm water surface with no evidence of vortices. The contours on Figure 4 indicate that water tended to pile up on the wall opposite the inlet to the chamber to a maximum elevation of 591.80. This elevation also
occurred immediately adjacent to the inlet on either side. A depression occurred in the centre area of the chamber to an elevation of 590.80. The flow pattern was characterized by a very gentle circular motion in each half of the influent chamber. On the left half a very gentle counter-clockwise motion was evident. On the right half a clockwise motion of equal magnitude was observed. Neither circular motion was strong enough to initiate a formation of vortices. There was no evidence of surging in the chamber. In the effluent chambers for these flow conditions, the flow was relatively smooth. However, slight tendencies for a vortex to form in a counter-clockwise direction near the discharge pipe was observed. The vortex formation was not strong enough to introduce air into the discharge pipe and in fact only amounted to a dimple in the water surface. The discharge from the effluent chamber was a free discharge and the maximum water level observed was 589.60 and reduced to 589.20 in the vicinity of the discharge pipe.

\[ Q = 83.5 \text{ c.f.s., No. 1 Closed} \]

For this flow, the TWL as determined from hydraulic calculations was 592.33. The contours on
Figure 5 indicate that the level elevations ranged from 592.40 to 591.00. The minimum water level occurred slightly to the right of centre between Nos. 2 and 4 discharge pipes. The maximum water level occurred at the wall opposite the inlet to the chamber as well as at the inlet. The effect of discharge pipe No. 1 being closed, was evident by a depression in the water surface between Nos. 2 and 4 discharge pipes. It was also observed that the swirling between Nos. 2 and 4 was much stronger than the swirling between Nos. 1 and 3.

The velocity of the counter-clockwise gentle rotation on the left side of the chamber was much less than the clockwise rotation on the right side of the chamber. The turbulence created by the velocity of flow in the chamber under these conditions may have prevented the formation of the vortex. However, splashing was evident at the wall opposite the inlet of the model at these flows. The path of the incoming water to the influent chamber tended to shift slightly to the right because discharge pipe No. 1 was closed.

The effluent chamber on the right side was discharging water from Nos. 2 and 4 discharge pipes, and was very turbulent with slight surging of the water
surface. There was vortex formation in the vicinity of the discharge pipe but the vortex was intermittent and not sustained because of the turbulent flow. However, the intermittent vortex caused air to be drawn into the discharge pipe of the effluent chamber. The effluent chamber on the left side was discharging water from No. 3 discharge pipe and as such, there was an unbalance in the flow. The effluent chamber on the left side also produced intermittent vortices and the flow was turbulent although not to the extent that it occurred in the effluent chamber on the right side. This is attributed to the fact that the flow in the effluent chamber on the left side was only one-half of the flow of the opposite effluent chamber. The discharge from the effluent chambers was a free discharge and the maximum and minimum water levels were 590.40 and 589.40 respectively.

4.1.3 $Q = 83.5$ c.f.s., No. 2 Closed

From a comparison of the contours in the chambers for No. 2 discharge pipe closed versus No. 1 discharge pipe closed, it can be seen that the effects were almost identical. In the influent chamber, the depression was between Nos. 1 and 3 discharge pipes.
as shown in Figure 6.

The maximum and minimum water levels however, were still the same and the pattern of flow was similar except that the incoming flow to the chamber was diverted slightly to the left of center as it entered due to No. 2 discharge pipe being closed. The effluent chambers had identical results except that the right effluent chamber had the unbalanced flow, under these conditions. Otherwise the water levels, flow patterns, vortex formations, turbulence and other observations were all identical.

4.1.4 \( Q = 83.5 \text{ c.f.s.}, \) No. 3 Closed

The flow was diverted slightly to the right upon entering the chamber. There was a gentle swirl on the left side of the chamber and a very strong swirl on the right half of the chamber which were counter-clockwise and clockwise respectively. Because of the turbulence created by the high velocities, vortices were not formed although there was a depression in the water surface occurring intermittently in the vicinity of No. 4 discharge pipe as shown in Figure 7. Depressions were also observed between discharge pipe Nos. 2 and 4, and near discharge pipe No. 1. Splashing was evident.
The maximum and minimum water levels were 592.60 and 591.20 respectively.

The flow patterns and observations for the effluent chamber on the right side were identical to those described in 4.1.2. The flow patterns and observations for the effluent chamber on the left half were identical to those in 4.1.3 except that the flow enters the chamber from the opposite side. The intermittent vortex formation was still in a counter-clockwise rotation.

4.1.5  Q = 83.5 c.f.s., No. 4 Closed

The observations and flow patterns in the influent chamber for these flow conditions were almost identical to 4.1.3 except the flow stream was diverted slightly to the left and the contours were a mirror image of that observed for No. 3 discharge pipe closed. The maximum and minimum water levels were 592.40 and 591.20 respectively as indicated in Figure 8. There was a gentle clockwise swirl in the right half of the chamber and a very strong counter-clockwise swirl in the left half of the chamber. The turbulence prevented the formation of vortices. However, there was a depression in the vicinity of discharge pipe No. 3.
This depression occurred intermittently but did not
develop into a vortex.

The observations for the effluent chamber on
the left side were identical to those for 4.1.3. The
observations for the effluent on the right side were
identical to 4.1.3 except that the flow enters the
effluent chamber from the opposite side. The vortex
formation was still in a counter-clockwise direction.
The maximum and minimum water levels were 590.40 and
589.40.

4.1.6 $Q = 111.5$ c.f.s., All Valves Open

The flow entering the influent chamber esta-
blished very strong counter-clockwise swirls and clock-
wise swirls on the left and right sides respectively.
The turbulence established by the velocity of flow
prevented the formation of any vortices. The TWL for
the influent chamber under these flow conditions as
established by hydraulic calculations for the proto-
type was 592.33. As shown in Figure 9, maximum and
minimum levels observed in the chamber were 592.40 and
591.20. The maximum water level occurred near the wall
opposite the inlet. A depression at elevation 591.20
occurred in the center of the influent chamber. Water
levels were very stable and no surging was evident.

Flow in the effluent chamber was very turbulent. There was a tendency for vortices to form in the vicinity of the discharge pipe, but the turbulence prevented the vortices from forming continuously. During the formation of the vortices, air was drawn into the discharge pipe. Slight surging in the water level was observed in each effluent chamber. Free discharge conditions existed at the discharge pipes and the maximum and minimum water levels in the effluent chambers were 590.40 and 589.60 respectively.

The flow of 111.5 c.f.s. is equivalent to 60 M.I.G.D. representing 2.5 D.W.F.

4.1.7 $Q = 125$ c.f.s., No. 1 Closed

The flow was diverted slightly to the right upon entering the influent chamber and the flow assumed a gentle counter-clockwise swirl in the left half of the chamber and a violent clockwise swirl in the right half of the chamber. A large depression in the water surface was formed in the vicinity of No. 4 discharge pipe as shown in Figure 10. The elevation of this depression was 591.20 as compared with the high water level near the wall opposite the inlet of 593.40. Surging of the
water level was observed in the model equivalent to 6" in the prototype at irregular intervals varying between 20 and 70 seconds. An intermittent vortex was formed in the vicinity of discharge pipe No. 4 during the low level condition of surging, but the vortex was broken by the turbulence in the chamber. The flow pattern in the effluent chamber on the right side was symmetrical about the discharge pipe. Flow was very turbulent, and intermittent vortices were formed in the vicinity of the discharge pipe at irregular intervals. During the formation of the vortices, air was drawn into the discharge pipe. Surging was observed in the model equivalent to approximately 9" in the prototype. The maximum and minimum water levels in the effluent chamber on the right side were 591.00 and 590.00 respectively.

Flow in the effluent chamber on the left side was unbalanced due to No. 1 discharge pipe being closed. Intermittent vortices occurred in the vicinity of the discharge pipe but the turbulent flow prevented the continuous formation of vortices. Air was drawn into the discharge pipe during the vortex formation. A slight surge amounting to approximately 4" in the prototype was observed. The maximum and minimum water levels
in the chamber were 590.60 and 589.80 respectively. All vortexes produced counter-clockwise rotation.

4.1.8 Q = 125 c.f.s., No. 2 Closed

The flow was diverted slightly to the left upon entering the influent chamber due to No. 2 discharge pipe being closed. The flow was deflected from the wall opposite the inlet and divided into two directions. A gentle clockwise swirl was observed in the right side of the chamber and a violent counterclockwise swirl was observed in the left half of the chamber. A large depression is indicated in Figure 11, and intermittent vortexes were formed in the vicinity of pipe No. 3. Surging of the water level equivalent to approximately 9" in the prototype was observed. The contours of the water surface in the influent chamber were almost a mirror image of those contours for the same flow with No. 1 discharge pipe closed.

The observations of flow in the effluent chamber on the right side were identical to those observed in the effluent chamber on the left side for the same flows with No. 1 closed. The contours however were a mirror image of those with No. 1 closed. The observations of flow in the effluent chamber on the
left side were identical to those observations for the same flow with No. 1 closed. However, the contours were a mirror image.

4.1.9  **Q = 125 c.f.s., No. 3 Closed**

The flow was diverted slightly to the right entering the chamber because discharge pipe No. 3 was closed. On striking the wall opposite the inlet, the flow was split into two directions with a counterclockwise swirl forming in the left half of the chamber, and a violent clockwise swirl occurring in the right half of the chamber. A large depression to elevation 591.40 was formed in the vicinity of discharge pipe No. 4 and vortices occurred in the vicinity of pipe No. 4 but were prevented from continuous formation by the turbulence in the chamber. Surging was observed to be equivalent to approximately 4" in the prototype. Vortices tended to form in the low level of the surging condition. Weak vortices tended to form occasionally in the vicinity of discharge pipe No. 1. The maximum water level in the chamber occurred near the wall opposite the inlet at elevation 593.40. Contours shown in Figure 12 indicate a slight depression in the vicinity of discharge pipe No. 1. The flow pattern
and observations in the effluent chamber on the right side were identical to 4.1.7. Flow in the effluent chamber on the left side was unbalanced since discharge pipe No. 3 was closed. Water entered the effluent chamber from only one direction. The flow was very turbulent and intermittent vortices were formed in the vicinity of the discharge pipe. Maximum and minimum water levels observed were 590.60 and 589.80 respectively. Air was trapped in the discharge pipe during the vortex formation and surging was equivalent to approximately 9" in the prototype.

4.1.10 Q = 125 c.f.s., No. 4 Closed

The flow was diverted slightly to the left, on entering the chamber because of the fact that No. 4 pipe was closed. Clockwise swirling flow was observed in the right half of the chamber and turbulent counterclockwise swirls were formed in the left half of the chamber. Vortices occurred in the vicinity of pipe No. 3 but were destroyed by the turbulence. Very weak intermittent vortices occurred occasionally in the vicinity of pipe No. 2, but were not as strong as those in the vicinity of pipe No. 3. Surging was observed in the chamber was equivalent to approximately 4" in the
prototype. A large depression occurred in the vicinity of pipe No. 3 and a smaller depression occurred in the vicinity of pipe No. 2. The maximum and minimum water levels observed in the chamber were 593.20 and 591.40 respectively.

Observations of the flow in the effluent chamber on the right side were identical to those observed in 4.1.9.

The flow observations and contours in the effluent chamber on the left side were identical to those noted in 4.1.8.

4.1.11 $Q = 167 \text{ c.f.s.}, \text{ All Valves Open}$

The flow pattern established for this arrangement was symmetrical about the centre line of the chamber. Flow entering the chamber was diverted in opposite directions after striking the wall opposite the inlet. Strong swirling flow was established in each half of the chamber. The swirls were counter-clockwise in the left half and clockwise in the right half. The turbulence in the chamber prevented the formation of any vortices. Although vortices did not form, the turbulence was considered undesirable and any baffle arrangement required to prevent vortex formation under
different flow conditions must also minimize turbulence during these high flows. Surging was evident for this flow and was equivalent to 7" in the prototype. The surging appeared to occur at regular intervals which produced an average period of surge of approximately 22 seconds in the model. From the contours it can be observed that two depressions were formed in the water surface between pipes Nos. 1 and 3 and between pipes Nos. 2 and 4. The elevation of these depressions was 592.00. The maximum water surface elevation occurred near the well opposite the inlet at elevation 593.80. The observations and contours for the effluent chambers on the right and left were identical to those observed for the flow conditions described in 4.1.9 and 4.1.10.

4.2 Observations with Baffles

4.2.1 Baffle considerations

The various flow conditions that may occur, as evidenced by the numerous possible arrangements of the discharge pipes, makes a mathematical evaluation of baffle arrangements very difficult, if not impossible. By studying the contours resulting from the various flow conditions with no baffles in place, and observing the movies taken of the flow patterns, established, the
baffle arrangement shown in Figure 18 was selected as a possible solution to the prevention of vortex formations. The arrangement was also determined from studying the literature available and knowing that the formation of a vortex is dependent among other things, on the existence of a tangential component of velocity. The baffles were arranged as simply as possible to destroy the tangential component of velocity in the vicinity of the discharge pipes as observed from the model studies in the chambers with no baffles present. Keeping in mind that reinforced concrete baffles would be most practical from the point of view of actual construction, it was necessary to keep the baffle shape as simple as possible. The baffle arrangement selected for testing in the influent chamber consisted of vertical walls extending radially from the edge of the discharge pipe to the outer wall of the influent chamber.

The baffle arrangement selected for the effluent chambers consisted of vertical walls extending from the edge of the discharge pipe to the walls of the effluent chamber as shown on Figure No. 18. These baffle arrangements satisfied the construction requirements of simplicity. The efficiency of these baffle arrange-
ments in preventing vortex formations could only be determined by model testing. The results of this model testing are submitted in the following pages.

4.2.2 \( Q = 44.6 \text{ c.f.s.}, \) All Valves Open

From previous observation, it was known that no vortices were formed for this flow in the influent chamber without baffles. It was therefore assumed that vortices would not be formed by the addition of the baffles. This proved to be the case. The water surface in the influent chamber was very smooth, with no indication of vortex formation. For this flow, the baffles had the effect of stilling the water surface further as evidenced by the contours. The variation from maximum to minimum water level for these flow conditions amounted to only 0.40' as compared to 1.00' without baffles. In general, the baffle arrangement was beneficial in the influent chamber for these flow conditions.

The flow pattern in the effluent chambers was very smooth with no evidence of vortices. Water entering the 48" discharge pipe flowed smoothly over the edge of the pipe from each direction. There was no evidence of air being drawn into the discharge pipe. The contours
do not vary considerably from those contours observed without baffles. This baffle arrangement in the effluent chambers was beneficial since it eliminated the slight tendency for vortices to form for these flow conditions with no baffles.

4.2.3 \( Q = 83.5 \text{ c.f.s., No. 1, Closed} \)

The flow patterns for these conditions consisted of a mild counter-clockwise swirling pattern in the left half of the chamber, and a strong clockwise swirl in the right half of the chamber. The swirl on each side was considerably reduced by the baffles. In addition, the baffles stilled the water surface so that the maximum variation in water level was only 0.40' as compared to 1.40' without baffles. The baffle arrangement proved beneficial for these flow conditions by virtue of the fact that the velocity of swirl and turbulence was considerably reduced and the water surface was smoother.

Flow patterns, in the effluent chamber, on the right side for these flow conditions, were smooth with no evidence of vortex formation. Differential water levels did not change from those obtained with no baffles. However, the contours were slightly different.
It was observed that small amounts of air were being drawn into the discharge pipe, even though vortices were not formed. Air entry into the discharge pipe was greatly reduced because of the baffle arrangement. The baffles also eliminated the surging observed without baffles.

The flow in the effluent chamber on the left side was very smooth with no evidence of vortices and no air entry into the discharge pipe. The flow into the discharge pipe was from one direction only.

The baffles eliminated the intermittent vortex that occurred without baffles.

4.2.4 \( Q = 83.5 \text{ c.f.s.}, \text{ No. 2 Closed} \)

The flow pattern in the influent chamber consisted of a mild swirl in the right half of the chamber and a slightly stronger swirl in the left half of the chamber. There was no evidence of vortex formation and no surging of the water level. In addition to eliminating vortex formation, the baffles also reduced the turbulence on the water surface as evidenced by the wide spacing of the contour lines. The maximum and minimum water levels were 592.60 and 592.20 respectively.
Flow in the effluent chamber on the right side was unbalanced since pipe No. 2 in the influent chamber was closed. There was no evidence of surging or vortex formation and no air entry into the discharge pipe. In the effluent chamber on the left side, for these flow conditions, there was no evidence of vortex formation. Some air however was being drawn into the discharge pipe although considerably less than that occurring with no baffles present. The contours of the water surface indicated a maximum elevation of 590.40 with a minimum of 589.40. The baffles eliminated vortex formation, and considerably reduced air accumulation in the discharge pipe.

4.2.5 Q = 83.5 c.f.s., No. 3 Closed

For these flow conditions, the water surface was relatively calm in the left half of the influent chamber with a slight clockwise swirl in the right half of the chamber. There was no vortex formation and the water surface was considerably stilled by the baffles as evidenced by the spacing of the contour lines. Maximum and minimum water surface elevations were 592.60 and 592.20 respectively as compared to 592.60 and 592.40 without baffles. There was no indication of surging
of the water surface. The flow pattern, contours, and other observations, in the effluent chamber on the right side were identical to those observed for the same flows with discharge pipe No. 1 closed.

The flow in the effluent chamber on the left side was unbalanced since discharge pipe No. 3 was closed.

There was no vortex formation, surging of the water surface, or air entry into the pipe. Maximum and minimum water levels observed were 590.40 and 589.40 respectively.

4.2.6 \( Q = 83.5 \text{ c.f.s.} \), No. 4 Closed

For these flow conditions in the influent chamber, the water surface on the right side of the chamber was relatively calm and there was a slight counter-clockwise swirl in the left half of the chamber. There was no vortex formation or surging of the water level. The baffles considerably reduced the turbulence in the influent chamber. The maximum and minimum water levels observed were 592.80 and 592.20 respectively.

The flow into the effluent chamber on the right side was unbalanced since discharge pipe No. 4 was closed. There was no evidence of surging, vortices,
or air accumulation in the discharge pipe. Maximum and minimum contours were 590.40 and 589.40 respectively. The flow pattern, contours and observations in the effluent chamber on the left side were identical to those observed for the same flows with No. 2 discharge pipe closed.

4.2.7 \( Q = 111.5 \text{ c.f.s., All Valves Open} \)

For these flow conditions, a very weak hydraulic jump occurred near the inlet to the influent chamber. Turbulence on the water surface was considerably reduced by the baffle. A slight surging on the water surface equivalent to approximately 4" in the prototype was observed. There was no evidence of vortex formation. The maximum and minimum water levels were 593.00 and 592.40 respectively.

The flow pattern, observations, and contours in the effluent chamber on the right side were identical to those observed in 4.2.3 and 4.2.5.

The flow patterns, observations, and contours observed in the effluent chamber on the left side were identical to those for 4.2.2 and 4.2.4.
4.2.8 Q = 125 c.f.s., No. 1 Closed

The flow patterns established in the influent chamber by these flow conditions consisted of a slight clockwise swirl in the right half of the chamber and a relatively calm water surface in the left half of the chamber. There was no evidence of vortex formation. However, surging was evident and was equivalent to approximately 9" in the prototype. The turbulence on the water surface was considerably reduced from that observed with no baffles present. The maximum and minimum levels observed were 593.40 and 592.80.

The flow pattern in the effluent chamber on the right side was symmetrical about the discharge pipe. The flow was relatively turbulent with air being drawn into the discharge pipe. However, no vortex formation was evident. A slight surging was observed in the water surface. However, the amount of the surge could not be measured in the model. The maximum and minimum water levels were 590.80 and 589.80 respectively.

The flow pattern in the effluent chamber on the left side was unbalanced because discharge pipe No. 1 was closed. The flow was relatively smooth with no evidence of vortex formation or air accumulation.
in the discharge pipe. The flow discharged directly into the discharge pipe except for occasional slight surges which carried the flow slightly beyond the discharge pipe. Maximum and minimum water levels observed were 590.80 and 589.60 respectively.

4.2.9 Q = 125 c.f.s., No. 2 Closed

For these flow conditions, the water surface on the right side of the influent chamber was relatively calm and there was a slight counter-clockwise swirl in the left half of the chamber. No vortices were evident. Surging was equivalent to approximately 9" in the prototype. The turbulence in the influent chamber was considerably reduced and the maximum and minimum water levels observed were 593.40 and 592.80 respectively.

The flow in the effluent chamber on the right side was unbalanced because discharge pipe No. 2 was closed. However, the flow into the discharge pipe was relatively smooth. There was no vortex formation, air entrainment or surging of the water surface. The maximum and minimum water levels observed in the chamber for these flow conditions were 590.80 and 589.80 respectively.
4.2.10 $Q = 125$ c.f.s., No. 3 Closed

The flow patterns established in the influent chamber under these flow conditions consisted of a relatively calm water surface on the left half of the chamber and a mild clockwise swirl in the right half of the chamber. There was no evidence of vortex formation although slight surges equivalent to approximately 9" in the prototype were observed at approximately 30 seconds intervals in the model. The baffles considerably reduced the turbulence on the water surface. The flow pattern, contours, and observations observed in the effluent chamber on the right half were identical to those observed for the same flows with discharge pipe No. 1 closed.

Flow in the effluent chamber on the left side was unbalanced because No. 3 discharge pipe was closed. The flow discharged directly into the discharge pipe except the flow occasionally carried slightly beyond the discharge pipe. There was no evidence of vortex formation, air accumulation in the discharge pipe or surging. The maximum and minimum water surface elevations observed were 590.80 and 589.60 respectively.
4.2.11 Q = 125 c.f.s., No. 4 Closed

The flow pattern established in the influent chamber under these flow conditions consisted of a relatively calm water surface in the right half of the chamber and a slight counter-clockwise swirl in the left half of the chamber. There was no evidence of vortex formation. Surging was equivalent to 9" in the prototype and occurred at approximately 30 second intervals in the model. Turbulence on the water surface was considerably reduced by the baffles. The maximum and minimum water level elevations were 593.40 and 592.60.

The flow in the effluent chamber on the right side was unbalanced because discharge pipe No. 4 was closed. The flow discharged directly into the discharge pipe and was relatively smooth. There was no evidence of vortex formation, air entrainment, or surging. Maximum and minimum water surface elevations were 590.80 and 589.60 respectively.

The flow patterns, observations, and contours in the effluent chamber on the left side were identical to those observed in 4.2.9.

4.2.12 Q = 167 c.f.s., All Valves Open

Upon entering the influent chamber, the
flow created a weak hydraulic jump between discharge pipes No. 3 and No. 4. The flow pattern consisted of slight swirls in each half of the chamber. The swirl on the left half of the chamber was counter-clockwise and that in the right half of the chamber was clockwise. There was no evidence of vortex formation. However, there appeared to be a very slight tendency for a dimple to form on the water surface in the vicinity of discharge Pipe No. 3. A vortex did not actually form. The turbulence on the water surface was considerably reduced by the baffles. The maximum and minimum water levels observed were 593.60 and 592.80 respectively.

The flow patterns, contours, and observations in the effluent chamber on the right side were identical to those observed in 4.2.8 and 4.2.10.

The flow patterns, contours, and observations in the effluent chamber on the left side were identical to those observed in 4.2.9 and 4.2.11.

4.3 Influent Chamber By-Pass

On rare occasions, it may be necessary to by-pass the influent chamber. If there is one or more primary settling tanks out of service or if the flows are in excess of those which the available settling
tanks can accept, portions of the flow will have to be by-passed. For these reasons, it was decided to study the flow pattern in the effluent chamber for various by-pass conditions. Since the effluent chambers are symmetrical, it was convenient to observe the flow patterns and observations in only one effluent chamber. For purposes of illustration however, the results have been plotted for both effluent chambers. In all cases of by-pass conditions, the flow was unbalanced in the chamber since it was coming from one direction.

4.4 Influent Chamber By-Pass Observations Without Baffles

4.4.1 $Q = 44.6 \text{ c.f.s.}$

For a flow of 44.6 c.f.s., that is 22.3 c.f.s. by-passed into each effluent chamber, strong swirls were formed in the vicinity of the discharge pipe. The flows were not large enough to fill the discharge pipe, and just flowed over the edge and down the sides of the pipe to the horizontal section of the discharge pipe. The maximum water surface elevation of 590.80 occurred at the by-pass gate. The minimum water surface elevation of 580.20 occurred slightly downstream of the by-pass gate where critical flow existed.
4.4.2 $Q = 111.5$ c.f.s.

For these flow conditions, the flow was very turbulent with intermittent vortices forming in the vicinity of the discharge pipe. There was very slight surging evident in the chamber. The maximum water surface elevation of 591.80 occurred at the by-pass gate. The minimum water surface elevation of 589.40 occurred slightly downstream from the by-pass gate where critical flow existed.

4.4.3 $Q = 167$ c.f.s.

The water surface for these flow conditions was very turbulent and prevented the formation of vortices. Air was drawn into the discharge pipe and the flow was very noisy. The maximum water surface elevation of 592.40 occurred at the by-pass gate and the minimum water surface elevation was 590.20 immediately downstream from the by-pass gate.

4.5 Influent Chamber By-Pass Observations with Baffles

4.5.1 $Q = 44.6$ c.f.s.

For these flow conditions, the flow was relatively smooth and discharged directly from the discharge gate into the discharge pipe with the occasional
trickle extending beyond the discharge pipe. The flow dropped smoothly over the edge of the pipe to the horizontal sections of the discharge pipe. There was no evidence of vortex formation, air entrainment, or surging.

4.5.2 \( Q = 111.5 \text{ c.f.s.} \)

For these flow conditions, the water surface was relatively turbulent, and there was a small amount of air being drawn into the discharge pipe. There was no evidence of vortices. The baffles had the affect of piling up the flow on the outer wall to a maximum elevation of 591.60.

4.5.3 \( Q = 167 \text{ c.f.s.}, \text{ Free Discharge} \)

For these flow conditions, the water surface was very turbulent. No vortices were formed, but air was drawn into the discharge pipe and the flow piled up along the outside wall to a maximum elevation of 592.40.

4.5.4 \( Q = 167, \text{ c.f.s.}, \text{ Downstream Elevation 589.67} \)

Under normal conditions of flow, the discharge from the effluent chamber is a free discharge. However, on occasion, particularly for maximum flow conditions, it is possible for a submerged discharge
condition to exist. This condition was simulated in the model and the observations noted. The flow pattern and turbulence were approximately the same as those that occurred for a free discharge condition. No vortices or air entrainment were observed. However, the average water surface elevation increased slightly as shown on the contours.

4.5.5 \( Q = 232 \text{ c.f.s.} \)

Although it was not anticipated that this flow would ever be discharged through the by-pass gate, there was a very slight possibility that unusual conditions could cause such a condition to exist. For these flows through the by-pass gates, very excessive turbulence was evident with splashing on the tops of the walls of the influent chamber. Air was drawn into the discharge pipe, and the flow through the pipe was very noisy. The turbulence prevented the formation of vortices. The water surface reached a maximum elevation of 593.00 at the upstream edge of the baffle on the outer wall. The minimum water level of 589.60 occurred downstream from the by-pass gate where critical flow was observed.
4.6 Observations in Prototype

The influent and effluent chambers have been constructed with baffles and have been in operation for approximately one year at the West Windsor Sewage Treatment Plant. At the present time, sewage is discharged into the Plant from a 78" diameter interceptor sewer with a capacity of 140 c.f.s. (75 M.I.G.D.). The present average flow to the Plant is approximately 22 c.f.s. (12 M.I.G.D.) and the maximum flow recorded to date has been approximately 60 M.I.G.D. For this range of flows, the prototype has exhibited characteristics very similar to those observed in the model. There has been no evidence of surging in the prototype at the higher flows as noted in the model. Vortex formation and air entrainment have not been evident. Splashing on the upper walkway has not occurred. In general, for flows up to 60 M.I.G.D., the prototype performance has been as effective as the model study indicated.
V. CONCLUSIONS

The baffle arrangement selected for model testing proved to very effective in the prevention of vortex formation, both in the influent chamber and the effluent chamber. The baffles in the model had the effect of reducing considerably the turbulence on the water surface. This has also been observed in the prototype and has prevented splashing on the walkway located on the periphery of the influent chamber. The baffles in the model did not entirely eliminate surging conditions. However, surging was reduced considerably.

There has been no evidence of surging to date in the prototype. It was hoped that the baffle arrangement would have prevented the accumulation of air in the model discharge pipe for all flow conditions. The baffles in the model were not entirely successful in achieving this goal. Excessive flows and some by-pass conditions were accompanied by air entrainment in the model discharge pipes. For the limited flow conditions observed to date in the prototype, no air entrainment has been
observed. In general, the baffle arrangement has proved to be very effective.
FIGURE NO. 1

VELOCITY DISTRIBUTION AND SURFACE PROFILE OF A VORTEX
FIGURE NO. 3
SCHEMATIC MODEL FLOW ARRANGEMENT
FIGURE No. 4

Qp = 44.6 CFS (24 MIGD)
FIGURE No. 5

$Q_p = 83.5\ \text{CFS (45 MIGD)}$

NO. 1 CLOSED
FIGURE No. 6
Qp = 83.5 CFS (45 MIGD)
No. 2 CLOSED
FIGURE No. 7

Qp = 83.5 CFS (45 MIGD)

No. 3 CLOSED
FIGURE No. 8

$Q_p = 83.5 \text{ CFS (45 MIGD )}$

No. 4 CLOSED
FIGURE No. 9
Qp = 11.5 CFS (60 MIGD)
FIGURE No. 10
$Q_p = 125 \text{ CFS (67.5 MIGD)}$
No. 1 CLOSED
FIGURE No. II
Qp = 125 CFS (67.5 MIGD)
No 2 CLOSED
FIGURE No. 12
Qp = 125 CFS (67.5 MIGD)
No. 3 CLOSED

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FIGURE No 13
Qp = 125 CFS (67.5 MIGD)
No 4 CLOSED
FIGURE No 15

\[ Q_p = 44.6 \text{ CFS (24 MIGD)} \]

BY-PASS
FIGURE No 16

\[ Q_p = 111.5 \text{ CFS} \quad (60 \text{ MIGD}) \]

BY-PASS

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FIGURE No. 17

Q_p = 167 CFS (90 MIGD)

BY-PASS
FIGURE NO. 18

PLAN OF INFLUENT AND EFFLUENT CHAMBERS
SHOWING BAFFLE ARRANGEMENT

NOTE:
- ELEVATIONS REFERRED TO MEAN SEA LEVEL.
- TOP ELEVATION OF ALL WALLS AND BAFFLES 596.00
- SCALE: 1/8" = 1'-0"
Figure No. 19

\[ Q_p = 44.6 \text{ CFS (24 MIGD)} \]
FIGURE NO. 20

Qp = 83.5 CFS (45 MIGD)

NO. 1 CLOSED
FIGURE No 21
$Q_p = 83.5 \text{ CFS (45 MIGD)}$
No 2 CLOSED
FIGURE NO. 22

**Q_p** = 83.5 CFS (45 MIGD)

NO. 3 CLOSED
FIGURE NO. 23

$Q_p = 83.5 \text{ CFS (45 MIGD)}$

NO. 4 CLOSED
FIGURE NO. 24

Qp = 311.5 CFS (60 MIGD)
FIGURE NO. 25
Qp 125 CFS (67.5 MIGD)
NO. 1 CLOSED
FIGURE NO. 26

$Q_p = 125 \text{ CFS (67.5 MIGD)}$

NO. 2 CLOSED
FIGURE NO. 27

Qp = 125 CFS (67.5 MIGD)

NO. 3 CLOSED
FIGURE NO. 28
Qp ≈ 125 CFS (67.5 MIGD)
NO. 4 CLOSED
FIGURE NO. 29

$Q_p = 167 \text{ CFS (90 MIGD)}$

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FIGURE NO 30

Qp = 44.6 CFS (24 MIGD)
BY-PASS
FIGURE NO. 31

$Q_p = 111.5 \text{ CFS (60 MIGD)}$

BY - PASS
FIGURE NO. 32

Qp = 167 CFS (90 MIGD)

BY-PASS
FIGURE NO. 33
Qp 167 CFS (90 MIGD)
BY-PASS (Downstream Elev. 589.67)
FIGURE NO. 34

Qp = 232 CFS (125 MIGD)
BY - PASS
$Q_p = 125 \text{ c.f.s.}, \text{ No. 1 Closed}$

$Q_p = 125 \text{ c.f.s.}, \text{ No. 3 Closed}$
Prototype Influent Chamber, Qp=22 MIGD

Prototype Effluent Chamber, Qp=22 MIGD
General Prototype Layout

Prototype Influent Chamber Showing Inlet
Qp = 22 MIGD

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